HHS Public Access
Author manuscript
Clin Oral Investig. Author manuscript; available in PMC 2020 December 15.

Published in final edited form as:
Clin Oral Investig. 2019 December ; 23(12): 4255–4262. doi:10.1007/s00784-019-02870-8.

Canal transportation and centering ratio after preparation in severely curved canals: analysis by micro-computed tomography and double-digital radiography

Ane Poly[1], **Fouad AlMalki**[2], **Fernando Marques**[1], **Bekir Karabucak**[2]

[1]Proclin Department, School of Dentistry, Rio de Janeiro State University, Boulevard 28 de Setembro, 157, Vila Isabel, Rio de Janeiro, RJ CEP: 20551-030, Brazil

[2]Department of Endodontics, School of Dental Medicine, University of Pennsylvania, 240 S 40th St, Philadelphia, PA 19104, USA

Abstract

Objectives—This study compared canal transportation and centering ratio produced after instrumentation with a single heat-treated reciprocating system, WaveOne Gold (WOG; Dentsply Sirona, Tulsa, OK, USA) and a single heat-treated rotary instrument, XP-endo Shaper (XPS; FKG, La Chaux-de-Fonds, Switzerland), using micro-computed tomographic (micro-CT) imaging, and evaluated the ability of double-digital radiography (DDR) to detect canal transportation.

Materials and methods—Mesial root canals of mandibular molars with severe curvature (25–70°) were randomly assigned to either WOG or XPS groups for preparation. Centering ratio was measured by micro-CT imaging, while canal transportation was measured by micro-CT and DDR methods at 3, 5, and 7 mm from the apex. Data were statistically compared between groups using the *t* test (α = 5%).

Results—The micro-CT method showed that XPS's shaping ability regarding the centering ability ($P = 0.030$) and canal transportation ($P = 0.028$) was significantly better than WOG only at the 7-mm level. The DDR technique detected no difference in canal transportation between groups at any level ($P > 0.05$); however, a significant difference between evaluation methods was detected at the 5-mm level in the WOG group ($P = 0.023$).

Conclusions—Micro-CT technique revealed a significantly better centering ability and less canal transportation with XPS compared to WOG. The DDR technique was not capable of detecting the significant difference between the tested groups.

Clinical relevance—Root canal curvatures may lead to procedural errors during endodontic treatment. Thus, differences on the shaping ability of single heat-treated reciprocating and rotary systems should be known.

Ane Poly, anepolyrocha@gmail.com.

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This study was approved by a panel from Pedro Ernesto University Hospital/Rio de Janeiro State University Ethical Committee (CAAE no. 62903316.3.0000.5259/CEP-HUPE).

Informed consent For this type of study, formal consent is not required.

Keywords

Canal transportation; Micro-computed tomography; Reciprocating motion; Rotary motion; Shaping ability; Single-file system

Introduction

The curvature of a root canal is considered a common anatomic challenge to an endodontic treatment [1]. The risk of straightening root canal and of apical transportation increases as the angle of curvature gets higher and the radius smaller [2]. Severe curvatures may lead to procedural errors such as the transportation or the straightening of the root canals and, consequently, to treatment failures [3]. Advancements in endodontic instruments with high flexibility and better cyclic fatigue resistance have been made to prevent procedural errors [4].

WaveOne Gold (WOG; Dentsply Sirona, Tulsa, OK, USA) is a system of files designed to operate with a reciprocation motion, made from a metal called gold wire, subsequently, heat-treated after manufacturing [5]. The triangular convex cross-sectional design of the WOG instruments is an offset parallelogram with two cutting edges resulting in only one or two points of contact between the cutting edges and the canal wall. This unique design results in improved efficiency and in fracture resistance [6].

XP-endo Shaper (XPS; FKG, La Chaux-de-Fonds, Switzerland) has a size 30 and 0.01 taper and is manufactured from NiTi MaxWire alloy. The XPS is in the martensitic phase at 20 °C, and it transforms to the austenitic phase when placed intracanal (37 °C). The file tip (Booster Tip) has six cutting edges that enable the instrument to start shaping gradually from sizes 15 to 30, maintaining the instrument centered and avoiding the straightening of the root canal [7]. XPS design has also shown good efficiency and fracture resistance [8].

