Comparative study of root canal mechanical preparation with two systems with different kinematics. Ex vivo micro-CT study

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ABSTRACT

*Oval and ribbed root canals present a major challenge in endodontic treatment due to their complex anatomy, which fosters the accumulation of debris and bacteria. Mechanical preparation systems have been developed to improve shaping efficiency and canal centricity in these anatomically complex canals. **Aim:** To compare, using micro-computed tomography, pulp space volume increase, untouched canal surface area, and apical transportation in oval root canals prepared with WaveOne Gold (WOG) or XP-endo Shaper (XPS). **Materials and Method:** 30 extracted single-rooted upper second premolars with oval root canals were randomly divided into two experimental groups and instrumented with WOG (n: 15) or XPS (n: 15). All specimens were scanned with micro-CT (SkyScan 1272; Bruker-microCT) for comparison before and after instrumentation using the following acquisition parameters: 19µm voxel, 30 kV, 800 mA, 0.6° rotation step, 360° rotation and 1 mm thick aluminum filter. Initial and final volumes, surface areas and centricities were analyzed to calculate pulp space volume increase, untouched surface area and transportation. Data were analyzed using paired Student's t-tests, Wilcoxon signed ranks or Mann-Whitney U tests, as appropriate (p < 0.05 significant). **Results:** There was no significant difference between WOG and XPS in pulp space volume increase (p=0.26) or untouched surface area (p>0.99). However, there were significant differences in centricity on the X and Y axes (p<0.05), while on the Z axis, the differences were not significant (p=0.05). **Conclusion:** WOG and XPS had similar shaping effectiveness. All files were able to clean and shape moderately curved canals with minimal apical transportation.*

***Keywords:** x ray micro-CT - mechanical preparation - transport - shaping ability - root canal preparation*

Estudio comparativo de preparación mecánica con dos sistemas de diferentes cinemáticas. Evaluación ex vivo mediante micro-CT.

RESUMEN

*Los conductos radiculares ovalados y con irregularidades son un desafío importante en el tratamiento endodóntico debido a su anatomía compleja, que favorece la acumulación de detritus y bacterias. Con el objetivo de mejorar la eficiencia del modelado y el centrado del conducto, se han desarrollado distintos sistemas de preparación mecánica para abordar estos conductos anatómicamente complejos. **Objetivo:** comparar mediante micro-CT el incremento de volumen del espacio pulpar, superficie no tocada y transporte apical producido en conductos ovalados tratados con: WOG o XPS. **Materiales y métodos:** fueron utilizados 30 segundos premolares superiores unirradiculares ovalados, divididos aleatoriamente en dos grupos experimentales instrumentados con: WOG (n:15) y XPS (n:15). Todas las muestras fueron escaneados con micro-CT inicial y post-instrumentación (SkyScan 1272; Bruker-microCT) utilizando parámetros de adquisición: vóxel 19µm, 30 kV, 800 mA, paso de rotación de 0,6°, rotación de 360° y filtro de aluminio de 1 mm de espesor, para ser comparadas entre sí. Se analizaron los volúmenes, superficies y centricidades iniciales y finales para calcular el incremento de volumen del espacio pulpar, superficie no tocadas y transporte. Los datos se analizaron mediante las pruebas t-Student apareada, de los rangos con signos de Wilcoxon o U de Mann-Whitney, según lo que correspondía (p< 0,05 significativo). **Resultados:** No hubo diferencias significativas entre WOG y XPS en el incremento de volumen del espacio pulpar (p=0,26) y superficie no tocada (p>0,99). Sin embargo, sí hubo diferencias significativas en la diferencia de centricidad en los ejes X e Y (p<0,05). En el eje Z, las diferencias no llegaron a ser significativas (p=0,05). **Conclusión:** WOG y XPS tuvieron efectividad de modelado similar. Todas las limas utilizadas fueron capaces de limpiar y dar forma a conductos moderadamente curvados con un mínimo transporte apical.*

***Palabras clave:** micro-CT - preparación mecanizada - transporte - desgaste - preparación del conducto radicular*

INTRODUCTION

The purpose of endodontics is to cure or prevent infectious pathologies of the periapical tissues. During the mechanical preparation of the root canal, no instrument can reach all the multiple irregularities of the internal anatomy, and there may remain untouched areas that harbor organic tissue debris and bacteria. Thus, the chemical action of irrigant solutions is essential to reach an adequate level of conformation and disinfection, facilitating a good three-dimensional seal[1,2]. This is especially important in the preparation of root canals that are not circular in section[3].

