TECHNICAL REPORT

A novel alignment device for cone beam computed tomography: principle and application

A Dawood^{1,2}, V Sauret-Jackson^{*,2}, S Patel¹ and A Darwood²

¹Specialist Practice, London, United Kingdom; ²Cavendish Imaging, London, United Kingdom

Objectives: The aim of this investigation was to optimize the positioning and size of the scanned field of view (FOV) in cone beam CT (CBCT) scanners using a practical external alignment device fitted in the patient's mouth in order to train radiographers and reduce radiation dose to the patient. This is particularly challenging when using small FOVs to cover small volumes of interest.

Methods: Test objects were positioned and scanned using the aligner to show that the design and geometry were correct and help the radiographer to superimpose the scanner and the volume of interest axis of rotation. An *in vivo* study was then undertaken comparing the accuracy of patient positioning when using the aligner, instead of scouts, to position the patient for small FOV (cylinders of 4–8 cm height and 4–8 cm diameter) dental scans. The scanners used were the Accuitomo F170 CBCT scanner (Morita, Kyoto, Japan) and the iCAT Next Gen CBCT scanner (Imaging Sciences, Hatfield, PA).

Results: There was no significant difference in positioning the patient when using the aligner compared with the scout images.

Conclusions: It is possible to rely on the aligner for patient positioning for a small volume scan and therefore spare the radiation dose associated with scout imaging.

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Introduction

Cone beam CT (CBCT) is an exciting technology, which, when used in the appropriate situation, aids diagnosis and management in dental and maxillofacial surgery.^{1–3} CBCT uses a rotating X-ray source and a reciprocal opposing digital sensor to capture multiple projections or basis images, which are then reconstructed using complex reconstruction algorithms to create a three-dimensional (3D) volume of image data. One or several preliminary scout views are used to ensure the correct positioning of the patient prior to the actual CBCT scan. Ideally, during the CBCT scan the axis of rotation of the X-ray source and sensor should correspond to the central axis of the field of the region of interest (ROI).

Using the smallest possible field of view (FOV) not only lowers patient radiation dose, but reduces the need to report anatomical structures which are imaged beyond the ROI.^{4–6} The importance of selecting the smallest

FOV compatible with the clinical situation has recently been highlighted by the European Academy of Dental and Maxillofacial Radiology.⁷ However, selecting a smaller FOV makes patient positioning within the apparatus more critical; because of this, there is sometimes a tendency to increase the size of the FOV to ensure that the ROI is comprehensively encompassed in the scan volume. Dose reduction mechanisms are also the concern of the pan-European SEDENTEX-CT project, which is supported by the Seventh Framework Programme of the European Atomic Energy Community (Eurotom, <http://cordis.europa.eu/fp7/euratom/>), through its work package on optimization of X-ray exposures in CBCT.⁸

The aim of this paper is to describe a novel device (patent application GB0901873.0) to assist and improve patient positioning, as well as to reduce patient radiation dose. The device design is described together with the validation study. The *in vivo* results when using it with an Accuitomo F170 CBCT scanner (Morita Corp, Kyoto, Japan) are presented, as well as the practical experience of how to use the device with an iCAT Next Gen CBCT scanner (Imaging Sciences, Hatfield, PA).

*Correspondence to: Veronique Sauret-Jackson, 44 Wimpole Street, London W1G 8SA; E-mail: veronique@cavendishimaging.com
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Figure 1 (a) The centre of the scanned volume is determined by the position of the laser illuminators on the patient's face; (b) the scanned volume in relation with the planes defined by the laser illuminators

Materials and methods

Device design

Most manufacturers of CBCT apparatus provide laser alignment illuminators to assist with positioning. The illuminators project the edge of an illuminated plane onto the patient's jaws. Typically, three planes intersect to indicate the centre of the central axis of the imaged FOV. Two vertical planes intersect along the axis of rotation and a third horizontal plane intersects at the mid-point (Figure 1).

With due consideration to the projection geometry of the alignment lasers, Pro/Desktop (Parametric Technology Corporation, Needham, MA) computer aided design (CAD) software was used to design an alignment device. Various designs with "bite" platforms, which indicated the axis of rotation for a range of volumes, and targets for the laser illuminators, were prototyped (Figure 2). When the laser planes were aligned with perpendicular intersecting lines on the targets, it was anticipated that it would be possible to pinpoint the central axis of the FOV. The lines marked on the

targets were numbered so that, once the aligning device was placed in the patient's mouth, the radiographer could decide which line to align with the illuminators to target the centre of the tooth or area of interest, as shown in Figure 3.

