Investigation of Dose Delivery

from On-Board CBCT for Head and Pelvis Regions

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Abstract

Introduction: The Varian 23EX Clinac at Siriraj Hospital is a linear accelerator with integrated On-Board Imager (OBI) system capable of producing cone beam computed tomography (CBCT) images of the patient in the treatment position. The increased use of CBCT for patient setup may significantly increase the dose to the patient's normal tissues.

Objective: To investigate the skin and organ dose from the CBCT system from the clinical protocol setup, with fixed technical setting for head and neck and pelvic scans.

Materials and Methods: CBCT scans were acquired in full-fan and half-fan mode with full and half bowtie filters for head and pelvic area, respectively. The technical setting of 100 kV, 20 mA and 20 ms for head region and 125 kV, 80 mA and 13 ms for pelvic were used. TLDs-100H were used for Rando phantom skin dose measurement at the point of interest for head and neck and pelvic area. Organ doses were also measured inside Rando phantom.

Results: For head and neck CBCT, The lateral surface dose was higher than anterior (include critical organ such as eyes, lip, chin and neck). The peripheral organ dose at Lt. lat area dose (0.28 cGy) was less than central dose (0.4 cGy), but Right lateral area such as temporal and parotid was about the same as the central dose (brainstem). For pelvic CBCT, The lateral surface dose was not symmetrical, with Left lateral side being ~ 20% higher than Rt. Lat. The anterior (AP) surface dose was higher than lateral especially at the pubic area (5.2 cGy). The dose at bladder, rectum and bowl were about the same as the central dose (~ 3 cGy). The highest dose was in the left hip joint region up to 7 cGy.

Conclusions: The use of CBCT for treatment verification provided a high dose to the patient. It is important to consider about the optimal protocol and amount of times to verify the patient position to keep additional doses as low as reasonably practicable.

Introduction

The introduction of advances in radiation treatment delivery, such as intensity-modulated radiation therapy (IMRT), has allowed to deliver large doses of radiation to a treatment volume with a high degree of conformity and reduce normal tissue dose. However, patient setup error and internal organ motion during treatment may alter the planned dose distribution and the delivered dose distribution. Therefore, it important that patient setup verification is properly monitored and ensured.

The recent incorporation of sophisticated imaging technology into the treatment delivery unit has enabled an increase in the precision of daily patient setup and prompted the implementation of image-guided radiation therapy (IGRT).

The need to accurately position the patient has led to the development and use of gantry mounted kilovoltage cone beam computed tomography (CBCT) systems.(1,2) While CBCT is a very useful tool for ensuring that a patient is properly aligned prior to treatment, daily or weekly use in a high fraction therapy regimen will result in an associated imaging radiation dose. However, CBCT just as a diagnostic CT scanner, uses kilovoltage x-ray transmission principle for image generation. (10) Because the imaging is performed with ionizing radiation, it becomes natural to be concerned with the quantity of dose deposition in the patients. (3-5) For this reason, the estimation of the total imaging dose delivered to the patient during the complete treatment process is very important because the dose measurement data should allow clinician to make reasonably informed judgments about their image-guidance procedures. Several authors have performed dose measurements in cylindrical acrylic phantoms, reporting measured doses a single scan.(3-7) And also several other authors have performed dose measurements within commercially available anthropomorphic phantoms for more accurately quantify patient dose .(3,8-9) However, recent studies have indicated that daily imaging procedures, such as CBCT, can potentially add significant radiation dose to patients

The objective of this work is to measure additional imaging dose to patient on head and pelvic regions with fixed technical and collimator setting. from a Varian's kV CBCT (Varian Medical System, Palo Alto, CA, USA) scan procedure. Our study, we measured phantom surface dose and organ dose using thermoluminescent dosimeters (TLD)

