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Micro-CT evaluation of root canal preparation with rotary instrumentation on prototyped primary incisors

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Abstract: This study aimed to evaluate the endodontic instrumentation outcomes with asymmetrical files compared to reciprocating and hand files (HFs) in 3D-printed prototypes of upper primary incisors using micro-computed tomography (micro-CT). For this purpose, 50 prototypes were randomly divided (n = 10) according to the instrumentation technique as follows: HFs, a reciprocating file (WaveOne® Gold [WOG]), and three asymmetrical movement files: XP-Endo® Shaper (XPS), XP-Endo® Finisher (XPF), and XP Clean (XPC). The specimens were scanned and, after registration of the baseline and instrumented volumes, changes in the root canal volume (RCV), debris accumulation, removed root material volume (RRMV), non-instrumented areas, and the presence of cracks/perforations were quantified. Data were analyzed by analysis of variance and Student's t-test, while the effect size was calculated for statistically significant outcomes. All groups showed an increase in RCV after instrumentation ($p < 0.05$), but this was higher with HFs ($p < 0.05$). Accumulated debris was higher for WOG and XPS ($p < 0.05$), but WOG exhibited more in the medium and apical third areas. HFs showed the highest RRMV ($p < 0.05$), especially at the apical third. The non-instrumented areas were lower for HFs and XPC than for the other systems ($p < 0.05$). Cracks were present in a few WOG (n = 2) and HF specimens (n = 3) and in this group, one of the cracked specimens and two others showed perforations. The asymmetric systems resulted in conservative dentin removal and fewer cracks/perforations as compared to HFs and a reciprocation file in prototyped primary upper incisors. XPC showed the best compromise between RRMV and non-instrumented areas with a low accumulation of debris.

Keywords: Pulpectomy; Tooth, Deciduous; Endodontics; X-Ray Microtomography.

Introduction

Pulpectomy is a common endodontic procedure indicated for primary teeth with irreversibly inflamed or necrotic pulps caused by dental caries or trauma.[1] In the transitional dentition, the aim is to eliminate infection and protect the tooth from future microbial invasion until physiologic exfoliation takes place. During this procedure, the root canals are cleaned and shaped (the so-called chemo-mechanical preparation) before being filled with a resorbable paste, followed by permanent crown restoration.[2]

This technique has conventionally been advocated with manual stainless steel endodontic files,[3] but its use is time-consuming and can lead to iatrogenic errors such as steps, apical transport, and root perforation.[4] The use of nickel-titanium files with either rotary or reciprocating movements in primary teeth has shown good results as compared to the conventional method of instrumentation with hand files (HFs),[5] even though these instruments are not dedicated to the specificities of primary dentin instrumentation, such as the reduced need to cut and shape the root canal. Primary teeth are prone to increased risk of perforation, as they have thinner root dentin walls and are subject to physiological or pathological root resorption.[6] The removal of organic debris to eliminate infection is thus the main purpose of canal instrumentation in primary teeth, instead of cutting and shaping procedures, since final obturation is performed with paste-like resorbable materials.[7]

In this sense, conventional mechanical methods or HFs may leave considerable untouched areas on the root walls, especially in ribbon-shaped root canals[8] as they present in maxillary primary incisors.[9] These non-instrumented areas may result in bacterial recontamination and failure of the endodontic treatment.[10] In an attempt to reduce the percentage of non-instrumented areas, new systems, presenting with a "snake-type" design on its longitudinal axis were developed, which in turn result in an asymmetric rotational movement and provide further surface contact with the root walls (XP Endo® Shaper, FKG). In addition, other files with asymmetric designs have been developed to aid in the cleaning process without removing dentin (XP Endo® Finisher, FKG; XP Clean, MK Life), which could have potential in maintaining the integrity of the root structure[11] and providing appropriate cleaning of primary teeth root walls without any significant root dentin removal.

Studies comparing the outcomes of different root canal (RC) instrumentation systems in primary teeth are extremely restricted, partly because the cost-effectiveness of pulpectomy procedures in children is challenged in some countries while also considering the general difficulty in collecting teeth of adequate root length. If primary teeth are prematurely extracted due to dental pathology, signs of root resorption are normally seen and the specimen is excluded. To overcome this issue, 3D-printed polymer prototypes of real tooth specimens can be used to test the contemporary instrumentation systems, their application, and their effectiveness in primary teeth.[12] The rationale is to simplify, while maintaining the effectiveness and the conservative approach, regarding dentin removal during instrumentation.

Micro-computed tomography (micro-CT) is considered as the gold standard among non-destructive methods for the evaluation of the results of RC instrumentation owing to its high resolution, the ability to quantitatively evaluate the whole 3D anatomy, and provide the baseline RC anatomic parameters in order to allow comparisons among appropriate groups.[13]

Therefore, in this study, we compared the outcomes of mechanical instrumentation (such as the increase in RC volume, the presence of non-instrumented areas, volume of material removed from the root, the accumulation of debris, and the presence of cracks/perforations after instrumentation) performed with asymmetric movement files to HF instrumentation and a reciprocating file system, using standardized and validated 3D-printed prototypes of a maxillary primary incisor. The null hypothesis is that asymmetric files result in mechanical instrumentation outcomes similar to those of HFs and reciprocating files in this tooth model.