The CAD files for the devices were given for 3D manufacture using laser sintered nylon technology (digits2widgets.com, London, UK), thus permitting the iterative design of a series of prototypes.

In vitro validation study

The aim of this investigation was to confirm the basic principle of the aligner device – that is, using the aligner device, was it possible to pinpoint the central axis of the FOV? Figure 4 shows the most advanced version of the series of prototypes placed in the iCAT Next Gen scanner, with the laser illuminators positioned on the aligner so that its scan is centred as shown in Figure 3a.

Figure 5 shows the same prototype positioned in a plastic test object representing the upper and lower dental arches and scanned using the Accuitomo F170

Figure 2 Screenshot of computer aided design front and side views showing the "bite" form and targets

Figure 3 (a) The relative position of the patient and the illuminators (bold lines) to perform a scan centred in the middle of the dental arch is such that the anterior illuminator falls on the line between the two “1” marks on the anterior target, and the side illuminator falls on the line next to the mark “6” on the side target. (b) The relative position of the patient and the illuminators to perform a 4 cm diameter scan centred on the patient’s tooth located above or below the intersection of the red lines is such that the anterior illuminator falls on the line between the marks “1” and “2” on the anterior target, and the side illuminator falls on the line between the mark “1” and “2” on the side target

scanner using the standard scanning procedure, where both lateral and anterior-posterior scouts are taken to position the scanner FOV over the area of interest, and the aligner targets to position the scanner FOV over the area of interest. The FOVs chosen were a 4 cm diameter by 4 cm height cylinder and a 6 cm diameter by 6 cm height cylinder. The areas of interest chosen on the object were, successively, the upper left central teeth and upper molar (21, 21–23 and 26), and the lower incisor to premolar teeth (42–44). For each case, the position of the scanner centre of rotation (X, Y and Z co-ordinates) was recorded, as shown in Figure 6. Moving the centre of rotation of the scanner more to the right or to the left changes the X co-ordinate. Moving the centre of rotation of the scanner more to the front (anterior) or to the back (posterior) changes the Y co-ordinate. Moving the centre of rotation of the scanner up or down changes the Z co-ordinate.

Figure 4 The aligner positioned in the iCAT scanner for an 8 cm diameter field of view scan centred where the bold lines of Figure 3a intersect

In vivo investigation

47 patients who were referred for small volume (4 or 6 cm diameter by 4 or 6 cm height) Accuitomo F170 scans in the mandible or the maxilla were selected for inclusion in this study. All patients gave their informed consent for the aligner to be used prior to the conventional scout exposure. First, the radiographer positioned the patient in the scanner using the aligner, and the X, Y and Z co-ordinates of the scanner centre of rotation were recorded. The radiographer then took the scout images and set the centre of rotation of the scanner on the ROI. The X, Y and Z co-ordinates of the scanner centre of rotation were recorded and the scan was performed. This protocol was, therefore, designed so that all scans were performed following the standard scanning protocol developed with the manufacturer and radiation protection adviser and established in the authors’ scanning centre (*i.e.* using the scout images). The two sets of co-ordinates were compared to assess whether using the aligner was equivalent to using the scout images so that, in the future, only the aligner, rather than the scout images, would be used and hence minimize the radiation to the patient.

It was not possible to carry out a quantitative comparison of the positioning of the patient using the aligner or the scout image with the iCAT scanner because the centre of rotation of the machine is fixed. The current design of the iCAT scanner is such that the side illuminator is only projected on to the right-hand side of the patient’s face. The iCAT *in vivo* investigation was, therefore, limited to the assessment of whether the aligner could be used to facilitate patient positioning off-centre to allow for a small FOV scan centred around a tooth on the arch, *i.e.* the tooth being in the scanner rotation axis. Two patients who were referred for visualizing a small ROI in the maxilla were selected for inclusion in this study. The patients gave their informed consent for the aligner to be used prior to the conventional scout exposure.

