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Determination of effective doses in image-guided radiation therapy system

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Abstract. The organ and effective doses in image-guided radiotherapy system are determined in this study. For 2D imaging, incident air kerma (K_i) was measured by 6cc ionization chamber with Accu-Pro dosimeter. The entrance surface air kerma (ESAK) was calculated by multiplying K_i with backscatter factor. The effective dose was calculated by multiplying ESAK with conversion coefficient. For 3D imaging, computed tomography/cone-beam dose index (CTDI/CBDI) measurements were performed by using 100mm pencil ionization chamber with Accu-Pro dosimeter. The dose index in air and in CTDI phantom from planning CT and cone-beam CT were measured. Then, effective dose was calculated by ImPACT software. The effective doses from 2D conventional simulator for anteroposterior and lateral projections were 0.01 and 0.02mSv for head, 0.15 and 0.16mSv for thorax, 0.22 and 0.21mSv for pelvis, respectively. The effective doses from 3D, planning CT and CBCT, were 3.3 and 0.1mSv for head, 13 and 2.4mSv for thorax and 7.2 and 4.9mSv for pelvis, respectively. Based on 30 fractions of treatment course, total effective dose (3D CT, 2D setup verification and 6 times CBCT) of head, thorax and pelvis were 3.93, 27.71 and 37.03mSv, respectively. Therefore, IGRT should be administered with significant parameters to reduce the dose.

1. Introduction

Radiation therapy is one of the most common treatment methods for cancer by delivering the high radiation dose to the tumor while avoiding the normal tissues from receiving doses above their limitation. The precision of radiation dose can be increased by new treatment modalities and advanced delivery techniques that can be applied to a cancer patient. To get the full benefit, accurate positioning of the target volume is needed and the magnitudes of both external and internal motion of the patient are minimized. Therefore, more imaging modalities are used for dose calculation in simulation process and for patient setup verification in the treatment process. However, this can result in additional dose contributions to the integral patient dose. This dose is possible to increase the risk of radiation (stochastic effects) and also the severity of side effects from the cancer therapy treatment.

Image-guided radiation therapy (IGRT) is the combination of imaging procedures in the treatment room and contemporary irradiation techniques. It involves multiple imaging procedures for simulation, planning, setup, and intrafraction monitoring. Common imaging procedures for IGRT are kilovoltage planar imaging, portal imaging, cone-beam computed tomography (CBCT), fan beam computed tomography. With the increasing use of IGRT, the chance for secondary cancer also increases. The

objective of this study was to determine the imaging dose of IGRT from the whole process of treatment.

2. Material and methods

The materials used in this study were from the Department of Therapeutic Radiology and Oncology, King Chulalongkorn Memorial Hospital

2.1. Effective dose calculation from setup imaging

The Acuity Simulator (Varian Medical System, Palo Alto, CA, USA) supports basic 2D simulation and complex treatment plan verification. For effective dose calculation, a 6 cc ionization chamber (Radcal Corporation, Monrovia, CA) was placed at the isocenter and exposed with the selected exposure parameters according to the protocol and records the dose from dosimeter. Then, Incident Air Kerma (K_i) and Entrance Surface Air Kerma (K_E) were calculated by using equation (1) and (2) [6], below. The effective dose for planar projection radiography is directly obtained from entrance skin dose (mGy) multiply with the conversion coefficient, equation (3) [4].

$$K_i = M_Q \, N_{K,\,Q0} \, k_Q \, k_{TP} \tag{1}$$

$$K_E = K_i * \text{Back Scatter Factor} \tag{2}$$

$$\text{Effective dose} = K_E * \text{conversion coefficient} \tag{3}$$

Where K_i = Incident Air Kerma, K_E = Entrance Surface Air Kerma, M_Q = mean value of the dose meter reading, $N_{k,Q0}$ = dosimeter calibration coefficient, k_Q = radiation quality factor, k_{TP} = temperature, pressure correction factor.

