EVALUATION OF SECONDARY DOSE AND CANCER RISK FOR OUT-OF-FIELD ORGAN IN ESOPHAGEAL CANCER IMRT IN A CHINESE HOSPITAL USING ATOM PHANTOM MEASUREMENTS

Yaping Qi¹, Lijuan He¹, Zhi Wang¹,², Yuanyuan Liu¹, Hongdong Liu¹, Wanli Huo¹, X. George Xu¹,³ and Zhi Chen¹*,
¹School of Nuclear Science and Technology, University of Science and Technology of China, Hefei, Anhui Province, PR China
²Department of Radiation Oncology, The First Affiliated Hospital of Anhui Medical University, Hefei, Anhui Province, PR China
³Nuclear Engineering Program, Rensselaer Polytechnic Institute, Troy, NY 12180, USA

*Corresponding author: zchen@ustc.edu.cn

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INTRODUCTION

It has been widely reported that patients treated with radiotherapy may have an increased risk of secondary cancer owing to radiation received in the out-of-field organs. Lee et al. (2) found that a secondary cancer risk of 305 per 100,000 population for thyroid after cervical cancer external radiotherapy, and Brenner et al. (1) reported that the relative risks of second cancer reached 15 and 34% for patients survived more than 5 and 10 years, respectively, after radiotherapy for prostate cancer. The goal of a radiation therapy is to deliver a lethal dose to the tumor and minimize the dose of neighboring healthy organs at risk (OARs). However, as analyzed by Xu et al., patients receive inevitable photon leakage radiation through the treatment head of the machine, radiation scattered from accelerator components and radiation scattered within the patient from the treatment beams. Therefore, patients carry risks of developing secondary cancer in their lifetimes. There is a growing concern about the radiation-induced secondary cancer associated with radiation treatments, especially for cancer survivors who are now younger and are living longer. Recently, American Association Physics Medicine (AAPM) reported in detail the risk of secondary cancer of out-of-field organs during radiation therapy (4). Attentiones have been paid to secondary cancer risk related to successful new clinical radiation treatment modalities (5) especially as the so-called intensity-modulated radiation therapy (IMRT) is widely employed to improve dose conformality (3). A guideline from National Cancer Institute (NCI) recognized that IMRT can result in a higher whole-body dose and the same conclusion was drawn from the research of Wang et al. (6, 7). The risk of secondary cancer has been studied for a long period and Hall and Wu were among the first to report that IMRT could result in an increase risk in secondary
malignancies for the two potential reasons: (1) IMRT uses more radiation fields and (2) IMRT requires the beam-on time to be longer\(^5\), which means IMRT requires more monitor units (MU) to deliver the same amount of prescribed dose to the tumor.

Since the late 1970s, many researchers and physicists studied secondary photon and neutron exposures\(^5\) for the protection of both patients and environment. Usually three principal methods were used to estimate absorbed doses: (1) anthropomorphic phantom measurement, (2) water phantom measurement and (3) Monte Carlo simulations. In particular, the Task Group 158 (TG-158) of AAPM considered several dosemeters that could be employed in dose measurement\(^4\), e.g. the thermoluminescence dosemeter (TLD), optically stimulated luminescence dosemeter (OSLD), diode metal oxide semiconductor field effect transistor (MOSFET), ion chamber and film. In the study of Stovall et al.\(^10\), they developed a systematic dosimetric method to determine tissue doses of about 20,000 patients treated of the cervix cancer at many institutions in United States, Canada and Europe from 1916 to 1975, and also assessed organ doses to several organs including brain, breasts, kidneys, lungs, ovaries, pancreas, salivary glands, stomach and thyroid with a RANDO\(^5\)\(\text{®}\) female phantom and 350 TLDs. Over several years, some investigations about out-of-field organ doses from IMRT procedures with the help of anthropomorphic phantoms and different kinds of dosemeters have been conducted\(^6\), \(^11\)–\(^14\).

Despite the relatively large volume of information on secondary cancer, the topic has received little attention in China where the number of patients treated with radiotherapy has been increased drastically in recent years. According to statistical data provided by the International Agency for Research on Cancer (IARC), esophageal cancer is the eighth most common cancer worldwide and the sixth most common cause of death from cancer, and around 50\% of these cases worldwide occurred in China. In addition, both of the incidence rate and mortality rate are ranked among the top four malignant tumor in China\(^15\). Besides, esophageal cancer is challenging for surgery owing to the specific anatomical structures.