Oval and ribbed canals present a challenge in endodontics because their complex anatomy fosters the accumulation of detritus and bacteria. The prevalence of this kind of anatomy is one third of teeth in their apical portion, being more frequent in incisors and lower second premolars[4].

In search of a more centered conformation, with minimum deviations from the main axis of the canal and greater respect for the internal anatomy, the metal alloys used in the systems may be subjected to any of several thermal treatments, and can also present different kinematics such as rotation, oscillation, reciprocating movement, and other adaptive forms[1,2,5,6].

Single file systems, which considerably reduce treatment time, subject each instrument to a high level of cyclic and torsional fatigue. Reciprocating systems have a longer service life than continuous rotation systems[7].

Among the continuous rotation systems is the XP-endo Shaper (XPS) (FKG Dentaire, La Chaux-de-Fond, Switzerland). Its serpentine dynamics and MaxWire alloy body give it superelasticity and shape memory, enabling it to adapt to the three-dimensionality of the canal due to variations caused by temperature changes, thereby improving cleaning and shaping during instrumentation[2,5,8].

Reciprocating kinematics provide an alternative technique to continuous rotation, based on the technique of manual instrumentation of balanced forces, which generates less anatomical distortion and reduces the risk of instrument fracture due to cyclic fatigue[2]. It consists of an oscillatory movement in which the instrument rotates and counter-rotates with different degrees of rotation[7]. This system includes the Wave-One Gold (WOG) (Dentsply Maillefer, Ballaigues, Switzerland), a single file

system with surface heat treatment on its gold metal alloy. It has an off-centered parallelogram cross-section with two 85° cutting edges. According to the manufacturer's instructions, it is used with pecking and planing movements[5,8].

X-ray microtomography (Micro-CT) is one of the most accurate methods for the investigation of root canal morphology, being non-invasive, non-destructive and reproducible[8]. It has been used in several studies to compare instrumented vs. non-instrumented areas of different mechanical preparation systems, often on oval internal anatomy[2-4,6,9-11].

The aim of the current study was to compare, by means of X-ray microtomography, the volume increase, uninstrumented surface area, and apical transport produced in oval root canals treated with the WOG or XPS systems.

MATERIALS AND METHOD

Thirty extracted single-rooted second upper premolars were selected according to the following inclusion criteria: single oval canal (type I classification according to Vertucci), complete apexogenesis, and curvature angles between 5° and 15° (mild grade according to Schneider). To corroborate this, a radiovisiograph (Kodak RVG 6100, Kodak) was used and two projections were made for each specimen: buccolingual and mesiodistal.

The specimens were standardized with an axial cut 19 mm in length from the anatomical apex. The selected teeth were stored in a 50% glycerin – 50% alcohol solution, following the methodology used in the Endodontics Department of the School of Dentistry of the University of Buenos Aires.

After standardization of the specimens, an initial microtomographic X-ray scan (SkyScan-1272; Bruker, USA) was performed using the following acquisition parameters: $19 \mu m$ voxel (resolution), 30kV (current), 800mA (voltage), 0.6° rotation step, 360° rotation around the vertical axis and 1mm thick aluminum filter. The acquired projections were reconstructed using NRecon software (Ruker, Kontich, Belgium). The specimens were randomly divided into two experimental groups to be instrumented with two different systems: group WOG (n=15) and group XPS (n=15).

Instrumentation was performed according to the protocol used in Endodontics Department of the

School of Dentistry of the University of Buenos Aires, and according to the manufacturer's indications for each system.

