TRENDS AND DISTRIBUTION ANALYSIS OF OCCUPATIONAL EXPOSURE FROM MEDICAL PRACTICES IN CHINA (2010–2016)

Jun Deng, Shengnan Fan, Tuo Wang, Shuxia Hao, Xiaohui Liu, Wen Guo, and Quanfu Sun

Abstract—Occupational exposure to ionizing radiation from medical practices in China has been collected for a 7 y period between 2010 and 2016 from roughly 220 individual monitoring service providers through the Chinese Registry of Radiation Workers. Statistical dose distributions and characteristic tendencies are presented based on the evaluation in terms of six occupational categories. A reduction can be seen in average annual effective dose for interventional radiology, nuclear medicine, diagnostic radiology, radiotherapy, dental radiology, and others by 52%, 47%, 46%, 34%, 69%, and 31%, respectively, for the 7 y period. More than 94.5% of radiation workers received annual doses less than the public dose limit (1 mSv) in 2016. Workers engaged in nuclear medicine and interventional radiology activities were found to receive relatively more dose than the other fields of practice. Diagnostic radiology makes the dominant contribution of 68% to the collective effective dose of 73,641.3 person mSv received by 211,613 radiation workers in medical practices in 2016. The observation of workers in medical practices receiving well below the recommended occupational dose limit (20 mSv) could be a result of an improvement in radiation protection practices in the medical field in China. However, it is still necessary to control and manage the workplace and radiation workers to avoid unnecessary exposures, in particular for the workers engaged in nuclear medicine and interventional radiology activities.

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Key words: effective dose; exposure, occupational; medical radiation; radiation, ionizing

INTRODUCTION

With the rapid development of radiation applications in medical practices, on a worldwide scale medical radiation has become the main source of artificial radiation, as it is responsible for one-fifth of the annual collective effective dose from artificial radiation (UNSCEAR 2010). Therefore, radiation protection for workers has become a significant issue; the as low as reasonably achievable (ALARA) principle, used by International Atomic Energy Agency (IAEA) safety standards to minimize occupational radiation exposure, has been applied to them (IAEA 2002).

In China, there are up to 250,000 radiation workers employed by about 70,000 medical units (Wang et al. 2016). Individual monitoring is mandatory by decree of the Ministry of Health of the People’s Republic of China (Decree 55) (Ministry of Health 2007) and the law of the People’s Republic of China on prevention and control of occupational disease (Standing Committee of the National People’s Congress 2011). In addition, data regarding individual monitoring is not only an important basis for implementing the three principles of radiation protection (justification, optimization, and dose limitation) but also a necessary part of the occupational health surveillance of radiation workers (ICRP 1990; Sun et al. 2014). Therefore, the Chinese Registry of Radiation Workers (CRRW) (Wang et al. 2016) was set up with the support of the IAEA and officially released by the Ministry of Health in 2009, so as to collect and analyze individual external dose data nationwide. In this work, trends in and analysis of the effective dose distribution from occupational exposure to medical practices in China (2010–2016) was the focus and is presented for the first time.

MATERIALS AND METHODS

The materials in this work are based on relevant information and data on personal dose monitoring for occupational external exposure of medical radiation workers collected through CRRW from roughly 220 individual monitoring service providers who were required to upload relevant data by a
notification issued in 2009 by the China Ministry of Health (Yu et al. 2010).

Thermoluminescent dosimeters, required by China statute (Ministry of Health 2002), were applied to most monitored individuals. The personal dose equivalent $H_p(d)$ recommended by the International Commission on Radiation Units and Measurements (ICRU) was applied, where a tissue depth $d = 10$ mm was selected to evaluate the effective dose from occupational exposure (ICRU 1993). In cases where the measured dose was below the minimum detectable level (MDL), the individual dose for radiation workers was reported as half of the MDL.

Evaluation of the dose distribution for each occupational group was carried out using quantities recommended by the International Commission on Radiological Protection (ICRP 2007) based on the effective dose. Recommended quantities include average annual effective dose, annual collective effective dose, individual dose distribution ratio, and collective dose distribution ratio (UNSCEAR 2000). The occupational groups are classified into diagnostic radiology, dental radiology, nuclear medicine, radiotherapy, interventional radiology, and others with applicable characteristics.

The collective effective dose is defined as the sum of the effective dose for the total number of radiation workers, by the following equation (UNSCEAR 2000):

$$S = \sum_{i=1}^{N} E_i$$

where $S$ represents the collective effective dose, $E_i$ is the effective dose, and $N$ is the total number of radiation workers.

The number distribution ratio $NR_E$ and the annual collective dose distribution ratio $SR_E$ were determined by the following equations:

$$NR_E = \frac{N(>E)}{N}$$

$$SR_E = \frac{S(>E)}{S}$$

where $N(>E)$ is the total number of workers who received annual effective doses exceeding $E$ mSv, $N$ is the number of workers monitored, and $S(>E)$ is the annual collective effective dose to workers who received annual effective doses exceeding $E$ mSv. $E$ is taken as 1, 5, 10, and 15 mSv, respectively. For example, $NR_E$ and $SR_E$ refer to $E = 5$ mSv.

