Available online at www.sciencedirect.com

ScienceDirect

journal homepage: http://www.elsevier.com/locate/rpor

Original research article

# Impact of reduction of flux overlap region on kilovoltage cone-beam computed tomography image quality and patients' exposure dose

Daisuke Kawahara[a,b], Shuichi Ozawa[c,*], Yuji Murakami[c], Takeo Nakashima[a], Masamichi Aita[a], Shintaro Tsuda[a], Yusuke Ochi[a], Takuro Okumura[a], Hirokazu Masuda[a], Yoshimi Ohno[a], Yasushi Nagata[c]

[a] Section of Radiation Therapy, Department of Clinical Support, Hiroshima University Hospital, Japan
[b] Course of Medical and Dental Sciences, Graduate School of Biomedical & Health Sciences, Hiroshima University, Japan
[c] Department of Radiation Oncology, Institute of Biomedical & Health Sciences, Hiroshima University, Japan

ARTICLE INFO

*Article history:*
Received 29 December 2015
Accepted 13 April 2016
Available online 16 May 2016

*Keywords:*
Cone beam CT
Flux overlap region
IGRT

ABSTRACT

*Aim:* In high-precision radiation therapy, kilovoltage cone-beam computed tomography plays an important role in verifying the position of patient and localization of the target. However, the exposure dose is a problem with kilovoltage cone-beam computed tomography. Flux overlap region increases the patient dose around the center when the scan is performed in a full-scan mode. We assessed the influence of flux overlap region in a full-scan mode to understand the relationship between dose and image quality and investigated methods to achieve a dose reduction.

*Method:* A Catphan phantom was scanned using various flux overlap region patterns in the pelvis on a full-scan mode. We used an intensity-modulated radiation therapy phantom for measuring the central dose. DoseLab was used to perform image analysis and to evaluate the linearity of the computed tomography values, uniformity, high-contrast resolution, and contrast-to-noise ratio.

*Results:* The Hounsfield unit value varied by ±40 Hounsfield unit of the acceptance value for the X1 field size of 3.5 cm. However, there were no differences in high-contrast resolution and contrast-to-noise ratio among different scan patterns. The absorbed dose decreased by 7% at maximum for the case within the tolerance value.

*Conclusion:* Dose reduction is possible by reducing the overlap region after calibration and by performing computed tomography in the appropriate overlap region.



* *Corresponding author at*: Department of Radiation Oncology, Institute of Biomedical & Health Sciences, Hiroshima University Hiroshima University, 1-2-3, Kasumi, Minami-ku, Hiroshima City 734-8551, Japan. Tel.: +81 82 257 1545; fax: +81 82 257 1545.
E-mail address: ozawa@hiroshima-u.ac.jp (S. Ozawa).

http://dx.doi.org/10.1016/j.rpor.2016.04.005
1507-1367/

## 1. Introduction

With advancements in radiation therapy (RT), intensity-modulated radiation therapy (IMRT) has facilitated the delivery of large irradiation doses in a treatment volume with a high degree of conformity. Although highly conformal treatment offers the advantage of sparing the delivery of high-dose radiation to the surrounding normal tissue, this advantage may only be achieved if patients are accurately positioned during each treatment session. Recently, image-guided radiotherapy (IGRT) systems have been developed to accurately set the patients' position.[1,2] Among IGRT systems, the use of kilovoltage cone-beam computed tomography (kV-CBCT) has become widespread.[3–6]

There are two types of kV-CBCT scanning methods used with the On-Board Imager system (OBI; Varian Medical Systems, Palo Alto, CA). One is a half-scan method that creates an image by rotating 200°, and the other is a full-scan method that creates an image by rotating 360°. The advantage of the full-scan method is the ability to expand the field of view. However, the exposed dose in the center region of the full-scan method is higher than that of the half-scan method due to a flux overlap region (FOR) around the center. Dose can be reduced during CBCT scan through two different methods: one is by reducing the tube current; the other is by reducing the projections used in volumetric imaging reconstruction.[7] The first method would result in a reduced signal-noise ratio due to less incident photons (reduced mAs) interacting with detectors, which ultimately degrade the image quality. Those degrading effects have been studied by several investigators, and solutions to alleviate them have been proposed.[8–10] Alternatively, the second strategy to reduce the patient's dose underlies the reduction of sampling frequency during image acquisition. However, there are no report that the higher dose in the center region, which was the disadvantage of the full scan method, is reduced.

