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# A Protocol for Void Detection in Root-filled Teeth Using Micro-CT: *Ex-vivo*

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## ABSTRACT

**Objective:** X-ray microtomography (micro-CT or XMT) has previously been used to measure residual voids in root fillings. However, there is no agreement on a protocol that critically identifies and attempts to solve artefacts inherent to the micro-computed tomography technique. This article aims to describe a protocol for automated detection of voids within root-filled canals taking into account the inherent artefacts, with special interest in the partial volume effect. This is to reduce human errors and increase the accuracy and efficiency of void detection.

**Methods:** Human maxillary premolars (n=33) were shaped, cleaned and root-filled using the cold lateral condensation (CLC) technique. Voids were identified using either individual tomographic slices or the new proposed protocol in which: (1) pre-obturation XMT slices were used to identify the coordinates of the canal space; (2) the post-obturation data sets were aligned to the pre-obturation data sets; (3) the voids were identified as voxels with a grey level below a set threshold after subtraction of pre-obturation from post-obturation data sets. A comparison of the voids from these two methods was made.

**Results:** The visual inspection of slice by slice of the scanned data resulted in full agreement between the tomographic slices and the results gained from the proposed protocol. This confirmed that this protocol provided an automated, effective and accurate method for detecting voids in root-filled canals.

**Conclusion:** The proposed protocol provides an automated method to eliminate inaccuracies from XMT artefacts so that accurate volumetric measurements can be easily obtained.

**Keywords:** Automated void detection, Micro-CT, registrations of scans, root canal obturation, voids

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## HIGHLIGHTS

- Micro-CT is a powerful tool for the detection of voids in root-filled teeth.
- There is no agreement on a protocol to avoid misinterpretation of data.
- To compare results from studies, an agreement is required for consistency of interpretation of micron-level data.

## INTRODUCTION

The main purpose of root canal treatment is to treat and prevent apical periodontitis. It is well established that the main cause of root canal treatment (RCT) failure is bacteria. Therefore, it is important after disinfecting the root canal system to fill the space with as hermetic seal as possible. This will reduce the chance for residual and/or newly introduced bacteria from multiplying and causing disease. In other words, provided disinfection had taken place, the fewer voids in a root filling on a post-operative radiograph the better the outcome of RCT should be (1, 2).

Micro-computed tomography (Micro-CT) or X-ray microtomography (XMT) is a non-destructive well-established technique for *ex-vivo*, 3D investigations in dentistry (3–8).

The use of Micro-CT in dental research is increasing, but analysis is mostly qualitative in nature whilst quantitative 3D analysis is at its early stage (9). As a non-destructive technique, Micro-CT can be applied repeatedly to follow changes over time (10, 11), or after successive stages of treatment such as in endodontics (3, 11–16).

There is currently no consensus on the optimal protocol for void detection in root fillings, ranging from manual methods, measuring from each tomographic slice (17, 18), to the use of differences in grey level between radiopaque GP and void in the post-obturation scan (12, 13). Whilst it may be possible to visually identify voids in filled root canals from tomographic images, however, automatic segmentation is difficult. Segmentation is classically defined as "the partitioning of an image into non-overlapping, constituent regions that are homogenous with respect to some characteristic such as intensity or texture" (19). For simple segmentation, one or more threshold grey levels are selected that best separate different classes in an image. However, because gutta-percha (GP) and root canal sealers are so radiopaque, partial volume effects, blurring and beam hardening artefacts (even when beam hardening correction is applied) cause an increase in the image intensity in small voids such that the grey level may exceed that of dentine. This makes it impossible to set a threshold that can distinguish between GP/sealant and voids. However, by performing a pre-obturation scan, the location and shape of the root canal can be determined, such that post-obturation void detection can be restricted to within the root canal space and thus a threshold above the grey-level of dentine can be set. This makes void detection more sensitive, meaning that small voids can be detected, and the volume of larger voids is not underestimated.

Researchers in published literature needed to identify voids in the data sets in a slice-by-slice fashion which would introduce an additional source of errors. Therefore, improving void detection can enhance the result in more accurate quantification of void volumes, especially in the case of voids close to the root canal walls. Automated detection of voids will also make the process more efficient and less time-consuming.

This article aimed to describe a protocol for the detection of voids within root-filled canals taking into account the inherent artefacts with special interest in the partial volume effect.