Subsequently, the samples were scanned again with the same initial parameters. The images were analyzed individually and in a geometric overlay of the pre- and post-instrumentation images with the visualization software Data Viewer v.1.5.1, (Bruker, Kontich, Belgium). Morphometric analysis of the images was performed using the CTan v.1 .14.4 software (Bruker, Kontich, Belgium) analyzing, for the whole canal: 1) Initial dentin volume (VID, mm^3); 2) Final dentin volume (VFD, mm^3); 3) Initial dentin surface (SID, mm^2); 4) Final dentin surface (SFD, mm^2); 5) X, Y, Z centroid pre-instrumentation (mm) and 6) X, Y, Z centroid post-instrumentation (mm). The following variables were calculated:

Endodontic space volume increases according to Gambril et al.[12]

$$\textbf{\textit{Volumetric increase \%}} = \frac{\textbf{\textit{Final volume}} \times \textbf{\textit{100}}}{\textbf{\textit{Initial volume}}}$$

The surface area of the uninstrumented endodontic space according to Gambril et al.[12]

$$\begin{array}{l}\textbf{\textit{Uninstrumented}} \\ \textbf{\textit{surface area \%}}\end{array} = \frac{\textbf{\textit{Uninstrumented surface}}\ \textbf{\textit{area}} \times \textbf{\textit{100}}}{\textbf{\textit{Final surface area}}}$$

Transportation was measured by means of the difference in position between the pre- and post-instrumentation centroids on each axis (X, Y, Z) according to Morales et al.[13] Negative numbers represented deviation in the mesial direction, while positive numbers represented deviation in the distal direction.

STATISTICAL ANALYSIS

The data sets were described by the following measures: minimum (Min), maximum (Max), mean, standard deviation (SD), median, first quartile (Q$_1$) and third quartile (Q$_3$). To compare two paired data sets, paired Student's *t*-test was used when the normality condition was met; otherwise, Wilcoxon signed-rank test was used. To compare two grouped data sets, the nonparametric Mann-Whitney U test was used. The parametric pooled *t*-Student test was

not used because the conditions of normality or homoscedasticity were not met. The assumptions of normality and homoscedasticity were analyzed using the Shapiro Wilk test with modifications, and the F test, respectively. In all inference tests, differences were considered significant when the p-value was less than 0.05 (p<0.05). The InfoStat v. 2020 program[14] was used.

RESULTS

With both systems, endodontic space volume increased significantly after instrumentation (Table 1). With the WaveOne Gold system (WOG), the median (Q1/Q3) pre-and post-instrumentation volumes (mm^3) were 7.68 (2.60/8.26) and 8.84 (7.79/9.70), respectively (Wilcoxon signed-rank: Z=-3.72; p<0.05); and with the XpShaper system (XPS), they were 5.50 (4.68/13.39) and 12.63 (7.87/17.75), respectively (ranges with Wilcoxon signed-rank: Z=-3.41; p<0.05).

The results for pulp space surface area were analogous to those found for volume. With both systems, the surface areas increased significantly after instrumentation (Table 2). With the WOG, the median (Q$_1$/Q$_3$) surfaces (mm^2) pre- and post-instrumentation were 50.63 (41.77/61.32) and 61.30 (60.84/62.50), respectively (Wilcoxon signed-rank: Z=-3.59; p<0.05); with XPS, they were 73.17 (51.68/78.77) and 92.37 (75.20/98.68), respectively (ranges with Wilcoxon signed-rank: Z=-3.41; p<0.05).

After the analysis of volume and surface area between instances, calculations were made to compare the percentage increase in pulp space volume and surface area after instrumentation between the two systems.

Regarding the percentage increase in pulp space volume, there was no statistically significant difference (Mann-Whitney U: W=286.00; p=0.26) (Table 3) between the two experimental groups: the median (Q$_1$/Q$_3$) was 33.49% for WOG (15.66/150.00), and 43.02% for XPS (31.81/50.69). For the untouched surface after instrumentation (Fig. 1), there was no statistically significant difference (Mann-Whitney U: W=255.00; p>0.99) (Table 4) between the two experimental groups: the median (Q$_1$/Q$_3$) was 81.45% for WOG (68.86/92.23), and 79.72% for XPS (77.18/80.13).

Table 1. Volume of the pulp space according to the system used, before (Pre) and after (Post) instrumentation.

