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RESEARCH ARTICLE

Comparison of microtomography and optical coherence tomography on apical endodontic filling analysis

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Objectives: To compare *in vitro* differences in the apical filling regarding working length (WL) change and presence of voids and to validate optical coherence tomography (OCT) in comparison with computerized microtomography (µCT) for the detection of failures in the apical filling.
Methods: Forty-five uniradicular teeth with round canals, divided into groups (n = 15) following the obturation protocols: LC (lateral condensation), TMC (thermomechanical compaction) and SC (single cone). Samples were scanned using µCT (parameters: 80 kV, 222 µA, and resolution of 11 µm), OCT (parameters: SSOCT, 1300 nm and axial resolution of 12 µm), and periapical digital radiography. The images were analyzsed by two blind and calibrated observers using ImageJ software to measure the boundary of the obturation WL and voids presence. Categorical and metric data were submitted to inferential analysis, and the validity of the OCT as a diagnostic test was assessed with performance and reliability tests.
Results: The WL average remained constant for all obturation techniques and image methods. OCT showed adequate sensitivity and specificity to detect voids in the WL of apical obturations *in vitro* in comparison with µCT. Both image methods found a higher number of voids for LC technique (µCT p = 0.011/OCT p = 0.002).
Conclusions: OCT can be used in apical obturation voids assessment and the LC technique revealed more voids with larger dimensions.
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Introduction

The endodontic obturation promotes a tridimensional filling of the modelled portion of the canal. Filling can be done apically, coronally and laterally with inert or antiseptic material that either stimulate or have no effect on the restoration process.[1] Clinically, obturation quality and working length is checked with the use of bidimensional periapical radiographies.

However, to compare apical filling resulting from obturation protocols of different techniques, in vivo and ex vivo micrometric methods seems to be essential. Computerized microtomography (µCT) represents a non-destructive method that generates root obturation images with histological correlation owing to its high 3D spatial resolution at the micrometric scale (~10 to 15 µm) and minimum artefacts.[2–4]

Another non-destructive imaging method with similar micrometric resolution is optical coherence tomography (OCT). It consists of a non-radioactive method that uses a near infrared (780 to 1550 nm) and wideband (100 nm) light source, which results in a spatial resolution of the order of 10 µm or less, and real time 2D or 3D images with *in vivo* and *in vitro* application in dentistry.[5–9] In

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endodontics, the use of OCT was described for the evaluation of intracanal anatomy, root perforations, vertical fractures, presence of smear layer on the root canal and analysis of the apical region.[5,10–12]

The apical filling consists of an important item of endodontic success, as it could be associated to apical sealing, and control of recontamination. The advent of NiTi instruments associated with single cone (SC) obturation technique, along with the obturation cement, avoids the use of accessory cones commonly used in lateral condensation (LC) technique. In addition, this technique is considered fast, simple, provides a better adaptation to the dentinary wall of the root canal and creates less stress to both patients and professionals.[13,14] Other advantage of NiTi rotary instruments, is the gutta-percha cone thermomechanical plasticizing, initially proposed by McSpaden[15] and allows a reduction of the working time and number of empty spaces with the heat generation by friction.[16,17]

Considering the micrometrical differences observed in apical filling, different obturation protocols were tested by both detection methods, with the following objectives: (i) to validate OCT in comparison with µCT for the detection of failures in the apical filling *in vitro*; (ii) to compare differences in the apical filling regarding working length change and the presence of voids.

Methods and materials

Sample preparation

After obtaining approval of the Ethics Committee of the State University of Paraíba (CAAE – 51498015.7.0000.5187), 45 inferior premolars with complete rhizogenesis single root canals tilted by ≤5° according to Schneider's[18] method. Teeth showing the presence of pulp nodules, internal resorption, previous endodontic treatment or root fracture were excluded from the samples. The teeth's crowns were removed with an incision perpendicular to the root axis at the amelo-cemental junction using a diamond disc (KG Sorensen, Zenith Dental ApS, Agerskov, Denmark). The samples were stored in saline solution (NaCl 0.9%).