## MATERIALS AND METHODS

Ethical approval for this study was obtained from the Research and Ethics Committee (QMREC 2009/38, University).

### Sample Selection and Preparation

extracted single or bi-rooted human maxillary premolars (n=33) that had been kept in 70% industrial methylated spirit were kept in deionized water with 0.1% Thymol throughout the study at room temperature. The teeth were examined under a light microscope. (Eclipse Ei, Nikon, Japan) Teeth with root fractures and/or immature apices were excluded. An initial periapical radiograph was taken to assess tooth length, number of root canals and presence of curvatures. Root ends were covered in ribbon wax (Metrodent Limited; Huddersfield, UK) and embedded in StoneBite® (Derve Dentamid GmbH, Unna, Germany), a radiopaque, rigid embedding material, in 5 ml plastic syringes. The crowns were positioned above the embedding material level. Teeth were assigned to groups based on internal anatomy using Vertucci's classification of canal anatomy (20). The teeth were accessed using diamond burs (Dentsply Maillefer; Ballaigues, Switzerland). Size 10 K files were used to scout the canals and secure apical patency based on working length (WL) radiographs.

The coronal and middle thirds were passively prepared with rotary ProTaper Universal (PTU) shaper files S1 and S2 (Dentsply Maillefer) and an X-SMART motor (Dentsply Maillefer). The WLs were confirmed using the periapical radiographs. The canals were shaped to the confirmed WL using S1, S2, and F1 rotary PTU files which were considered sufficient for necessary apical enlargement. The apical stops were created using NiTi K files using the files that engaged with most apical 1–2 mm of the canal. Canals were irrigated throughout treatment with 1 ml NaOCl (1%) solution (Adams Healthcare; Nelson, Lancashire, UK) after each instrument, and a final 5 ml irrigation, and dried using paper points. Master GP point radiographs were obtained using snuggly fitting ISO GP points (Kerr; Uxbridge, UK) and were filled using the cold lateral condensation of master GP, accessory GP points (Dentsply Maillefer) and TubliSeal EWT sealer (Kerr Corporation).

### Micro-CT Scanning

A wide range of custom-built and commercial scanners were used (21). The operator might have limited control over experimental parameters and methods of analysis. The MuCAT2 scanner (QMUL; London, UK) (22) used in this experiment has a time delay integration feature to avoid ring-artefact and a rotating carousel for equivalent monochromatic calibration to 40 keV to reduce polychromatic dishing (23). The samples were kept moist throughout the scans.

### Parameters: Voltage, Current

The X-ray voltage was selected for optimal contrast and the current was set as high as possible without risk of melting the anode.

### Scanning Protocol

Projections (no=601) were recorded over 360° (rotational step=360/601=0.599°), with an effective voxel size of 30 µm, with 12 seconds exposure time for each projection. Modelling software was used to correct beam hardening (23). Data reconstruction was performed using a standard Feldkamp back-projection algorithm (24). The samples were scanned before any treatment (for baseline reference and classification of canals), and before and after filling the canals (to be used for the current study).

Pre-operative Scans were taken for each sample using a generating voltage of 90 kV (180 µA) with 1.2 mm Al and 50 µm Cu filtering. Pre-obturation scans took place at this stage with the same parameters used for the pre-operative scan. Post-obturation scans took place with higher voltage and more current to maintain X-ray penetration through the radio-opaque GP points and sealer. The proportionately current was reduced to keep the same power and avoid anode melting. Therefore, for the post-obturation scans, the X-ray settings were 120 kV (135 µA) with 0.4 mm Cu filtering with no change to the rotational step or voxel size.

Scans took place within the next 24 hours after obturation to allow materials to set with the same parameters used for the pre-operative scan.

**Registrations of Scans**

In order to align different volumes from data sets, an in-house written application, "Tomalign" (QMUL; London, UK) (22), was used to align the pre-obturation and the post-obturation scans with seven degrees of freedom of movement, namely, translation in the X-, Y-, Z planes, rotation about X-, Y-, Z axes and isotropic scale matching. The alignment was based on edge-enhanced "Sobel Operator" images of the three orthogonal 2D slices to ensure that the "filled and unfilled" canals from the two scans were optimally aligned.