System	Instance	Volume (mm^3)								p*
		n	Mean	SD	Min	Max	Median	Q$_1$	Q$_3$	
WOG	Pre	15	6.10	2.92	1.47	8.80	7.68	2.60	8.26	<0.05
	Post	15	9.04	1.79	6.50	12.31	8.84	7.79	9.70	
XPS	Pre	15	8.71	4.80	4.36	15.61	5.50	4.68	13.39	<0.05
	Post	15	13.03	5.47	6.57	20.35	12.63	7.87	17.75	

Wilcoxon signed-rank test

Table 2. Pulp space surface according to the system used, before (Pre) and after (Post) instrumentation.

System	Instance	Surface (mm^2)								p*
		n	Mean	SD	Min	Max	Median	Q$_1$	Q$_3$	
WOG	Pre	15	52.55	19.05	25.44	85.46	50.63	41.77	61.32	<0.05
	Post	15	69.30	25.77	46.05	124.08	61.30	60.84	62.50	
XPS	Pre	15	65.12	19.82	34.59	87.47	73.17	51.68	78.77	<0.05
	Post	15	84.12	23.23	44.72	109.63	92.37	75.20	98.68	

Wilcoxon signed-rank test

Table 3. Percentage increase in pulp volume after instrumentation, according to the system used.

System	Increase in volume (%)								p*
	n	Mean	SD	Min	Max	Median	Q$_1$	Q$_3$	
WOG	15	104.77	139.78	7.43	429.93	33.49	15.66	150.00	0.26
XPS	15	63.44	50.96	30.36	169.87	43.02	31.81	50.69	

Mann-Whitney U test

Centricity and Transportation

The centricities of the X, Y and Z axes were compared before (pre) and after (post) instrumentation in order to determine whether there is transportation in the canal. For the X axis, no statistically significant difference was found in the WOG group: the medians
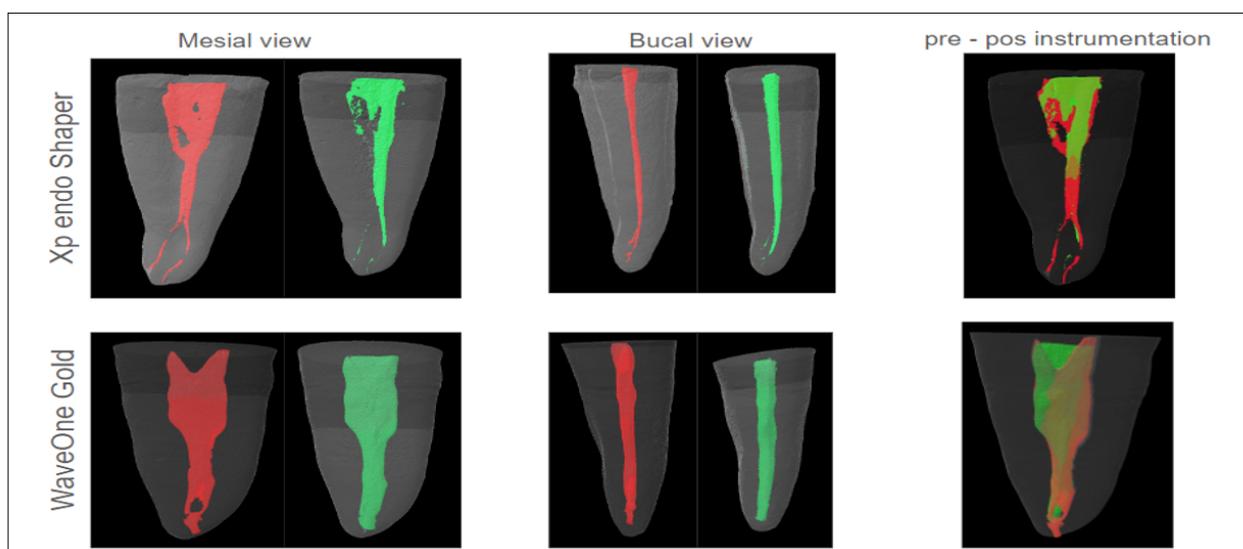

Fig 1: Microcomputed tomography images in mesial view, buccal view and overlay taken before (red) and after (green) the use of rotary and reciprocating instruments reveal areas that were not prepared (red).

