

## TECHNICAL REPORT

# Volumetric tomography – a new tomographic technique for panoramic units

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**Objectives:** To introduce a new three-dimensional dental imaging technique named volumetric tomography (VT).

**Methods:** The new VT imaging method utilizes an iterative frequency-based reconstruction technique. With iterative algorithms each voxel value is defined multiple times during reconstruction. Computation time is therefore relatively lengthy. However, multicore processors and graphic board programming reduce the reconstruction time, making it possible to utilize this iterative reconstruction technique in clinical practice. The new VT technique is an add-on to a standard panoramic unit (Orthopantomograph OP 200 D; Instrumentarium Oy, Tuusula, Finland). Unit enhancements include a device for patient positioning and additional software. Preliminary clinical examinations have been performed.

**Results:** Examinations demonstrated that the new VT technique gives satisfactory volumetric patient data from which tomographs may be derived for different clinical applications.

**Conclusions:** The new VT method may be employed when tomographic examinations are required for dental clinical work.

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## Introduction

Over the last decade there has been an increasing interest in dental cone beam CT (CBCT). So far, all systems have been based on existing medical CT principles and only some mechanical modifications have been implemented to meet dental clinical requirements. Therefore, current dental CBCT systems are not optimized with regard to patient dose, price, workflow and image quality.

Most dental CBCT systems still utilize filtered back-projection (FBP) techniques for reconstructions. With FBP, clinically acceptable three-dimensional (3D) image quality requires the unit to be manufactured to a high degree of accuracy and sufficient patient stability. Moreover, to attain acceptable image quality a large number of radiographs need to be taken of the same region from different directions. In practice, this means a high patient dose<sup>1</sup> and a high device cost.

Because of the disadvantages described above, we have devised a new type of reconstruction method and a device called volumetric tomography (VT). Unlike CBCT, which acquires hundreds of radiographs, VT only uses a maximum of 11 radiographs to calculate multiple slices based on these radiographs. The reconstruction is performed with a computer using state-of-the-art techniques. Since the system is an add-on to existing panoramic units, there is no need to modify the unit.

### *The principle of 3D systems*

Digital X-ray imaging is basically an attenuation measurement where each pixel corresponds to a sum of attenuations from the ray source to individual pixels. Mathematically, this is an integral across a line between the source and a pixel in the detector. Therefore, the distribution of the varying attenuation along the X-ray beam cannot be defined from a single radiograph. However, if a number of radiographs are taken of the same object from different angles, the distribution of the attenuation may be calculated

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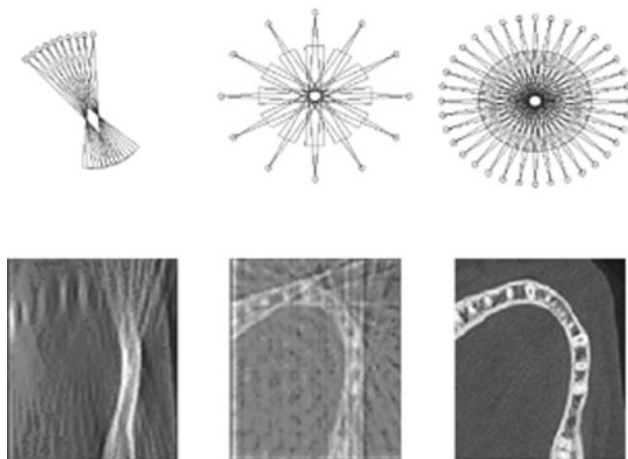
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inside a volume. This can be performed by dividing the object into volume elements (voxels) and then calculating the attenuation in each voxel. This kind of operation, where attenuation values inside a volume are calculated from their sums, is called a reconstruction.<sup>2</sup>

Besides radiographs and reconstruction parameters, a reconstruction requires accurate information concerning the imaging geometry, which describes the position of the X-ray source and the corners of the detector. Based on this information, imaging angles can be defined. The difference between the minimum and maximum angle is called the viewing angle or aperture. The wider the aperture and the more radiographs that are available from different angles, the better the information will be about the object. Consequently, a more accurate reconstruction can be achieved. It should, however, be noted that this statement only holds true if noise, discretization, singularities and tolerances in the imaging geometry are ignored.<sup>3</sup>