Data sets for eleven teeth were used for validation of registration. The post-instrumentation and post-obturation data sets were aligned for each specimen as described above. The post-instrumentation data sets were used to define the boundaries of each of the canal spaces. The coordinates of these boundaries were applied to the post-obturation data sets. Voxels within the applied boundaries that had grey levels less than the set threshold were defined as voids.

New data sets containing the coordinates of these voxels were created. An in-house written software that allows the visualisation of data sets slice by slice; Tomview was used to view the post-obturation data sets and the detected voids in those eleven samples compared with the generated void data sets to validate the measurement program in terms of the presence of a void and its spatial position and size.

**Void Detection in the Obturated Canals**

The partial volume effect is an inherited problem with 3D scanning where the edge of the scanned object only fills part of the volume measurement unit (voxel) where the rest of that voxel is empty. In the current study, less than full voxels could have an apparent linear attenuation coefficient (LAC; grey level) above that of dentine due to the presence of a very highly radiopaque element. Therefore, it was necessary to invent a method that allowed the elimination of this problem.

In order to overcome the partial volume effect problem, "Rootvoid" an in-house written algorithm, was used to first define the boundary of the root canal space from the pre-obturation scan, which was then transferred as a mask to the post-obturation images as the definition for canal space.

Voids were then determined in the post-obturation scans by setting the grey level value (GLV) threshold halfway between that of GP/sealer and dentine within the root canal space, and Euclidean distance transform map (25) was created that gave the distance of each voxel from the canal wall. Then a thickness transform (14) was performed on the voids, giving a map of void thickness. The thickness for each voxel within the void was defined as the diameter of largest sphere that can fit within the void containing that voxel.

To eliminate false voids caused by misalignment and errors in the registration of the canal space, any void regions with a thickness of less than two voxels that lie within one voxel of the root boundary were removed. The recorded parameters for each defined void were volume, minimum distance from the canal wall, area in contact with the wall, the volumes and areas within each of the three-thirds of the root canal, the closest distance to the apex and the position of the centre of "mass".

**Void Measurement**

After aligning the 3D datasets of the post-instrumented and obturated canals, the coronal and the apical borders of the canal were defined. The closest slice apical to enamel was chosen as the coronal border slice. This point was designated to represent the end of the crown and the start of the root. The apical border slice was defined arbitrarily at 1 mm from the most apical slice that contained tooth structure. The lower slice, was chosen to represent the connection between the filling and apical converted muffle shape apex (26).

The region growing algorithm was used to identify canal space that needed to be obturated. Using Rootvoid to subtract the obturated root canal from the ideal root canal space, the voxels that had a grey level of less than 125 were assigned to be the void voxels. The reason for the 125 grey level threshold was to count those voxels that might partially contain dentine debris which had a grey level of about 70. The numbers of voxels were then converted to volume by the voxel volume. For comparisons between teeth, the volumes were expressed as a percentage of the root canal volume.

**Separation of Voids**

Incrementing through the voxels, a region-growing function was seeded at the first voxel within the masked canal space that exceeded the threshold, thus defining an individual void. Once this void was quantified, the corresponding grey levels were set to 255 and the process repeated until no voids remained.

**Data Presentation and Statistical Analyses**

Void volumes in the samples used for the registration test were used to test the sensitivity and sensitivity of the new software compared to manual detection of voids from the individual slices in the 3D data set. No statistical test was deemed required as there was 100% agreement between the results from both tests.

## RESULTS

Visual inspection of the aligned datasets conforms to perfect registration of the pre- and post-obturation datasets Perfect registration is essential for a more accurate outcome. It is important to remember that voids will only be calculated if

