Measurement of eye lens dose for Varian On-Board Imaging with different cone-beam computed tomography acquisition techniques

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ABSTRACT

The objective of this work was to measure patient eye lens dose for different cone-beam computed tomography (CBCT) acquisition protocols of Varian's On-Board Imaging (OBI) system using optically stimulated luminescence dosimeter (OSLD) and to study the variation in eye lens dose with patient geometry and distance of isocenter to the eye lens. During the experimental measurements, OSLD was placed on the patient between the eyebrows of both eyes in line of nose during CBCT image acquisition to measure eye lens doses. The eye lens dose measurements were carried out for three different cone-beam acquisition protocols (standard dose head, low-dose head [LDH], and high-quality head [HQH]) of Varian OBI. Measured doses were correlated with patient geometry and distance between isocenter and eye lens. Measured eye lens doses for standard head and HQH protocols were in the range of 1.8–3.2 mGy and 4.5–9.9 mGy, respectively. However, the measured eye lens dose for the LDH protocol was in the range of 0.3–0.7 mGy. The measured data indicate that eye lens dose to patient depends on the selected imaging protocol. It was also observed that eye lens dose does not depend on patient geometry but strongly depends on distance between eye lens and treatment field isocenter. However, undoubted advantages of imaging system should not be counterbalanced by inappropriate selection of imaging protocol, especially for very intense imaging protocol.

Key words: Eye lens dose; optically stimulated luminescence dosimeter; Varian cone-beam computed tomography

Introduction

Advancement in imaging techniques plays a vital role in further innovation in radiotherapy practice. The accuracy of target delineation has been improved by the use of magnetic resonance imaging, positron emission tomography-computed tomography (CT), and CT/four-dimensional CT whereas localization of tumor on the treatment delivery machine (i.e., accuracy of treatment delivery) has been improved using megavoltage portal imaging, kilovoltage (kV) planar imaging, cone-beam CT (CBCT), and stereoscopic imaging. A survey performed by Simpson *et al*.[1] showed that use of image-guided radiotherapy (IGRT) technology is increasing and is expected to grow further. Full potential of advanced technology such as intensity-modulated radiation therapy (IMRT) can be exploited better if it is combined with IGRT.[2,3] The support of imaging system during treatment enables planning staff to reduce additional margin during target delineation. The use of imaging system in due course of treatment not only provides positional accuracy but also gives the opportunity to individualize the treatment for each patient. Adaptive radiotherapy has shown

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improvement in radiation treatment plan for head and neck region.[4] Repeated imaging is considered as mandatory for individualized treatment to cope with anatomical changes that occur during treatment.[5-7] Schwarz *et al*.[8] have reported on an average 30 CT sets in addition to the planning CT for adaptive radiotherapy; Court *et al*.[9] have reported daily use of portal images for patient setup verification. A downside of the increased imaging is the additional dose burden to the patient during the radiotherapy that increases the risk for deterministic effects to organs at risk in and outside the primary treatment area; the risk for stochastic effects cannot be excluded even for small doses.[10] CBCT acquisitions modes are designed to reduce dose to a minimum and are sufficient for soft tissue and bone contrast for daily setup corrections. However, the reduced dose may lead to limitations in the usability of the acquired image sets as the image quality and accuracy of CT numbers may decrease accordingly.[11] To overcome this problem, IGRT systems have task-specific image acquisition protocol. If images are used for alteration of plan or review change in anatomy of patient, high-quality images are acquired with high imaging dose to patient; otherwise, for daily setup verification, low-dose images are acquired.

On the basis of recent epidemiological studies on cataracts of the eye lens, the International Commission on Radiological Protection has recommended to set a new lower threshold dose (2000 mGy) for radiation-induced cataract.[12] This step by the Commission compels to estimate the eye lens dose in different medical procedure and evolve a methodology to justify and optimize it. The purpose of this study was to directly measure eye lens dose to patients, using the indigenously developed optically stimulated luminescence (OSL)-based eye dose monitoring badge, subjected to different imaging protocols of Varian On-Board Imaging (OBI) system used for IGRT.

