Quantitative Assessment of Dimensional Evaluation and Artefacts from Filling Materials with CBCT Using Standard Phantom Roots

Xiao Bo CHEN1,2, Zhe Jun WANG2, Ya SHEN2, Andrea ESTEVES2, He LIU2,3, Gui Bin HUANG4, Xiao Yan WANG4, Lin YUE4, Markus HAAPASALO2

Objective: To investigate the accuracy of dimensional evaluation and representation of artefacts generated by different gutta-percha (GP) cones with or without sealer with CBCT using a reproducible, standardised phantom root methodology.

Methods: The reproducible artificial phantom roots with six root canal sizes from #25 to #50 and 0.04 taper were aligned according to the jaw curvature in a stone model for dimensional measurements. Each root was scanned while empty and filled with four types of filling materials. The specimens were scanned using the CS 9300 3D (Carestream Dental, Rochester, NY, USA) (at two different resolutions), 3D Accuitomo (J Morita, Kyoto, Japan) and NewTom VGi (Verona, Italy) CBCT systems. The hyperdense and hypodense axial slice artefacts from root canal sizes #40, #45 and #50 were recorded.

Results: Dimensions were significantly smaller and more accurate with CS 9300/0.09 mm voxel size than with other protocols. The hypodense band was found mostly in the CS 9300 3D system with 0.18 mm voxel size, especially in the buccal-lingual (95%) and coronal (64%) sections. The 3D Accuitomo CBCT system showed the lowest presence of the hypodense band. Areas of both light and dark artefacts were significantly larger in the coronal third than in the apical and middle thirds.

Conclusion: Artefacts in the coronal locations and in buccal-lingual sections were more evident in the CS 9300 3D system with a 0.18-mm voxel size.

Key words: artefact, CBCT, gutta-percha, measurement, zirconium

dense materials are either caused by beam hardening or by the complete extinction of the beam. Since these materials have extremely high atomic numbers and are highly dense. In this case, zero energy is recorded on the detector “behind” such material.

Artefacts resulting from root-filling material along the long axis of the alveolar bones may result in difficulties with diagnosis6. Some previous studies used extracted teeth as the study models to assess the artefacts produced by vertical root fracture7,8. Others showed that artefacts might obscure or resemble pathology, and therefore impede accurate diagnosis and subsequent treatment planning9-14.

Phantom teeth15 and phantom blocks with pins5,16 were used in previous studies for artefact assessment. The development of a phantom tooth model with standardised and reproducible root canal morphology can offer a platform to evaluate the accuracy (e.g., area, maximum and minimum diameters) of different obturation materials in the root canal system. So far, few studies have been able to quantify high-density artefacts in CBCT images, especially in standardised phantom roots.

Zinc oxide and barium sulphate in gutta-percha (GP) contribute to the radiopacity of the material. Zirconium is a weak attenuator used in endodontic bioceramic sealers, which may influence the artefacts and the grey values in CBCT images15. The grey value has been recognised as the index to assess the density or quality of the material17. Despite the good physical, chemical and biological properties of the bioceramic sealer materials18, properly depicting obturation material in 3D images is challenging. So far, little is known about the impact of obturation materials and bioceramic sealers on CBCT artefacts and accuracy.

The present study aims to develop a reproducible novel artificial phantom root to investigate the artefacts and accuracy of the dimensional evaluation of different root canal filling materials using four CBCT protocols.