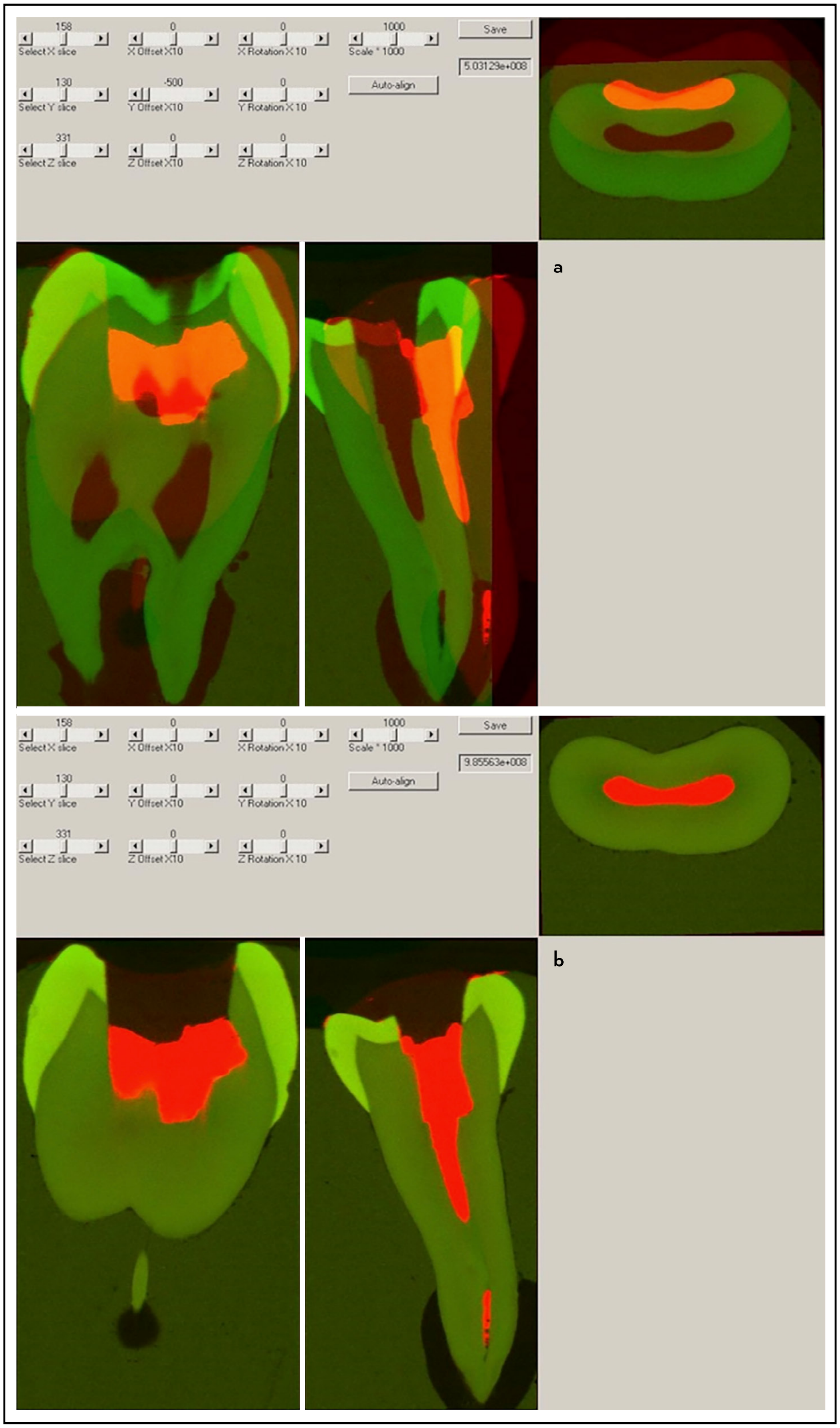


**Figure 1.** In-house written software with 7 degrees of freedom. (a) Data from pre-obturation and post-obturation of a sample before alignment and (b) after alignment

they fall within the canal space area that was identified in the pre-obturation stage. Therefore, a perfect registration is important, especially for the detection of voids that are in close proximity with the canal walls, which in turn affects the reliability of the results. An example is shown in Figure 1.

Visual inspection of each slice was performed to confirm agreement between voids detected in each of the tomographic slices and voids detected using the "Rootvoid" algorithm, in terms of position and size. An example of voids detected in the post-obturation scan and those detected