#### Limited angle tomography

Limited angle tomography is an imaging method where too few radiographs are available to generate a unique volume. The typical origin of a limited angle situation is either too small differences between angles or a limited image capturing frequency during the scan. The absence of information can typically be observed as the appearance of reconstruction artefacts (Figure 1). There are also other phenomena that theoretically lead to similar reconstruction problems: local tomography and singularities in volume which occur when there are radiation opaque materials, such as metal or amalgam, present in the volume. X-rays that intersect radiopaque materials are fully absorbed and the attenuation before or after such materials has no effect on the X-ray count on the detector, *i.e.* pixel values.



**Figure 1** Imaging geometry and reconstruction artefacts in a limited angle system (left), a sparse angle system (middle) and a full angle system (right)

#### Local tomography

Local tomography is an imaging method where part of the volume is not covered by all projections, typically due to a limited detector size or a limited volume size. In this case, some attenuation occurs outside the relevant volume. Therefore, the sums of attenuations do not match the sums of attenuations in the reconstructed volume. This conflict leads to similar artefacts as with limited-angle tomography.<sup>4</sup>

#### Frequency-based reconstruction technique

It has been shown that FBP is not a suitable reconstruction method when we do not have a sufficient number of radiographs to unambiguously define the object. Moreover, even with a high number of radiographs, FBP is very sensitive to patient movement, mechanical inaccuracy and noise.<sup>5</sup>

Unlike FBP, the algebraic reconstruction technique (ART) does not try to find an exact volume that matches the radiographs. Instead, it generates a volume that best fits the projection radiographs.<sup>6</sup> Since noise or inaccurate geometry generates inconsistent information about the object, a volume calculated with ART is less sensitive to noise and non-ideal conditions than a volume calculated using FBP. Conditions that are adequate for noisy situations are established if information about the object, *a priori*, is added to the reconstruction process.<sup>7</sup>

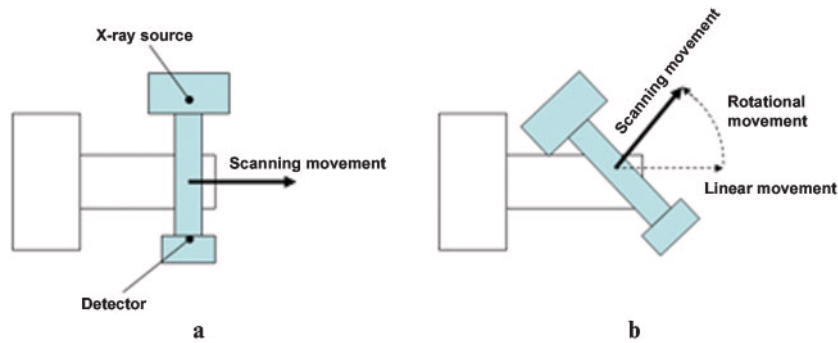
Despite the fact that ART gives a higher image quality than FBP, it is not widely used. The reason is the computational burden of the algorithm. However, multicore processors and graphic board programming (GPU) reduce reconstruction time enough to enable the method to be utilized for clinical work.<sup>8</sup>

For a number of reasons, the reconstruction algorithm was evolved to run in the frequency domain. First, since the spatially sparse information is localized in the low frequency domain, the iterative calculation is simplified. Second, *a priori* information can be applied effectively to the frequency domain to achieve higher image quality. Finally, the reconstruction is faster in the frequency domain because the random access problem can be avoided.

The drawback of the frequency-based iteration algorithm is that a discrete fourier transform (DFT) has to be performed before the reconstruction and an inverse DFT has to be performed after the reconstruction. In practice, this means an increase in computation time. However, since each transform has to be performed only once during the procedure, the frequency-based algorithm is, overall, faster than conventional iterative algorithms (Patents US2007127801 and EP1793347/A2/).

