Beam alignment and image distortion assessment of dental cone beam computed tomography (CBCT) system

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Abstract. Cone-beam computed tomography (CBCT) technique has been widely used in dental imaging as it offers different image views such as panoramic, cephalometric, tomographic, and three dimensions (3D). This study aimed to assess image distortion due to beam misalignment for CBCT system using phantom study. A ball phantom was scanned with default exposure setting for standard panoramic imaging (68 kV, 8 mA and patient size of M) using Planmeca ProMax CBCT unit. Three different measurements were performed on the phantom images such as distance measurement between the centre of the middle ball and rear middle ball, distance measured from the centre of middle ball to tenth ball (left and right), and measurement of both vertical and horizontal distance of any four balls. From the findings, most of measured distance between middle ball and rear middle ball were below the acceptable level, but two measurements exceeded the reference value by 6% and 75%. Similar with the measured distances of the tenth balls, two measurements exceeded the acceptable level by 3% and 28%. The vertical and horizontal distance of 4 balls were slightly differ from standard value with overall magnification of 1.06 and percentage error of 6%. The beam alignment and patient positioning should be accurately evaluated to avoid image distortion and misdiagnosis in dental CBCT images.

1. Introduction
Dental CBCT imaging has been widely used to aid the diagnosis and treatment planning task in clinical dentistry. CBCT imaging uses a conical shape x-ray beam for rapid data acquisition and produce high spatial resolution image (Tang et al., 2017; Abramovitch and Rice, 2014; Scarfe, 2006). CBCT techniques offers various image views such as panoramic, cephalometric, and tomographic images. Besides, CBCT imaging provide image volumes of the maxillofacial region in 3D view, which overcoming magnification and superimposition problems with 2D panoramic imaging (Hatcher, 2010).

Digital panoramic view is preferable in diagnosing and treatment of dental diseases as it includes overall anatomical information of teeth and jaw (Bing et al., 2011). The panoramic view is limited by image magnification of about 15–25% due to patient mispositioning which the patient’s jaws are not properly positioned at the focal of x-ray beam (Devlin and Yuan, 2013). Magnification can also be influenced by variation in patient’s jaw shape and size, and teeth positions. This work aimed to evaluate beam alignment accuracy of digital CBCT system and investigate the effect of patient mispositioning on image quality.
2. Materials and Methods
The digital CBCT system, Planmeca ProMax 3D Mid CBCT unit (Planmeca, Helsinki, Finland) was installed at Imaging Unit, Advanced Medical and Dental Institute (AMDI), Universiti Sains Malaysia, Penang in 2014. In this study, a ball phantom provided by the manufacturer was scanned using Planmeca ProMax CBCT unit for the evaluation of the beam alignment and image distortion. The ball phantom has an arch shape representing the standard size of mandibular dental arch and consists of 23 metal balls (as shown in Figure 1). The phantom study aims to verify the x-ray beam alignment. Figure 1 shows the experimental setup for ball phantom scanning with the CBCT unit. A central y-line on the ball phantom was accurately positioned on reference line of the laser lights. The C-arm of the CBCT unit were set at zero position. The phantom was scanned with standard panoramic mode at 68 kV and 8 mA, and selected patient size was M size.

In local practice, the x-ray beam alignment test was performed on daily and weekly basis before the clinical procedure is performed. A retrospective study was performed on previous phantom image datasets obtained from January 2019 until July 2019. All image analysis was performed on the CBCT workstation using Planmeca Romexis viewer software (Version 3.6.0.r). There were 3 measurements were performed on the ball phantom image using Romexis measuring tool, which were (1) distance between the centre of middle ball and rear middle ball (shadow ball) were performed on phantom images for each selected date. Figure 2A shows the distance measurement on the phantom image. A centre line was drawn on both middle ball and rear middle ball and the gap between both lines was determined. The recommended value by the manufacturer for the measured distance is less than 1.6 mm.