Materials and methods

Phantom setup

A reproducible phantom, including a stone model19 with a standardised straight phantom single root and root canal, was fabricated to measure accuracy and artefacts. To determine the accuracy of dimensional evaluation, the dental stone phantom was fabricated by mixing equal volumes of type III stone plaster (Whip Mix, Louisville, KY, USA) and sawdust, with the shape like the alveolar process of the maxilla. Six sockets were created by arranging MicroAmp tubes (Thermo Fisher Scientific, Waltham, MA, USA), coated with a thin layer of Vaseline, according to the jaw curvature in the phantom model with 6 mm distance between the cervical plane of each root. Equal volumes of epoxy resin (ArtResin, Carrollton, TX, USA) and calcium carbonate (C5929-100G, MilliporeSigma, Burlington, MA, USA) were mixed thoroughly in the tubes, then the filled tubes were vibrated in a VWR Mini Vortexer (Henry Troemner, Thorofare, NJ, USA) for 90 seconds each to eliminate any visible bubbles. Before the resin was set, a 0.04-taper vaseline-coated paper point (Brasseler, Savannah, GA, USA) for one of six different sizes (#25, #30, #35, #40, #45 and #50), was inserted gently in the centre of each resin-filled tube. The top of each tube was covered with a
thin layer of wax to centre the paper points precisely. The paper points were pulled out after the resin was cured, leaving a standard size canal space. Five groups of artificial root fillings, each in six sizes (taper 0.04, size #25 to #50), were prepared: group 1, with no filling; group 2 (GPE), filled with EndoSequence BC GP cones (Brasseler); group 3 (GPV), filled with Vortex GP cones (Dentsply Sirona Endodontics, Tulsa, OK, USA); group 4 (GPEB), filled with EndoSequence BC GP with iRoot SP, root canal sealer (Innovative BioCeramix, Burnaby, BC, Canada); and group 5 (GPVA), filled with Vortex GP with AH Plus sealer (Dentsply DeTrey, Konstanz, Germany). For groups 4 and 5, CBCT scanning was performed after allowing the sealer to set for 72 hours in a water bath at $37^\circ$C.

For the artefact measurements, using the same phantom model, the artificial root canals of three sizes (#40, #45, and #50, taper 0.04) were aligned according to the jaw curvature in sequence (#50 in the posterior region of the dental arch, #45 in the premolar region and #40 in the anterior region) as shown in Fig 1. The artificial root and the real root showed similar radiographic contrast and grey value, as shown by a similar threshold of grey values in Fig 2. Each sample was scanned as unrestored and then restored with four types of root filling materials: EndoSequence BC GP cones only; Vortex GP cones only; EndoSequence BC GP with iRoot SP, injectable root canal sealer; and Vortex GP with AH Plus sealer. The artificial roots for accuracy of dimensional evaluation and artefact measurements were coated with a thin layer of wax (white utility wax strips; Coltene Whaledent, Alstätten, Switzerland) and then placed in the corresponding sockets in the phantom stone model, aligned to the same position for the CBCT scan (Fig 3).

**CBCT image acquisition and processing**

The phantom model was positioned on a reproducible platform kept in the same location. The phantom jaw was placed in a round plastic box full of water on the CBCT jig, which was equivalent to a soft tissue surrounding the skull. Images were taken using the following endodontic scanning protocols:

1. CS 9300 3D system (Carestream Dental) with two exposure protocols: 84 kV 5 mA and 90 kV 5 mA. Voxel size and FOV were fixed at 0.09 mm, 5 cm × 5 cm and 0.18 mm, 8 cm × 8 cm (CS0.09, CS0.18);
2. 3D Accuitomo (J. Morita, Kyoto, Japan) with 80 kV 3 mA 0.125 mm, 6 cm × 6 cm (Morita);
3. NewTom VGi (QR SRL, Verona, Italy) with 110 kV 5.2 mA 0.10 mm, 5 cm × 5 cm.
Exposure parameters were optimised for the phantom roots. The exposure protocols for each device are listed in Table 1. For the qualitative analysis of the CBCT image, all data were exported as DICOM files and imported into Image J software (version 1.52a, National Institutes of Health, Bethesda, MD, USA) for measurement.