#### Scanning motion

The original purpose of the OP 200 panoramic unit (Instrumentarium Oy, Tuusula, Finland) was to gen-



**Figure 2** The principal movements in the OP 200. (a) When the scanning is linear, the scanning of projection radiographs is straight. (b) When the desired scanning direction differs from the linear movement, scanning is performed by utilizing a combination of linear and rotational movements

erate panoramic radiographs of the jaws. Therefore, the rigid assembly comprising the ray source and detector of the OP 200 has two mechanical movements, rotational and linear towards and away from the column (Figure 2a). Moreover, panoramic imaging utilizes a narrow beam to produce panoramic radiographs. To match the narrow beam, the OP 200 only has a 6 mm wide detector

The size of the reconstructed volume will be limited by the total projection angle and the size of the registered radiographs. Because of the limited width of the CCD detector, all projection radiographs have to be generated using a scanning movement in order to obtain a clinically acceptable volume size. When radiographs for VT reconstruction are acquired, the OP 200 utilizes a combination of a rotational and a linear movement to achieve the scanning motion needed for each projection angle as shown in Figure 2.

## Implementation

The VT system consists of a panoramic unit, patient positioning devices and specially designed reconstruction and viewing software (Cliniview (CV); Instrumentarium Dental, PaloDEX Group Oy, Tuusula, Finland).

Each VT examination consists of a panoramic radiograph and a series of 5–11 radiographs that are centred on the desired region. The panoramic radiograph is used for reference while the reconstruction of the volume is performed using exposed radiographs. The series of radiographs are exposed successively by employing an automated change of the projection angle (Figure 3).

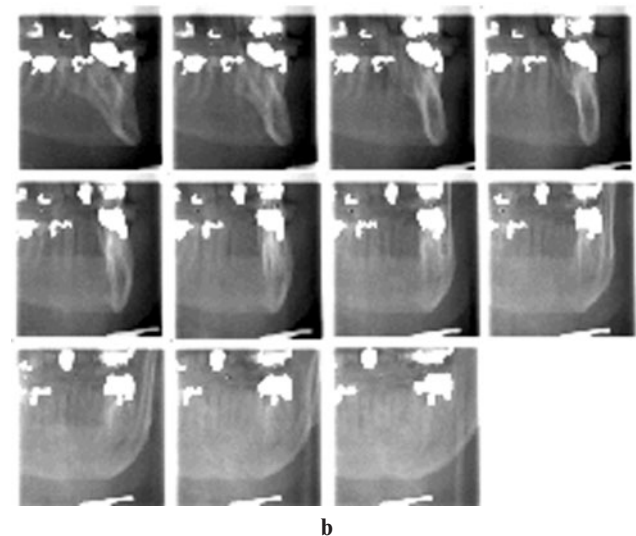
### Patient positioning

To acquire a panoramic reference radiograph and a series of originals that are suitable for the subsequent volume reconstruction, specially designed patient positioning devices are attached to the panoramic unit during exposures.

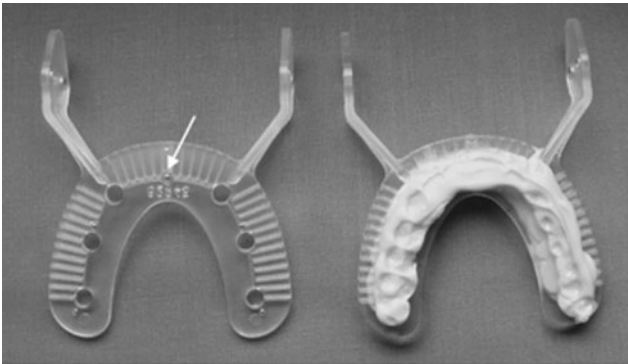
The first step of the radiographic process is to make a dental impression by asking the patient to bite on a

tooth arch-shaped plate (Figure 4). Two plate sizes are available.

During the second step, the bite plate with the impression is attached to the positioning device



**Figure 3** (a) Panoramic radiograph and (b) 11 radiographs taken for the reconstruction of a volume covering the region of the left first lower molar



**Figure 4** Bite plate without and with the impression. There are five steel balls in the bite plate, each with a diameter of 1.5 mm, that are used as fiducial points; one steel ball is marked with an arrow

(Figure 5a) by means of the two forked extensions on the bite plate. This assembly is then attached to the panoramic unit, the patient is asked to step into the unit, bite on the impression (Figure 5b) and a panoramic radiograph is exposed (cf. Figure 3a).