There are no studies available comparing the shaping ability of gold wire heat-treated WOG and the MaxWire heat-treated XPS in severely curved canals using micro-CT. Until the present moment, there is only one study evaluating centering ability and canal transportation of XPS and comparing it to Wave One (Dentsply Sirona) and Oneshape (Micro Mega, Besancon, France) systems [7]. However, cone beam computed tomography (CBCT) was used as a method of evaluation, which produces images with fewer details than micro-CT [9-12].

Therefore, the objectives of this ex vivo study were (1) to evaluate the shaping ability, mainly, canal centering ratio and transportation caused after the instrumentation of severely curved root canals with a rotary (XPS) and a reciprocating (WOG) single-file systems using micro-CT imaging; (2) to compare the ability of double-digital radiographic (DDR) technique and micro-CT imaging to identify canal transportation.

Materials and methods

Sample size estimation

The sample size was calculated based on a previous study [7]. A given 1.93 effect size was input together with an alpha-type error of 0.05 and a power beta of 0.95 into an a priori independent samples test from the *t* tests family (G*Power 3.1.9.3 for Macintosh; Heinrich Heine, Universität Dusseldorf, Dusseldorf, Germany). The results demonstrated the need for a minimum of nine specimens per group.

Sample selection

The research protocol was approved by the Ethics in Human Research Committee. One hundred and thirty permanent mandibular first and second molars extracted for reasons not related to this study were selected. The teeth were decoronated approximately 3 mm above the cementoenamel junction (CEJ), and distal roots were resected. Mesial roots with fractures, cemental-dentinal defects, internal calcifications, or artificial alterations were excluded. Each mesial root was radiographed in the mesiodistal direction, to detect anatomies with two separated canals, and buccolingual direction, to determine the angle and radius of curvature according to the Schneider method [13] (AutoCAD 2015 software; Autodesk, San Rafael, CA). Mesial roots with severe curvature (25–70°) [13]; $4 < r \leq 8$ mm main curvature radius [14, 15]; and a point of maximum curvature located within the middle third of the root canal were selected. Apical patency was confirmed by inserting a size 10 K-File into the root canal until its tip was visible at the apical foramen; the working length (WL) was established by deducting 0.5 mm from the canal length and a glide path was created by scouting a stainless steel size 15 K-File up to the WL.

The specimens were scanned using a micro-CT system (vivaCT-40, Scanco Medical, Bassersdorf, Switzerland) at 15 µm nominal voxel size, 55 kVp energy, and 145 µA intensity, with an integration time of 300 ms. The acquired projection images were reconstructed, and preoperative 3D models were rendered by Scanco software (Scanco Medical). The region of interest was selected extending from the furcation level to the apex of the mesial root, and initial measurements were calculated by Scanco software.

Twenty mesial roots of mandibular molars with two independent canals (Vertucci type IV) were selected, and the normality of the preoperative morphological parameters (length, curvature, radius, and volume) was confirmed (the Shapiro-Wilk test).

The apical foramens were sealed with Opaldam (Ultradent, South Jordan, UT, USA) to create a closed-end system. Each specimen was mounted on a plastic base with a thermoplastic adhesive. A size 15 K-File was inserted into the root canal to the WL. The mounted samples were positioned on a turntable within a plexiglass jig that allows taking reproducible radiographs [16]. A series of radiographs were taken until a straight-line radiograph of the file was obtained. The mounted specimens were then rotated 90° on the turntable, the rotation angle was recorded, and radiography of the maximum curvature of each root canal before mechanical instrumentation was taken.

Root canal preparation

Specimens were randomly assigned (www.random.org) to one of the two experimental groups, WaveOne Gold (WOG) and XP-endo Shaper (XPS) (n = 10). Samples were immersed up to the CEJ in a warm water bath (37 °C) and prepared in accordance with the manufacturer's recommendations as follows:

In the WOG group, the primary file (25/.07 red) was used to progress down to the WL with the "WaveOne All" mode. After shaping 2–3 mm, the file was removed and cleaned, the canal was irrigated, and patency was rechecked, re-irrigated, and restarted again. The apical dimension was confirmed with a 25/.07 gutta-percha (GP) point.