**Imaging processing**

Dimensional evaluation

A total of 120 volumes were acquired (five groups of six sizes of four exposure protocols). Axial images of roots were selected from three regions: apical (2 mm above the apical end of the root filling/canal), middle (5 mm above the apical end of the root filling/canal) and coronal (8 mm above the apical end of the root filling/canal). Each root adjusted the position according to the axis line from the apex to the central point of the crown plane to make sure the cross-section was perpendicular to the long axis of the root while measuring. For each region, five images at the slice thickness intervals were selected (segment slice and two adjacent slices in both apical and coronal directions). The diameters of phantom root fillings at the three measurement locations (2 mm, 5 mm, 8 mm above the apical end of the root filling) were measured using a digital Vernier caliper before being placed in each phantom root canal, which was used as a “ground truth”. A total of 450 images were selected for each exposure protocol (15 slices with five groups, three sizes). Longitudinal images were acquired from four directions (Figs 1a to d), all passing through the centre of the tooth. As such, a set of four longitudinal images for each group were obtained as follows: one in sagittal view and one in coronal views (Figs 1e and f), one in buccal-lingual (B-L) view, and one in mesio-distal (M-D) view (Figs 1g and h). The hypodense band in a total of 60 longitudinal images in TIFF format was selected for each exposure protocol (slices of four directions with five groups, three sizes). The score for the hypodense band was recorded in all acquired longitudinal images with scores given according to the absence (0) or presence (1) of the dark band. Continuous and linear change of grey value was analysed in longitudinal sections using plot profile tools and surface profile tools in ImageJ. A total of 900 (225*4) axial images and 240 (60*4) longitudinal images were analysed twice over a 2-week period under the same display condition.

All CBCT scanning, evaluation and measurement were performed by the same three experienced radiologists and endodontists trained in CBCT diagnostic applications.

**Artefact measurement**

The artefact pixel intensity value ranges were established for the hyperdense zone (light) and hypodense (dark) artefacts for each protocol, respectively. Threshold tools and fixed ROI tools were used manually, along with standardised segmentation of the area for light and dark artefacts for each axial section. Within the ROIs, areas of light and dark artefacts were measured according to the grey value threshold using the software. Both light and dark artefacts were seldom observed in the apical part of sizes #25, #30 and #35. Thus, axial slice artefacts from root canal sizes #40, #45 and #50 were recorded. A total of 225 axial images in TIFF format were selected for each exposure protocol (15 slices with five groups, three sizes). Longitudinal images were acquired from four directions (Figs 1a to d), all passing through the centre of the tooth. As such, a set of four longitudinal images for each group were obtained as follows: one in sagittal view and one in coronal views (Figs 1e and f), one in buccal-lingual (B-L) view, and one in mesio-distal (M-D) view (Figs 1g and h). The hypodense band in a total of 60 longitudinal images in TIFF format was selected for each exposure protocol (slices of four directions with five groups, three sizes). The score for the hypodense band was recorded in all acquired longitudinal images with scores given according to the absence (0) or presence (1) of the dark band. Continuous and linear change of grey value was analysed in longitudinal sections using plot profile tools and surface profile tools in ImageJ. A total of 900 (225*4) axial images and 240 (60*4) longitudinal images were analysed twice over a 2-week period under the same display condition.

All CBCT scanning, evaluation and measurement were performed by the same three experienced radiologists and endodontists trained in CBCT diagnostic applications.

**Statistical analysis**

SPSS (version 25; IBM, Armonk, NY, USA) was used for statistical tests. The level of statistical significance was set at $P < 0.05$. The data were analysed statistically using a
one-way analysis of variance followed by a Tukey test and multiple linear regression. A Kappa test was used to assess interobserver and intraobserver agreement for the three observers. A chi-squared test was applied to compare the average presence of artefacts evaluated by the three observers (two experienced endodontists and one experienced oral radiologist) for different slice orientations.

**Results**

The interobserver and intraobserver agreement ranged from 0.706 to 0.838 (substantial) for reading of the longitudinal sections.

**Dimensional evaluation**

Both the areas and diameters of root fillings with CS 9300/0.09 mm voxel size were significantly smaller than for the other three CBCT protocols as shown in Fig 4 ($P < 0.001$) in all root filling sizes. The maximum/minimum diameters of root filling of #30 canal fillings in CS 9300, for example, were $0.42 \pm 0.09$ mm/$0.30 \pm 0.08$ mm (2 mm above the apical end of the root filling); $0.60 \pm 0.15$ mm/$0.47 \pm 0.15$ mm in the middle part (5 mm above the apical end of the root filling); and $0.83 \pm 0.22$ mm/$0.68 \pm 0.20$ mm in the coronal part (8 mm above the apical end of the root filling), depending on the CBCT protocol (Table 2). CS 9300/0.18 mm voxel size produced the largest filling area and diameters, especially when compared to CS 9300 using a voxel size of 0.09 mm ($P < 0.05$).