2.2. Effective dose calculation from planning CT

Computed tomography dose index (CTDI) measurements were performed with the Philips Brilliance Big Bore CT scanner (Philips Healthcare, Andover, MA, USA). This CT scanner has an 85cm bore and true 60cm scan field of view. This 85 cm bore size can be used to scan patients with immobilization devices. The $CTDI^{air}$ measurement was done by placing the 100 mm ionization chamber in air at the isocenter and recorded the dose from dosimeter. Then, $CTDI^{center}$ and $CTDI^{periphery}$ were measured by placing the chamber at the center, 12, 3, 6, and 9 o'clock positions of the CTDI phantom (16 cm in diameter for head protocol and 32 cm in diameter for chest and pelvis protocol).The CTDI weighted was calculated by using the equation (4), the $CTDI^{air}$, $CTDI^{weighted}$, type of CT unit, total mAs and scan range of each protocol were entered into the ImPACT (Imaging Performance Assessment of CT scanners) software (version 1.0.4) for the organ and effective doses calculation.

$$CTDI/CBDI_{100}^{weighted} = \frac{1}{3} CTDI/CBDI_{100}^{center} + CTDI/CBDI_{100}^{periphery} \tag{4}$$

Where $CTDI/CBDI_{100}^{weighted}$, $CTDI/CBDI_{100}^{center}$, $CTDI/CBDI_{100}^{periphery}$ were CT/Cone-beam Dose Index measured in air, center of phantom and average of the four peripherals position of the phantom, respectively.

2.3. Effective dose calculation from cone beam CT

The Cone-beam CT system (Varian Medical System, Palo Alto, CA) attached to the Varian TrueBeam Linear Accelerator (version 2.0), is designed to verify for motion and setup errors in patients undergoing radiation therapy. For Cone-beam CT effective dose calculation, Cone-beam Dose Index (CBDI) measurements were performed as the same as in planning CT, figure 1. As the ImPACT software is designed specifically for the CT scanner, for the cone-beam CT, we used ImPACT factor as shown in equation (4) to match with ImPACT software to select the suitable reference CT unit.

$$\text{ImPACT factor} = a\ \frac{CBDI_{100}^{center}}{CBDI_{100}^{air}} + b\ \frac{CBDI_{100}^{periphery}}{CBDI_{100}^{air}} + c \quad (5)$$

Where a, b, c = Empirical factors developed by ImPACT group.

Figure 1. The setup of 100mm pencil ionization chamber in 16 cm diameter CTDI phantom for CBCT head protocol.

3. Results

The effective dose calculation from 2D kilovoltage setup imaging was performed as the AAPM Task Group 75 recommendation [5]. The conversion coefficients were determined according to the exposure parameters and half value layer of the machine. The parameters and total effective doses are shown in table 1.

Table 1. Effective doses and acquisition parameters for each protocol of acuity simulator.

Parameters	Head		Chest		Pelvis	
	AP	Lateral	AP	Lateral	AP	Lateral
kV	85	90	99	100	110	110
mAs	9.97	19.46	10.16	21.58	11.86	20
Field size (cm)	15.3*15.3	15.3*15.3	20.03*20.03	20.03*20.03	20.03*20.03	20.03*20.03
Conversion coefficient	0.01	0.01	0.12	0.05	0.13	0.07
Effective dose (mSv)	0.01	0.02	0.15	0.16	0.22	0.21
Total effective dose (mSv)	**0.03**		**0.31**		**0.43**	

The organ and effective doses from the planning fan beam CT and cone-beam CT are shown in table 2 and 3 for each region. The dose calculations were performed based on the departmental routine of the planning CT and manufacturer protocol of the Varian cone-beam CT system. For effective dose calculation, the organ and tissue weighting factors were used as recommended by ICRP 103 [6].

Table 2. Organ and effective doses from Philips Brilliance Big Bore CT.

Organs	**W_T**	**Organ Dose, (H_T), (mSv)**			**Effective Dose, ($H_T.W_T$), (mSv)**		
		Head	**Chest**	**Pelvis**	**Head**	**Chest**	**Pelvis**
Gonads	0.08	0.000032	0.056	28	0	0.0045	2.3
Bone Marrow	0.12	2.5	9.3	7.4	0.3	1.1	0.88
Colon	0.12	0.0011	0.4	16	0.00013	0.048	1.9
Lung	0.12	0.88	31	0.04	0.11	3.7	0
Stomach	0.12	0.027	9.2	0.84	0.0032	1.1	0.1
Bladder	0.04	0	0.025	31	0	0.001	1.2
Breast	0.12	0.13	24	0.04	0.016	2.8	0
Liver	0.04	0.043	13	0.51	0.0017	0.54	0.02
Esophagus (Thymus)	0.04	0.69	34	0.01	0.028	1.4	0
Thyroid	0.04	29	18	0	1.2	0.71	0
Skin	0.01	3.1	6.8	6.7	0.031	0.068	0.07
Bone Surface	0.01	9.7	17	11	0.097	0.17	0.11
Brain	0.01	19	0.39	0	0.19	0.0039	0
Salivary Glands (Brain)	0.01	19	0.39	0	0.19	0.0039	0
Remainder	0.12	4.1	12	5	0.49	1.4	0.59
Total Effective Dose (mSv)					**3.3**	**13**	**7.2**

Table 3. Organ and effective doses from Cone-beam CT attached to the Varian TrueBeam Linear Accelerator.