Materials and Methods

Varian on-board imaging

The kV CBCT beam used in this study was Varian OBI (version 1.4) system integrated into a Clinac iX linear accelerator (Varian Medical Systems, Palo Alto, CA, USA). The X-ray tube with imaging system was equipped with a rotating W-Re target (G242). The tube potential can be set in the range of 40–125 kV. The isocenter of the CBCT is at 100 cm from the X-ray source, and the source-to-detector distance can be 140, 150, or 170 cm. The maximum X-ray field size at 100 cm is 50 cm × 50 cm. The OBI system has two working modes: full-fan beam mode and half-fan beam mode. In the full-fan beam mode, the detector is centered on the axis of rotation and is used to visualize regions with a small diameter or small soft-tissue organs, such as the prostate. The diameter of the field of view (FOV) is 25 cm. In the half-fan mode, the detector is shifted in a direction perpendicular to the kV X-ray beam, increasing the scanned area, hence enlarging the diameter of the FOV from 25 to 45 cm. In both cases, a filter is placed at the exit of the X-ray tube. The full-fan mode filter is symmetric with respect to the beam axis in the axial plane, being narrower at the center. The half-fan mode filter is asymmetric, narrow in the central part with increasing thickness toward the edge of the X-ray beam. These filters absorb part of the incident radiation and they are used to compensate for the difference in the thickness traversed by the beam on the patient so that the photon fluence that reaches the detector is as uniform as possible. In addition, the absorption of low energy X-rays reduces the dose received by the patient and the noise generated in the detector.

Optically stimulated luminescence-based eye lens dosimeter

The α-Al_2O_3:C OSL-based eye lens dosimeter [Figure 1] used in this study is a BARC-designed eye lens dosimeter (Bhabha Atomic Research Centre, Mumbai, Maharashtra, India) which contains two discs loaded in a cassette having two filter regions, namely, (i) first region having 0.135 cm thick Teflon filter, and (ii) second region having 0.03 cm Cu and 0.08 cm Al filter on both sides of the dosimeter. The OSL badge has dimension of 2 cm × 1.5 cm × and 0.5 cm. The eye lens dosimeter is capable of measuring doses in the range of 0.10 mSv to 1 Sv.[13] The α-Al_2O_3:C OSL discs used in the above dosimeter have a diameter of 0.7 cm and thickness of 0.014 cm and are prepared by sandwiching the α-Al_2O_3:C powder of grain size (75–100 μm) between two thin transparent plastic sheets.

For the present study, only those dosimeter discs were used which have spread in sensitivity $\leq \pm 5\%$. After experimental irradiation, the OSL discs were read individually using RISO TL/OSL reading system TL/OSL-DA-15 which has a cluster of 42 blue light emitting diodes ($\lambda = 470 \pm 30$ nm) for stimulation. A green long pass GG-420 filter minimizes the directly scattered blue light from reaching the

Figure 1: Photograph showing Bhabha Atomic Research Centre-designed eye lens dosimeter used in this study

photomultiplier tube (EMI 9235QA). The blue light stimulated signal was detected using a 0.75 cm thick ×3.5 cm diameter HOYA U-340 ($\lambda p \sim 340$ nm, FWHM ~80 nm) filter.[14] The OSL was recorded at a power of 22.5 mW-cm^2 for 60 s. After subtraction of control counts from irradiated dosimeters, the dose received by the eye lens dosimeter was estimated. This eye lens dosimeter is capable of measuring doses ranging from 0.10 mSv to 1 Sv in general for energy ranges of 15 keV to 1.25 MeV. The ratio of the readout of the OSL discs under Teflon to Cu filter during the study with 100 kV CBCT beam was found to be 3.4 ± 0.25. This indicates average energy of 40 keV at which over-response correction factor having value of 3.15 was applied to the readout of the OSL disc under Teflon filter. This makes the response of the OSL disc nearly equivalent to the response at ^{137}Cs photons. Water-filled cylindrical phantom having diameter and height of 20 cm each was used while establishing calibration with ^{137}Cs photons. Comprehensive details about this eye lens dosimeter badge are available elsewhere.[13,15]

Eye lens dose measurements

Three different CBCT acquisition protocols, namely, standard dose head (SDH), high-quality head (HQH), and low-dose head (LDH) protocols are available for head and neck region imaging in Varian OBI system. Table 1 enlists the parameters for CBCT acquisitions protocols of Varian OBI system. As per these protocols, three groups of head and neck cancer patients were formed. Five patients per group were selected randomly in this study. These five patients in each of the groups cover a wide range of distance between isocenter and eye lens.