In this study, we investigated the influence of the FOR using the full-scan method on kV-CBCT image quality and patients' exposure dose.

## 2. Methods and materials

### 2.1. CBCT system and scan parameters

All measurements in this study were performed using an OBI system mounted on a Varian Clinac iX linear accelerator (Varian Medical Systems). The kV-CBCT scanning parameters were as follows: tube voltage of 125 kV, tube current of 80 mA, slice thickness of 2.5 mm, tube rotation angle of 364°, and use of a half-fan filter. The default field size at the time of the scan was $X1 = 6.8$ cm, $X2 = 23.5$ cm, and Y1 and Y2 = 8.0 cm. FOR reduction of the kV-CBCT scans was performed by varying the field size ($X1 = 6.8$ cm, 6.5 cm, 6.0 cm, 5.5 cm, 5.0 cm, 4.5 cm, 4.0 cm, 3.5 cm, 3.0 cm, 2.5 cm, 2.0 cm, 1.5 cm, 1.0 cm, 0.5 cm, and 0 cm). We performed a visual evaluation of the image and the image quality according to the FOR reduction, as described below.

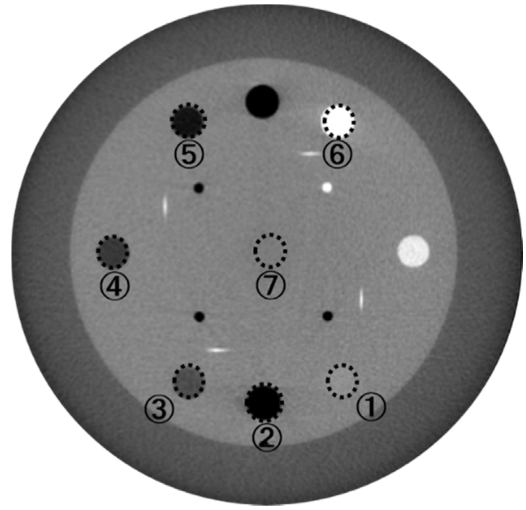


**Fig. 1 – CBCT image of HU reproducibility (Catphan CTP 404).**

### 2.2. Evaluation of artifacts by FOR reduction

A Catphan phantom (The Phantom Laboratory, Salem, NY), which comprises several modules with geometrical structures, was set at the top of the couch and kV-CBCT scans of the Catphan phantom according to FOR reduction were performed. Then, we visually evaluated the presence of artifacts in the image according to FOR reduction against the CBCT image at the default condition.

### 2.3. Evaluation of image quality according to FOR reduction

The image data of the Catphan phantom was analyzed using the image analysis software DoseLab (Mobius Medical Systems, LP). The image quality was evaluated by the reproducibility of Hounsfield unit (HU) values, high-contrast resolution, low-contrast resolution, and uniformity.

#### 2.3.1. Reproducibility of HU values

The reproducibility of HU values was measured using the scanned data of the Catphan module CTP404 (Fig. 1). In this module, there are six regions of interest (ROI) with different compositions, namely acrylic, air, polystyrene, low-density polyethylene, polymethylpentene, and Teflon®. The measured HU values of those six ROI were compared with the reference HU values of the CTP404. The deviation between the reference HU values and the measured HU values were calculated. In this study, tolerance of the deviation was defined as values within 40 HU.

