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ARTICLE

Secondary Cancer Risks in Out-of-field Organs for 3-D Conformal Radiation Therapy

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The risk of secondary cancers after radiation therapy has become an important issue, mainly because advanced treatment techniques such as 3-D conformal radiation therapy (CRT) and intensity-modulated radiation therapy (IMRT) tend to increase the radiation dose to out-of-field organs. Moreover, cancer patients' average survival period, following those advances in treatment techniques, also has increased, effectively raising the risks for the same levels of radiation exposure. In the present study, the secondary cancer risks to out-of-field organs were determined for some representative cases of 3-D CRT by measuring organ doses with LiF thermoluminescence (TL) dosimeters and an ATOM^{TM} male phantom. Our results show that the secondary cancer risks are similar (difference: < 20%) for 6 and 10 MV X-ray beams for the same prostate treatment case. The total secondary cancer risks of the out-of-field organs were on the order of 2-4% for the treatment cases considered in the present study.

KEYWORDS: secondary cancer risk, 3-D conformal radiation therapy, out-of-field organs, anthropomorphic phantom, TLD

I. Introduction

In radiation therapy, organs located far from the tumor volume ("out-of-field" organs) are assumed to receive very low doses of radiation and, therefore, frequently ignored in treatment planning[1)], even though it is well known that small radiation doses to these organs nonetheless can induce cancers. Recently, interest in the implications of such secondary caners has significantly grown, mainly because advanced treatment techniques such as 3-D conformal radiation therapy (CRT) and intensity-modulated radiation therapy (IMRT) tend to increase the radiation dose to out-of-field organs[2-5)]. Cancer patients' average survival period also has increased along with the advances of treatment techniques, resulting in raised secondary cancer risks for the same level of radiation exposure [5,6)].

The importance of secondary cancer risks attendant on radiation therapy has been recognized by several international organizations, including the International Commission on Radiological Protection (ICRP)[7)], the National Council on Radiation Protection and Measurement (NCRP), and the American Association of Physicists in Medicine (AAPM). Also, several researchers recently have measured out-of-field organ doses and determined the effective dose[2,5)].

In the present study, the secondary cancer risks to out-of-field organs for some representative treatment cases of 3D-CRT, currently the most popular treatment technique in radiation therapy, were directly determined based on the sex-averaged nominal cancer risk coefficients[8)]. To that end, out-of-field organ doses were measured with tissue-equivalent thermoluminescence (TL) dosimeters placed in an anthropomorphic phantom, after which the measured doses were multiplied by the cancer risk coefficients, thereby yielding the cancer risks.

II. Materials and Method

The secondary cancer risks were directly determined for the 8 out-of-field organs for which cancer risk coefficients are available, including the colon, lung, stomach, breast, bladder, esophagus, liver, and thyroid, as based on the nominal cancer risks that were derived by averaging the sex and

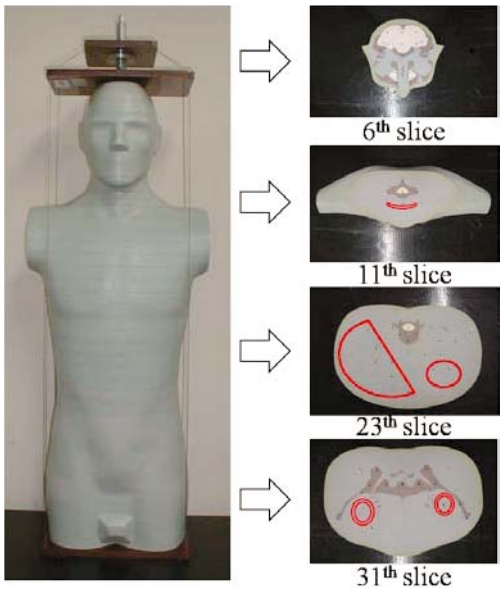

Fig. 1 ATOM adult male phantom (left) and defined organs based on MIRD5 mathematical phantom (right)

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Table 1 Number of TL dosimeters used to measure organ doses

Organ	Number of TLDs
Bone	28
Colon	14
Lung	20
Stomach	5
Breast	2
Gonads (Testes)	2
Bladder	3
Esophagus	5
Liver	10
Thyroid	2
Brain	5
Salivary gland	2
Skin	2

age-at-exposure lifetime risk estimates for whole populations[8].