Materials and Methods

1. On-Board Imager System

In this study cone-beam CT images were obtained using an On-Board Imager (OBI) system that was retrofitted on a Varian 23 EX Clinac (Varian Medical Systems, Palo Alto, CA, USA). The OBI system consists of a kV X-ray source (KVS) and flat-panel detector (KVD) mounted to the gantry by two robotic arms (ExactArms™) with a fixed source to isocenter distance of 100 cm and sharing a common axis of rotation with the MV treatment beam. This system offers two different collimators and kV filter combinations which are able based on the desired volume to be scanned : full- and half-fan

as shown in Fig 1. In the full-fan mode, a full bow-tie filter is used and the collimation is automatically adjusted by a set of dynamic jaws mounted to the X-ray source. In our study, a "half-fan" acquisition mode was used to image the pelvis phantom, while full-fan scan was used for head and neck imaging due to its smaller FOV. Use of the bowtie filter reduces patient dose, and reduces x-ray scatter thus improving image quality

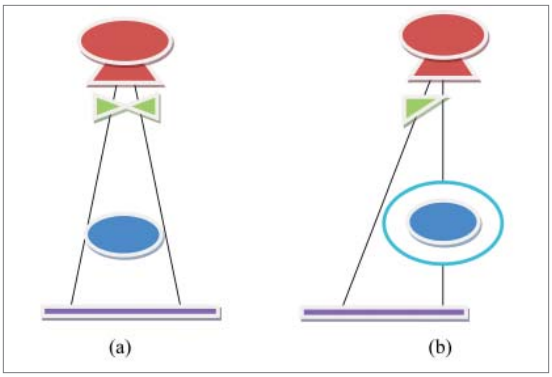


Fig.1 OBI cone beam CT acquisition mode
(a) Full fan mode with full bow-tie filter, the KVD is centered with x-ray axis
(b) Half-fan mode with half bowtie filter, imaging panel shifted, 45 cm FOV.

2. The measurement of X-ray beam quality

As TG61 protocol 12 recommended, the beam qualities were characterized by measuring the first half-value layers (HVL) of aluminum (Al) at central axis in narrow beam geometry. The measurements were performed by using the radiographic mode of OBI system with a technical setting of 100 kV, 20 mA and 160 ms with full bowties and 125 kV, 80 mA and 160 ms with half bowties for head and neck and pelvic region, respectively. The Al attenuator was placed 50 cm away from RadCal ionization chamber (Radcal Corp., Monrovia, CA, USA) and the x-ray collimators were set as 2 cm x 2 cm to make a narrow beam measurement.

3. TLD calibration

In our study, LiF TLD-100H rods (Harshaw, Erlangen, Germany) were used for measurement. They were calibrated with a 6 cc ionization chamber (Radcal model 9660 ion chamber digitizer) and a Radcal Accu Pro™ (model 9096) dose meter under the OBI's radiographic mode using 100 kVp with full bow-tie filter and 125 kVp with half bow-tie filter.

200 rods of LiF TLD-100H were annealed at 240 °C for 10 minutes 3 times to eliminate the residual signals and were read background TL signal. TLDs were divided into two groups.

First 100 TLDs were put on acrylic plate and were exposed from x-ray system with 100 kVp, 20 mA and 20 ms at 100 cm SSD for head region. The second 100 TLDs were exposed with 125 kVp, 80 mA and 13 ms x-rays at 100 cm SSD for pelvis regions. All TL signals were read and recorded. This process repeated for three times. The correction factor for sensitivity of each TLD group was calculated by following equation

Correction factor for sensitivity = X / Xi

Where X is average TL signal of all TLDs and Xi is average TL signal of TLDs in the i^{th} group.

A Radcal chamber was used to measure the absorbed dose in air with 100 kV, 20 mA and 20 ms and 125 kV, 80 mA and 13 ms for full-fan bowtie and half-fan bowtie, respectively. The measured air kerma was converted to absorbed dose according to the equation (1).