#### 2.3.2. High-contrast resolution

High-contrast resolution was evaluated with the modulation transfer function (MTF), which obtains information about the spatial resolution of the imaging system. In this study, the MTF was calculated using HU values of multiple ROI that were set for 21 different line bar patterns (Fig. 2) in the Catphan module

**Fig. 2 – CBCT image of the high-contrast resolution phantom (Catphan CTP 528).**

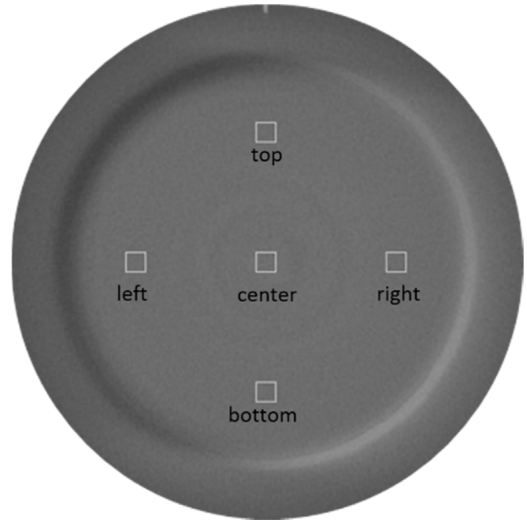


**Fig. 4 – CBCT image of the uniformity phantom (Catphan CTP 486).**

CTP528. The evaluation value was 50% of the MTF value from MTF curves.

### 2.3.3. *Low-contrast resolution*

Low-contrast resolution was evaluated with the contrast-to-noise ratio (CNR) determined by Eq. (1) using the data of the two ROI of regions 1 and 2 in the Catphan CTP404 module (Fig. 3):

$$\mathrm{CNR} = \frac{\sqrt{(\sigma_1)^2 + (\sigma_2)^2} / \sqrt{(S_1)^2 + (S_2)^2}}{(S_2 - S_1)/(S_2 + S_1)} \qquad (1)$$

In Eq. (1), $\sigma_1$ is the standard deviation of the signal value of region 1, $\sigma_2$ is the standard deviation of the signal value of region 2, $S_1$ is the mean signal value (mean pixel value) of region 1, and $S_2$ is the mean signal value of region 2.

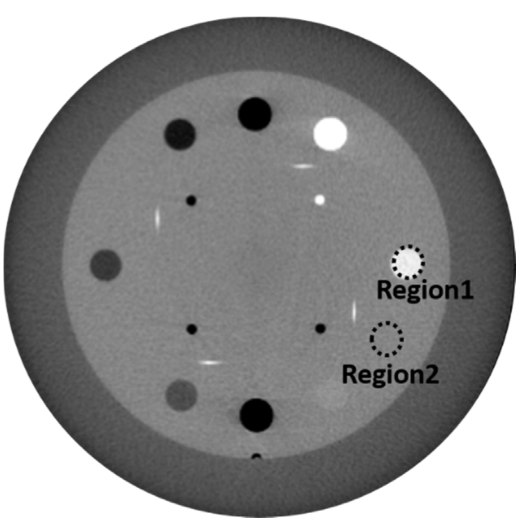


**Fig. 3 – CBCT image of the low-contrast phantom (Catphan CTP 404).**

### 2.3.4. *Uniformity*

The uniformity of the images was evaluated using the HU values in the five ROI of the module CTP486. These five ROI were positioned in the center, right, bottom, left, and top of the images, as shown in Fig. 4. The deviations of the measured HU values from the reference HU values were calculated. In this study, the tolerance of the deviations was defined as values within 40 HU.

## 2.4. *Evaluation of the absorbed dose according to FOR reduction*

The I'mRT Phantom (IBA Dosimetry) was used for this experiment (Fig. 5). The center doses in the I'mRT phantom according to FOR reduction were measured with a TN30013 (PTW), which is a Farmer-type ionization chamber, and a RAMTEC SMART (Toyo Medic), which is an electrometer. We evaluated the relative charge amount as the exposure dose. The charge amount of each field size was normalized by that of the default field size (X1 = 6.8 cm).