In the XPS group, the file was operated at 800 rpm and 1 Ncm. The XPS file was inserted into the root canal, and three gentle strokes (in-and-out motion) to progress down to the WL were applied. If the WL was not reached, the file was removed and cleaned, the canal was irrigated, patency was rechecked, re-irrigated, and restarted again. Once the WL was reached, ten up-and-down gentle long strokes (3–4 mm) to the WL were applied. The apical dimension was confirmed with a 30/.04 GP point.

After the glide path and between each NiTi file, each canal was irrigated with 2 ml of 5% sodium hypochlorite using disposable syringes, and 30 ga NaviTip® (Ultradent) inserted up to 3-mm short of the WL. A final rinse up to 1-mm short of the WL was performed with 1 ml of 5% NaOCl followed by 1 ml of 17% EDTA. The canals were then slightly dried with absorbent paper points. Moreover, a single new file was used in preparing each sample, and samples were prepared by a single-experienced dentist with expertise in both systems.

The final GP point was introduced to the WL; each sample was positioned on the turntable at the previously recorded angulation and postoperative radiography was taken. Then, samples were demounted from the plastic base and a new micro-CT scan was performed applying the same parameter settings previously described.

DDR processing and analysis

The digital radiograph images were transferred to GIMP 2.10 software (available from https://www.gimp.org) where the Edge Detect feature was used to sharpen the edges for detection of the outline of the files and GP points within the canals. The images were then imported to AutoCAD 2015 software, horizontal lines were drawn from the edges, and the midpoints of these lines were connected to draw the central axes of the pre-instrumentation file and the postoperative GP point. The images were superimposed, and distances between the central axes of the initial file and final GP point were measured at 3, 5, and 7 mm from the apex (Fig. 1a-c).

Micro-CT image processing and analysis

The 3D Slicer 4.6.2 software (available from http://www.slicer.org) [17] was used to co-register the 3D models from both pre- and postoperative phases using a rigid registration module (Fig. 1d-f).

Canal transportation and centering ratio—The co-registered images were imported to ITK-SNAP 3.6.0 software (available from http://www.itksnap.org) [18], overlapped, and the canal transportation and centering ability were calculated at three cross-sections levels: 3, 5, and 7 mm from the apical end of the root [19, 20] by the formulas described by Gambill et al. [21]. A result of 0 from the canal transportation formula indicates no canal transportation. The mean centering ratio is a measure of the ability of the instrument to stay centered in the canal, and a result of 1 would indicate perfect centering.

Dentine removed, unprepared areas, and debris remaining—Fiji 1.46r software (ImageJ, Madison, WI) [22] was used to calculate the dentine removed (in mm^3), the unprepared areas, and remaining debris of the root canal. The unprepared area was calculated as described elsewhere [23] and was expressed as a percentage of the total number of voxels present on the canal surface. Materials with a density similar to that of dentine were identified as debris [24, 25].

Statistical analysis

Pre- and postoperative parameters between groups were compared using an unpaired t test, as well as the canal transportation and canal centering ratio at 7, 5, and 3 mm. Ordinary one-way ANOVA was used to compare canal transportation and centering ratio between levels, and the paired *t* test was used to compare the methods of transportation assessment at 7, 5, and 3 mm. (GraphPad Prism 6.2; GraphPad Software Inc., San Diego, CA, USA). The level of significance was established at 5%.

Results

There was no instrument separation during the experiment. *T* tests on pre- (length, curvature, radius, and volume) and postoperative (percentage of unprepared area, amount of dentine removed, and debris remaining) data revealed the absence of differences between the groups ($P > 0.05$) (Table 1).

The micro-CT imaging analysis revealed that the XPS has significantly better ability to maintain within the central axis of the root canal ($P = 0.030$) (Table 2) with significantly less canal transportation ($P = 0.028$) (Table 3) than WOG at 7-mm level. Root canals instrumented with either WOG or XPS systems had no difference in canal centering ratio between inspected levels ($P > 0.05$) (Table 2). However, a significant difference for canal transportation in the XPS group was observed between 3- and 7-mm levels ($P = 0.011$) (Table 3). A tendency to outcurve transportation was seen for both groups, except in WOG group at 3 mm that showed a tendency to inner curve transportation.

The DDR technique did not find any significant differences in canal transportation between groups at any level ($P > 0.05$). Moreover, the root canals prepared with either WOG or XPS systems showed no difference in canal transportation between levels ($P > 0.05$) (Table 3). DDR technique revealed a tendency of canal transportation with WOG towards the inner curve at 7 mm and towards the outcurve at 3 mm.