Taking root canal filling size #30 as an example, images of groups of EndoSequence BC GP with BC iRoot SP sealer (GPEB) and Vortex GP with AH Plus sealer (GPVA) both showed significantly larger areas (Fig 4; $P < 0.001$), and bigger maximum (Fig 4; $P < 0.001$) and minimum diameters (Fig 4; $P < 0.001$) than those of the
Table 2  Maximum and minimum diameters of root filling.

<table>
<thead>
<tr>
<th>W</th>
<th>Location</th>
<th>#25 Dmax/Dmin (mm)</th>
<th>#30 Dmax/Dmin (mm)</th>
<th>#35 Dmax/Dmin (mm)</th>
<th>#40 Dmax/Dmin (mm)</th>
<th>#45 Dmax/Dmin (mm)</th>
<th>#50 Dmax/Dmin (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CS 0.18</td>
<td>Apical</td>
<td>0.79 + 0.11/0.56 + 0.11</td>
<td>0.83 + 0.13/0.65 + 0.13</td>
<td>0.97 + 0.16/0.71 + 0.15</td>
<td>1.06 + 0.18/0.79 + 0.15</td>
<td>1.18 + 0.15/0.85 + 0.11</td>
<td>1.24 + 0.13/0.87 + 0.10</td>
</tr>
<tr>
<td></td>
<td>Middle</td>
<td>1.07 + 0.12/0.79 + 0.11</td>
<td>1.14 + 0.18/0.92 + 0.17</td>
<td>1.23 + 0.19/1.01 + 0.10</td>
<td>1.31 + 0.10/1.10 + 0.14</td>
<td>1.41 + 0.12/1.13 + 0.13</td>
<td>1.54 + 0.15/1.19 + 0.14</td>
</tr>
<tr>
<td></td>
<td>Coronal</td>
<td>1.40 + 0.16/1.09 + 0.15</td>
<td>1.56 + 0.16/1.20 + 0.14</td>
<td>1.59 + 0.16/1.25 + 0.14</td>
<td>1.63 + 0.18/1.32 + 0.12</td>
<td>1.71 + 0.19/1.32 + 0.18</td>
<td>1.77 + 0.19/1.36 + 0.19</td>
</tr>
<tr>
<td>*CS 0.09</td>
<td>Apical</td>
<td>0.38 + 0.10/0.27 + 0.09</td>
<td>0.42 + 0.09/0.30 + 0.08</td>
<td>0.45 + 0.12/0.33 + 0.10</td>
<td>0.56 + 0.12/0.45 + 0.11</td>
<td>0.65 + 0.11/0.56 + 0.14</td>
<td>0.79 + 0.13/0.67 + 0.12</td>
</tr>
<tr>
<td></td>
<td>Middle</td>
<td>0.57 + 0.17/0.42 + 0.12</td>
<td>0.60 + 0.15/0.47 + 0.15</td>
<td>0.63 + 0.15/0.53 + 0.13</td>
<td>0.79 + 0.11/0.65 + 0.10</td>
<td>0.85 + 0.10/0.72 + 0.11</td>
<td>0.90 + 0.11/0.76 + 0.12</td>
</tr>
<tr>
<td></td>
<td>Coronal</td>
<td>0.78 + 0.17/0.60 + 0.16</td>
<td>0.83 + 0.22/0.68 + 0.20</td>
<td>0.89 + 0.21/0.71 + 0.81</td>
<td>1.03 + 0.13/0.87 + 0.10</td>
<td>1.11 + 0.16/0.96 + 0.11</td>
<td>1.15 + 0.17/0.99 + 0.15</td>
</tr>
<tr>
<td>NewTom</td>
<td>Apical</td>
<td>0.71 + 0.14/0.54 + 0.17</td>
<td>0.76 + 0.15/0.57 + 0.14</td>
<td>0.81 + 0.18/0.62 + 0.16</td>
<td>0.91 + 0.25/0.72 + 0.20</td>
<td>0.95 + 0.26/0.80 + 0.20</td>
<td>0.79 + 0.13</td>
</tr>
<tr>
<td></td>
<td>Middle</td>
<td>1/02 + 0.21/0.75 + 0.12</td>
<td>0.98 + 0.21/0.81 + 0.14</td>
<td>1.02 + 0.12/0.86 + 0.17</td>
<td>1.14 + 0.22/0.90 + 0.19</td>
<td>1.17 + 0.21/0.99 + 0.12</td>
<td>1.25 + 0.24/1.02 + 0.15</td>
</tr>
<tr>
<td></td>
<td>Coronal</td>
<td>1.26 + 0.24/0.97 + 0.15</td>
<td>1.24 + 0.23/0.98 + 0.12</td>
<td>1.39 + 0.27/1.06 + 0.21</td>
<td>1.40 + 0.30/1.12 + 0.21</td>
<td>1.49 + 0.18/1.18 + 0.22</td>
<td>1.52 + 0.17/1.22 + 0.12</td>
</tr>
<tr>
<td>Morita</td>
<td>Apical</td>
<td>0.82 + 0.13/0.63 + 0.16</td>
<td>0.86 + 0.19/0.65 + 0.18</td>
<td>0.86 + 0.19/0.67 + 0.23</td>
<td>0.86 + 0.19/0.67 + 0.18</td>
<td>0.86 + 0.19/0.71 + 0.14</td>
<td>0.86 + 0.19/0.75 + 0.13</td>
</tr>
<tr>
<td></td>
<td>Middle</td>
<td>1.07 + 0.20/0.79 + 0.18</td>
<td>1.11 + 0.17/0.88 + 0.14</td>
<td>1.11 + 0.17/0.89 + 0.16</td>
<td>1.11 + 0.17/0.87 + 0.17</td>
<td>1.11 + 0.17/0.94 + 0.15</td>
<td>1.11 + 0.17/0.97 + 0.16</td>
</tr>
<tr>
<td></td>
<td>Coronal</td>
<td>1.35 + 0.19/1.08 + 0.15</td>
<td>1.41 + 0.24/1.17 + 0.16</td>
<td>1.41 + 0.24/1.15 + 0.21</td>
<td>1.41 + 0.24/1.14 + 0.15</td>
<td>1.41 + 0.24/1.19 + 0.17</td>
<td>1.21 + 0.13</td>
</tr>
</tbody>
</table>