To measure the radiation doses to the out-of-field organs, an ATOM^{TM} phantom (Model: 701-C, CIRS, USA) representing an adult male of 173 cm in height and 73 kg in weight was used[9]. The anthropomorphic phantom is composed of 2.5 cm-thick slices in which there are a number of small holes for TL or other small dosimeter chips. The phantom is made of tissue equivalent materials, including bone, soft tissue, brain, and lung. The phantom, however, lacks the other internal organs, which therefore in the present study were defined using the organ information of the MIRD5 mathematical phantom[10] (See **Fig. 1**).

The organ doses were measured by inserting very tiny rod-type (1 mm diameter, 6 mm length) LiF TLD-100 dosimeters (Harshaw, USA) into the holes in the ATOM^{TM} phantom. A total of 100 TL dosimeter chips were inserted for each measurement. The locations of the TL dosimeters were determined carefully, considering not only the volume and tissue weighting factor[11], but also the shape of the organs. **Table 1** shows the number of the TL dosimeters used for each organ.

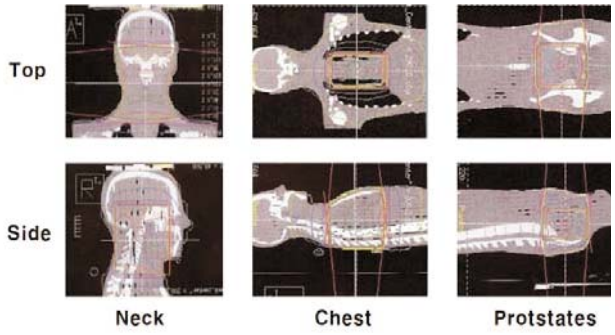

Fig. 2 Treatment cases considered in the present study

The 6 and 10 MV X-ray beams were delivered with a Siemens ONCOR^{TM} linear accelerator for several representative 3-D CRT treatment cases: that is, neck (6 MV), chest (6 MV), prostate (6MV), and prostate (10 MV), the details of which are given in **Table 2** and **Fig. 2**. The 2D treatment cases of this study were selected from the treatment planning which are mainly used with a linear accelerator in Hanyang University Medical Center. The target center dose of organ was about 2 Gy for all treatment case.

The TL dosimeters were calibrated with the 6 MV X-ray beam of the Siemens ONCOR^{TM} linear accelerator. The beam size was 10 cm x 10 cm, and the irradiated dose for each calibration was 2 Gy. The calibrations were repeated three times. The uncertainty of the calibration factor, with this type of calibration, normally is less than 2-3%[12], which is negligible considering that the secondary cancer risks were calculated based on the nominal cancer coefficients, for which the uncertainty is very large.

III. Results and Discussion

Table 3 shows the nominal cancer risk coefficients and the equivalent doses of the organs measured in the present study. Measured doses by TLDs into organs are regarded as equivalent doses of organs, because radiation weighting factor, $w_{R,}$ is one for photons. The secondary cancer risks were determined only for the out-of-field organs, which are frequently ignored in treatment planning. Note that the dose values were not significantly different in any of the treatment cases for the skin and bone, because the skin and bone are

Table 2 Treatment cases investigated in the present study

Treatment case	Beam size	Number of fields	MU (per unit field)	Target center dose
Neck (6 MV)	14 cm x 17 cm	2	106	2.00 Gy
Chest (6 MV)	11 cm x 19 cm	2	127	2.00 Gy
Prostates (6 MV)	15 cm x 16 cm	4	67	1.99 Gy
Prostates (10 MV)	15 cm x 16 cm	4	60	2.01 Gy