The comparison between techniques (DDR versus micro-CT) used to evaluate canal transportation showed statistical differences in the WOG group at 5-mm level (Table 3), where the micro-CT method showed a significantly higher value than the DDR method (P = 0.023). Figure 1 shows representative illustrations of a sample pre- and post-preparation, under each method of canal transportation evaluation.

Discussion

The risk of canal transportation depends on the degree and the radius of canal curvature, and the instruments used in these canals [2]. To minimize the variables and to have better standardization, samples were decoronated, preoperative data from each canal was calculated, and the samples were randomly distributed leading to two groups without statistical differences (Table 1). Furthermore, specimens were decoronated leading to better preservation of the root canal anatomy [14], and glide path with a size 15 K-File was established to remove intracanal irregularities and facilitate canal preparation [26]. Additionally, a single-experienced dentist performed all the root canal preparations.

A recent study analyzing the centering ability of reciprocating motion instruments, and using plastic training blocks with curved root canals as samples, observed that significant differences among operators have been contributing more to canal transportation than the file system [27].

The reciprocating motion relieves the stress on the instrument by asymmetric counterclockwise and clockwise movements, increasing the NiTi instruments' resistance to cyclic fatigue and torsional stresses [28,29]. Gold wire alloy systems work during preparation in a mix of more R-phase and martensitic phase than the austenitic phase [30]. It has been shown that the more martensitic the NiTi alloy is, the more flexible and fatigue resistant an instrument becomes [31]. Some studies have found no statistical differences between rotary and reciprocating systems [32, 33]. When compared to the reciprocating motion system, WaveOne (Dentsply Sirona) and to the rotary motion system, OneShape (Micro Mega, Besancon, France), XPS produced the lowest statistically significant mean canal transportation [7].

In contrast, our study showed similar shaping ability in general but significantly better at mid-root level from the file in the austenitic phase (XPS) than the file in the martensitic phase (WOG) at 37 °C (Tables 2 and 3), suggesting that alloy flexibility may be partially responsible for the performance and mechanical behavior of endodontic instruments while preparing curved canals.

Wu et al. [34] argued that the apical canal transportation smaller than 0.3 mm would have minimum impact on prognosis. Due to that, the quality of the images evaluated is crucial for the accuracy of the results. Even though it is known that the CBCT produces images with poorer details than micro-CT [9-12], the CBCT has been used as a method of evaluation in recent studies [7, 33, 35-37]. Recent studies with the same purpose and using micro-CT as a 3D method of evaluation presented voxel sizes ranging from 20 to 22.8 µm [38-40]. As the root canal anatomy changes gradually in the z-axis, it was shown that a 34-µm voxel size provides an acceptable image quality of the root canal anatomy, and that smaller voxel sizes provide greater accuracy for root canal preparation evaluation [41, 42]. Thus, the present study used micro-CT as a 3D method of evaluation choosing a 15-µm voxel size intending to obtain a better image quality.

Even though our results showed mean transportation values smaller than 0.3 mm, it is important to point out that the statistical differences between groups occurred at the 7-mm level within the middle third of the root canals, where the point of maximum curvature was located (Tables 2 and 3). Our results suggest that the statistical difference in the mean values might be attributed to the larger taper of WOG and the increased stresses on the file at the point of maximum curvature.

Independent of the alloy, the flexibility and the stiffness of a file change as the file size and the core diameter increase as well as the instrument taper [2]. This suggests that the smaller size and taper of the XPS (30/.01) could lead to better-centered canal preparation than the WOG Primary (25/.07). Moreover, gold wire heat-treated instruments present a surface layer relatively harder than untreated NiTi files and at least five times harder than dentine [43]. It could be speculated that the higher canal transportation caused by the WOG group might be due to its surface hardness however more studies are needed.

A recent study comparing bacterial reduction with WOG and XPS observed that WOG left thick and dense debris accumulation on canal walls compared to XPS [44]. Based on those findings, the quantity of debris remaining was also calculated with the purpose of further investigate any connection between debris accumulation and canal transportation. However, no statistical differences were found between groups. It is important to point out that the present study mainly aimed to evaluate centering ability and canal transportation; therefore, further studies with a proper study design to test the association between debris accumulation and canal transportation are needed to test this hypothesis.