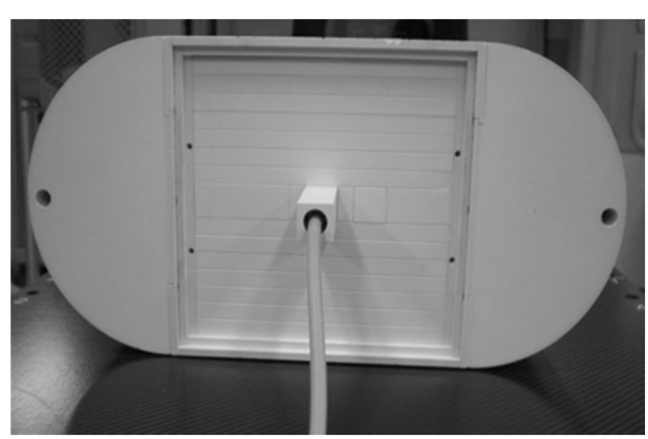

**Fig. 5 – Inserted I'mRT phantom Farmer chamber.**

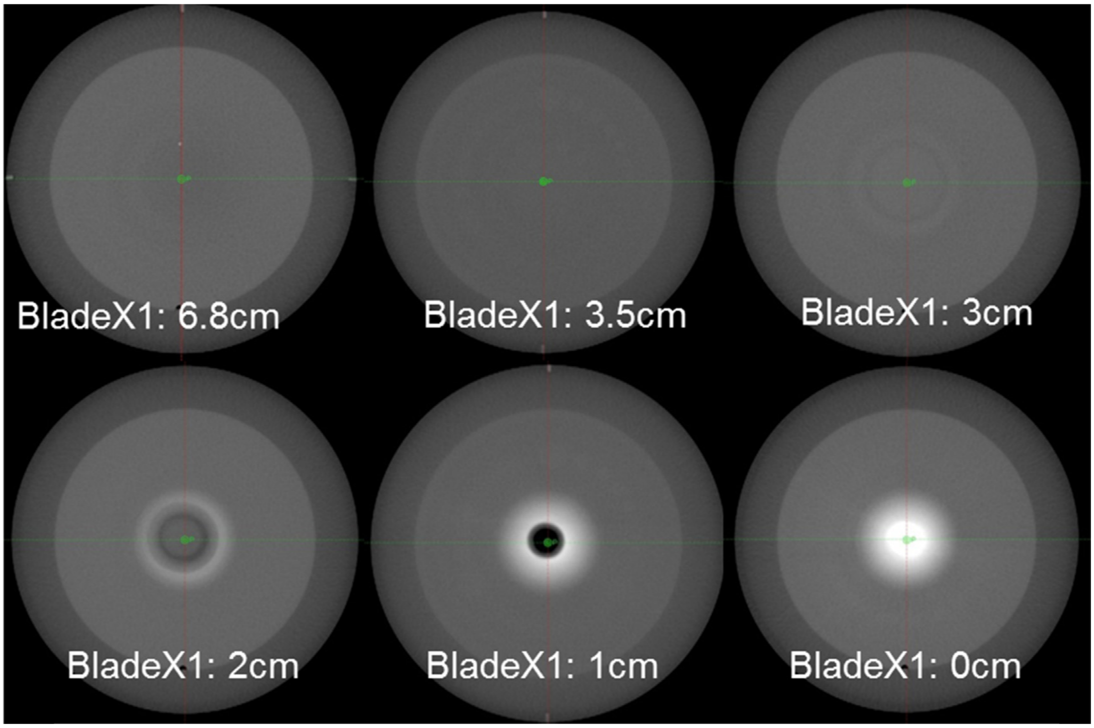


**Fig. 6 – CBCT image of the overlap region reduction.**

## 3. Results

### 3.1. *Evaluation of artifacts according to FOR reduction*

Fig. 6 shows the obtained Catphan phantom images. There was almost no visual difference in image at the field sizes of X1 from 6.8 cm to 3.5 cm. However, a ring artifact was detected at the X1 field size of ≤3 cm; this artifact became larger as the X1 became smaller.

### 3.2. *Effect on image quality in a case in which the FOR size was decreased*

(A) The deviation between the measured HU values and the reference HU values in the six ROI are shown in Table 1. The deviation beyond the tolerance value was observed at the X1 field sizes of ≤4.0 cm in Teflon. Although the deviation tended to be larger as the FOR size became smaller, all other deviations were within the tolerance value.
(B) There was no tendency for the high-contrast resolution to be degraded in the evaluation of MTF for all kV-CBCT images according to the FOR reduction (Table 2).
(C) There was no tendency for the low-contrast resolution to be degraded in the evaluation of CNR for all kV-CBCT images according to FOR reduction (Table 2).
(D) The deviations between the measured HU values and the reference HU values in the five ROI are shown in Table 3. The deviation beyond the tolerance value was observed at the X1 field sizes of ≤3.5 cm in the center. Although the deviation tended to be larger as the FOR became smaller, all other deviations were within the tolerance values. The deviation increased with FOR reduction; the maximum error became 2835 HU when the field size of X1 was 0 cm.