2.1. Centre Ball
The measurement of the distance from the centre of the middle ball to the centre of rear middle ball (shadow ball) were performed on phantom images for each selected date. Figure 2A shows the distance measurement on the phantom image. A centre line was drawn on both middle ball and rear middle ball and the gap between both lines was determined. The recommended value by the manufacturer for the measured distance is less than 1.6 mm.

2.2. The 10th Ball
The second measurement was the distance from the centre of the middle ball to the centre of the tenth balls to the left and right. Figure 2B shows the measurement of the tenth ball distance (both left and right side) on the phantom image. The difference between the two measured distances (left and right side) must not be greater than 3.2 mm, as recommended by the manufacturer.
Figure 2. Measurement performed on ball phantom image including (A) distance between centre of middle ball to rear middle ball and (B) distance between centre ball to tenth balls (left and right).

2.3. Four ball dimensions
The vertical and horizontal distance of any four balls were taken. All 23 balls must appear round with same recommended size of 6 mm diameter. The magnification factor for each ball was calculated using Equation 1 (Delvin and Yuan, 2013). The values of $\alpha$ and $\beta$ representing the horizontal and vertical magnification of the balls.

$$y = \sqrt{\alpha \beta} = \sqrt{\frac{\text{image width} \times \text{image height}}{\text{BB diameter}}}$$ (1)

3. Results and Discussion
A total of 23 ball phantom images were retrospectively evaluated from January 2019 until July 2019. All 23 balls should appear round, although not in the same size but must be evenly spaced (Figure 2B). As recommended, the centre of middle ball and the centre of rear middle ball must be aligned with a small gap between them, as shown in Figure 2A. The outermost balls (10th balls) for both left and right sides should appear symmetrical (Figure 2B). Figure 3 shows two scatter plots of measured distance between the centre middle and rear middle balls. The first graph shows 95% of the measured distances between middle and rear middle ball were below the acceptable level (< 1.6 mm). However, there were two measurements exceeded the reference value (6% and 75% higher). This reveals that there was shift in x-ray beam alignment of the CBCT unit as measured distances exceeded the recommended value. For distance measurement between middle ball to tenth balls, most of the measured distances were higher at left side as compared to right side (with distance shift ranged between 0.2 to 4.1 mm). This indicates that the beam alignment was laterally displaced to the left. However, about 14% of total measurements showed the beam displacement was laterally to the right side. Second graph shows the scatter plot of differences of measured distances between middle ball to tenth ball for both sides. From the graph, most of the measured distances were within the acceptable level (with difference between both sides ≤ 3.2 mm), except for two measurements that exceeded the recommended value by 3% and 28%. It can be observed that these exceeded values of measured distances for tenth balls were noticed on the same test date for centre and rear middle ball. From the observation, there were distortion seen at the middle area of ball phantom images. The neighbouring balls near the middle ball seem to have greater vertical diameter as compared to their horizontal dimension. From the findings, the measured vertical and horizontal distance of four selected balls were slightly differ from the actual size (6 cm diameter). The range of measured distance were between 5.9 – 6.9 cm and 5.4 – 8.3 cm for vertically and horizontally. The mean overall magnification was 1.06 with the highest magnification of 1.1185. The percentage error for magnification was 6%. The magnification of the ball phantom images indicates poor beam alignment of the CBCT unit.
Figure 3. The measured distance between the centre and rear ball (left) and the differences of measured distance between centre and tenth balls for both sides (right)

4. Conclusions
It can be concluded that the CBCT unit at AMDI USM, Penang is well calibrated as most of the measurements were within acceptable values. However, few exceeded values of measured distance for certain test dates indicates inconsistent performance of the dental CBCT unit that lead to beam misalignment and image distortion, which need further investigation. The beam alignment and patient positioning should be accurately evaluated to avoid image distortion and magnification on dental CBCT images that may lead to misdiagnosis in routine clinical practice. Beam distortion issues can be rectified by establishment of a good and frequent quality assurance program, continuous education and well-trained professional at the department.

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