Methodology

Preparation of the specimens

The protocol for producing the prototypes has been described previously.[12] For this study, 50 prototypes were selected and categorized into five groups of 10 each, based on the type of instrumentation. The printed specimens were accessed through the palatal surface with a small spherical diamond bur (#FG1012, KG Sorensen, Cotia, Brazil) attached to a high-speed motor under water irrigation. An initial root canal exploration was performed with a Kerr #15 file (Dentsply–Maillefer, Ballaigues, Switzerland) and saline irrigation (5 mL) to clear and remove the resin residues from the canal interior. Next, a Kerr #10 file was introduced into the canal until it could visually reach the apical foramen, being slightly removed to a point that was no longer visible. The penetration limiter was slid to the incisal surface of the tooth, and the file was removed and then measured. From this measurement, 1 mm was subtracted, giving a final working length (WL) of 15 mm.

Next, the specimens were scanned by micro-CT to obtain the baseline root canal data. After the instrumentation, the micro-CT scanning was repeated (see information on micro-CT acquisition, reconstruction, and analysis).

Instrumentation techniques

For the rotary instrumentation, the file systems were powered by the X-Smart™ Plus Endodontic Motor (Dentsply–Maillefer, Ballaigues, Switzerland) following the manufacturer's instructions for each file system. All prototypes were instrumented by an experienced single operator. Each file was used on five prototypes and then replaced with a fresh one, with the claim that all mechanical instruments were indicated for use in molars with multiple canals. No sterilization was performed between the uses as no microbiological evaluation was required.

The instrumentation techniques used in the present study included the following:

a. Manual instrumentation with 21 mm Kerr files (Dentsply–Maillefer, Ballaigues, Switzerland): Second-series Kerr files were used using the apex-crown step-back technique. The first file used was #45 (taper 0.02), followed by three files in the same series. Between the different files, irrigation with 5 mL of 0.9% saline solution was performed as described later in this section.
b. WaveOne® GOLD (WOG) System (Dentsply-Sirona, USA): The 21 mm large (#45/0.05) file was used in its reciprocating instrumentation preprogramming, making it suitable for the WOG system. The instrument was moved slowly and with gentle movement from the inside out. After three pecking movements, the instrument was cleaned with gauze and the movement was repeated until the WL was reached.
c. XP-Endo® Shaper (XPS) System (#30/0.04-FKG Dentaire, La Chaux-de-Fonds, Switzerland): The instrument was driven with 1000 rpm and at 1N torque. The file was introduced in the root canal in motion, and if the motor stopped due to canal resistance, the file was retrieved to allow the motor to be started. Long gentle strokes were performed until reaching the WL. Once the WL was reached, this movement was repeated 15 times.
d. XP-Endo® Finisher (XPF) System (#25/0 taper-FKG Dentaire, La Chaux-de-Fonds, Switzerland): The instrument was driven with 1000 rpm and 1N torque. The file was slightly introduced into the canal with the motor stopped and then driven. Slow and gentle 7–8 mm longitudinal movements were made for 1 min to reach the WL.
e. XP Clean (XPC) System (#25/0.02-MK Life, Porto Alegre, Brazil): The instrument was driven with 1000 rpm and 1N torque. The file was slightly introduced into the canal with the motor stopped and then driven. Slow and gentle 7–8 mm longitudinal movements were made for 1 min to reach the WL.

The final irrigation protocol was the same for all prototypes and consisted of using 10 mL of 0.9% saline solution with a 20G NaviTip needle (Ultradent, Indaiatuba, Sao Paulo, Brazil) inserted up to 2 mm WL with simultaneous aspiration.

Micro-CT acquisition, reconstruction, and analysis

The specimens were scanned before and after the instrumentation using a high-energy micro-CT device (Skyscan 1173, Bruker micro-CT, Kontich, Belgium) at the following settings: 40 kV, 150 mA, 7.8 μm pixel size, 2240 × 2240 pixel matrix, 1 mm-thick Al filter, 800 ms exposure, 1° step, and 360° rotation around the vertical axis, resulting in a total scan time of approximately 30 min. The images were acquired in a 16-bit TIFF format. After the acquisition, cross-sectional reconstruction was performed in a dedicated workstation and using the software (NRecon, Bruker, Kontich, Belgium) by using the following standardized parameters: noise removal (7), correction of ring artifacts (9), correction of beam hardening (45%), and contrast limits of 0.04–0.5.

After the volumetric reconstruction, volume pairs (same specimen before and after instrumentation) were registered to ensure that they were positioned in the same spatial coordinates. For this purpose, they were exported in the "*.nrrd" format to a dedicated software (3D Slicer).[14] The sound canal volume was considered as the reference volume, to which the volume of the specimen after instrumentation was to be moved. A "Rigid + Scale" algorithm with 7 degrees of freedom was used for this purpose.