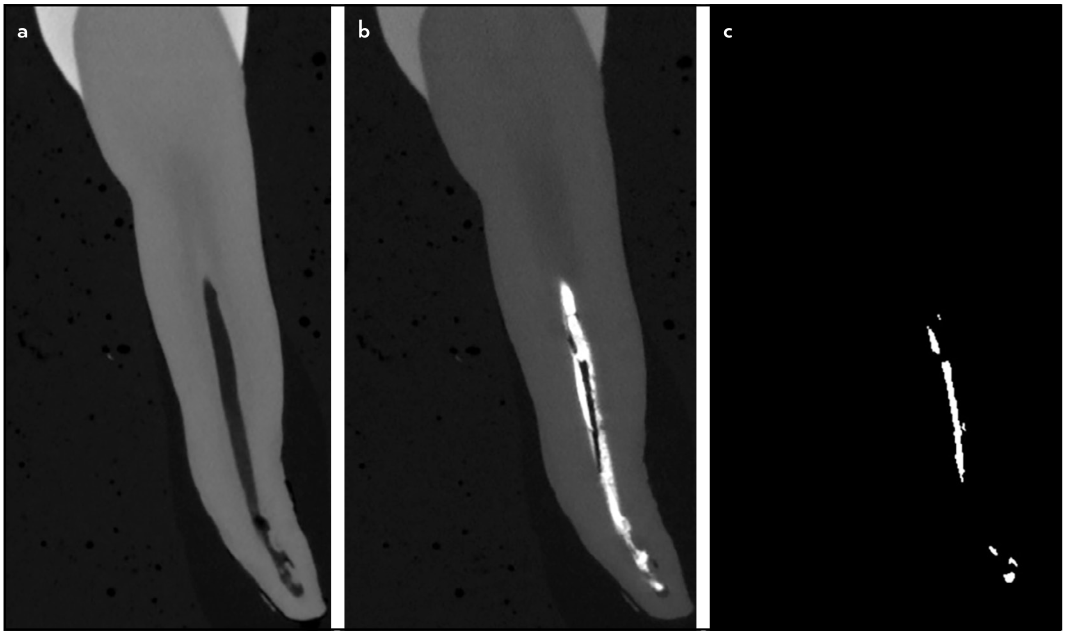


**Figure 2.** Micro-CT slice (a) post instrumentation showing canal space in black, (b) post obturation showing canal space in black and filling material in white and (c) voids shown in white

CT: Computed tomography

in the same tomographic slice are shown in Figure 2. Small voids that were present at the interface between the GP and the root canal wall and inside the bulk of the filling material were all detected by the "Rootvoid" program. Table 1 shows that this program was 100% sensitive and specific in detecting these voids.

**TABLE 1.** Sensitivity and specificity of the void measurement program Micro-CT

| | Micro-CT | |
|---|---|---|
| | **Detected voids** | **Detected filled area** |
| TomView | | |
| Void | 158 | 0 |
| Filled area | 0 | 11 |

CT: Computed tomography

### Total Void Volumes (Measured as a Percentage of the Total Canal Space)

There was 100% agreement between voids detected using the proposed software "Root void" and the visual inspection of data sets slice by slice, therefore, no statistical test was needed. Within the limitations of the current study, the calculated percentage of total void volumes in root canals filled using the CLC technique was 0.75% (±0.45).

The main challenge encountered in this study was the lack of a consensus on methodology. Also, in this study, extracted maxillary premolars were used due to the scarcity of other types of teeth available for research which in turn resulted in a sample that was impossible to standardise.

## DISCUSSION

In the present study, we utilised the data from the pre and post-obturation scans to automatically calculate void volumes and propose this as a standardised method for future studies. The use of the pre-obturation scan allowed a much higher threshold value to be used for detecting voids in the post-obturation scans, greatly increasing the sensitivity.

### Validation of Void Measurement Program

It is important that the program used for void measurements was validated in order to report on the results from the present study. Misalignment of the datasets could result in false voids along the canal walls. However, this experiment demonstrated that narrow voids were detected along the canal wall in canals filled with lateral condensation technique in the post-obturation Micro-CT slices and could be seen in the "void" data sets. The threshold was set arbitrarily at 125 grey level which is halfway between the grey level of sealant and dentine, and it was deemed to be appropriate.

Because the grey levels represent the mineral concentration, (i.e. space is shown as black and root filling materials as white) discerning voxels filled in with a single phase of matter should be easy. However, voxels at the interface containing different phases could be represented by any intermediate grey level; this is the partial volume effect (including blurring and beam-hardening effects). Furthermore, because of the substantial opacity properties of root filling materials (27), small voids within root canal sealer may have a grey level that is higher than that of dentine. Therefore a grey level threshold ought to be set for the software to classify these voxels as either more likely to be empty or more likely to be filled.