Less data are available in literature about evaluating out-of-field organ doses and secondary cancer risks from radiotherapy of esophageal cancer especially in China\(^16\), \(^17\). This present research is focused on the measurement of in-phantom absorbed dose and calculation of the lifetime attribute risks (LARs) to out-of-field organs after the IMRT treatment for the upper esophageal cancer.

METHODOLOGICAL AND MATERIALS

The measurements involved an ATOM\(^5\)\(\text{®}\) phantom (model ATOM 701-D, CIRS Inc., VA), and total of 200 TLD chips (CTLD-1000, US). A medical linear accelerator (Artiste Linear Accelerator, Siemens, Germany) in the First Affiliated Hospital of Anhui Medical University was used. The calculation of secondary cancer risks was performed with the biological effects of ionizing radiation (BEIR) VII model\(^18\).

Atom\(^5\)\(\text{®}\) phantom and TLD system

One of the popular lines of commercially available anthropomorphic phantoms is the ATOM\(^5\)\(\text{®}\) dosimetry phantoms (model ATOM 701-D, CIRS Inc., VA). They have been widely applied in the evaluation of radiation dosimetry and medical image quality\(^19\), \(^20\). This study used an adult male ATOM\(^5\)\(\text{®}\) phantom, which is 173 cm in height, 73 kg in weight and 23 cm × 32 cm in thorax dimensions. The phantom contains 20 organs and/or tissues, including soft tissue organs, bone, spinal cord, lungs, brain, active bone marrow and so on. The phantom is designed with 25 mm thick contiguous sections, and 268 holes filled with 5 mm in diameter, 25 mm in length solid plugs of corresponding tissue. Especially, unlike other anthropomorphic phantoms, ATOM\(^5\)\(\text{®}\) phantom are constructed of CIRS proprietary tissue equivalent materials. Linear attenuation for the simulated tissue is within 1\% of actual attenuation for the soft tissues and the bone, and within 3\% for the lung from 50 keV to 15 MeV\(^21\).

As mentioned above, there are several options of radiotherapy dosemeter. Although MOSFET dosemeter can provide the real-time readings\(^6\), it is uneasy to simultaneously measure so many doses owning to the electronic probes. By contrast, the TLD is a desirable tool because of its availability, small size, tissue equivalency and ease in dosemeter placement\(^22\). The size of TLD chips employed in this study is 4.5 mm in diameter and 0.8 mm in thickness, made of lithium fluoride (LiF) doping with Mg, Cu and P.

Calibration of TLDs

TLDs are relative dosemeters that need to be calibrated using the exposed radiation beams. Before the calibration, uniformity selection was made using \(^90\)Sr beta-ray source. All TLDs were annealed at 240°C for 10 min to set the sensitivity at a standard initial value and to eliminate their accumulated TL\(^23\). After annealing, these TLDs were irradiated ten circles with \(^90\)Sr source with dose rate of 26.4 μGy per circle. Subsequently TLDs were read out with a TLD reader (Harshaw 3500, USA). TLDs were selected depending on sensitivities, and dispersion <2\% was used to meet the radiation therapy measurement needs\(^24\). After the dispersion selection, the TLDs were irradiated in the same place with ten circles.
condition and the read-out process was repeated to verify the repeatability. The repeatability verification was conducted twice. TLDs with repeatability <3% were selected for clinical radiation measurements. Then the TLDs were calibrated against the 6 MV accelerator output at the depth of maximum absorbed dose ($d_{max}$) on the central axis, which has dose rate of 10 mGy/MU. A total of 25 selected TLDs were placed inside a solid water phantom. A 1.5 cm thick solid water slab with mass density of 1.0 g/cm$^3$ was used as a build-up material. The TLD chips were uniformly distributed and the source skin distance was 100 cm. Five different doses of 0.5, 1, 1.5, 2 and 2.5 Gy were delivered. The calibration factor was found to be 12.25 mGy/nC.