After reconstruction and registration, no pre-processing of the images was deemed necessary, as they showed low noise levels due to the filtering procedures performed at the reconstruction stage. All further stages of image analysis were performed using the open-access FIJI software interface.[15] The first segmentation step consisted of obtaining the initial volume of the sound canal using a subtraction method. The initial root canal volume was obtained after segmentation of the sound specimens using a fixed value (30). This image volume was duplicated and the root canal was filled from the duplicated stack. The initial root canal volume was subtracted to give the sound canal volume as shown in Figure 1. To obtain the instrumented canal volume, the same procedure and segmentation value were performed; however, in this case, the image stacks after instrumentation were used. For the quantitative analysis of accumulated debris, non-instrumented areas, and the volume of root material removed, a previously proposed methodology was used to obtain these parameters in micro-CT.[8] These procedures are summarized below.

Figure 2 illustrates the results of segmentation of the sound and instrumented root canal volumes (RCVs). For the calculation of accumulated debris, a higher segmentation value was selected (70) in the instrumented specimens' stacks to keep the debris (which has a slightly lower gray value than the resin compacted at the root structure) in the segmentation result. After this step, this set of images was subtracted from the volume of the instrumented canal to give the volume of accumulated debris inside the root canal.

To calculate the removed root material volume (RRMV) from the canal during the instrumentation procedures, the sound canal volume was subtracted from the instrumented canal volume; whereas, for the calculation of the non-instrumented areas, the opposite was done (the instrumented canal volume was subtracted from the sound canal volume). All volumetric calculations were performed in the FIJI software with the aid of the 3D Object Counter plugin.[16] Figure 2 illustrates these methodological steps.

Furthermore, for the comparison of the amount of non-instrumented areas after obtaining the volume of images, these values were calculated in terms of the percentage of external surface of canal walls that were untouched by the instrument. For this purpose, first, the number of surface voxels corresponding to the external contours of the sound canal was obtained in the sound root canal stacks through the 3D Object Counter plugin. Considering this value as 100% of canal walls, the percentage of non-instrumented areas was calculated using the number of surface voxels obtained after the arithmetic operation described above for obtaining the non-instrumented volumes (Figure 2).

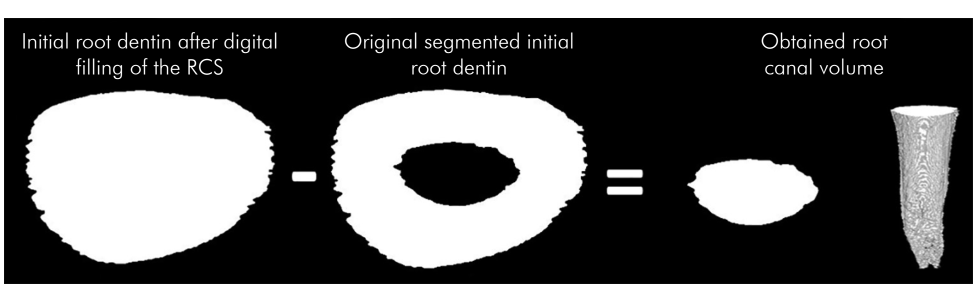

Figure 1. Depiction of the method used to obtain the sound root canal volume through arithmetic operations from baseline and instrumented stacks.