The root canal was irrigated with 2 ml of sodium hypochlorite 2.5% (Ciclo farma, Serrana, SP, Brazil). K-type hand files #10 (DentsplyMaillefer, Ballaigues, Switzerland) were introduced up to the apical foramen and the length measured, referring to the tooth's length (TL), was defined as the working length (WL). The apical limit of instrumentation and obturation was defined as 0.0 mm (WL = TL).

The root canal preparation was carried out by a specialist with a single use NiTi Reciproc file (VDW, Munich, Germany) according to the manufacturer's instructions, an R50 instrument (50.05) for wide canals or R40 (40.06) for medium canals . The reciprocal system was actuated with the electrical motor VDW Silver (VDW GmbH, Munich, Germany) with speed and torque automatically calibrated.

Following the instrumentation, the root canals were irrigated with 2 ml of ehtylenediaminotetraacetic acid (EDTA) 17% (Biodinâmica Química e Farmacêutica Ltda, Ibipora, PR, Brazil) for 3 min under stirring with a type k-15 hand file, followed by a second irrigation with 2 ml of sodium hypochloride 2.5% and drying on paper cone.

Obturation protocols

Samples were randomly divided into three groups (n = 15), as follows:

Group LC: lateral condensation technique: Insertion of the main gutta-percha cone with 40.02 or 50.02 of conicity smeared on the cement on the WL, and accessory cones (DentsplyMaillefer, Ballaigues, Switzerland) embedded in cement Ah Plus (DentsplyMaillefer, Ballaigues, Switzerland). The NiTi spacer (DentsplyMaillefer, Ballaigues, Switzerland) was used to provide adequate space for the accessory cones. The process was repeated until the complete filling of the canal. The excessive gutta-percha was removed with heat and the crown was compacted with an appropriate presser (Odous de Deus, Belo Horizonte, Brazil).

Group SC: single cone: Adaptation of the gutta-percha cone with identical size and conicity to those of the instrument used in the mechanical preparation (40.06 or 50.05), followed by the smearing of cement on the WL, removing the cervical excess with a heated presser and subsequent cold vertical compaction.

Group TMC: thermomechanical compaction: Adaptation of the cone with identical size and conicity to those of the instrument used in the mechanical preparation (40.06 or 50.05), smeared on the cement on the WL. The thermocompactor PacMac 45.04 of 21 mm (SybronEndo Dental Specialties, Glendora, CA) mounted at the counter-angle with rotation to the right, was inserted beside the cone, actuated in back and forth movements to obtain the apical filling.

Computerized microtomography

Samples were scanned in the microtomogram NIKON (model XTEK XT-H 225 ST, 225 kV *microfocus* source, Brighton, MI, EUA), with the parameters: 80 kV voltage, 222 µA current. The resolution adopted in this protocol is 11 µm to adjust to the volumetric limits of the sample and to match OCT's resolution. The volume of interest is the apical portion (1.5 × 3 × 3 mm). The samples were inserted in pairs into Styrofoam blocks of 14 × 14 × 15 cm given that its radiographic density close to the air. The blocks were then tied to the support for scanning.

The images obtained were reconstructed along the three planes (axial, sagittal and coronal) using the software XTEK-CT PRO 3D (Brighton, MI, EUA), and imported to the software VG Studio Max 2.2 (Volume Graphics Gmbh, Heidelberg, Germany). The assignment of values was established according to predetermined parameters based on the Hounsfield scale (HOUNSFIELD, 1973) for the Geosciences (Air = 0; water = 1000). In the sequence, a Gaussian filter (3 × 3 × 3 mm) was applied to smooth artefacts and noise. The images were finally exported in TIFF format.

Optical coherence tomography
Samples were scanned with Swept Source-Optical Coherence System SSOCS 1300 nm (Thorlabs Inc., New Jersey, EUA, Thorlabs GmbH, Dachau, Germany), with spectral domain near infrared source (1300 nm), lateral resolution of 25 µm, and axial resolution of 12 µm, in high speed. The tomographic scanning 3 × 3 × 1.5 mm took around 40 s, resulting in 540 axial images. The samples were positioned in a condensation silicone support (Perfil, Coltene, Rio de Janeiro, Brazil) placing the root canal opening perpendicular to the beam of light, enabling the detection of apical voids.