Table 4. Percentage of untouched surface, according to the system used.

| System | Untouched surface (%) | | | | | | | p* |
| | n | Mean | SD | Min | Max | Median | Q₁ | Q₃ | |

System	n	Mean	SD	Min	Max	Median	Q_1	Q_3	p*
WOG	15	77.69	20.11	41.40	100.79	81.45	68.86	92.23	>0.99
XPS	15	78.00	13.36	56.00	97.30	79.72	77.18	80.13	

Mann-Whitney U test

(Q_1/Q_3) pre- and post-instrumentation were 8.43 (7.64/13.35) and 8.86 (5.77/12.40), respectively (paired t-Student: T=1.69; p=0.11). However, in the XPS group transportation before and after instrumentation differed significantly (Table 5), with medians (Q_1/Q_3) 5.70 (5.16/7.81) and 8.10 (6.46/12.97), respectively (Wilcoxon signed-rank: Z=-3.42; p<0.05).

As in the X-axis, for the Y-axis, no statistically significant difference was found in the WOG group: the medians (Q_1/Q_3) pre- and post-instrumentation (mm) were 8.40 (7.63/12.09) and 9.81 (5.92/12.91),

Table 5. X-axis centricity according to the system used, before (Pre) and after (Post) instrumentation.

System	Instance	X-axis (mm)							p
		n	Mean	SD	Min	Max	Median	Q_1	Q_3	
WOG	Pre	15	9.56	3.14	5.45	13.99	8.43	7.64	13.35	0.11*
	Post	15	8.75	3.69	3.87	12.78	8.86	5.77	12.40	
XPS	Pre	15	6.25	1.40	4.45	8.02	5.70	5.16	7.81	<0.05 **
	Post	15	9.38	3.11	6.26	13.07	8.10	6.46	12.97	

* t-Student paired
**Wilcoxon signed-rank test*

respectively (paired t-Student: T=-0.26; p=0.80). However, there was a statistically significant deviation for the XPS group after instrumentation (Table 6), where the medians (Q_1/Q_3) pre- and post-instrumentation (mm) were 5.51 (5.29/6.96) and 8.30 (6.31/13.66), respectively (Wilcoxon-signed rank: Z=-3.41; p<0.05).

For the Z axis, the results were inverse compared to axes X and Y: in the WOG group, statistically

Table 6. Y-axis centricity according to the system used, before (Pre) and after (Post) instrumentation.

System	Instance	Y-axis (mm)							p
		n	Mean	SD	Min	Max	Median	Q_1	Q_3	
WOG	Pre	15	9.08	2.82	4.87	13.10	8.40	7.63	12.09	0.80*
	Post	15	9.26	3.99	3.66	13.44	9.81	5.92	12.91	
XPS	Pre	15	6.06	1.02	4.91	7.66	5.51	5.29	6.96	<0.05**
	Post	15	9.67	3.51	6.11	13.99	8.30	6.31	13.66	

* t-Student paired
**Wilcoxon signed-rank test*

significant differences in centricity (mm) were found: the medians (Q_1/Q_3) pre- and post-instrumentation were 10.47 (4.77/15.03) and 8.80 (5.87/11.66), respectively (Wilcoxon signed-rank: Z=2.81; p<0.05). However, for the XPS group

there was no significant difference before and after instrumentation (Table 7), where the medians (Q_1/Q_3) were 7.46 (5.65/16.87) and 6.84 (5.94/17.64), respectively (ranges with Wilcoxon signed-rank: Z=-1.25; p=0.21).

Table 7. Centricity of the Z axis according to the system used, before (Pre) and after (Post) instrumentation.

System	Instance	Z-axis (mm)								p*
		n	Mean	SD	Min	Max	Median	Q_1	Q_3	
WOG	Pre	15	10.38	5.50	4.28	17.13	10.47	4.77	15.03	<0.05
	Post	15	8.78	3.57	4.19	13.36	8.80	5.87	11.66	
XPS	Pre	15	10.41	5.72	4.60	17.53	7.46	5.65	16.87	0.21
	Post	15	10.69	5.88	5.26	17.84	6.84	5.94	17.64	