During the third step, the bite plate is moved and attached to the positioning device for taking the series of radiographs for VT reconstruction; again, the forked extensions of the bite plate are used for attachment (Figure 6). The positioning device has five settings for obtaining radiographs in different regions: incisors, left and right canines, and left and right molars. The first premolar regions are covered by using the canine settings, and the second premolar regions by using the molar settings. Upper or lower jaw can be selected by attaching the biteplate in a high or low position.

When the positioning device for exposing the series of radiographs for VT reconstruction of the pre-selected region is attached to the panoramic unit (Figure 7a), the patient once again steps into the unit and bites on the impression (Figure 7b). The series of radiographs is taken (cf. Figure 3b).

#### *Correction for projection discrepancies*

Before the VT reconstruction starts, pattern recognition algorithms are used to identify in all radiographs five fiducial points that are placed in fixed and defined positions in the bite plate (Figure 4). These fiducial points are, together with the corners of the radiographs, used to define the radiographic projection of each individual radiograph in the series. Then, corrections may be performed for small discrepancies between the projections due to, for example, patient movement or slight movement inaccuracies of the panoramic unit. Since 3D coordinates for the fiducial points are known, small discrepancies between the radiographic projections are easily detected and can be compensated for by means of coordinate transformations of radiographic data. The fiducial points are also used to relate the panoramic radiograph to VT data so that it can be used for reference purposes.



a

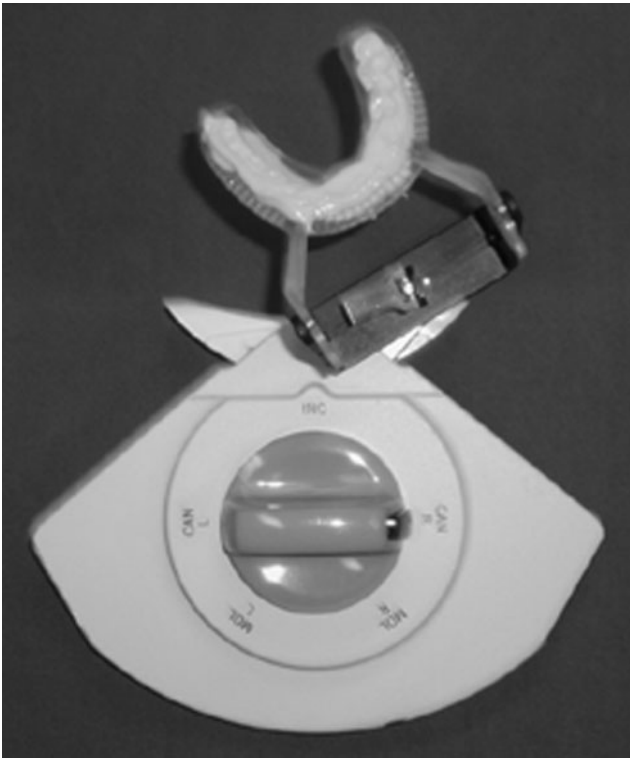


b

**Figure 5** (a) Bite plate with impression attached to the positioning device for the panoramic exposures; (b) patient biting on the impression and positioned for exposure of the panoramic reference radiograph

#### *Reconstructing VT data*

After correction for possible projection inaccuracies, VT data are reconstructed as described above. The reconstruction time for  $256 \times 256 \times 256$  voxels in the volume that is  $60 \times 60 \times 60$  mm, including pre- and post-processing, takes from 5 min to 10 min depending on the capacity of the computer. When the reconstruction is finished and the volume is displayed, it is possible to scroll through the volume to select proper



**Figure 6** Bite plate and impression attached to the positioning device which is positioned to take radiographs of the patient's right canine region