Table 3 Nominal cancer risk coefficients and measured equivalent doses of organs

Organ	Nominal cancer risk coefficient[1]	Equivalent dose of Measured organs (Sv)			
		Neck (6 MV)	Chest (6 MV)	Prostates (6 MV)	Prostates (10 MV)
Bone	7	(0.469)[3]	(0.399)	(0.481)	(0.508)
Colon	65	0.005	0.012	(1.003)	(1.020)
Lung	114	0.041	(0.387)	0.010	0.011
Stomach	79	0.009	0.031	0.033	0.037
Breast	112	0.017	(0.146)	0.007	0.009
Gonads (testes)	n.a.[2]	0.003	0.004	0.099	0.085
Bladder	43	0.005	0.006	(2.146)	(2.126)
Esophagus	15	0.030	(2.157)	0.010	0.012
Liver	30	0.008	0.033	0.031	0.030
Thyroid	33	(2.103)	0.167	0.006	0.011
Brain	n.a.	(1.053)	0.016	0.007	0.020
Salivary gland	n.a.	(2.550)	0.044	0.007	0.012
Skin	1000	(0.016)	(0.030)	(0.032)	(0.049)

[1] Nominal cancer risk coefficient [= cases per 10,000 persons per Sv].
[2] Nominal cancer risk coefficient is not available for this organ.
[3] The organs that are directly irradiated by the X-ray beam during treatment were placed in a parenthesis.

Table 4 Estimated secondary cancer risks in out-of-field organs

Organ	Neck (6 MV)	Chest (6 MV)	Prostate (6 MV)	Prostate (10 MV)
Bone	-	-	-	-
Colon	3.19×10^{-5}	7.90×10^{-5}	-	-
Lung	4.73×10^{-4}	-	1.11×10^{-4}	1.30×10^{-4}
Stomach	6.91×10^{-5}	2.44×10^{-4}	2.61×10^{-4}	2.95×10^{-4}
Breast	1.88×10^{-4}	-	8.12×10^{-5}	1.05×10^{-4}
Bladder	2.07×10^{-5}	2.39×10^{-5}	-	-
Esophagus	4.55×10^{-5}	-	1.46×10^{-5}	1.80×10^{-5}
Liver	2.47×10^{-5}	9.88×10^{-5}	9.20×10^{-5}	9.10×10^{-5}
Thyroid	-	5.52×10^{-4}	1.85×10^{-5}	3.57×10^{-5}
Skin	-	-	-	-
Total (2 Gy)	8.53×10^{-4}	9.98×10^{-4}	5.78×10^{-4}	6.75×10^{-4}
Total (70 Gy)	2.99×10^{-2}	3.49×10^{-2}	2.02×10^{-2}	2.36×10^{-2}

Note: The values given should not be taken to imply undue precision but are presented to 3 significant figures to facilitate the traceability of the calculations made.

always directly irradiated by the X-ray beam during radiation therapy. The skin and bone cases were, therefore, not considered in the secondary cancer risk estimation. The equivalent doses of organ that likewise reflect irradiation by the X-ray beam are placed in parentheses in Table 3.

Table 4 shows the total secondary cancer risks for the out-of-field organs as determined based on the nominal cancer risk coefficients and the equivalent doses of the measured organs. The secondary cancer risks were calculated simply by multiplying the measured doses by the nominal cancer risk coefficients of organ. Our results show that for the same prostate treatment case, the total secondary cancer risks with the 6 and 10 MV X-ray beams are similar. The 10 MV X-ray beam showed a slightly higher (difference: ~20%) cancer risk, due mainly to the increased leakage from the linear accelerator (LINAC) head.

The total secondary cancer risks to the out-of-field organs, for 70 Gy target dose, were estimated to be about 2-4% for the treatment cases considered in the present study: that is, 3.0%, 3.5%, 2.0%, and 2.4% for the neck (6 MV), chest (6 MV), prostate (6 MV), and prostate (10 MV) treatment cases, respectively. The lung was responsible for 55% of the total cancer risk to the neck (6 MV) treatment case. Note that the lung showed not only the highest cancer risk coefficients, but also the highest dose value among the out-of-field organs. For the chest (6 MV) and prostate (6 and 10 MV) cases, the thyroid and stomach were responsible for 55% and 45% of the total cancer risks, respectively, which is reasonable considering the locations of those organs with respect to the target organs. The lethality of the thyroid, however, is very low, which should be considered in any interpretation of secondary cancer risks.