*Statistically significant difference compared with the other groups in the same location, P < 0.05.

Table 3  Presence of hypodense halo in longitudinal sections.

<table>
<thead>
<tr>
<th>CBCT protocol</th>
<th>Sagittal</th>
<th>Coronal</th>
<th>Buccal-lingual</th>
<th>Mesiodistal</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS 0.18</td>
<td>0.25</td>
<td>0.64ab</td>
<td>0.95ab</td>
<td>0.31abc</td>
</tr>
<tr>
<td>CS 0.09</td>
<td>0.19</td>
<td>0.50c</td>
<td>0.61</td>
<td>0.06a</td>
</tr>
<tr>
<td>NewTom</td>
<td>0.08</td>
<td>0.08b</td>
<td>0.36a</td>
<td>0.00b</td>
</tr>
<tr>
<td>Morita</td>
<td>0.00</td>
<td>0.00bc</td>
<td>0.36b</td>
<td>0.00c</td>
</tr>
</tbody>
</table>

ab以色列different superscript letters in each line indicate a significant difference (P < 0.05).

GPE and GPV groups in the apical, middle and coronal parts of the roots. The smallest area and maximum diameter were found in the GPV group (P < 0.001). When comparing the GPV group to the GPE group, there was no significant difference in the minimum diameter. The GPVA group showed the largest areas in all filling groups (P < 0.001).