**Experimental procedures of the dose measurements**

By employing an ATOM® phantom and TLDs, the steps to obtain organ doses in this study were as follows: First, a full scan of ATOM® phantom was performed using a CT scanner, and a set of 3-mm thick original 2D virtual images with a resolution of 512×512 pixels are generated. Second, the planning target volume (PTV), lungs, spinal cord and other regions of interest were countered on the CT images by the radiation oncologist to prepare for the esophageal cancer treatment planning process. The contours of PTV and OARs were based on human sectional anatomy because the ATOM® phantom did not contain all specific organs. Third, a treatment plan for esophageal cancer was designed at the First Affiliated Hospital of Anhui Medical University using Pinnacle (Version 9.8) treatment planning system (Pinnacle, Philips Medical Systems, Andover, MA). A five-field IMRT plan with gantry angles of 181 220°, 340°, 20° and 140° was designed; the beam energy was 6 MV and the prescribed dose of 60 Gy (2 Gy, 30 fractions) was delivered in the isocenter and required totally 397.1 MU per fraction.

Before the measurement with TLDs and ATOM® phantom, TLD chips were repeated the annealing and cooling process, and then divided into 36 groups, including one unirradiated group to provide background readings. Three TLD chips were placed equally spaced inside each pre-selected hole representing the typical organ locations, such as the esophagus, lungs, spinal cord, stomach, thyroid and liver, and then filled with solid plugs of corresponding tissue. Figure 1 shows the outlines of the ATOM® phantom organs and the organs locations. Table 1 summarizes these measurement locations. The ATOM® phantom was fixed on the treatment couch according to the CT markers and isocenter. Finally, the esophageal cancer treatment plan was delivered on the same 6 MV photon beam linear accelerator equipped with 80 pairs of multi-leaf collimator and the phantom was in the supine position.

The dose rate was determined to be 300 MU/min. The readings of TLDs were recorded for each measurement point by averaging three TLD readings to obtain the final TLD measured dose for that measurement location.

All the TLDs were carefully classified depending on the ID number for the hole where the TLDs were placed. The TLD measurement data were analyzed and adjusted for background reading using the following equation:

$$D_{meas} = (R_{TLD} - R_{Bkg}) \times CF,$$

where $D_{meas}$ is the measured dose by TLD, $R_{TLD}$ and $R_{Bkg}$ are measured readings by TLDs and background readings (nC) and CF is calibration factor to convert from nC to Gy. The point doses of each organ were averaged to represent the organ absorbed dose. Since the measurement involved photon only, the radiation weighing factor is 1. Thus, the equivalent dose of each organ was calculated by multiplying 1 with the measured absorbed dose. In the esophageal cancer IMRT plan, the exposed target volume focused on the upper esophagus and the target isocenter was considered in the Slice #13 where the upper esophagus center was defined.

**Secondary cancer risk calculation model**

Secondary cancer risks from IMRT treatment involving esophageal cancer were estimated using BEIR VII model$^{18, 25}$. The relationship between the risk of second cancer induction in exposed populations and the unexposed populations can be quantified by their difference known as the excess absolute risk (EAR) and the excess relative risk (ERR). In this study, the age-dependent organ-specific ERRs and EARs were calculated for a variety of organ sites. The BEIR VII report defines the ERR and EAR as a function of attained age ($\alpha$), and normalizing the attained age to the reference age of 60, the ERR is as follows:

$$ERR(D, s, e, \alpha) = D \cdot \bar{\beta}_s \cdot \exp(\gamma e^\alpha) \left(\frac{\alpha}{60}\right)\eta,$$  \hspace{1cm} (2)

where $D$ is the equivalent dose (Sv), $s$ represents male or female, $e$ is the age at exposure (years), $e^\alpha$ is $(e - 30)/10$ for $e < 30$ and zero for $e \geq 30$, and $\alpha$ is the attained age (years). The model parameters $\gamma$, $\bar{\beta}_s$ and $\eta$ are provided for several organs in the BEIR VII report$^{18}$. Using the values of ERR and EAR, the lifetime attribute risk which is defined as the probability that an irradiated individual would develop cancer during their lifetime was calculated by the following equation:
where $L$ is the latency period (5 years for solid cancer), $\lambda_f$ represents the baseline cancer risk and data are from the research of Chen et al.\(^{26}\), and $S(a)/S(e)$ is the probability of the patient surviving from their age at exposure ($e$) to their attained age ($a$) and the values are based on the data presented in NCMI\(^{27}\). The weights 0.7 and 0.3 are recommended by the BEIR committee for most organs. They reflect the greater support for relative risk transport between populations rather than absolute risk. The weights of 0.7 and 0.3 are reversed for lung; only the EAR model is recommended for breast\(^{28}\) and for thyroid, there is no EAR model and LAR is calculated using the ERR model only. A dose and dose rate effective factor of 1.5, as recommended in the BEIR VII report\(^{18}\), was applied to calculate LAR. The age at exposure was set at 40, 50, 60 and 70 years old and the attained age was at 80 years, which is based on the current life expectancy at birth of Chinese male of 76.6 years.