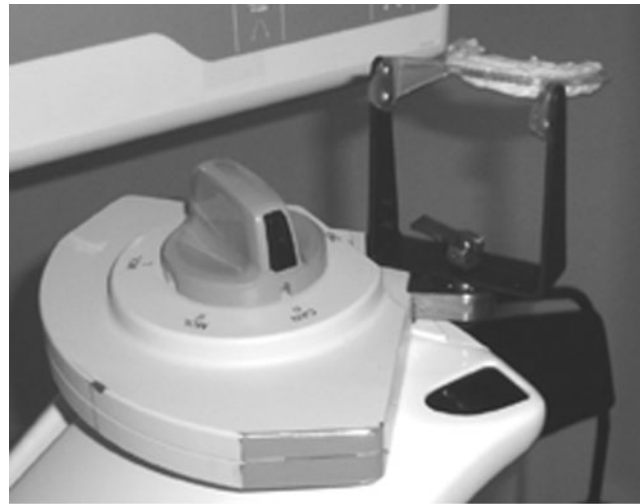
cross-sectional slices of the exposed region (Figure 8a). These slices are in every region automatically perpendicular to the tooth arch. Next to the volumetric data, a reference radiograph derived from the panoramic radiograph is displayed. As one scrolls through the volume, a line in the reference radiograph indicates the position of the slice relative to the tooth arch (Figure 8b).

#### *Measurement accuracy*

To verify measurement accuracy, a U-shaped acrylic phantom was designed with four reference balls, each with a diameter of 1 mm. Distances between the reference balls were measured. The phantom was placed in a dry skull in ten different positions and VT radiographs were taken. Finally, the distances between the balls were measured in the reconstructed volumes. Since the distances between the balls were known, the measurement error in all ten positions could be calculated. The maximum error in VT volumes was less than 0.47 mm and the relative error was less than 2.7% in all directions.

#### *Clinical examples*

The case that was employed above to describe the imaging process (Figure 8) was examined in order to plan implant therapy in the region of the lower left first molar. It can be readily seen in Figures 8a and 9a that the outline of the mandible in the cross-sectional slices is well defined and that the mandibular canal can be



**a**

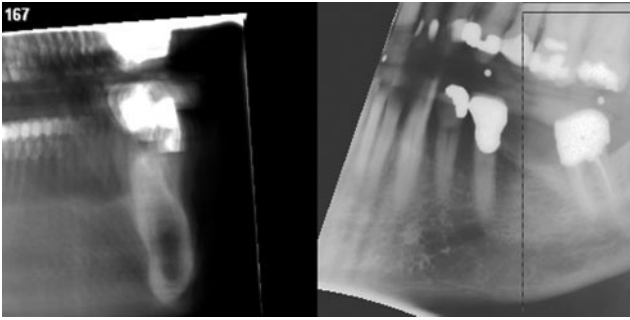


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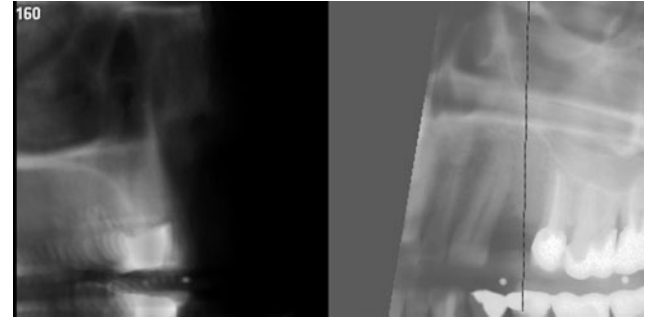
**Figure 7** (a) The positioning device attached to the panoramic unit; the bite plate is positioned in the high position for taking of radiographs in the lower jaw. (b) The patient is positioned for the exposure of a series of radiographs of the lower right canine region

identified. The width of the alveolar process and the distance between its crest and the mandibular canal may be measured.