Artefact measurement

Artefacts appeared like streaks and hypodense areas (Fig 1). In a total of 192 CBCT images, hypodense areas were found mostly in the CS 9300 3D system with a voxel size of 0.18 mm in all four longitudinal sections: 64% in coronal, 25% in sagittal, 95% in buccal-lingual and 31% in mesiodistal sections (Table 3), followed by the CS 9300 system with a voxel size of 0.09 mm. The 3D Accuitomo CBCT system showed a low presence of artefacts, and only in buccal-lingual sections of size #40 (anterior zone). Hypodense artefacts were observed significantly more often in coronal and buccal-lingual sections, but less in sagittal and mesiodistal sections in all four protocols.

The roots filled with Vortex GP (GPV group) exhibited the smallest light areas (hyperdense artefacts) in all four CBCT protocols and in all three locations (P < 0.001). EndoSequence GP with BC sealer (GPEB group) and Vortex GP with AH Plus sealer (GPVA group) showed the largest light areas. With the CS 9300 3D
system with a voxel size of 0.18 mm, the light areas in the GPEB group were significantly larger than for the GPVA group ($P = 0.009$). Measurements of the dark areas (hypodense artefacts) were performed only in the size #50 group. The GPV group showed the smallest dark areas with NewTom protocols, and the GPEB group had the largest dark areas with the CS 0.09 protocol. When using CS 9300/0.18mm and Morita protocols, dark areas of the four root-filling groups showed no significant differences. With the CS 9300 3D system with a voxel size of 0.18 mm, light and dark area artefacts were both significantly larger than for the other three CBCT protocols in apical, middle and coronal locations ($P < 0.001$). Both light and dark areas were significantly larger in the coronal part than in the apical and middle part ($P < 0.001$) in all four CBCT protocols and all four types of filling materials. Figure 5 shows the performance of the size #50 group. The dark areas of the middle location were significantly larger than those of the apical location for the CS 0.18 mm, NewTom, and Morita CBCT protocols ($P < 0.001$, $P < 0.001$, $P = 0.003$, respectively).

In the longitudinal sections exhibiting hypodense haloes, the plot profile analysis demonstrated an obvious decline in grey value adjacent to the GP in the coronal section, approaching zero in the nearest portion, when compared to the control group with no filling material (Fig 6); however, in the sagittal section, a slight increase in grey value was detected for the GP close to the root wall.

**Discussion**

This study used an artificial phantom root to quantitatively evaluate the dimensional evaluation and metal (high-density) artefacts generated by different filling materials. The advantage of artificial roots created in this study is that they are reproducible and with the same size (length and width) similar to real teeth. The model is easy to build and enables reliable comparison of parameters from CBCT images taken using different protocols. Furthermore, the material selected for the artificial roots has a similar radiopacity to real roots (Fig 2).

Besides the widely used AH Plus sealer and traditional GP cones, where barium and zinc are the main contributors to radiopacity, the newly introduced bioceramic sealer and GP were also investigated. New root canal obturation materials (e.g., Endosequence GP cones and sealer) with lower radiopacity profiles and improved CBCT software algorithms are expected to minimise imaging artefacts. EndoSequence BC Sealer was investigated and no significant difference was detected in fracture diagnostics between the zirconium-based filling material and traditional ones. In the present study, although the areas of artefacts in
roots filled with zirconium-based fillings appeared to be smaller than those in roots filled with GP Vortex and AH Plus sealer, no significant difference was detected. The thresholding method\textsuperscript{15,21} was applied and a fixed ROI was used in the present study. The present study developed a reproducible methodology for characterising artefacts generated from GP with or without sealers and to quantitatively assess artefacts based on phantom roots.

It has been reported that identical tissues may appear to present different greyscale intensity values depending upon their position relative to other tissues in the irradiated field\textsuperscript{17}. To minimise this, each root was kept in the same position in the same model during each scan. A previous study claimed that if the grey value is too high, artefacts may occur and compromise measurement accuracy, especially in the border area of the images\textsuperscript{17}. In fact, it is not the grey value that causes these effects; it is the density and atomic number of the real object that causes beam hardening or even beam extinction. It is important to remember that radiography always measures absorption, which translates into the physical parameter “density”. In other words, reconstructed CBCT images represent a reasonable estimation of density within the object at that location represented in the particular voxel. Artefacts in the vicinity of highly dense (extremely high atomic numbers) materials are mostly caused by beam hardening. In this context, this might also explain why more artefacts were observed in the buccolingual dimension and in parts of thicker root-filling material, as shown in Table 3. Following the explanation above, this is simply due to more (non-linear) absorption in these regions/directions and thus more incorrect redistribution of the recorded values, i.e., more prominent artefacts.