### 3.3. *Effect of FOR reduction on the absorbed dose*

Fig. 7 and Table 4 show the center doses of the I'mRT phantom according to FOR reduction. The center dose decreased with FOR reduction. The dose was reduced over 10% at the field size of X ≤3.5 cm compared with X1 = 6.8 cm and was reduced by 60% at the field size of X1 = 0 cm for X1 = 6.8 cm.

## 4. Discussion

Pearce et al. have recently reported that CT scans in children that deliver cumulative doses of approximately 50 mGy may increase almost three times the risk of leukemia and brain tumor.[11,12] CBCT is useful in high-precision RT but is associated with a low-dose exposure to patients. It is critical to reduce this low-dose exposure. Additionally, previous study reported that for pelvis scan, the OBI delivers a dose 16.8 cGy higher to the gonads, over the course of a 30-fraction regimen by comparing with the XVI.[13,14] Therefore, a full scan of the OBI should reduce the dose in the center region. In this study, we investigated the possibility of decreasing the exposure dose in CBCT of OBI by reducing FOR.

The image quality between the X1 field sizes of 6.8 cm and 4.0 cm was within the tolerance value of HU reproducibility and uniformity. Also, there were no differences between high-contrast and low-contrast resolutions with regard to FOR reduction. Based on this result, the field size of X1 could be reduced to 4.0 cm and then the absorbed dose in CBCT could be decreased by 7%.

**Table 1 – The deviation between measured values and referenced HU values (Catphan CTP404).**

| X1 (cm) | (A) Reproducibility of HU values (HU) | | | | | |
|---|---|---|---|---|---|---|
| | ① Acrylic | ② Air | ③ Polystyrene | ④ LDPE | ⑤ PMP | ⑥ Teflon |
| 6.8 | 9.02 | 4.32 | 10.00 | 0.15 | 6.25 | 8.66 |
| 6.5 | 6.36 | 3.77 | 7.14 | 0.05 | 5.89 | 12.15 |
| 6 | 1.21 | 2.88 | 9.00 | 3.29 | 11.39 | 14.60 |
| 5.5 | 2.31 | 2.32 | 6.24 | 1.65 | 9.79 | 29.29 |
| 5 | 4.46 | 1.64 | 3.00 | 7.30 | 11.51 | 31.34 |
| 4.5 | 3.12 | 2.53 | 0.05 | 4.00 | 11.70 | 37.46 |
| 4 | 8.12 | 1.42 | 0.47 | 8.73 | 12.19 | 39.24 |
| 3.5 | 7.81 | 1.50 | 1.66 | 6.68 | 13.16 | 63.80 |
| 3 | 12.81 | 1.52 | 2.32 | 10.70 | 12.30 | 68.07 |
| 2.5 | 13.67 | 1.40 | 5.76 | 7.55 | 14.72 | 82.15 |
| 2 | 17.53 | 1.23 | 4.15 | 13.42 | 16.33 | 79.72 |
| 1.5 | 18.83 | 1.43 | 11.85 | 11.88 | 21.51 | 82.03 |
| 1 | 24.24 | 1.23 | 11.63 | 19.72 | 24.14 | 83.77 |
| 0.5 | 22.60 | 1.98 | 18.53 | 25.83 | 30.60 | 82.69 |
| 0 | 30.21 | 11.78 | 11.67 | 37.23 | 36.91 | 82.33 |