Absorbed dose (mGy)

$$= \text{Reading}. N_a . k_Q . k_{T,P} . F \quad (1)$$

Where Q is the user's energy measured in terms of HVL;

N_a is an exposure calibration factor;

k_Q is a correction factor for radiation quality;

$k_{T,P}$ is a correction factor for temperature and pressure;

F is a conversion factor used to convert exposure to absorbed dose (0.00876 mGy/mR)

TLDs were loaded on acrylic plate and were calibrated with the same condition as the measurement of absorbed doses in air using ionization chamber.

4. The skin dose measurement

The measurement of skin dose was assessed by using TLD-100H. For head and neck region of a male anthropomorphic phantom (the Rando phantom, The Phantom Laboratory, Salem, NY). TLDs were places on the laser setting points in AP, left lateral (Lt. Lat) and right lateral (Rt. Lat), and some critical organs such as right and left eyes, right and left cheek, lip, chin and neck. CBCT were scan with 100 kV, 20 mA and 20 ms and acquired in full-fan with full bowtie for standard head protocol. Three measurements were made for each set up for improved dose statistics. For pelvis region, TLD capsules were placed on the Rando phantom's skin at three laser setting points: AP, left lateral (Lt. Lat) and right lateral (Rt. Lat), Pubic and posterior (bottom). The technical setting of 125 kV, 80 mA and 13 ms was used. CBCT scans were acquired in half-fan with half bowtie for pelvis protocol. The measurement points for both regions are shown in Fig 2.

Fig 2. The measurements point of skin dose for head and pelvis area using TLD 100H

The skin dose on phantom can be derived as :

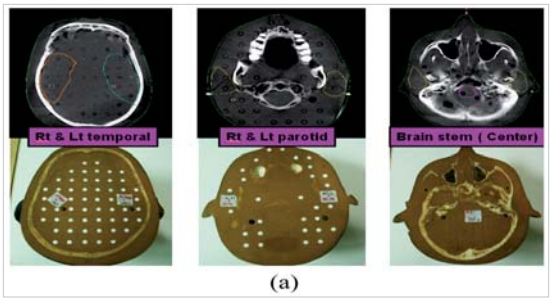
$$\text{Dskin} = \text{Avg RTLD-BG} \times \text{calibration factor} \times (\mu_{en}/\rho)^{musle}_{air} \text{ cGy} \quad (1)$$

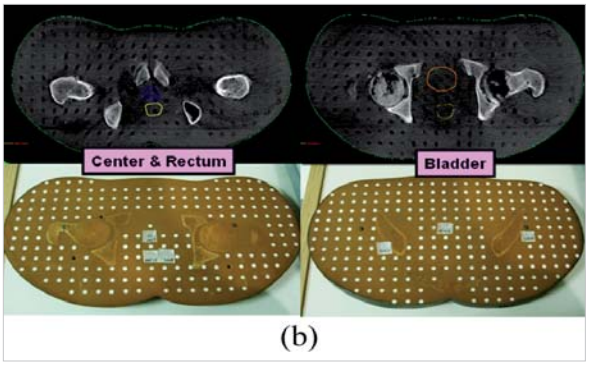
Where Avg RTLD-BG is the average TLD reading from skin dose measurement; BG is the background reading of TLD and $(\mu_{en}/\rho)^{musle}_{air}$ is the ratio of mass energy absorption coefficient of muscle to air (2).

5. The organ dose measurement

Organ doses were measured inside the Rando phantom using TLDs. For head and neck, TLDs were loaded at the position of organ of interest such as right and left temporal, right and left parotid and brain stem. A technical setting of 100 kV, 20 mA and 20 ms was used. CBCT scans were acquired in full-fan mode with full bowtie for standard head protocol. For pelvis, TLDs were loaded at the position of organ of interest such as rectum, bladder, right and left femur and bowel. A technical setting of 125 kV, 80 mA and 13 ms was used. CBCT scans were acquired in half-fan mode with half bowtie for pelvic

protocol. Three TLDs per location and three measurements were made for each set up for improve dose statistics for both regions. Fig 3 shows a picture of the Rando phantom and the positions at which doses were measured for CBCT scanning for both head and pelvis regions.