Digital radiography
To improve the clinical correlation of the obturation analysis, the samples were subjected to bidimensional radiographies with the X-ray apparatus digital Heliodent with the parameters: 7 mA, 70 kV voltage and 0.05 s of exposure time. To ensure reproducible imaging geometry, the samples were inserted into Styrofoam cubes for fixation and arranged over the solid sensor Kodak RVG 6100 digital radiography system #2, with the distance between sample and tube given by the acrylic support.

Image analysis
All images were analysed and measured using an ImageJ software (National Institutes of Health, Bethesda, MD, http:// rsb.info.nih.gov/ij/), employing the analysis of cuts (axial, frontal and sagittal) in the tridimensional images and the Straight Line tool to measure limits of working length and voids.

At first, images were analysed twice by a randomly assigned blind and calibrated observer (intraobserver Cohen κ 0.790) for the real working length. The apical limit of 0.0 mm was adopted for instrumentation and obturation, and alterations were considered normal if within 0.5 mm from the foramen.

Owing to the less resolution of digital radiography, this technique was not used as a reference to detect of voids in the apical filling. The presence, depth and width dimension of voids resulting of different obturation procedures were analysed between µCT and OCT tridimensional images by a examiner randomly assigned and masked (Interobserver Cohen κ 0.864). Each void dimension was also measured on the three axes by two calibrated and blind examiners and the intraclass correlation coefficient in each method of analysis was for number of voids (µCT 0.88/OCT 0.88), for depth (µCT 0.96/OCT 0.97) and for width (µCT 0.73/OCT 0.81).

Statistical analysis
Statistical analysis was both descriptive and inferential. Categorical data of WL and presence of voids were analysed using Fisher's exact test, and sensitivity and specificity tests applied to evaluate OCT and digital radiography agreement to µCT.

Voids dimensions of depth and width, as numerical data, were submitted to Kolmogorov–Smirnov test, that indicated the applicability of non-parametric tests, such as Kruskal–Wallis test used owing to the observance of the alternative hypothesis of difference between groups ($p < 0.05$) and Mann–Whitney's test was applied for the pairwise comparison between groups.

The analyses were conducted on SPSS for Windows v. 20.0 (SPSS, Inc, Chicago, IL).

Results

The millimetric measurement of the predetermined apical limit (0.0 ± 0.5 mm) showed that all obturation techniques were efficient considering WL, as observed in Table 1, and illustrated by Figure 1a.

Regarding apical working length, the periapical digital radiography showed lower κ concordance when compared with µCT. OCT was in agreement with µCT also to voids detections with good sensitivity, specificity and accuracy, as demonstrated in Table 1.

Table 1 Comparison of WL changes and the presence of voids according to three diagnostic imaging methods and tests of performance and reliability compared with µCT

	Diagnostic methods	*Obturation technique*				*Diagnostic tests*			
		CL	*SC*	*TMC*	*p*[a]	*κ concordance*	*Sensitivity*	*Specificity*	*Accuracy*
WL	µCT	1 (6.7%)	2 (13.3%)	2 (13.3%)	0.001	–	–	–	–
	OCT	0 (0.0%)	0 (0.0%)	1 (6.7%)		0.737	97%	73%	89%
	Radiography	1 (6.7%)	0 (0.0%)	4 (26.7%)		0.125	97%	13%	69%
Voids	µCT	14 (93.3%)	6 (40%)	1 (6.7%)	0.000	–	–	–	–
	OCT	11 (73.3%)	4 (26.6%)	1(6.7%)		0.684	96%	71%	84%

µCT, computerized microtomography; CL, lateral condensation; OCT, optical coherence tomography; SC, single cone; TMC, thermo mechanical compaction; WL, working length.
[a]Fisher's exact test.