Organs	W_T	Organ Dose, (H_T), (mSv)			Effective Dose, ($H_T.W_T$), (mSv)		
		Head	Chest	Pelvis	Head	Chest	Pelvis
Gonads	0.08	<0.01	<0.01	19	<0.01	<0.01	1.5
Bone Marrow	0.12	0.22	1.6	4	0.026	0.2	0.48
Colon	0.12	0.000032	0.017	9.3	<0.01	<0.01	1.1
Lung	0.12	0.015	5.7	0.01	0.0018	0.69	0.001
Stomach	0.12	0.00058	0.29	0.2	0.00007	0.034	0.024
Bladder	0.04	0	0.0023	34	0	0.00009	1.3
Breast	0.12	0.0037	6.6	0.02	0.00044	0.79	0.002
Liver	0.04	0.00088	0.44	0.13	0.000035	0.017	0.005
Esophagus (Thymus)	0.04	0.013	10	0	0.0005	0.4	0
Thyroid	0.04	0.42	0.76	0	0.017	0.03	0
Skin	0.01	0.23	1	4.4	0.0023	0.01	0.044
Bone Surface	0.01	0.95	3.1	6.1	0.0095	0.031	0.061
Brain	0.01	2.5	0.039	0	0.025	0.00039	0
Salivary Glands (Brain)	0.01	2.5	0.039	0	0.025	0.00039	0
Remainder	0.12	0.25	1.4	3.1	0.03	0.17	0.37
Total Effective Dose (mSv)					**0.1**	**2.4**	**4.9**

4. Discussion

The effective doses from the Acuity simulator were very small compared with the other modalities. The maximum was observed at pelvis protocol of 0.43 mSv due to the highest exposure parameters. From the planning CT, lung and breast tissue acquired 31 mSv and 24 mSv, gonads and colon acquired 28 mSv and 16 mSv from chest and pelvis protocols. The thyroid, esophagus, and bladder obtained the highest organ dose of 29 mSv, 34 mSv and 31 mSv for the head, chest and pelvis protocols, respectively. The effective dose from planning CT chest protocol was higher than that of the pelvis protocol because the scan length for chest protocol was longer than the pelvis protocol to cover the metastasis area, as shown in table (4). In cone-beam CT imaging, salivary gland, esophagus, and bladder received the highest organ dose of 2.5, 10 and 34 mSv for the standard head, low dose thorax, and pelvis protocols. However, the highest radiation sensitive organ, the lungs acquired 5.7 mSv in low dose thorax, gonads and colon acquired 19 and 9.3 mSv from pelvis protocols. The effective doses from CBCT were lower than that of the planning CT; however, to achieve the precise and accuracy treatment, CBCT has to perform every week to every day which increasing the amount of radiation dose to the patient.

Table 4. Acquisition parameters for planning CT.

Parameter	Head	Chest	Pelvis
kV	120	120	120
mA	325	325	325
Collimation (mm)	16 x 1.5	16 x 1.5	16 x 1.5
Rotation Time (second)	0.75	1	1
Pitch	0.938	0.938	0.938
Scan Length (mm)	357	355	280
$CTDI_{air}$ (mGy)	15.23	15.24	15.24
${}^{n}CTDI_{weighted}$ (mGy)	12.41	8.05	8.05
$CTDI_{vol}$ (mGy)	32.2	27.9	27.9
DLP (mGy.cm)	790	990	781

5. Conclusion

In summary, for 30 fractions of the treatment course, at least, one scan of 3D planning CT and 2D setup verification and 6 times CBCT have been performed. Therefore, the total effective doses of the

head, thorax, and pelvis regions are 3.93, 27.71and 37.03 mSv, respectively. This can attribute more radiation dose to the already high treatment dose burden to the patient. Therefore, to reduce the chance of secondary cancer, image-guided radiotherapy should be administered with significant parameters to reduce the dose.

References

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