Wilcoxon signed-rank test

Following the centricity comparisons before and after instrumentation of each system, we compared the centricity differences (transportation, mm) between the systems on each axis. On the X and Y axes, significant differences were found: the difference in centricity (mm) was greater with XPS than with WOG. On the X axis, the median (Q_1/Q_3) was -1.03 (-1.78/0.32) for WOG and 3.55 for XPS (1.17/5.05) (Mann-Whitney U: W=372.00; p<0.05; Table 8). On the Y-axis, the median (Q1/Q3) was 0.26 for WOG (-2.17/1.84) and 3.29 for XPS (0.94/6.11) (Mann-Whitney U: W=345.00; p<0.05; Table 8). On the Z-axis, the differences were not significant: the median (Q_1/Q_3) was -2.49 for WOG (-3.47/1.10) and 0.01 (-.039/1.06) for XPS (Mann-Whitney U: W=309.00; p=0.05; Table 8).

Table 8. Difference in centricity of the X, Y, Z axes post- and pre-instrumentation, according to the system used.

Axis	System n	Difference (mm)								p*
		Mean	SD	Min	Max	Median	Q_1	Q_3		
X	WOG	15	-0.81	2.03	-3.87	2.65	-1.03	-1.78	0.32	<0.05
	XPS	15	3.13	1.97	0.66	5.35	3.55	1.17	5.05	
Y	WOG	15	0.18	2.83	-3.87	4.74	0.26	-2.17	1.84	<0.05
	XPS	15	3.61	2.64	0.80	7.03	3.29	0.94	6.11	
Z	WOG	15	-1.60	2.27	-3.88	1.73	-2.49	-3.47	1.10	0.05
	XPS	15	0.28	0.79	-0.61	1.34	0.01	-0.39	1.06	

Mann-Whitney U test

DISCUSSION

This study evaluated canal preparation and transportation in extracted single-rooted upper premolar canals using different instruments. Despite the limitations for sample standardization, the use of extracted teeth remains the best option, since resin-fabricated teeth have a critical limitation in terms of the difference in hardness between dentin and resin[15]. To minimize the variables and achieve better standardization, the specimens were standardized with cuts from the apical limit up to 19mm towards apical, and randomly distributed, resulting in two groups without differences. However, previous "narrowing" of the canals was not taken into account, and this could have influenced the result, since the

mostly calcified canals could have shown increased volume. For future studies, it would be interesting to homogenize the sample by standardizing the volume previously. Ane Poly et al.[16], compared the same systems as in our study, and found better centering of XPS with respect to WOG but greater wear with the former. The differences in the results could be due to the fact that the authors measured the volumes of each canal prior to instrumentation by means of a fast X-ray scan.

In the current study, all specimens were handled by the same operator. In contrast, a study by Hofmann analyzing the centering ability of reciprocating instruments and using plastic plugs with curved root canals observed that significant differences between

operators contributed more to canal transport than did the file system itself[15].

Despite differences in cross-sectional design and kinematics that affect the shaping ability of NiTi preparation systems[17-20], we agree with Mamede-Neto I et al., Saberi E et al.[21] and Versiani et al.[17] that there were no significant statistical differences in wear and transportation between rotating and reciprocating systems.

Wu et al.[22] argued that apical canal transportation of less than 0.3 mm would have minimal impact on prognosis. Therefore, the quality of the images evaluated is crucial for the accuracy of the results. Although CBCT is known to produce less detailed images than micro-CT[23-26], CBCT has been used as an evaluation method in recent studies[27-29].

Recent studies with the same purpose and using micro-CT as a 3D evaluation method presented voxel sizes ranging from 20 to 22.8μm. As root canal anatomy gradually changes along the z-axis, a voxel size of 34μm was shown to provide acceptable image quality, while smaller voxel sizes provide greater accuracy for evaluating root canal preparation. The present study therefore used micro-CT as the 3D evaluation method, choosing a voxel size of 18μm with the aim of obtaining better image quality. However, Zanesco et al.[30] showed that the digital subtraction radiographic technique was reliable and there was no statistical difference with micro-CT images in apical transportation analysis.

CONCLUSION
WOG and XPS showed similar shaping effectiveness. All instruments were able to clean and shape moderately curved canals with minimal apical transportation. These results emphasize the relevance of adequate irrigation, since mechanical preparation alone does not ensure complete cleaning of the root canal system.

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