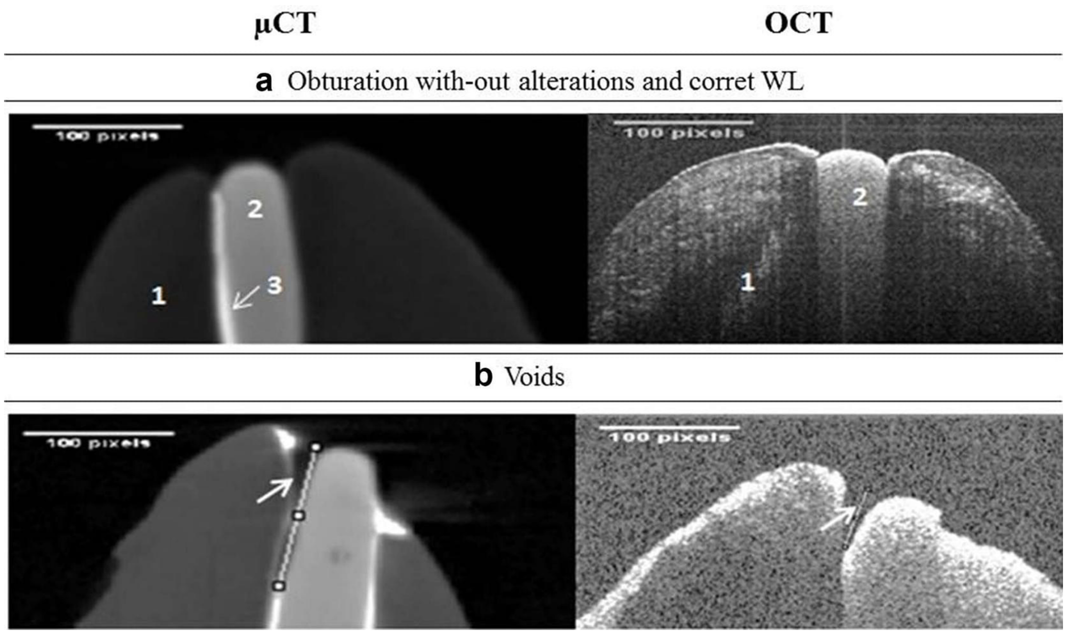

Figure 1 (a) Efficent aspect of apical filling by μCT and OCT images 1, dentine; 2, gutta-percha cone; 3, endodotic cement. (b) Void on apical filling are demarcated by arrows. μCT, computerized microtomography; OCT, optical coherence tomography; WL, working length.

The micrometric evaluation methods (μCT and OCT) showed voids on the apical filling, frequently between gutta-percha cone/dentine and gutta-percha cone/cement interfaces, as demonstrated in Figure 1b.

Regarding the size of voids, there are significant differences between obturation techniques in the pairwise comparison of samples subjected to LC (Table 2).

Discussion

The complex anatomy of the root canal apical region is a challenge to endodontics, mainly in apical obturation and filling.[19–21] The presence of apical voids is associated to a higher risk of marginal apical infiltration and consequent endodontic failure. This is influenced by several variables, such as obturation techniques, apical filling limit, chemical and physical properties of the chosen material, and smear layer permanency.[21] *In vivo*, the endodontic obturation is evaluated by apical Rx (X-rays), and in specific cases patients may be submitted to cone beam CT, although these are not indicated for the observation of voids.[22]

One of the criteria to evaluate the apical filling was by the WL, that was defined as adequate in the range between +0.5 mm, and results demonstrated that the three protocols tested performed similarly ($p > 0.05$). The real WL measured by μCT was considered the reference,

Table 2 Comparison of mode of the number, mean and standard deviation of width and depth of voids by two observer, for each obturation type using two different methods of analysis.