The DDR technique showed no difference between experimental groups, neither within groups, and the micro-CT technique highlighted significant transportation difference between groups (Table 3). The DDR technique uses the Edge Detect feature (GIMP 2.10 software) to detect the outline of the size 15 K-Files and GP points within the canals in the pre- and postoperative images, respectively. Thus, it is clear to assume that the central axes identified using the AutoCAD 2015 software might not represent the center of the root canal but the center of the file or the GP instead. DDR data hang in the balance of this question and should be considered as a reason for the reduced sensitivity of the technique.

The micro-CT method has been claimed to be superior to conventional methods [45]; however, Zanesco et al. [46] have shown in their study that the digital subtraction radiographic technique was reliable with no statistical differences from micro-CT imaging in apical transportation analysis. Considering the simplicity of a radiographic method, it could be considered as an alternative instead of the DDR technique.

Conclusion

In conclusion, micro-CT technique showed that the XPS resulted in significantly better centering ability and less canal transportation than WOG. The DDR technique was not capable of detecting significant differences between XPS and WOG.

Acknowledgments

We thank the Penn Center for Musculoskeletal Disorders (NIH/NIAMSP30AR069619) for micro-CT access.

Funding The work was supported by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior, Brazil (CAPES), Finance Code 001 (PDSE-88881.131856/2016-01), and The University of Pennsylvania Department of Endodontics Research fund.

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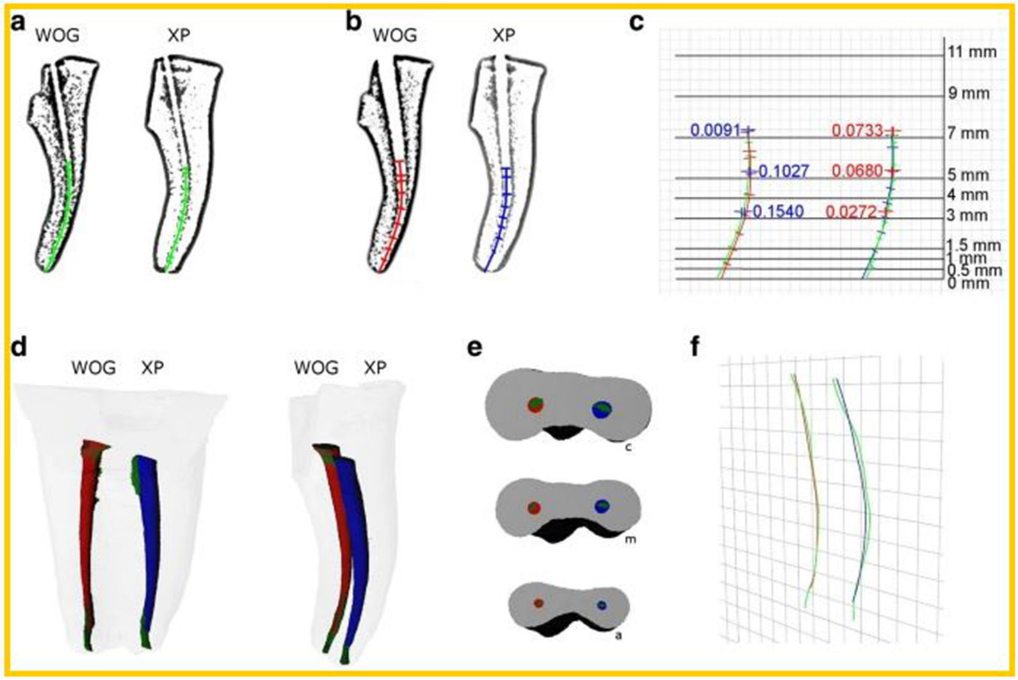

Fig. 1.