Only one threshold can be applied at one time of visualisation. This means that a threshold higher than that of dentine will result in dentine being registered as void, while a threshold lower than that of dentine will result in partially filled voxels being counted as full of matter and small voids will not be detected due to the partial volume effect (28). This is because less-than-full voxels at the interface between a void and the highly radiopaque materials may have a grey level that is higher than that of dentine. As a result, these voxels will not be counted as voids despite being mostly empty. Therefore, in this study, dentine was eliminated from the equation by identifying the root canal space from the pre-obturation scans, making the "scanned" voxels either full or less than full of filling material. An arbitrarily chosen threshold, well below that of the filling material, but still higher than that of dentine was used to allow counting the voxels that are likely to be less than full with better confidence.

To do this, the pre obturation scan was used to define the root canal space that should ideally be completely filled with GP and sealer. Using this defined space as a mask in the aligned post-obturation scan allowed a much higher threshold to be set, as long as it is below the grey level of GP and/or sealer, again allowing for natural variation and statistical noise. Even though regions may be detected below this threshold that still had a grey level above that of dentine, they should not contain dentine if they were detected within the canal space. The exception would be the inclusion of dentine debris within the canal region (displaced from its original position in the pre-obturation scan). However, identifying debris as a void is probably a lesser error than identifying it as healthy dentine, especially when the canal was thoroughly washed with irrigants. This automated approach, of identifying root canal space, also eliminates errors that may arise from manually and laboriously outlining the canal spaces in tomographic slices.

The efficacy of this method, compared with direct detection using a threshold below the grey level of dentine, was demonstrated by comparing the void detection results with those obtained with the lower threshold value. This showed conclusively that defining the root volume from the pre-obturation scan to facilitate the use of a higher detection threshold was a vital step for automated void detection and justified the additional scan time. Going one step further and including a pre-instrumentation scan would allow combined analysis of both instrumentation and obturation.

The registration software "Tomalign" allowed best alignment of sequential scans with seven degrees of freedom including scale which allowed the outlines of scanned objects to match automatically not only by rotating and sliding the data, but also by re-sizing one of the scans to perfectly match with other.

The use of the pre-obturation scans as a reference for spatial positioning of the canal space allowed a much higher threshold value to be used for detecting voids in the post-obturation scans. The use of this automated protocol is aimed at removing human errors in the calculation of voids within filled root canals. The latter could be due to the inability to accurately identify the canal space boundaries. Especially in the apical third where canals branch and deviate. Using this protocol, more accurate identification of empty voxels within the root canal filling can be achieved automatically with fewer human errors and better efficiency.

### Quantitative Study of Voids in Obturated Root Canals

#### *Percentage of the total void volumes in root canals filled using cold lateral condensation technique*

As the method of calculating TVVs in the present study is different to previous studies, it is not possible to compare the value of the void volume with others. Nevertheless, the results from this study are in agreement with previous studies (15, 29).

Regarding absolute values in general, the TVV in the present study appears to be lower than those recorded previously. For example, Naseri et al. (16) reported that of the percentage void volume with CLC was 19.6%, compared to 0.75% in the present study. This could be down to many factors including but not limited to the choice of imaging threshold, the type of tooth and the scanning parameters. Therefore, the call for an agreed protocol for all XMT (Micro-CT) researchers to use when comparing results, otherwise this invaluable technique will not reach its optimal potential in detecting voids within root-filled canals.

Studies have shown that voids are found within canals filled using cold lateral condensation, continuous wave, or the single cone technique (13, 30, 31). Due to recent advances in root canal filling materials, manufacturers are promoting the single matching cone technique, relying on sealer to fill the space around the GP point. Outcomes from clinical studies on the SC technique have shown it to be a viable option for obturation (32).

## CONCLUSION

Automated detection of voids in obturated canals using Micro-CT is difficult because of the inherent limitations of Micro-CT. The proposed protocol is a novel method using data from pre- and post-obturation scans to avoid subjective void detection and to improve sensitivity. The proposed protocol allowed more effective and accurate detection of voids in root-filled canals.

**Disclosures**

**Ethics Committee Approval:** The study was approved by the Queen Mary University Research and Ethics Committee (no: QMREC 2009/38, date: 01/09/2009).

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