For the first group of patients, CBCT was performed using SDH protocol; for the second group of patients, CBCT was performed with HQH protocol; and for the third group of patients, CBCT was performed with LDH protocol. All CBCT acquisitions were performed with fixed geometry for all measurements. CBCT images were acquired with full-fan cone with bow-tie filtration, source-to-detector distance of 150 cm, 0.25 cm slice thickness, transversal FOV of 25 cm, and scan length of 18 cm giving a longitudinal FOV of approximately 17.5 cm. All scans were performed with 200° rotation of the gantry. The OSL dosimeter was positioned between the eyebrows of both eyes in line of nose [Figure 2] to measure eye lens dose during CBCT acquisition. To get a reasonable signal, dosimeters were irradiated with five consecutive scans for the CBCT imaging protocols and average reading was estimated for each scan. Effect of patient head geometry on eye lens dose was also studied. Equivalent diameter (EQD) of head was determined using the following relation:[16]

$$\text{EQD} = \sqrt{(\text{APD} \times \text{LD})} \qquad (1)$$

Where APD is the largest anterior–posterior diameter and LD is the largest lateral diameter at isocenter slice of planning CT scan. The distance between the isocenter and eye lens dosimeter was recorded to assess the impact of position of isocenter on dose to eye lens.

Table 1: Parameters for cone-beam computed tomography acquisitions protocols of Varian On-Board Imaging system

	Standard dose head	*Low-dose head*	*High-dose head*
Tube voltage (kVp)	100	100	100
Tube current (mA)	20	10	80
Time per projection (ms)	20	20	25
Gantry rotation range (°)	200	200	200
Number of projections	360	360	720
Exposure (mAs)	145	72	720
Fan type	Full fan	Full fan	Full fan
Default pixel size	384×384	384×384	384×384
Slice thickness (cm)	0.25	0.25	0.25
Reconstruction filter	Sharp	Standard	Sharp
Ring suppression algorithm	Medium	Medium	Medium

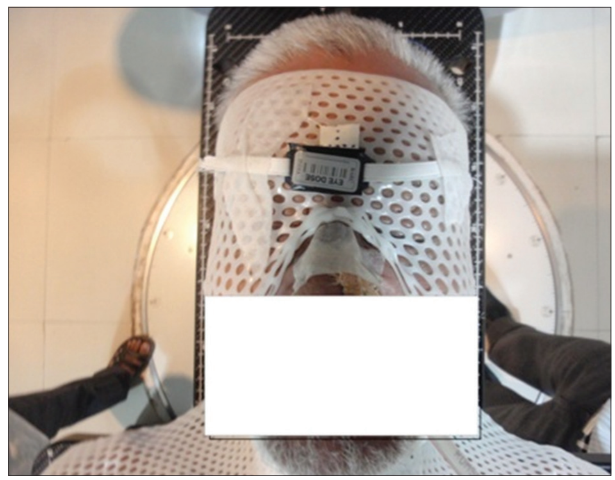

Figure 2: Position of optically stimulated luminescence dosimeter on a patient

Results

The eye lens dose measured for different imaging protocol of head and neck region is shown in Figure 3. As shown in Figure 3, dose to the eye lens varied significantly with acquisition protocol. The maximum dose was observed for HQH imaging protocol which ranges from 4.5 to 9.9 mGy and minimum for LDH imaging protocol which ranges from 0.3 to 0.7 mGy. For standard head dose imaging protocol, dose received by eye lens was in the range of 1.81–3.22 mGy. The impact of patient head geometry on eye lens dose is shown in Figure 4. Average EQD was 16.65 cm while minimum value was 15.75 cm and maximum value was 17.90 cm. As shown in Figure 4, the eye lens dose for any particular protocol does not show any relation with the equivalent head diameter. Table 2 presents the eye lens dose

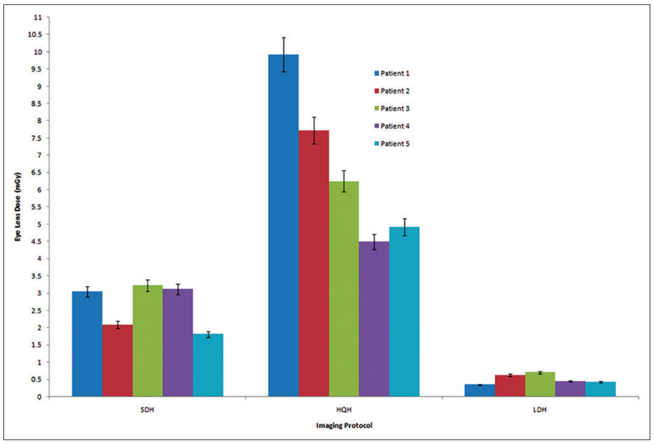

Figure 3: Eye lens dose per cone-beam computed tomography acquisition for different imaging protocols (SDH: Standard dose head, HQH: High-quality head, LDH: Low-dose head)