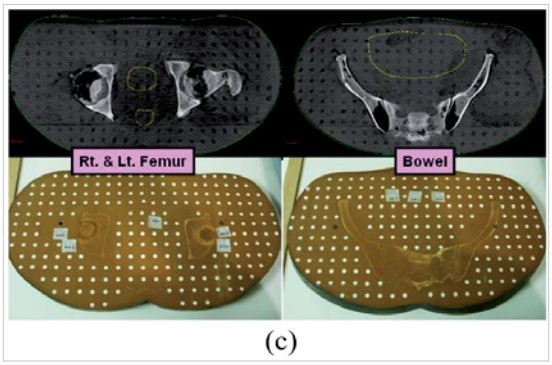


Fig 3. TLD 100H measured dose in mGy in the Rando phantom and the positions at which doses were easured for CBCT scanning

(a) For head

(b) and (c) for pelvis regions.

The organ doses inside the Rando phantom can be derived similarly as for equation (1), but the (μ_{en}/ρ) ratio was in muscle or bone:

$$D_{muscle} = \text{Avg RTLD-BG x calibration factor x } (\mu_{en}/\rho)^{musle}_{air} \text{ cGy} \quad (2)$$

$$Dbone = \text{Avg RTLD-BG x calibration factor x } (\mu_{en}/\rho)^{musle}_{air} \text{ cGy} \quad (3)$$

Where $(\mu_{en}/\rho)^{musle}_{air}$ is the ratio of mass energy absorption coefficient of bone to air

Results

The X-ray beam quality

The beam quality measurement for both technical exposure settings were found that the measured HVL for 100 kV, 20mA exposure setting with full bowtie filter was found to be 2.7 mm Al and determined with the corresponding TG61 parameter $(\mu_{en}/\rho)^{musle}_{air} = 1.0527$) used for dose calculation. And the quality of 125 kV, 80 mA with half bowtie filter was 5.4 mm of HVL in Al correspond to $(\mu_{en}/\rho)^{musle}_{air} = 1.0657$ and $(\mu_{en}/\rho)^{musle}_{air} = 3.8214$

The skin dose measurement

Table 1 shows the average skin dose on head Rando phantom at anterior include central- axis and critical organ such as eyes, lip, chin and neck and right and left lateral. AP dose was lower than lateral dose. Rt. lat dose was 0.51 cGy, which was higher than Lt. lat dose of 0.39 cGy by about 30%.

Table 1 The skin dose for head Rando phantom

Point of measurement	Dose (cGy) CBCT 100 kV, 20 mA, 20 ms
AP CR	0.033
Rt. Lat	0.510
Lt. Lat	0.390
Rt. Cheek	0.072
Lt. Cheek	0.061
Rt. Eye	0.054
Lt. Eye	0.048
Lip	0.049
Chin	0.050
Neck	0.079
Fore head	0.033

Table 2 shows the average skin dose on pelvis Rando Phantom at AP and lateral area. The lateral surface dose is not symmetrical, with Lt. lat being ~ 20% higher than Rt. Lat. AP surface dose was higher than lateral especially at the pubic area.

Table 2 The skin dose for pelvis Rando phantom

Point of measurement	Dose (cGy) CBCT 125 kV, 80 mA, 13 ms
AP	3.130-5.100(CR)
Pubic	5.210
Rt. Lat	2.350
Lt. Lat	2.830
Bottom	3.130

The organ dose measurement

Table 3 summarizes the average organ dose measurements at different positions inside head Rando phantom using TLDs. The peripheral organ dose at Lt. lat area dose (0.28 cGy) was less than central dose (0.4 cGy), but Rt. Lat area (temporal and parotid) was about the same as the central dose (brainstem).

Table 3 The organ dose for head Rando phantom

Point of measurement	Dose (cGy) CBCT 100 kV, 20 mA, 20 ms
Rt. Temporal	0.361
Lt. Temporal	0.286
Brainstem (CR)	0.396
Rt. Parotid	0.400
Lt. Parotid	0.282

Table 4 shows the average organ dose inside pelvis Rando phantom. The dose at bladder, rectum and bowl were about the same as the central dose (~ 3 cGy). The highest dose was inside the left hip joint region up to 7 cGy while the right one received 6 cGy.