Data related to the personal dose monitoring for occupational external exposure of medical radiation workers from CRRW was exported to a Microsoft Access database (Microsoft Corp., Redmond, Washington, US), and then the data was collated and statistically analyzed using Stata13.0 (StataCorp 2013). With respect to statistical test rules, $P < 0.05$ was considered statistically significant.

RESULTS AND DISCUSSION

Occupational composition of medical radiation workers in 2016

As of 2016, external exposure dose monitoring data and other relevant information for a total of 211,613 radiation workers was collected by CRRW, covering 85% of total medical radiation workers in the whole country. Fig. 1 shows the composition of occupational categories for medical radiation workers in China in 2016.

Diagnostic radiological workers are the largest category at 70% of the total amount. Interventional radiology and radiotherapy rank second and third, with 12% and 8%, respectively. The other three occupational exposure categories represent 10% of total workers, with the smallest percentage being engaged in dental radiology.

Trends in occupational exposure from medical practices

The number of medical radiation workers who have been registered by CRRW has consistently increased over the 7 y study starting from 2010. In 2016, there were 211,613 such workers compared with 83,895 in 2010—an increase of 152%.

As seen in Fig. 2, the average annual effective dose to medical radiation workers shows a steady descending trend for the consecutive 7 y from 2010 to 2016. The same trend is seen for the occupational categories of both interventional radiology and diagnostic radiology. According to the linear regression, the annual average descending rate for effective dose is 4.2%, 4.18%, and 7.7% for total, diagnostic radiology, and interventional radiology, respectively (with an $R^2$ value greater than 0.95). In 2016, the average annual effective dose to all medical radiation workers was 0.35 mSv, which is considerably lower than the value of 1.2 mSv for 1996–2000 in China (Wu et al. 2005) and a reduction of

Fig. 1. Composition of the occupational categories of medical radiation workers collected by CRRW in 2016 in China.
46% compared to 2010. This reduction is also seen in each of the six occupational categories in medical practices, with decreases of 52%, 47%, 46%, 34%, 69%, and 31% for interventional radiology, nuclear medicine, diagnostic radiology, radiotherapy, dental radiology, and the others, respectively.

The average annual effective dose to all medical radiation workers in 2016 in China is a little lower than the world average level of 0.48 mSv in 2000–2002, according to the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 2008 report (UNSCEAR 2010). For comparison purposes with some national data, the average annual effective dose in China was roughly half of the dose in Ghana in 2000–2009 (0.69 mSv) (Hasford et al. 2011) and at the same level as Ireland in 2001–2005 (0.32 mSv) (Colgan et al. 2007). The average annual effective dose for interventional radiology workers was 0.54 and 0.43 mSv in 2015 and 2016, respectively, comparable with the average values in Iran in 2014 (Fereidoun et al. 2018).

### Distribution of occupational exposure from medical practices in 2016

Monitoring data for occupational exposure of radiation workers in medical practices, such as the number of workers, collective effective dose, and $S_R$ as well as $N_R$, in 2016 are presented in Table 1. More than 94.5% of radiation workers in medical practices in China received an annual dose less than the public dose limit (1 mSv) in 2016.

The collective effective dose received by 211,613 radiation workers in medical practices was 73,641.3 person mSv in 2016. Both the number of radiation workers and the collective effective dose for the diagnostic radiology category ranked in first place among the six occupational categories, resulting in its prominent contribution to exposures from all medical applications of radiation. The smallest number of radiation workers in dental radiology had the lowest collective effective dose, which is 1,315.3 person mSv for 4,783 workers. Although the number of workers in nuclear medicine is comparable with dental radiology (5,552 vs. 4,783), the collective effective dose received by nuclear medicine workers is much greater than that received by dental radiology workers (2,320.7 person mSv vs. 1,315.3 person mSv). This clearly suggests that radiation workers in nuclear medicine are occupationally exposed to more radiation than those in dental radiology.

The analysis of variance carried out on individual monitoring data showed that there was a statistically significant difference ($P < 0.001$) in the average annual effective dose for each occupational category of medical practice. These findings are consistent with the classification of occupational categories applied in China.