The following two cases also illustrate examinations in different regions performed in association with implant therapy planning. In the case illustrated in Figure 9, the region of the lower second premolar and first molar on the right-hand side have been examined. Figure 9a shows a cross-sectional slice in the second premolar region where the mental foramen can be seen as well as the outline of the mandible. In the cross-sectional slice illustrated in Figure 9b, additional



**Figure 8** (a) One slice selected from volumetric tomography data. (b) The reference radiograph indicates the position of the slice relative to the tooth arch

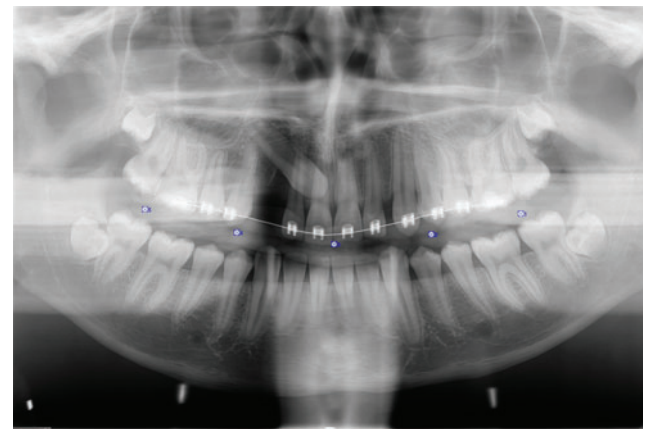


**Figure 10** Cross-sectional slice and reference radiograph showing the upper left premolar region

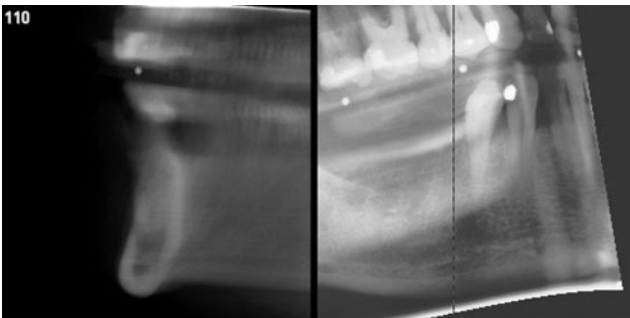
information about the position of the mandibular canal can also be seen.

Figure 10 exemplifies how the present VT technique portrays the alveolar process in the edentulous region of the upper left first premolar between the canine and the second premolar. It should be noted that the delineation of the alveolar process can clearly be seen. Its width can be measured, as well as the distance from the alveolar crest to the floor of the nasal cavity.

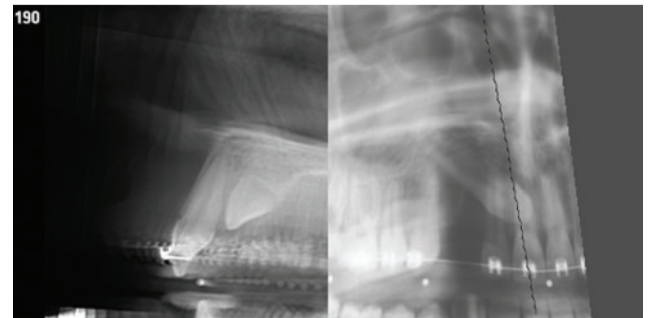
The present VT technique may also be employed to determine the position of, for example, impacted teeth, as is shown in Figure 11. The panoramic radiograph (Figure 11a) shows that the right upper canine is markedly inclined and positioned with its crown projected over the roots of the central and lateral



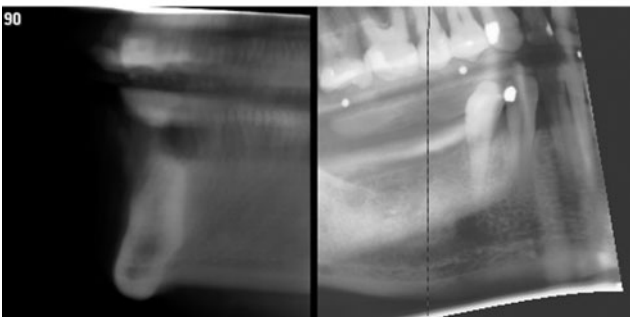
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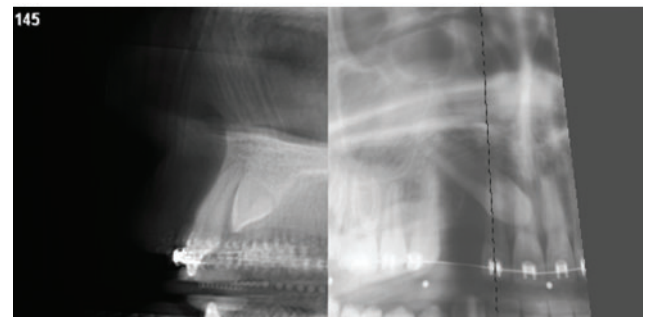
a



b



b



c

**Figure 9** Two cross-sectional slices together with reference radiographs indicating the positions of the slices in the regions of (a) the right second premolar and (b) the first molar