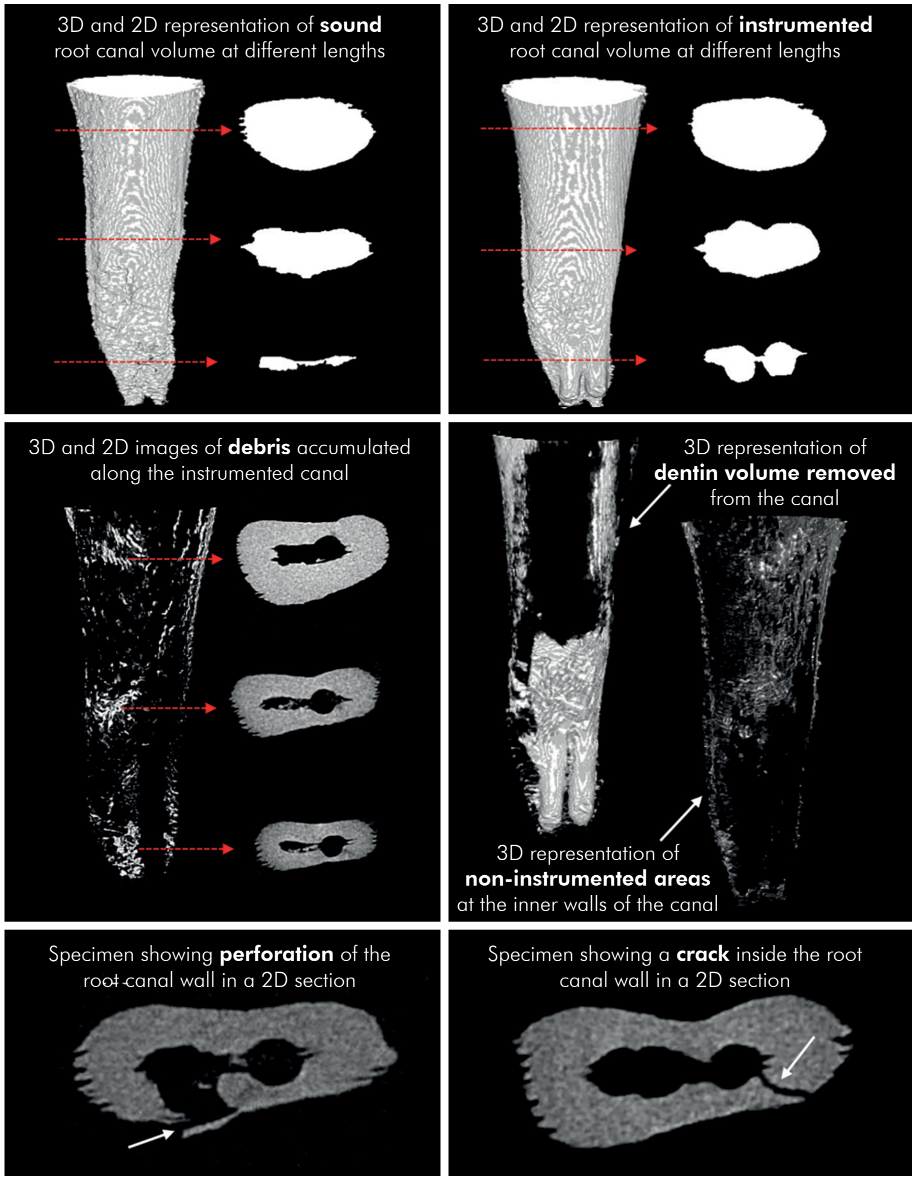

Figure 2. Representative 2D and 3D images of sound and instrumented canals, mechanical outcomes (accumulated hard tissue debris, removed root material volume, and non-instrumented areas) and the type of defects evaluated in the present study.

Cracks and perforations were detected in each instrumented specimen by checking the 2D slices for each of the instrumented stacks of images and recorded at the specimen level, if they were not present at the baseline volume.

Statistical analysis

All data were inserted in the SPSS 21.0 software (IBM, Chicago, USA) to be analyzed. The Shapiro–Wilk test was applied to verify the normality of the data. Considering the significant difference in the variance of the data, a non-parametric analysis was applied to compare the means of the initial and final canal volume, accumulated debris, RRMV, and percentage of the non-instrumented areas among the instrumentation groups. A significance level of 5% was considered for all analysis and the effect sizes for the significant associations were reported since *a priori* sample size calculation was not feasible due to the lack of studies with similar designs. The effect size for Wilcoxon signed-rank test was reported as *r* (correlations) using the formula and thresholds described for Cohen's effect size: 0.10 = small; 0.30 = medium; and 0.50 = large.[17] The effect size for Kruskal–Wallis test was estimated with the generalized eta square (η^2) using the formula and thresholds as described previously (0.02 = small; 0.13 = medium; and large = 0.26).[17]

The presence of cracks and/or perforations along the canal was recorded, followed by a qualitative description of its presence.

Results

No statistically significant difference was observed in sound RCVs among the experimental groups (Table 1). After instrumentation, all experimental groups showed a statistically significant increase (with a large effect size; r = 0.63) in the instrumented RCVs when compared to sound values. However, among them, only the increase caused by HFs was significantly different from the other experimental groups (with a medium effect size; η^2 = 0.18) (Table 1).

With respect to the total accumulated debris, WOG and XPS resulted in significantly higher values than HFs, XPF, and XPC (Table 2, Figure 3), although this effect was especially disclosed at the medium-third of the root canal (Figure 4). At the apical third, WOG revealed significantly greater accumulated debris than the other experimental groups (with a large effect size; η^2 = 0.45) (Figure 4).

The mean RRMV from the whole root canal length was significantly higher in the HF group, with XPC also showing high values that were, however, only significantly higher than XPF (Table 2). Analysis among the root thirds disclosed that HFs could remove most root materials from the medium and apical regions (large effect size; η^2 = 0.28 and 0.32; Figure 4); whereas, XPC showed a more homogeneous root material removal along the root canal (Figure 4). On the apical third, HFs showed significantly higher RRMV when compared to all the other systems (Figure 4), with a large effect size (η^2 = 0.32).

With respect to the presence of non-instrumented areas, HFs and XPC showed significantly lower values when compared to the other groups (medium effect size; η^2 = 0.18; Table 2). This effect was more

Table 1. Mean (±SD) sound and instrumented root canal volume (RCV) among the experimental groups.

Experimental gGroups	Mean sound RCV (mm3)	Mean instrumented RCV (mm^3)
Hand files	22.08 (± 2.05) $^{A, a}$	25.63 (± 2.05) $^{B, a}$
WaveOne® GOLD	21.75 (± 2.23) $^{A, a}$	23.17 (± 2.12) $^{B, b}$
XP-Endo® Shaper	20.38 (± 2.70) $^{A, a}$	21.83 (± 2.23) $^{B, b}$
XP-Endo® Finisher	20.96 (± 2.55) $^{A, a}$	22.06 (± 2.99) $^{B, b}$
XP Clean	20.54 (± 1.55) $^{A, a}$	22.74 (± 1.06) $^{B, b}$
Effect size among the rows	-	η^2 = 0.18 (medium)

*Different superscript uppercase letters indicate statistical difference ($p < 0.05$) within the columns (Wilcoxon signed-rank test). Effect size (r) was 0.63 (large) for all comparisons. Different superscripted lowercase letters indicate statistical difference ($p < 0.05$) among the rows (Kruskal–Wallis test followed by Student–Newman–Keuls comparison).