Uncertainty in dose measurement by TLDs
During the whole experimental set-up, inaccuracies in the out-of-field organ dose determination may be mainly affected by the following aspects: selection of TLDs including batch homogeneity and repeatability, energy response in calibration and stability of the TLD reader. Combined standard uncertainty ($U_C$) was taken on to calculate uncertainties related to dose measurement by TLDs using the following equation:

$$U_C = \sqrt{U_A^2 + U_B^2},$$

where $U_A$ refers to uncertainties resulted from repeated independent measurements, $U_B$ is the systematic error resulted from instruments and should be divide $\sqrt{3}$ when calculated.

RESULTS AND DISCUSSIONS

Absorbed dose in various organs measured by TLDs
The organ absorbed doses obtained from TLDs are summarized in Table 1 (these values were obtained from one fraction). Each point dose corresponds an average dose measured by three TLD chips at the equivalent position in the phantom. All data were normalized by the prescription dose (2 Gy per fraction). The measurement values had great relationship with the distance from the radiation field. The high dose (162.5 and 149 mGy/Gy) were in the lower esophagus and spinal cord which were near the radiation field, but prostate and testis, far away from the target volume, received the lowest doses, which were nearly zero (0.2 mGy/Gy). In order to obtain a more explicit dose-distance relationship, a function of measured organ doses at different locations was plotted in Figure 2. The distance was calculated from the center of measured hole to the target isocenter. So several in-field doses are contained in the figure together with out-of-field doses. It is clear that the measured doses decrease exponentially as the distance from the isocenter increases. Furthermore, for distances $< 15$ cm, the organ doses fall off rapidly and almost decrease by 99.55%. As for the low dose region, the doses at 40 cm away from the target isocenter decrease by 99.97%. The exponential dose
falling trend in out-of-field region is in good agreement with those three cases reported for IMRT plans with different radiation fields in these literatures\(^3\), \(^6\), \(^13\), as shown in Figure 3. Results in this article were however found to be somewhat lower compared with the cases in references, the reason may have to do with the number of irradiation fields. More fields required more MUs leading to greater exposure to out-of-field organs.

Owing to its vicinity to the esophagus, the spinal cord was considered as OAR, and seven points were placed at two or three slices interval in the spinal cord. The max point dose of the spinal cord was found to be 2.04 Gy/fraction, and after 30 same fractions, the total dose would exceed 48 Gy according to OAR dose constraints\(^{29}\). So a physicist would need to modify treatment plans with the process of radiotherapy to protect neighboring organs. Since the upper esophagus was designated as the PTV, the absorbed dose in the lower esophagus was also measured. It can be seen that the dose rapidly decreases by 99.65% in the lower esophagus compared with the dose in upper esophagus. When designing this study, more attention was paid to the lungs, so eight points were selected in all the lung-containing slices (Slice #12, #14, #16 and #18). The doses in the same slice are quite different in the left lung and right lung varying from 67.5 to 172 mGy in the Slice #12. For all measured points in lungs, the right lung doses were higher than doses in the left lung. This can be attributed to the gantry angles and beam setup. Similarly, the doses of other interesting organs were found to be relatively low without obvious dose fluctuations in those organs. For the organs far away the target volume, such as the bladder, prostate and testis, the doses were found to be almost zero.

Comparison measured dose by TLD with calculated dose by TPS

Less data are available in out-of-field organ absorbed doses for esophageal cancer radiotherapy especially in China. Within the TPS, point doses were determined in the interesting points using the point dose measurement tool. Absorbed doses calculated by TPS related to each organ are listed in Table 1 together with the ratio of calculated dose and measured dose. The difference in ratio reflects the