**Table 2 – The MTF values which is high-contrast resolution (Catphan CTP 528), and CNR values which is the low contrast resolution (Catphan CTP 404).**

| X1 (cm) | (B) High contrast resolution (MTF, lp/mm) | (C) Low contrast resolution |
|---|---|---|
| 6.8 | 5.9 | 9.5 |
| 6.5 | 5.9 | 10.0 |
| 6 | 5.9 | 10.0 |
| 5.5 | 5.9 | 9.2 |
| 5 | 5.8 | 8.4 |
| 4.5 | 5.8 | 10.1 |
| 4 | 5.8 | 8.6 |
| 3.5 | 5.8 | 10.7 |
| 3 | 5.8 | 9.1 |
| 2.5 | 5.8 | 9.5 |
| 2 | 5.9 | 8.8 |
| 1.5 | 5.7 | 9.6 |
| 1 | 5.7 | 10.3 |
| 0.5 | 5.6 | 9.4 |
| 0 | 5.5 | 8.9 |

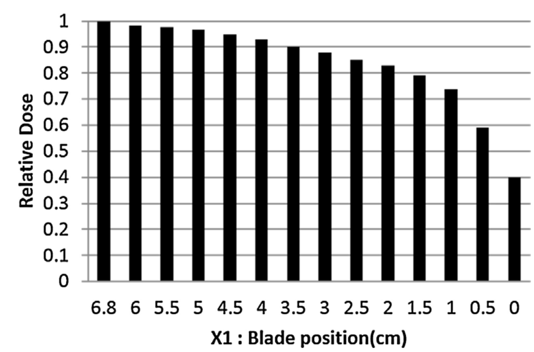


**Fig. 7 – Center dose in the overlap region reduction.**

The quality of the image deteriorated at the X1 field size of ≤3.5 cm with regard to HU reproducibility and uniformity in case of FOR reduction. This was the effect of the ring artifact that was generated from the reduction of the center dose. The region that detected X-rays in the norm-phantom calibration but did not detect X-rays according to FOR reduction was processed as high-density areas during image processing.

**Table 3 – The deviation between measured values and referenced HU values (Catphan CTP486).**

| FOR(cm) | (D) Uniformity (HU) | | | | |
|---|---|---|---|---|---|
| | Center | Right | Bottom | Left | Top |
| 6.8 | 1.16 | 3.07 | 0.00 | 2.23 | 2.12 |
| 6.5 | 4.63 | 6.17 | 1.94 | 0.64 | 4.05 |
| 6 | 10.20 | 3.10 | 4.45 | 6.06 | 5.84 |
| 5.5 | 17.01 | 10.50 | 5.86 | 2.72 | 8.22 |
| 5 | 22.81 | 7.45 | 8.51 | 9.63 | 9.56 |
| 4.5 | 29.64 | 14.43 | 9.35 | 6.92 | 12.27 |
| 4 | 36.25 | 11.83 | 12.04 | 13.06 | 13.29 |
| 3.5 | 42.07 | 17.91 | 12.99 | 11.08 | 16.33 |
| 3 | 47.35 | 15.86 | 15.66 | 17.40 | 17.61 |
| 2.5 | 37.62 | 22.22 | 17.33 | 14.71 | 19.36 |
| 2 | 42.82 | 20.33 | 19.62 | 21.76 | 21.06 |
| 1.5 | 208.27 | 27.67 | 20.77 | 19.22 | 23.21 |
| 1 | 65.47 | 27.57 | 22.69 | 25.07 | 23.43 |
| 0.5 | 1193.99 | 34.02 | 22.36 | 26.21 | 23.96 |
| 0 | 2834.99 | 32.20 | 25.38 | 32.14 | 25.34 |

**Table 4 – The deviation from the default (X1 = 6.8 cm).**

| X1 (cm) | The deviation from the default (%) |
|---|---|
| 6.5 | 0.9 |
| 6 | 1.8 |
| 5.5 | 2.4 |
| 5 | 3.3 |
| 4.5 | 5.2 |
| 4 | 7.1 |
| 3.5 | 9.9 |
| 3 | 12.1 |
| 2.5 | 14.8 |
| 2 | 17.0 |
| 1.5 | 21.0 |
| 1 | 26.3 |
| 0.5 | 41.1 |
| 0 | 59.9 |

The *X*1 field size of the norm-phantom calibration was 6.8 cm; however, the contribution of the scattered radiation according to FOR reduction scan was considered to be lesser than that of the calibration. From these results, we assumed that FOR reduction was not acceptable at the *X*1 field size of $\leq$3.5 cm.