Table 2. Accumulated debris after instrumentation, removed dentin volume, and percentage of non-instrumented areas among the experimental groups.

Experimental groups	Mean accumulated debris (mm^3)	Mean removed dentin volume (mm^3)	Mean non-instrumented areas (%)
Hand Files	0.05 (±0.04) ^{a}	2.90 (±0.39) ^{a}	16.83 (±7.85) ^{a}
WaveOne® GOLD	0.12 (±0.09) ^{b}	1.44 (±0.89) ^{b}	32.76 (±18.94) ^{b}
XP-Endo® Shaper	0.13 (±0.12) ^{b}	1.36 (±0.87) ^{b}	32.20 (±10.22) ^{b}
XP-Endo® Finisher	0.04 (±0.04) ^{a}	0.99 (±0.68) $^{b, c}$	33.54 (±18.07) ^{b}
XP Clean	0.02 (±0.03) ^{a}	1.76 (±1.03) $^{b, d}$	16.96 (±10.07) ^{a}
Effect size	η^2 = 0.23 (medium)	η^2 = 0.31 (large)	η^2 = 0.18 (medium)

*Different superscripted lowercase letters indicate statistical difference ($p < 0.05$) within the columns (Kruskal–Wallis test followed by Student–Newman–Keuls comparison).

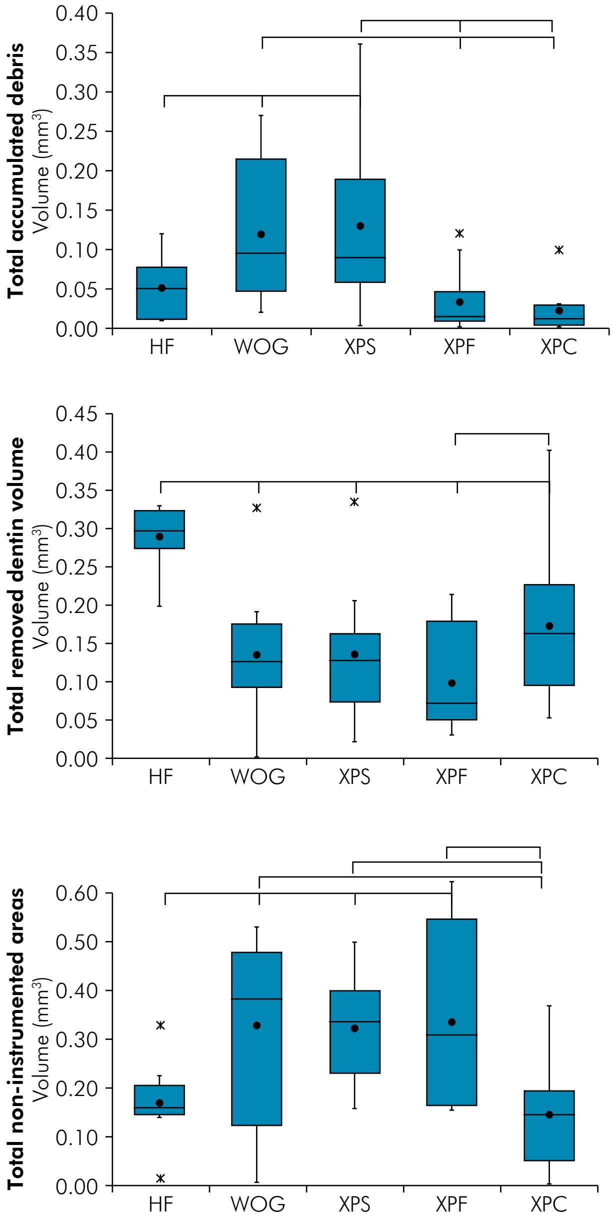

Figure 3. Quantitative results of the mechanical outcomes of instrumentation (accumulated hard tissue debris, removed root material volume, and non-instrumented areas) for all root canal lengths, according to the different instrumentation techniques.

evident in the medium-third of the RC (Figure 4). In the apical portion, XPF also showed a low percentage of non-instrumented areas similar to HFs and XPC (Figure 4).

As shown in Table 3, only five prototypes showed cracks (three in the HF group and two in the WOG group). Root perforation was only observed in three specimens of the HF group, and from these, one also had cracks. All cracks and root perforations occurred in the apical third of the roots.

Figure 5 depicts the volumetric renderings of the studied mechanical outcomes of representative specimens from each of the experimental groups.

Discussion

In the present study, the effectiveness of some rotary systems on prototyped primary maxillary incisors was compared to the use of HFs. Several studies in the literature have presented with good outcomes when the rotary systems were used in root canal instrumentation of primary teeth.[18-21] However, no tomography-based study on the effectiveness of these systems on anterior primary teeth has been published so far.