**Figure 11** (a) Impacted upper right canine that is markedly inclined and positioned with its crown in the region of the central and lateral incisors. (b,c) The crown of the canine is situated on the palatal side of the roots of the incisors

**Table 1** Exposures and dose values of a typical volumetric tomography (VT) study compared with the panoramic radiograph. All values are measured from the same OP 200 panoramic unit with the VT option

Type of radiograph	Number of radiographs	Tube potential (kV)	Tube current (mA)	Time (s)	DAP (mGy cm <sup>-2</sup> )	Times panoramic radiograph
Panoramic radiograph	1	66	8.0	17.6	40.2	1.0
VT, incisor region	11	66	4.0	44.0	63.9	1.6
VT, canine region	11	77	3.2	44.0	67.7	1.7
VT, molar region	5	77	5.0	20.0	48.8	1.2
VT, molar region	7	77	5.0	28.0	68.4	1.7
VT, molar region	11	77	5.0	44.0	107.0	2.7

DAP, dose-area product

incisors. The crown is situated on the palatal side of the incisors. The relationship between the crown of the canine and the roots of the incisors is illustrated in the two cross-sectional slices acquired from the regions of the medial and lateral incisors (Figure 11b,c). The crown lies close to the roots of the incisors but there are no definite signs of root resorption.

## Discussion

The above clinical examples show that the new VT technique described in the present work provides volume data that can be used to obtain cross-sectional slices of the jaws. These slices may be used to assess the volume of the alveolar processes, for example, their widths and heights, prior to implant therapy. Examinations of impacted teeth may also be performed. Their positions within the jaws may be determined as well as their relationship to neighbouring teeth and to anatomical structures such as the mandibular canal, the maxillary sinuses, the nasal cavity and so on. Although no such examples are given in this present work, the new technique has many other applications in clinical radiography. Thus, the size and extension of large pathological processes, such as cysts and tumours, and their correlation to surrounding structures may be examined; expansions of the jaws in association with large pathological processes may be studied as well as possible involvement of, for example, the maxillary sinuses.

With the present technique, the dose to the patient is relatively low. It has been calculated that the panoramic radiograph, which is part of the examination, requires an absorbed dose of about 40 mGy cm<sup>-2</sup>. A series of 11 radiographs for the volumetric reconstruction results

in a patient dose that is less than 2.7 times that of the panoramic radiograph. Thus, with 11 radiographs for reconstruction, the total dose to the patient will be equivalent to 3 ordinary panoramic radiographs. If the reconstruction is made from a smaller number of radiographs, the patient dose will be reduced proportionally to the number of volumetric exposures taken (Table 1).

VT is an add-on to the conventional Orthopantomograph OP 200 panoramic unit. The only additional features that are needed are the positioning devices and the software, which includes programs for taking the panoramic radiograph and the series of 5–11 radiographs for volumetric reconstruction. The software also has routines for viewing and digital image processing. Major advantages are simplicity and an investment that is considerably lower than that for a CBCT unit.

For obvious reasons, the image quality of the new technique is inferior to images acquired with a dental CBCT. With the present technique volumes are reconstructed from a maximum of 11 original radiographs. Consequently, the radiographic information should not be compared with that from images reconstructed from several hundred originals. Any such comparison is iniquitous. The question is not whether images obtained with the new VT technique can be compared with those obtained with CBCT. The right question is, does the new VT technique provide images with satisfactory information content for such radiographic purposes as described above? The clinical examples presented here indicate that this is the case. To confirm this, work is in progress where measurements of defined distances are taken and compared with measurements of the same distances taken from CBCT radiographs.

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