		Number of voids	*Width*		*Depth*	
Obturation technique	*N*	*Mode*	*Mean (SD) obs 1*	*Mean (SD) obs 2*	*Mean (SD) obs 1*	*Mean (SD) obs 2*
		μCT				
LC	15	2^b	0.11^b (±0.09)	0.12^b (±0,1)	0.37^b (±0.27)	0.4^b (±0,33)
SC	15	1^b	0.10^b (±0.13)	0.08^b (±0.09)	0.13^b (±0.14)	0.14^b (±0.15)
TMC	15	0^b	0.09^b (±0.25)	0.13^b (±0.29)	0.16^b (±0.22)	0.16^b (±0.22)
p^a		**0.011**	**0.027**		**0.005**	
		OCT				
LC	15	1^b	0.13^b (±0.17)	0.14^b (±0.18)	0.04^b (±0.05)	0.3^b (±0.05)
SC	15	0^b	0.00^b (±0.02)	0.00^b(±0.01)	0.00^b (±0.01)	0.01^b (±0.04)
TMC	15	0^b	0.04^b(±0.17)	0.04^b(±0.18)	0.00^b (±0.00)	0.00^b (±0.00)
p^a		**0.002**	**0.006**		**0.001**	

LC, lateral condensation; SC, single cone; TMC, thermo mechanical compaction.
[a]Kruskal–Wallis' test.
[b]Pairwise comparison using Mann–Whitney's test, with Bonferroni penalty ($p < 0.01$).

and showed poor agreement with digital radiography, which represents a limit of the clinical technique more commonly used, with limitations of bidimensional image, as lacking coincidence of the anatomical apex with apical foramen.[2,4,16,19,20]

Beyond WL fails, the presence or combination of multiples voids intern and external can form a gap between the filing materials and the dentinal walls, which possibly results in percolation of periradicular tissue fluids, microorganisms and toxins, as defined by American Association of Endodontists.[23] As the clinical detection of apical voids is limited, even through the use of the cone beam CT,[22,23] the evaluation of endodontic obturation protocols considering the aspect of apical filling must be *in vitro*, by imaging methods of micrometric resolution, such as μCT, the standard technique, and OCT, an alternative method.

The use of OCT as an alternative method was validated for the visualization of voids in the WL of apical obturations *in vitro*, with good sensitivity, specificity and accuracy relative to the standard method, μCT. These results strengthen the correlation between micrometric methods of image analysis found by Majkut et al[8] Minamino et al[9] and Oliveira et al.[10] It is worth stressing that OCT, a tomographic option free from ionizing radiation, offers high resolution and velocity of acquisition with a wide range of clinical applications in dentistry.[9] It is believed that the lower specificity of OCT can be attributed to the interposition between anatomical structures resulting in less and short voids than what is observed with μCT.

LC technique showed more and larger voids in average in comparison with the other techniques, corroborating the studies of Kierklo et al[3] and Ho et al[1] It is also noticed that voids created by LC technique are deeper and wider in average, probably owinge to the protocol of lateral adaptation of several gutta-percha cones with ISO-sized gauge.[24] However, as in the work of Zogheib et al[25] the voids found can be results of root filling procedures.

The two other protocols - SC and thermomechanical techniques - recommend the adaptation of one gutta-percha cone that match the memory instrument of the biomechanical preparation procedures,[17] assuring a more homogeneous filling with less cement.[26,27] There is no statistical difference for frequency and size of voids between the SC and thermomechanical technique, and good results were also found for the last one by Antunes et al[28] and Hwang et al[29]

The limitations of this study were related to the images acquisition processes. The OCT requires directly visualization of the region to be scanned to minimize the presence of shadows, superpositions or regions not well-reproduced. Considering resolution aspects of SS-OCTs, typical axial resolution in commercial products is limited to 5–15 µm owing to the optical source employed. Experimental laboratory systems can provide submicrometer resolution.[30] As for the lateral resolution, although the work of Watanabe et al[31] describes resolutions of ten's of micrometers, with proper adjustments of the collecting optics, this value can be reduced to less than 10 µm.

Further developments in dental OCT, including a hand piece for practical clinical devices, are needed to improve more applications with good imaging depth and quality.[32]

Conclusion

OCT showed good results for the visualization of apical voids in obturation when compared with μCT *in vitro*, validating the use of the technique to this aim. The obturation techniques did not alter the working length, although the LC technique showed the largest number of voids.

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