For this reason, *a priori* sample size calculations were impaired. No studies involving similar specimens (of anterior primary teeth), similar experimental technique (*i.e.*, tomography-based), or similar mechanical outcomes (*i.e.*, accumulated intracanal debris, RRMV, or non-instrumented areas) have been identified so far. Hence, the choice of 10 specimens per group was based on empirical judgment, previous experience, and the consideration of complete homogeneous specimen anatomy among the experimental groups, in the light of previous studies on anterior permanent teeth.[22, 23]

In this study, WOG instrumentation provided more accumulated hard tissue debris inside the RC, especially at the apical portion, which partially corroborates with the findings of a previous study that also evaluated accumulated debris inside the RC in primary molars by using scanning electron microscopy.[24] However, when the extrusion of apical debris was quantified, others could detect further extrusion of debris by HFs when compared to that by mechanical files in primary molars.[25, 26] The similarity for debris resulting from WOG and XPS was noted in the present study, which conforms to the findings of permanent teeth.[27] Therefore, it is important to emphasize that the quantification of accumulated intracanal debris in the present study may have been overestimated for all experimental groups, since the chemical effect between the irrigation solution and the

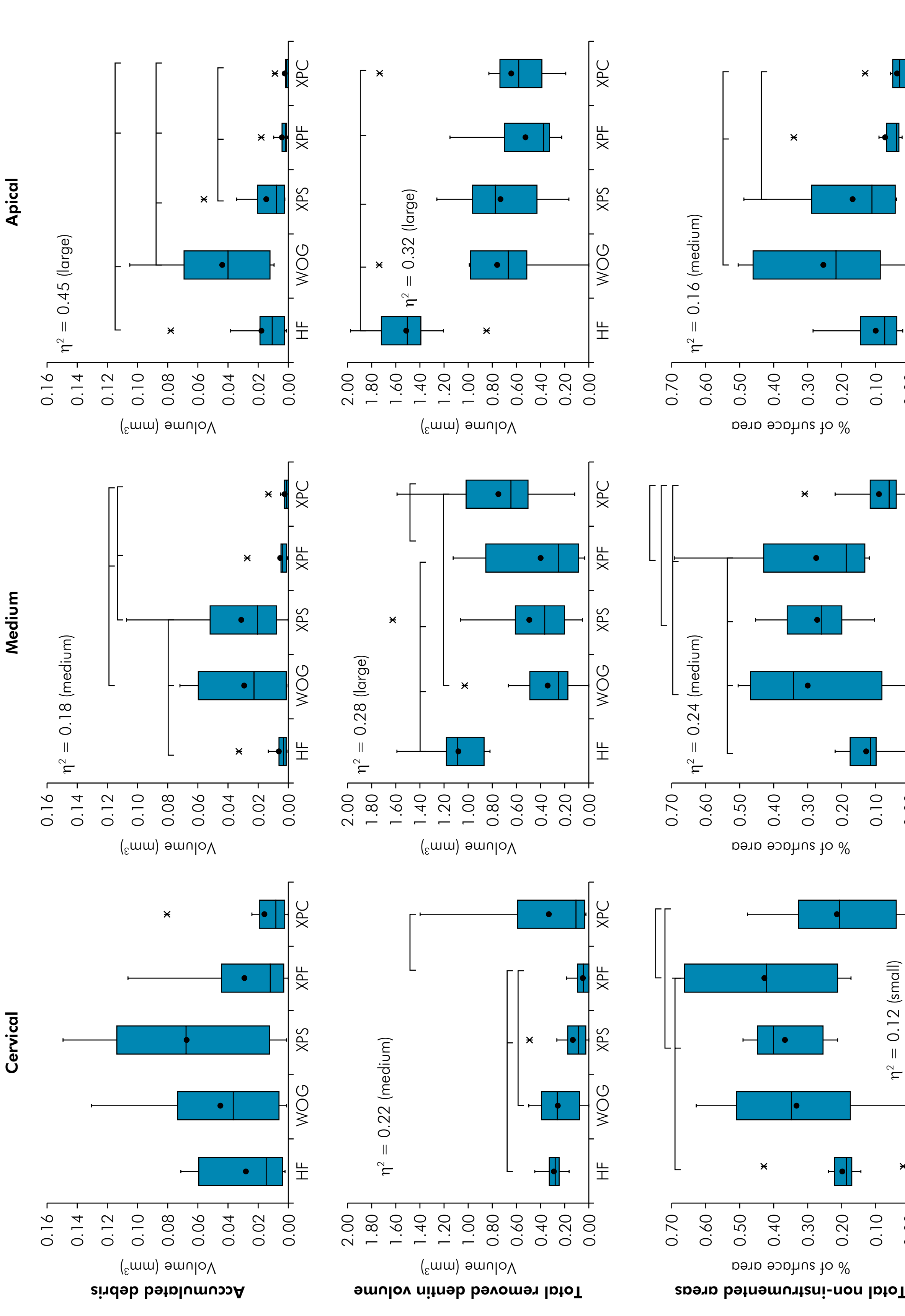

Figure 4. Mechanical outcomes of instrumentation (accumulated hard tissue debris, removed root material volume, and non-instrumented areas) at different root canal levels (*i.e.*, cervical, medium, and apical), according to the different instrumentation techniques.