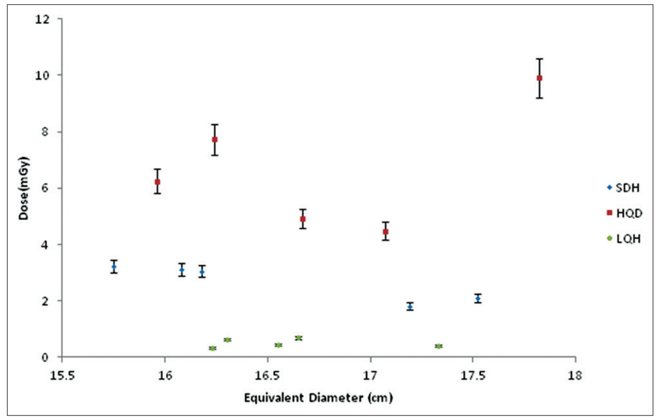

Figure 4: Eye lens dose as function of patient geometry with different imaging protocol (SDH: Standard dose head, HQH: High-quality head, LDH: Low-dose head)

Table 2: Eye lens dose as a function of isocenter distance from eye lens with different imaging protocols

Protocol	*Patient ID*	*Distance of eye lens from isocenter (cm)*	*Measured dose (mGy)*
Standard dose head	#1	5.6	3.22
	#2	6.1	3.11
	#3	6.7	3.05
	#4	7.1	2.09
	#5	11.1	1.81
High-quality head	#1	6.0	9.92
	#2	8.2	7.73
	#3	9.7	6.25
	#4	11.8	4.92
	#5	12.0	4.49
Low-quality head	#1	7.1	0.70
	#2	8.4	0.63
	#3	8.7	0.42
	#4	9.3	0.44
	#5	11.3	0.34

as a function of distance between isocenter and eye lens. In general, for all the imaging protocols, eye dose mainly depends on distance between isocenter and eye lens, and eye lens dose is maximum when the distance between eye lens and isocenter is minimum.

Discussion

The lens of the eye is one of the most radiation-sensitive tissues in the body. High radiation dose to eye lens causes radiation-induced cataract. In radiotherapy, the patient is already exposed to leakage and scattered radiation dose coming out from the treatment equipment. The imaging dose will also contribute to patient dose. This study provides comprehensive information about eye lens doses from Varian CBCT head and neck protocols. Several researchers have reported the eye lens dose measured on anthropomorphic phantom[17,18] or using Monte-Carlo simulation.[20,21] Limitation of phantom-based dosimetry is its fixed geometry. In this study, the impact of patient geometry and distance of isocenter on eye lens dose has been reported. Ding *et al*.[20] have reported eye lens dose <1 mGy for LDH protocol using Monte-Carlo simulation technique which is in agreement with our measured data which is found to be in the range of 0.3–0.7 mGy.

For standard dose quality imaging protocol, Cheng *et al*.[19] have reported eye lens dose about 3.5 mGy while we have measured the same in the range of 2.2–3.3 mGy. The large variation in the dose to lens among different protocols is because of mAs used for image acquisition. From Table 1, it is clear that LDH acquisition uses only 72 mAs, SDH uses 145 mAs and HDH 720 mAs. Alvarado *et al*.[22] have shown reduction of CBCT dose to half by changing mAs from 20 to 10.

Frequency of CBCT image acquisition for head and neck region varies from institution to institution. As reported in literature,[23] for off-line protocol, CBCT should be done daily for first three consecutive days and thereafter once in a week. In this way, total 8–10 sets of CBCT images are acquired during the complete course of treatment. However, for on-line protocol, every day CBCT is required; there will be 30–35 acquisitions for the entire course of treatment. Eye lens dose will be nearly three times more in on-line correction protocol. Total dose to eye lens will depend on selection of acquisition protocol. Suitable safety measures such as blades can be used to shield the lens during image guidance which can effectively reduce the additional radiation dose delivered to both lenses from CBCT if the region of eyeball is not essential for field matching.[19] It was observed that the more posterior the isocenter is located, lesser will be the absorbed dose to the optic structures.

Conclusions

The measured data indicate that the eye lens dose depends on selection of imaging protocol and frequency of imaging. We also observed that the eye lens dose does not depend on patient geometry but strongly depends on distance between eye lens and the isocenter of the treatment field. However, undoubted advantages of imaging system should not be counterbalanced by inappropriate consideration of imaging protocol, especially for very intense imaging sequences for adaptive radiotherapy or IMRT. Daily image guidance should be used with great caution in certain cases, for example, where the treatment dose already reaches limits for organs at risk, particularly for the children. Results of this investigation are expected to guide the clinician and physicist to select the most suitable imaging protocol which will help in reducing the imaging dose to the radiosensitive organ of the patients.

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Conflicts of interest

There are no conflicts of interest.

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