Figure 5 The aligner in a test object in a Accuitomo F170 scanner. (a) The positioning of the area of interest for a 4 or 6 cm diameter by 4 or 6 cm height cylindrical field of view scan can be based on the scout images or (b) the illuminators

Figure 6 The co-ordinates of the centre of rotation of the scanner can be recorded directly from the Accuitomo F170 scanner control panel

Figure 7 (a) Axial and (b) sagittal slices through the aligner positioned as per Figure 4 in the iCAT scanner with an 8 cm diameter field of view. Measurements are 39 mm

Figure 8 (a) Coronal and (b) axial slices through the aligner positioned as per Figure 4 in the iCAT scanner with a 5 cm diameter by 4 cm height field of view. The measurements on the coronal slice are both 20 mm and the measurement on the axial slice measures 25 mm

Results

In vitro validation study

The aligner in the iCAT scanner was positioned as shown in Figures 3a and 4, and an 8 cm diameter scan was carried out. The distance from the intersection of the illuminator lines measured to the edge of the aligner was 3 cm, and 39 mm to the edge of the FOV (Figure 7). Having performed a 5 cm diameter scan with the same set-up, the distance from the intersection of the illuminator lines to the edge of the scan was 25 mm (Figure 8). This, therefore, shows that the aligner is a suitable device to find the central axis of the iCAT scanner.

The *in vitro* comparison of the two methods that the radiographer used to centre the scans of the dental test object on specific teeth of interest is summarized in Table 1. The range of position adjustments that the radiographer performed between the set-up using the aligner and using the scout was no more than 7 mm in the right-left (X co-ordinates) and anterior-posterior (Y co-ordinates) directions and 5 mm in the up-down (Z co-ordinates) direction. In clinical terms, with the aim of scanning a single tooth in a 4 cm diameter by 4 cm height FOV or a few teeth in a 6 cm diameter by

6 cm height FOV, this small range of movement in all three directions showed that the scanning position obtained using the aligner would encompass the entire clinical volume of interest.

In vivo investigation

Figures 9–11 show that the two methods to position the Accuitomo F170 scanner centre of rotation were not significantly different, hence validating that using the aligner was equivalent to using the scout images.

Figure 12 shows the resulting scan with the radiographer using the aligner to perform a 5 cm diameter scan around the left upper first molar. As there was no illuminator line on the left-hand side of the patient, the aligner was, therefore, very useful to position the patient so that the tooth of interest was on the axis of the scanner centre of rotation. The aligner was put in the patient's mouth and the radiographer "read" which line on the aligner targets the anterior and which side the illuminators should be aligned on in order to intersect on the tooth of interest.

Discussion

To minimize patient radiation dose it is essential to first use suitably trained radiographers, and second to optimize the technical factors, such as exposure parameters and the FOV size.^{6,7,9,10}

The challenge of patient positioning in a CBCT scanner is to position the patient so that the centre of the ROI within the FOV coincides with the rotational axis of the X-ray source and reciprocal sensor, thus optimizing the geometry.

The aligner device described in this paper has been successfully used to minimize patient radiation dose, whilst still maintaining CBCT data sets with diagnostic quality at acceptable levels.⁸ The results of this study

Table 1 Adjustment in the scanner position when using the aligner (Xa,Ya,Za co-ordinates) and when using the scout images (Xs,Ys,Zs co-ordinates) on the dental test object for imaging the upper left central teeth and upper molar (21, 21–23 and 26) and the lower incisor to premolar teeth (42–44) in the *in vitro* study

Region	FOV	Differences		
		Xa – Xs (mm)	Ya – Ys (mm)	Za – Zs (mm)
42–44	6 cm × 6 cm	7	–7	–5
21–23	6 cm × 6 cm	4	–7	1
21	4 cm × 4 cm	0	0	–2
26	4 cm × 4 cm	6	–1	–2

FOV, field of view

Figure 9 Differences in the lateral position (X) of the Accuitomo F170 scanner centre of rotation ($\text{mean} \pm 2\text{SD} = 0.3 \pm 8.8 \text{ mm}$)

confirm that the aligner device may be used to replace preliminary scout views prior to CBCT scanning by confidently using smaller FOV examinations and thus reducing patient X-ray dose.

In addition it was found that the alignment device was an extremely useful training tool, allowing radiographers

and clinicians to appreciate the boundaries of each FOV, and increase the understanding of CBCT geometry and technology.

As an anecdotal finding, the radiographers reported that the use of the alignment device resulted in a quicker overall scanning time.

Figure 10 Differences in the anterior-posterior position (Y) of the Accuitomo F170 scanner centre of rotation ($\text{mean} \pm 2\text{SD} = 0.4 \pm 14.4 \text{ mm}$)

Figure 11 Differences in the vertical position (Z) of the Accutomo F170 scanner centre of rotation ($\text{mean} \pm 2\text{SD} = 0.1 \pm 11.4$)

Figure 12 Patient positioned in the iCAT scanner for a small field of view examination of the upper left first molar

In conclusion, training with the aligner has the potential to communicate a more profound understanding of the positioning process, whilst improving its accuracy and reducing patient radiation dose.

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