Table 3. Distribution of specimens, showing cracks and perforations after instrumentation, among the experimental groups.

Groups	Cracks %(n)	Perforation % (n)
Hand Files	30 (3)	30 (3)
WaveOne® Gold	20 (2)	0
XP-Endo® Shaper	0	0
XP-Endo® Finisher	0	0
XP Clean	0	0

dentin tissue[28] was not detected in the experimental model used in the present study.

The RRMV was greater in the present study when HFs were used when compared to that estimated by using mechanical instruments. However, the available published tomography-based studies on primary teeth (all undertaken in molars) have reported mixed outcomes; whereas, some studies have reported more dentin removal with HFs as compared to that by the mechanical systems,[29,30] while others have

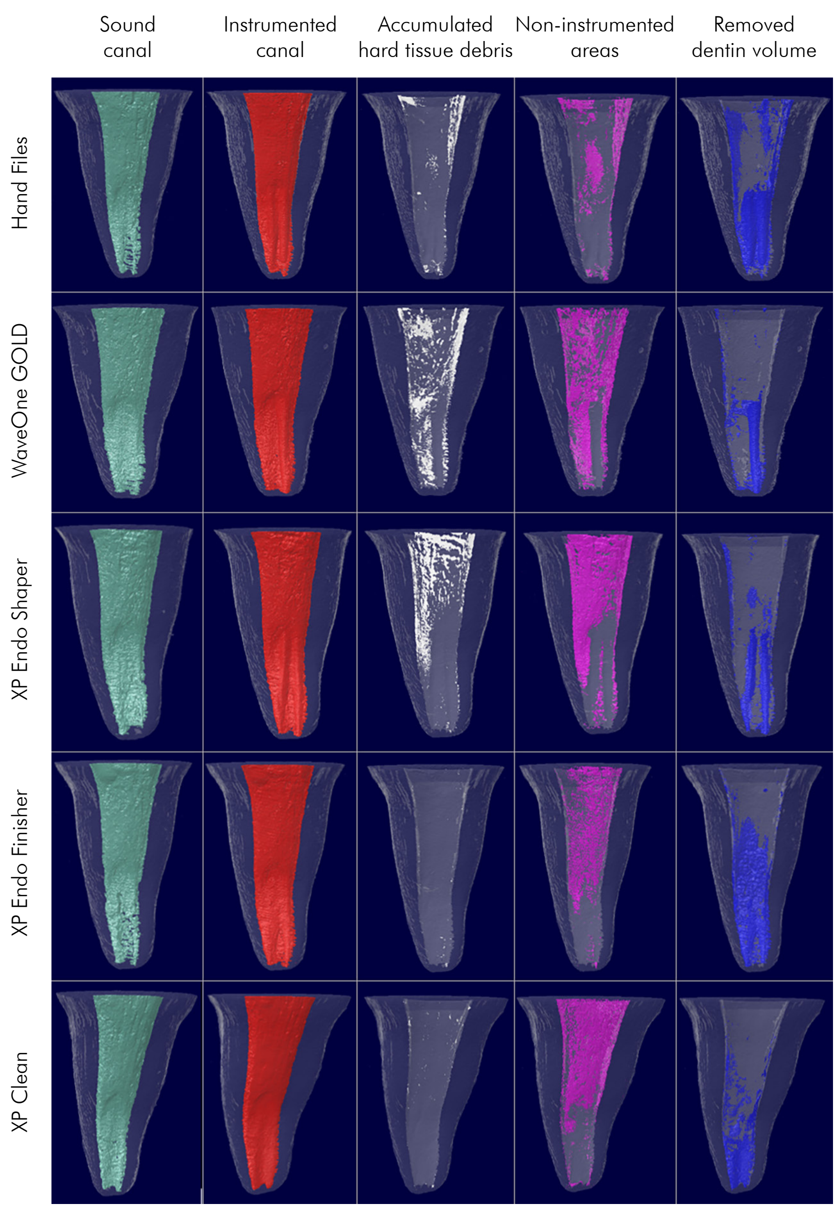

Figure 5. Three-dimensional renderings of the evaluated mechanical outcomes of a representative specimen from each instrumentation group.

reported mechanical systems that resulted in more dentin removal,[31,32] either by using conventional or reciprocating movements. This divergence of results may be attributed to the lack of adequate pairing of RC anatomy in the past studies; however, in the present study, this was a well-controlled parameter. The prototypes reproduced the same RC anatomy, and the similarity in the baseline RCVs among the groups confirmed this fact. We rather attributed the increased RRMV observed for HFs (especially in medium and apical thirds) to the instrumentation technique used (step-back), where the increased diameter files were worked from the apex to up to 3 mm toward the medium-third of the RC (thereby varying the final instrumented taper), while the mechanical instrumentation in this study employed a single-file (and hence, a single-taper) system.