<table>
<thead>
<tr>
<th>Organ</th>
<th>Hole ID number</th>
<th>(D_{meas} ) (mGy/Gy)(^a)</th>
<th>(D_{cal} ) (mGy/Gy)</th>
<th>(D_{cal}/D_{meas})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brain (2)(^b)</td>
<td>4(12,13)</td>
<td>1.55</td>
<td>0.05</td>
<td>0.032</td>
</tr>
<tr>
<td>Thyroid (2)</td>
<td>11(28,29)</td>
<td>27.55</td>
<td>28.09</td>
<td>1.019</td>
</tr>
<tr>
<td>Left lung (4)</td>
<td>12(33);14(50);16(72);18(97)</td>
<td>16.85</td>
<td>34.3</td>
<td>2.036</td>
</tr>
<tr>
<td>Right lung (4)</td>
<td>12(34);14(53);16(78);18(103)</td>
<td>36.5</td>
<td>53</td>
<td>1.452</td>
</tr>
<tr>
<td>Lower Esophagus (2)(^c)</td>
<td>15(68);19(107)</td>
<td>162.5</td>
<td>157.5</td>
<td>0.969</td>
</tr>
<tr>
<td>Spinal cord (7)</td>
<td>13(48);16(82);19(108);22(163);25(200);27(211)</td>
<td>149</td>
<td>137.05</td>
<td>0.920</td>
</tr>
<tr>
<td>Liver (2)</td>
<td>22(152);23(165)</td>
<td>1.09</td>
<td>0.53</td>
<td>0.484</td>
</tr>
<tr>
<td>Stomach (3)</td>
<td>22(147);24(176,178)</td>
<td>1</td>
<td>0.71</td>
<td>0.714</td>
</tr>
<tr>
<td>Kidneys (2)</td>
<td>24(186,187)</td>
<td>0.94</td>
<td>0.06</td>
<td>0.064</td>
</tr>
<tr>
<td>Intestine (2)</td>
<td>26(201,204)</td>
<td>0.56</td>
<td>0.08</td>
<td>0.134</td>
</tr>
<tr>
<td>Bladder (2)</td>
<td>33(239,241)</td>
<td>0.23</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Prostate (1)</td>
<td>35(258)</td>
<td>0.2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Testis (1)</td>
<td>38(267)</td>
<td>0.2</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

\(^a\)mGy/Gy means the organ doses divided the prescription dose (2 Gy per fraction).

\(^b\)The number out of the parenthesis is slice number and number in the parenthesis is the numbers of the measured points in each organ according to organ map of ATOM\(^k\) phantom.

\(^c\)One group of three TLDs was placed in the radiation field for the upper esophagus.

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EVALUATION OF SECONDARY DOSE AND CANCER RISK FOR OUT-OF-FIELD ORGAN

Table 1. The mean measured doses \(D_{meas}\) and calculated doses \(D_{cal}\) for different organs in ATOM phantom.

![Figure 2. Both of measured organ doses and calculated doses at different distance. The measured doses (the solid square) decrease exponentially as the distance increase from the measured site to the target volume while the doses calculated by TPS (the hollow triangle) are in fluctuating distribution.](image-url)
deviation between TLD measurement and TPS calculation. The ratio varies from zero (underestimated by 100%) to 2.036 (overestimated by 103.6%). Apparently, the TPS calculation results underestimated the out-of-field doses for most organs, and this underestimation trend became worse for organs located far away from the target isocenter. The large underestimation in the bladder, prostate and testis may be attributed to the long distance away from the field edge and doses were zero in TPS according to the dose algorithm. However, owning to the secondary radiation generated from patient body scattering, collimator scattering and accelerator treatment head leakage during the radiation therapy, these organs unavoidably received low dose radiation during the radiation therapy\(^3\). This study also found that there were exceptions that doses in lungs were much higher in TPS than TLD measurements. This was caused by imbalance of lateral electron and inaccurate algorithm for correcting the influence of inhomogeneous tissues. As also plotted in Figure 3, the calculated doses in TPS do not show the exponential fall trend and the values appear to be fluctuating at the large distance out of the radiation field. Similar results were reported by Huang et al. and Howell et al.\(^{30, 31}\). Our study which focuses on esophageal cancer radiotherapy confirms the previous findings that TPS-reported dose could not be used to estimate secondary radiation doses.