The CBCT protocol was shown to be the most reliable predictor of both hyperdense and hypodense artefacts by multiple regression. The hypodense (dark) area was most obvious in the CS9300 3D system, especially with a voxel size of 0.18 mm. In B-L sections, it even reached an incidence of 0.95 in the dark band, while dark areas larger than 2 mm\textsuperscript{2} were seen in the coronal location. Artificial lines in the oblique directions resulting from root-filling material may resemble root fractures. These hypodense artefacts were not observed with Accuitomo previously\textsuperscript{2,22}, which is consistent with the findings of the present study. The 3D Accuitomo CBCT system only showed a 36% incidence of artefacts in B-L sections (#40 size: anterior region), whereas the incidence for the other three sections was all zero.

Both light and dark areas were largest in the coronal parts of the canals, especially for the dark area in the coronal location with CS 0.18, which is consistent with previous studies\textsuperscript{2,15}. The greater light artefact area in the coronal third was associated with the larger volume of root fillings in this third. For the middle and apical thirds of the canal, fewer light artefacts were observed because of the smaller volume of root fillings. This may explain the difficulty in reading and segmentation in sizes #40 and #45 of the root canal fillings for the dark artefacts. This finding is also in line with the notion of strengthening minimal instrumentation in modern endodontics to save dentine by reducing instrumentation sizes\textsuperscript{23}, leading to lighter artefacts.

Artefacts may have a significant impact on diagnosis, planning and follow-up\textsuperscript{24}. An image-reading approach\textsuperscript{25}
suggests that a map-reading strategy of viewing sequential axial slices resolved the problem\(^2\). Longitudinal images were obtained and analysed according to this protocol in the present study. The surface plot of grey value in Fig 6 demonstrated an evident decline adjacent to GP in this apparently hypodense band. B-L and coronal sections showed the highest incidence of the hypodense band even with the 3D Accuitomo, indicating that careful interpretation is essential to avoid an incorrect diagnosis of fracture lines or under-obturation\(^2\). In the back-projection process, which is no more than a highly simplified inversion of the true physical projection process, the recorded energy is “smeared back” from the detector pixels along the ray paths towards the source, and in such cases incorrect (relatively too high) energies are distributed in the reconstruction volume. This causes dark (hyperdense) bands that are always along the back-projection lines. Extinction would cause hyperdense (light) stripes along those lines; however, a posteriori “correction” of the reconstructed volume as implemented by manufacturers may often alter the colour of the stripes. This makes it difficult to correct, as the information on the true density cannot be derived from the projections as they are the only source used for CBCT scans. Thus, the present study described the performance of artefacts induced by root canal fillings rather than revealing the internal cause of artefacts. Such information could be derived from evaluating thousands of existing computed tomography or CBCT scans and using this information in learning systems, such as artificial intelligence.

Conclusion
CBCT showed acceptable accuracy of measurement of filling material dimensions. More artefacts were detected in the CS 9300 3D system with a voxel size of 0.18 mm in the coronal location and in the B-L section.

Conflicts of interest
The authors declare no conflicts of interest related to this study.

Author contribution
Dr Xiao Bo CHEN contributed to the conceptualisation of the study and drafted the manuscript; Drs Zhe Jun WANG, Ya SHEN, Andrea ESTEVES and He LIU contributed to the analysis and interpretation of data; Gui Bin HUANG contributed to drafting the manuscript and finalising the article; Dr Xiao Yan WANG contributed to drafting the manuscript; Drs Lin YUE and Markus HAAPASALO contributed to the conception and design of the study and the supervision of the project.

(Received Sep 21, 2022; accepted Jan 31, 2023)

References