The percentage of non-instrumented areas of the canal in this study is in agreement with that reported by other studies performed on permanent teeth[10,13,33,34] and by a pilot study using a reciprocating file system in prototypes of a primary incisor.[12] Unfortunately, no published studies on primary teeth are available with which the results of the present study can be compared. Similar to the results obtained for permanent teeth, mechanical instrumentation does not replace chemical disinfection of RC in primary teeth, since the non-instrumented areas represent biofilm-covered surfaces with the potential to cause reinfection.

The root canals of maxillary primary teeth are generally readily accessible, and its ribbon-shaped anatomy could be a disadvantage to the use of conventional or reciprocating file movements, as considerably non-instrumented areas are present at the sides of the root canal.[23] This information was corroborated by the present results, with WOG showing high values for the non-instrumented areas. Interestingly, XPS also resulted in high values of the non-instrumented areas; however, for this group, they were more frequently inclined toward the coronal area. On the other hand, for WOG, they were spread throughout the RC length. As the cutting and shaping abilities of the endodontic instrument are less important than the cleaning and disinfection abilities of the chemo-mechanical preparation and the frequent use of obturation materials with antibacterial properties in primary teeth, asymmetric movement finishing files, with their less invasiveness, may offer an advantage in this regard.

In this context, the XPF has been introduced as a new concept of finishing file that can be used after the root canal instrumentation, as the final step to improve cleaning while conserving dentin. According to the manufacturer, it changes its shape. At room temperature (the martensitic phase), the file stands straight, but when submitted to the body temperature, its final 10 mm assumes a "spoon shape" (the austenitic phase). This file has been shown to effectively remove accumulated hard tissue debris and the smear layer from the root canal system of permanent teeth.[35,36] The XPC, with its long axis "snake-type" design, shares similar cleaning indications with XPF, albeit different mechanical properties.[37] In the present study, a lower percentage of non-instrumented areas was noted after XPC use when compared to that for the other rotary systems; however, a small compromise in RRMV was noted in the apical third (*i.e.*, increased value compared to XPF). XPC also resulted in extremely low accumulated hard tissue debris inside the root canal. For these reasons and the added possibility of considerably reducing treatment times, this finishing file may demonstrate a significant potential for effective and simplified RC instrumentation of the primary anterior teeth. The less-than-ideal results of XPF, especially regarding the presence of non-instrumented areas in the present study may have been influenced by the heat-induced phase transformation suffered by this file, which was probably not ideally reproduced in the present study.

Perforations and cracks occurred mostly with HFs, followed by WOG instrumentation. This finding corroborates with previous evidence on the safety of mechanical instrumentation in primary molars.[4,5,20,21] However, it has also been acknowledged that the operator's strength may influence its occurrence. Therefore, it is important to mention that the prototypes used in the present study did not share the same mechanical properties as the RC dentin of primary teeth. The difference in elastic modulus between the resin prototype material (2GPa)[12] and primary root dentin (11.6GPa)[38] indicates that the prototype can probably sustain higher elastic deformation than primary root dentin, which is at least five times stiffer. Crack formation in primary root dentin, in response to mechanical instrumentation, can occur more promptly than that recorded in the present study.

Other limitations of the study should also be acknowledged. For instance, this study was performed on artificial teeth, which certainly do not represent the biological interactions occurring between dentin and endodontic instruments or solutions. A laser stereolithographic printing technique was used to produce the specimens,[12] but the small defects caused by printing resolution inaccuracies could still be identified at the external specimen surface and at the internal root canal surface (Figure 2). These defects, however, were not believed to have significantly influenced the results since they were detected both on the baseline and the instrumented image volume pairs. Therefore, with the exception of the non-instrumented area calculations, they were not included in the outcome calculations. For the non-instrumented areas, we considered that a standard error could have been equally included among all the specimens, with a low impact on the outcomes.

Finally, although the most indicated file size and tapers belonging to each instrumentation system were selected to fit the experimental model, it is acknowledged that the compared files showed some differences with regard to the size and tapers. The rationale for selecting these instruments/tapers are based on the evidence suggesting that the minimum apical taper instrumentation for primary incisors lies between #40 and #50 (K-files),[39,40] which is also the reason for the use of HF#45 in this study. With respect to the reciprocating movement, a previous study showed that the R40 file has been the most suited one for apical preparation of the prototype used in the present study, which offers the best compromise between dentin removal, non-instrumented areas, and the presence of debris.[12] Among the reciprocating files present on the system used in this study, the WOG#45/0.05 was the most matching one. As for the other instruments used (*i.e.*, XPS, XPF, and XPC), all employed asymmetric movement kinematics and also focused more on "cleaning" than on "shaping," and smaller tapers were deemed necessary to achieve the appropriate movement amplitude inside the root canal. However, as the main comparison presented was between the types of instrumentation movement, the conclusions of the present study could be used to substantiate further investigations on root canal instrumentation of primary teeth.

Conclusions

The asymmetric movement rotary systems demonstrated improved mechanical outcomes in prototyped primary maxillary incisors, including a more conservative root material removal and fewer iatrogenic errors such as cracks and perforations, as compared to instrumentation with manual files and a reciprocation system. From the mechanical asymmetrical systems, XPC provided a good compromise between dentin removal and the percentage of non-instrumented areas with a low accumulation of hard tissue debris inside the root canal.

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