The secondary cancer risk was mainly influenced by nominal cancer risk coefficient because the equivalent doses of out-of-field organ were very low and similar. As an exception, the equivalent dose of the out-of-field organs which is very close to the irradiated beam more affected the secondary cancer risk because these values are considerably large when compared with the equivalent dose of other organs.

IV. Conclusions

In the present study, the secondary cancer risks to out-of-field organs for some representative cases of 3-D CRT were determined by measuring organ doses with LiF TL dosimeters and the ATOM^{TM} male phantom. Our results show that the total secondary cancer risks with the 6 and 10 MV X-ray beams, for the same prostate treatment case, are similar, differing only by ~20%. . The total secondary cancer risks of the out-of-field organs were on the order of 2-4% for the treatment cases considered in the present study. The procedure developed in the present study will be applied to IMRT treatment cases in which, compared with 3-D CRT treatments, more monitor units are used, resulting in even higher secondary cancer risks.

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References

1) B. Bednarz, X. G. Xu, "Monte Carlo modeling of a 6 and 18 MV Varian Clinac medical accelerator for in-field and out-of-field dose calculations: development and validation," *Phys. Med. Biol.,* **54**[4], 43-57 (2009).
2) F. Vanhavere, D. Huyskens, L. Struelens, "Peripheral neutron and gamma doses in radiotherapy with an 18 MV linear accelerator," *Radia. Prot. Dosim.*, **110**[1-4], 607-612 (2004).
3) S. F. Kry, M. Salehpour, D. S. Followill, M. Stovall, D. A. Kuban, R. A. White, I. I. Rosen, "Out-of-field photon and neutron dose equivalents from step-and-shoot intensity-modulated radiation therapy," *Int. J. Radiation Oncology Biol. Phys.*, **62**[4], 1204-1216 (2005).
4) E. J. Hall, C. S. Wuu, "Radiation-induced second cancers: the impact of 3D-CRT and IMRT," *Int. J. Radiation Oncology Biol. Phys.*, **56**[1], 83-88 (2003)
5) U. Schneider, A. Lomax, J. Besserer, P. Pemler, N. Lombriser, B. Kaser-Hotz, "The impact of dose escalation on secondary cancer risk after radiotherapy of prostate cancer," *Int. J. Radiation Oncology Biol. Phys.*, **68**[3], 892-897 (2007).
6) B. Wang, X. G. Xu, "Measurements of non-target organ doses using MOSFET dosemeters for selected IMRT and 3D CRT radiation treatment procedures," *Radiat. Prot. Dosim.*, **128**[3], 336-342 (2008).
7) International Commission on Radiological Protection, *1990 Recommendations of the International Commission on Radiological Protection*, Pergamon Press, Oxford, 91-193 (1991).
8) International Commission on Radiological Protection, *The 2007 recommendations of the International Commission on Radiological Protection*, J. Valentin, Elsevier, New York, 173-213 (2008).
9) International Commission on Radiological Protection, *Report of the task group on reference man,* Pergamon Press, Oxford, 8-27 (1975).
10) M. Cristy, K. F. Eckerman, *Specific absorbed fractions of energy at various ages from internal photon sources*, TM-8381/V1, Oak Ridge National Laboratory, (1987).
11) International Commission on Radiological Protection, *The 2007 recommendations of the International Commission on Radiological Protection*, J. Valentin, Elsevier, New York, 61-79 (2008).
12) T. C. S. Woo, J. P. Pignol, E. Rakovitch, T. Vu, D. Hicks, P. O'Brien, K. Pritchard, "Body radiation exposure in breast cancer radiotherapy: impact of breast IMRT and virtual wedge compensation techniques," *Int. J. Radiation Oncology Biol. Phys.*, **65**[1], 52-58 (2006).