The Bonferroni method (Cabin and Mitchell 2000) was applied to compare the average effective annual dose for the six occupational categories, and it was found that the average

### Table 1. The distribution of occupational exposure from medical practices in China in 2016.

<table>
<thead>
<tr>
<th>-</th>
<th>-</th>
<th>Interventional radiology</th>
<th>Nuclear medicine</th>
<th>Diagnostic radiology</th>
<th>Radiotherapy</th>
<th>Dental radiology</th>
<th>Others</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of workers</td>
<td>-</td>
<td>25,804</td>
<td>5,552</td>
<td>14,783</td>
<td>16,509</td>
<td>4,783</td>
<td>11,127</td>
<td>211,613</td>
</tr>
<tr>
<td>Collective effective dose (person mSv)</td>
<td>-</td>
<td>11,069.9</td>
<td>2,320.7</td>
<td>50,264.9</td>
<td>4,771.1</td>
<td>1,315.3</td>
<td>3,916.7</td>
<td>7,3641.3</td>
</tr>
<tr>
<td>$N_R$ value (number distribution ratio)</td>
<td>$N_R_1$</td>
<td>0.077</td>
<td>0.085</td>
<td>0.054</td>
<td>0.038</td>
<td>0.035</td>
<td>0.04</td>
<td>0.055</td>
</tr>
<tr>
<td></td>
<td>$N_R_3$</td>
<td>0.014</td>
<td>0.006</td>
<td>0.004</td>
<td>0.002</td>
<td>0.001</td>
<td>0.008</td>
<td>0.005</td>
</tr>
<tr>
<td></td>
<td>$N_R_{10}$</td>
<td>0.004</td>
<td>0.001</td>
<td>0.002</td>
<td>0.001</td>
<td>0</td>
<td>0.003</td>
<td>0.002</td>
</tr>
<tr>
<td></td>
<td>$N_R_{15}$</td>
<td>0.002</td>
<td>0</td>
<td>0.001</td>
<td>0.001</td>
<td>0</td>
<td>0.002</td>
<td>0.001</td>
</tr>
<tr>
<td>$S_R$ value (collective effective dose distribution ratio)</td>
<td>$S_R_1$</td>
<td>0.575</td>
<td>0.432</td>
<td>0.398</td>
<td>0.335</td>
<td>0.198</td>
<td>0.479</td>
<td>0.422</td>
</tr>
<tr>
<td></td>
<td>$S_R_3$</td>
<td>0.298</td>
<td>0.11</td>
<td>0.155</td>
<td>0.148</td>
<td>0.017</td>
<td>0.302</td>
<td>0.18</td>
</tr>
<tr>
<td></td>
<td>$S_R_{10}$</td>
<td>0.203</td>
<td>0.036</td>
<td>0.109</td>
<td>0.121</td>
<td>0</td>
<td>0.215</td>
<td>0.126</td>
</tr>
<tr>
<td></td>
<td>$S_R_{15}$</td>
<td>0.141</td>
<td>0.022</td>
<td>0.089</td>
<td>0.105</td>
<td>0</td>
<td>0.186</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Figure 2. Curve of average annual effective dose (mSv) for different occupational categories in medical practices (2010–16) in China.
annual effective dose to nuclear medicine and interventional radiology workers was statistically significantly higher than the other four occupational categories ($P < 0.05$). In addition, the number of workers with individual doses greater than 1 mSv $y^{-1}$ in these two occupational categories was almost 2 times greater than for the other four categories ($NR_3 = 0.085$ and $0.077$ vs. $NR_1 = 0.054$, $0.035$, $0.038$, and $0.04$). This finding is in accordance with the conclusion that occupational exposures of interventional radiology and nuclear medicine workers are higher than exposures of others (IAEA 2006; Motevalli and Borhanazad 2015).

Nuclear medicine involves the direct use of unsealed radioactive sources where workers are more likely exposed to radiation during close-range operations such as preparation and injections of radiopharmaceuticals (Yao et al. 2012). Nuclear medicine patients who have been injected with radiopharmaceuticals also cause some exposure to workers (Huang et al. 2008), which may lead to higher occupational exposure. Therefore, it is necessary to strengthen the professional skills and radiation protection training of nuclear medicine workers for radionuclide preparation, dispensing, and injections. The facts that the annual effective dose to interventional radiology staff is relatively high and that the proportion of those receiving more than 5 mSv is relatively high ($NR_3 = 0.014$) may be ascribed to factors such as prolonged exposure to scattered beam radiation, inadequate protective measures, etc. So strengthening professional skills and radiation protection training is also necessary in this category of radiation workers. It would also be helpful to improve operating proficiency and protection awareness to try to shorten operating time (through a rotation system, if necessary) and strictly ensure the use of related protective equipment to control individual dose to a level as low as reasonably achievable.

CONCLUSION

The annual effective dose to radiation workers in medical practices in China declined consistently from 2010 to 2016, in particular for the occupational categories of interventional radiology and diagnostic radiology. The average occupational exposures of workers in six different medical categories were well below the recommended occupational dose limit for radiation workers (20 mSv) (ICRP 2007). These observations could be a result of improvements in radiological protection for radiation workers engaged in medical practices in China.

However, it is still necessary to control the workplace and manage radiation workers to avoid unnecessary radiation exposures, in particular for workers engaged in nuclear medicine and interventional radiology activities, who were found to receive more dose than radiation workers in other medical occupational categories. Although this study covers whole-body exposure of occupational radiation workers, research on occupational exposure of the eye lens of interventional radiology workers still needs to be accomplished. It is also necessary to take into account that internal dosimetry must be included in occupational dose monitoring programs for nuclear medicine workers.

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