A representative sample analyzed by DDR and micro-CT techniques. Pre- (green) (**a**) and postoperative images of the central axes after WaveOne Gold (WOG) (red) or XP Shaper (XPS) (blue) preparation (**b**); graph illustrating the superimposition and canal transportation measurements before (green) and after preparation using either WOG (red) and XPS (blue) systems (**c**). Representative 3D reconstructions of the same sample analyzed by micro-CT showing the canal before (green) and after WOG (red) or XPS (blue) preparation (**d**); cross-sectional view at the coronal (c), middle (m), and apical (a) canal thirds (**e**); graph illustrating the root canal transportation evaluated by the center of gravity variation before (green) and after preparation using either WOG (red) and XPS (blue) systems (**f)**

Table 1

Pre- and postoperative parameters evaluated according to group

	WaveOne Gold		XP Shaper	
Parameter	**Mean ± SD**	**Median (range)**	**Mean ± SD**	**Median (range)**
Preoperative				
Length (mm)	15.17 ± 1.68	15.50 (12.50–17.00)	15.28 ± 1.42	16.00 (12.00–16.50)
Curvature angle	41.56 ± 13.07	43.00 (25.00–59.00)	40.78 ± 13.41	36.00 (29.00–69.00)
Curvature radius	6.58 ± 1.21	6.88 (4.37–7.93)	6.26 ± 0.97	6.17 (4.87–8.00)
Volume (mm^3)	1.28 ± 0.54	1.12 (0.62–2.39)	1.76 ± 0.53	1.52 (1.32–2.53)
Postoperative				
Dentine removed (mm^3)	2.53 ± 0.95	2.87 (0.76–3.39)	2.85 ± 0.94	2.68 (1.83–4.61)
Debris remaining (mm^3)	0.39 ± 0.51	0.12 (0.00–1.21)	0.16 ± 0.19	0.09 (0.02–0.58)
Unprepared area (%)	2.80 ± 2.98	1.29 (0.22–8.71)	2.45 ± 1.12	1.96 (0.82–4.27)

SD standard deviation

No statistically significant difference was found between groups (unpaired t test, $P > 0.05$)

Table 2

Centering ratio (mm) at 3, 5, and 7 mm according to group analyzed by micro-CT imaging

	WaveOne Gold		XP Shaper	
Level	**Mean ± SD**	**Median (range)**	**Mean ± SD**	**Median (range)**
7 mm	0.33 ± 0.13^{A}	0.36 (0.14–0.53)	0.52 ± 0.21^{B}	0.57 (0.17–0.86)
5 mm	0.41 ± 0.17	0.45 (0.17–0.65)	0.52 ± 0.22	0.59 (0.12–0.79)
3 mm	0.56 ± 0.32	0.69 (0.10–0.97)	0.64 ± 0.21	0.73 (0.29–0.90)

SD standard deviation

Values closer to 0 indicates instrument's poor ability to maintain the central axis of the root canal

Values equal to 1 indicated perfect centering ability of the instrument

No statistically significant difference was found within groups (one-way ANOVA, $P > 0.05$)

Different letters in the same row indicate a statistically significant difference between groups (unpaired *t* test, $P < 0.05$)

Table 3

Canal transportation (mm) at 3, 5, and 7 mm according to group analyzed by micro-CT imaging and double-digital radiography (DDR) techniques

	Micro-CT				DDR			
	WaveOne Gold		XP Shaper		WaveOne Gold		XP Shaper	
Level	**Mean ± SD**	**Median (range)**	**Mean ± SD**	**Median (range)**	**Mean ± SD**	**Median (range)**	**Mean ± SD**	**Median (range)**
7 mm	0.19 ± 0.07[A]	0.20 (0.08–0.32)	*0.12 ± 0.06*[B]	0.12 (0.03–0.21)	0.10 ±0.10	0.08 (0.01–0.33)	0.09 ± 0.06	0.08 (0.01–0.18)
5 mm	0.17 ± 0.13*	0.13 (0.02–0.44)	0.11 ±0.08	0.07 (0.04–0.28)	0.06 ± 0.04*	0.06 (0.00–0.12)	0.05 ± 0.05	0.04 (0.00–0.15)
3 mm	0.11 ±0.12	0.04 (0.01–0.35)	*0.05 ± 0.02*	0.04 (0.02–0.09)	0.09 ± 0.09	0.08 (0.00–0.28)	0.07 ± 0.05	0.07 (0.01–0.13)

SD standard deviation

Canal transportation equal to 0 means that no transportation occurred

*Means statistically significant difference between techniques of analysis (paired t test, $P < 0.05$)

Italic values mean statistically significant difference within groups (one-way ANOVA, $P < 0.05$)

Different letters in the same line indicate a statistically significant difference between groups (unpaired t test, $P < 0.05$)