Table 4 The organ dose for pelvis Rando phantom

Point of measurement	Dose (cGy) OBI 125 kV, 80 mA, 13 ms
Center	2.835
Rectum	3.150
Bladder	2.555
Rt. Femur	6.110
Lt. Femur	6.950
Bowl	2.730

Discussions

For head CBCT, the Ant skin dose was less than lateral dose. Because the head scan protocol for full-fan mode is partial rotation scan. The KVS rotated from 292º to 88º, image acquisition moves from left to right lateral while rotating around the posterior surface of the Rando phantom. The Lateral skin dose from our measurement was higher than the dose measured by Amer et al [4] using X-ray volumetric images (XVI) system. From that study, the surface dose (Ant), surface dose (Lat) and eye dose were 0.13, 0.12 and 0.13 cGy, respectively. Because of the total mAs used for XVI system was less than Varian OBI. But the Ant skin doses in the current study were clearly lower than the data presented by Kan et al [9]. Because image acquisition for OBI (old version) consisted of full rotation scan and the previous protocols for the OBI were all at a fixed tube voltage (125 kVp). While the updated OBI head protocol utilizes tube voltage 100 kV and uses partial rotation scan (2000). All of these changes result in lower patient doses. The results of organ dose for head CBCT was confirm that the dose of critical organ at lateral part higher than anterior part. Due to KVS rotated from 292º to 88º, more side projection at right side than left side. Therefore, the right lateral dose was higher than left lateral dose by about 30%.

The pelvis CBCT were utilized a full rotation scan, The lateral surface dose is not symmetrical, with Lt. lat being ~ 20% higher than Rt. Lat. This dose asymmetry was found because the KVS always starts and ends at the left side. Gantry rotation gets much slower near the end but dose rate stays constant and the effect is caused by a small overscan5. The Ant. surface dose was higher than lateral possible because more side projection become incident rather than transmitted, which offset the dose decrement from the larger anterior SSD but for the Lt Lat and Rt Lat doses has little change. The skin dose from our measurement was agreement with Wen et al [5], but higher than XVI system [3,4,7]. The results of organ dose for pelvis CBCT was confirm that the dose of critical organ at Lt Lat higher Rt Lat. The left femoral bone received the highest doses of 7 cGy. This results was agreement with Wen et al.'s study [5]

Conclusion

The dose measurements have been made for head and pelvic CBCT with fixed technical and setting using TLDs. For one rotation CBCT scan of head region, the lateral surface dose was higher than anterior such as critical organ such as eyes, lip, chin and neck. The peripheral organ dose at Lt. lat area dose (0.28 cGy) was less than central dose (0.4 cGy), but Rt. Lat area (temporal and parotid) was about the same as the central dose (brainstem). For pelvic CBCT, the lateral surface dose is not symmetrical, with Lt. lat being ~ 20% higher than Rt. Lat. AP surface dose was higher than lateral especially at the pubic area (5.2 cGy). The dose at bladder, rectum and bowel were about the same as the central dose (~ 3 cGy). The highest dose was inside the left hip joint region up to 7 cGy.

At Siriraj Hospital, CBCT images were used to verify the patient positioning once a week. For 33 fractions of nasopharynx IMRT, CBCT were scanned

average seven times per course. The CBCT dose delivered to head site can range from ~2.8 cGy to central and peripheral dose and ~3.5 cGy to lateral skin dose. For 39 fractions of prostate IMRT, CBCT were scanned average eight times per course. The CBCT dose delivered to pelvic site can range from ~24 cGy to central and peripheral dose, ~41.6 cGy to anterior skin dose, and more than ~56 cGy to left hip joint region.

The total patient dose from CBCT was led to amount of time to verify the patient positioning. It is important to consider about the optimal protocol to keep additional doses as low as reasonably practicable.

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