### Evaluation of secondary cancer risks

In order to evaluate the risk of secondary cancer incidence for out-of-field organs more reliably, measured doses were converted into dose equivalents by 30 fractions, and then to calculate LARs. Table 2 shows the LAR results associated with IMRT radiotherapy depending on the age at exposure. The LARs are found to decrease with the age at exposure increases for all organs considered, because younger patients are more sensitive for radiation. The risk value of 60 years old was as a reference value, the highest LAR per 100 000 of population was found to be in lower esophagus (103) and the relatively lowest value was in prostate (0.05). Figure 4 provides the LARs to different organs for an adult male exposed at the age of 60 years (the mean age of esophageal cancer incidence is 57 years old) compared with the baseline risk\(^{25}\). As the figure illustrates, the secondary cancer risks for organs near the target have the higher LAR values but much lower than the baseline risks. Another risk model to calculate secondary cancer risks was proposed by the National Council of Radiation Protection and Measurements (NCRP) in Report 116\(^{32}\). These risk coefficients were predominantly based on the data from Japanese atomic bomb survivors. Unlike those recommended in the BEIR VII report, the NCRP model was for all age groups and entire population. The risks were calculated by multiplying the dose equivalent at each organ by the whole-body risk coefficient of 5%/Sv\(^{33}\). Maximal absolute risks of secondary cancer using NCRP model are shown in Table 3. All NCRP model data were found to be two or even three orders of magnitude higher than in BEIR VII model. The risks were as high as 8% in neighboring organs and even reached 48.75% in lower esophagus. Few data were available to compare with work in this study regarding secondary cancer risks for esophageal cancer IMRT plan. And risks of secondary cancer will be different using different risk models. BEIR VII report was based on site-specific, age-specific risk model and has been adopted in the literature. By contrast, the BEIR VII model was more reliable than NCRP model\(^{25}\). Thus this work was based on the BEIR VII risk model and Chinese

![Figure 3. Measured organ doses in this work and in literatures at different distance. The measured doses decrease exponentially as the distance increases from the measured site to the field edge in the three spot lines. This unit is dose per MU.](image)

#### Table 2. LAR for organs at different exposure age (per 100 000 population) using BEIR VII risk model.

<table>
<thead>
<tr>
<th>Organ</th>
<th>Age at exposure (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>40</td>
</tr>
<tr>
<td>Brain</td>
<td>0.92</td>
</tr>
<tr>
<td>Thyroid</td>
<td>6.48</td>
</tr>
<tr>
<td>Lungs</td>
<td>93.2</td>
</tr>
<tr>
<td>Lower esophagus</td>
<td>186</td>
</tr>
<tr>
<td>Liver</td>
<td>2.18</td>
</tr>
<tr>
<td>Stomach</td>
<td>1.78</td>
</tr>
<tr>
<td>Intestine</td>
<td>1.86</td>
</tr>
<tr>
<td>Bladder</td>
<td>0.28</td>
</tr>
<tr>
<td>Prostate</td>
<td>0.03</td>
</tr>
</tbody>
</table>
population. Organs near the target had the higher LAR values but much lower than the baseline risks. It is noted that only when patients survive at least 5 years after treatment which is the typical latency period, the risk of secondary cancers could be considered. However, if a patient will survive only for a short period such as a few weeks or months after radiotherapy, the risk of secondary cancer may be quite close to zero.

Uncertainty analysis

Finally, the uncertainties associated with the second cancer risk data were provided in this paper. On the one hand, during the whole measurement process, inaccuracies in the out-of-field organ dose determination may be affected by several aspects: the reading uncertainty of TLD dosemeters, including uncertainty in the batch homogeneity (2%), uncertainty in the TLD response reproducibility (1.5%), uncertainty in the stability of the reader (2%) and uncertainty in the calibration curve (3%). A relative expanded uncertainty of 5.1% was generated combining these uncertainties for the dose estimated by TLD. Besides, although the assignment of TLD dosemeters to different organs was facilitated by CIRS organ maps, there still be uncertainty in the location of measured organ sites. On the other hand, the fitting parameters and assumption of the risk model would be another source of uncertainty. A majority of the epidemiological data used to produce the fitting parameters are based on atomic bomb survivor data which contain uncertainty.

CONCLUSIONS

Radiation dose to organs outside the radiotherapy treatment field is significant and therefore is worthy of clinical investigation. This study was conducted to measure the absorbed dose and evaluate the risks of out-of-field organs away from the target after an IMRT plan for esophageal cancer in China. And employing frequently used TLDs and a popular anthropomorphic phantom is a more valid method for dose estimations. The study involving an esophageal cancer treatment plan demonstrates clearly that the organ doses decrease exponentially with the distance from the target increases which is in good accordance with literature. Besides, more out-of-field organs are considered compared with other researches and the risks of secondary cancers in all concerned organs are evaluated. In all sites considered, the overall secondary primary cancer risks are lower than the baseline risks. The subsequent study is needed to establish a database on secondary cancer risks connected to radiotherapy in esophageal cancer patients, and to provide more helpful information to optimize the treatment plans especially when patient undergoes radiological diagnosis and radiotherapy more than once.

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