The quality of the image in the high-contrast resolution did not deteriorate by the FOR reduction. Nor did the quality of the image in the low-contrast resolution deteriorate by the FOR reduction. The differences in these parameters were probably not detected because the method of analysis by the Doselab does not include the measurement of the central region.

As described above, the FOR could reduce the X1 field size to 4.0 cm in this study. However, all detectors in the FPD are irradiated if the X1 field size is set at 3.5 cm. Therefore, the contribution of scattered radiation at the calibration becomes the same as that during the scans by performing the calibration at the *X*1 field size of 3.5 cm; it is possible to further reduce the dose.

In addition, we used the acceptance value as the reference in this study. The quality of the image differs depending on the IGRT device in the clinical facility for each CBCT. Therefore, the acceptable tolerance value needs to be further determined taking into account the clinical image quality in each facility.

## 5. Conclusion

Using the full-scan method for kV-CBCT, it was possible to decrease the dose without decreasing the image quality by reducing FOR. FOR could reduce the X1 field size to 4.0 cm, and the absorbed dose in CBCT could be reduced by 7% at the center dose.

## Conflict of interest

None declared.

## Financial disclosure

None declared.

## REFERENCES


1. Ning R, Chen B, Yu RF, Conover D, Tang XY, Ning Y. Flat panel detector-based cone-beam volume CT angiography imaging: system evaluation. *IEEE Trans Med Imaging* 2000;**19**:949–63.
2. Nakamori N, Sudou T, Kanamori H, Endo M, Kusakabe M. Effects of scattered X-rays on cone-beam 3-D CT images. *Jpn J Appl Phys* 1995;**12**:91–9.
3. Wen N, Guan H, Hammoud R, et al. Dose delivered from Varian's CBCT to patients receiving IMRT for prostate cancer. *Phys Med Biol* 2007;**52**:2267–76.
4. Song WY, Kamath S, Ozawa S, et al. A dose comparison study between XVI and OBI CBCT systems. *Med Phys* 2008;**35**:480–6.
5. Ding GX, Duggan DM, Coffey CW. Accurate patient dosimetry of kilovoltage cone-beam CT in radiation therapy. *Med Phys* 2008;**35**:1135–44.
6. Ding GX, Duggan DM, Coffey CW. Characteristics of kilovoltage X-ray beams used for cone-beam computed tomography in radiation therapy. *Phys Med Biol* 2007;**52**:1595–615.
7. Murphy MJ, Balter J, Balter S, et al. The management of imaging dose during image-guided radiotherapy: report of the AAPM Task Group 75. *Med Phys* 2007;**34**(10):4041–63.
8. Li T, Li X, Wang J, et al. Nonlinear sinogram smoothing for low-dose X-ray CT. *IEEE Trans Nucl Sci* 2004;**51**(4):2505–13.
9. Wang J, Li T, Liang Z, Xing L. Dose reduction for kilovoltage cone-beam computed tomography in radiation therapy. *Phys Med Biol* 2008;**53**(11):2897–909.
10. Sykes JR, Amer A, Czajka J, Moore CJ. A feasibility study for image guided radiotherapy using low dose, high speed, cone beam X-ray volumetric imaging. *Radiother Oncol* 2005;**77**(1):45–52.
11. Pearce MS, Salotti JA, Little MP, et al. Radiation exposure from CT scans in childhood and subsequent risk of leukaemia and brain tumours: a retrospective cohort study. *Lancet* 2012;**380**:499–505.
12. Brenner DJ, Hall EJ. Computed tomography – an increasing source of radiation exposure. *N Engl J Med* 2007;**357**:2277–84.
13. Hyer DE, Serago CF, Kim S, Li JG, Hintenlang DE. An organ and effective dose study of XVI and OBI cone-beam CT systems. *J Appl Clin Med Phys* 2010;**11**(April (2)):3183.
14. Kamath S, Song W, Chvetsov A, et al. An image quality comparison study between XVI and OBI CBCT systems. *J Appl Clin Med Phys* 2011;**12**(February (2)):3435.