Application of Cancer-free Survival Function for Estimating Lifetime Attributable Risk of Radiation-induced Thyroid Cancer Incidence of Korean Population

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1. Introduction

Lifetime cancer risk due to radiation is mainly estimated in terms of Lifetime Attributable Risk (LAR) which is calculated with statistical data of target population such as population distribution, baseline cancer incidence and mortality rates, and the probability of survival (i.e. survival function) [1]. In the health risk assessment of Fukushima nuclear accident performed by World Health Organization (WHO), a group of experts primarily applied cancer-free survival function, which meant the probability of being alive without any cancer incidence chances before, to calculating LAR of cancer incidence because the occurrence of cancer did not result in deaths due to high cure rate [2,3].

It is agreed that the cancer-free survival is theoretically appropriate in estimating lifetime risk of cancer incidence induced by radiation in this study. Since thyroid cancer having high occurrence and cure rates results in in low death rate in Korea, it is expected that there are considerable differences between results applying overall and cancer-free survival functions. Therefore, we performed estimation of LAR of thyroid cancer incidence induced by 0.1 Gy using overall and cancer-free survival, respectively. In this calculation, the Preston et al. (2007) model was used for estimating excess thyroid cancer incidence risk from radiation , as it was considered to be adopted for the level 3 Probabilistic Safety Assessment (PSA) in Korea.

2. Methods

2.1. Thyroid Cancer Risk Model

The Preston et al. (2007) model [4] was derived from the data of Japanese atomic bomb survivors and the formula for Excess Relative Risk (ERR) and Excess Absolute Risk (EAR) are as follows:

$ERR(D,e,a,g)$ [per Gy]

$$= \beta_g\, D \times exp\left[\left(\frac{e-30}{10}\right) \times\ ln(0.69)\right] \times \left(\frac{a}{70}\right)^{-1.5}$$

$EAR(D,e,a,g)$ [per 10^4 person·year·Gy]

$$= \beta_g\, D \times exp\left[\left(\frac{e-30}{10}\right) \times\ ln(0.54)\right] \times \left(\frac{a}{70}\right)^{-0.6}$$

where D, g, e, and a are dose (Gy), gender (i.e. male or female), age at exposure and attained age, respectively. And, β_{male} and β_{female} are applied as 0.49 and 0.65 for ERR and 0.5 and 1.9 for EAR, respectively.

The excess risk of thyroid cancer is written as $M(D,e,a,g)$ and calculated as $ERR(D,e,a,g) \times \lambda_i(a,g) \times \frac{\lambda_m(a,g)}{\lambda_i(a,g)}$ and $EAR(D,e,a,g) \times \frac{\lambda_m(a,g)}{\lambda_i(a,g)}$ in multiplicative and additive models, respectively. Here, $\lambda_i(a,g)$ is baseline cancer incidence rate and $\lambda_m(a,g)$ is baseline cancer mortality rate. $M(D,e,a,g)$ is adjusted by the arithmetic mean of $M(D,e,a,g)$ from multiplicative and additive models.

2.2. Lifetime Risk Estimation

LAR means a total risk summed from age at exposure to life expectancy. In this calculation, the life expectancy was assumed to be 100 years, and the survival function was expressed as $S(a,g)$.

$$LAR(D,e,g) = \int_{e+5}^{100} M(D,e,a,g) \times \frac{S(a,g)}{S(e,g)}\, da$$

For comparing lifetime risk between radiation exposed and unexposed situations, Lifetime Baseline Risk (LBR) was also calculated as a lifetime cancer risk without radiation exposure, which was totally accumulated baseline cancer incidence or mortality rate from matched age of age at exposure to 100 years. Additionally, Lifetime Fractional Risk (LFR) is defined for reflecting the relative increase over the whole lifespan.

$$LBR(g) = \int_{a}^{100} Baseline\ rate(a,g) \times S(a,g)\, da$$

$$LFR = \frac{LAR}{LBR}$$

As LAR and LBR are age-specific values, these were averaged with population distribution of Korea for estimating population-averaged LAR and LBR. For Korean population, the statistical data, population distribution, baseline cancer incidence and mortality data, and survival function were obtained from the latest data available in the Korean statistical information service (KOSIS) [5]. Moreover, there was no adjustment for low dose exposure.

2.3. Overall and Cancer-free Survival Function

Overall survival function, *S(a)*, is the probability of being alive at a (age) and calculated by the probability of death. And, cancer-free survival function, $S_{ad}(a)$, is the adjusted probability of being alive without cancer incidence at a (age), which is derived by the probabilities of death and all-cancer incidence. Figure 1 presents the comparison result of overall and cancer-free survival for Korean population. From this figure, it was found that there were significant differences in ages ranging from 40 to 80 due to high occurrence rate of cancers.

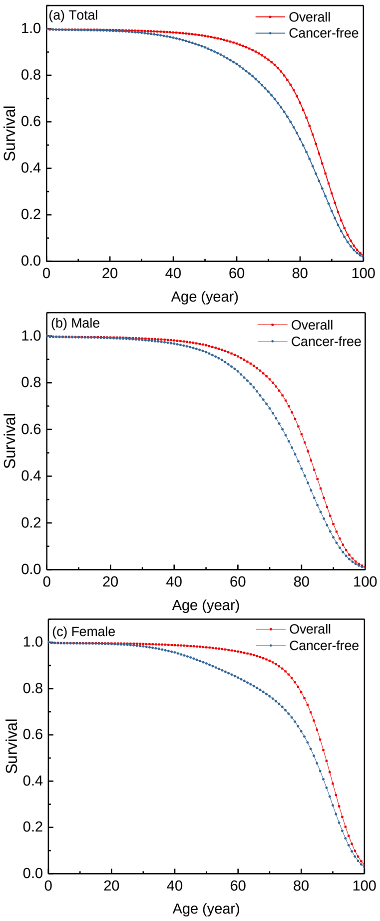

Fig. 1. Curves of the overall and cancer-free survival as a function of age for Korean population in 2016

3. Results

For the LAR calculation for Korean population, the exposure scenario of 0.1 Gy was applied on the basis of the statistical data in 2016. Figure 2 shows the population-averaged LAR and LBR of thyroid cancer incidence when using overall or cancer-free survival.

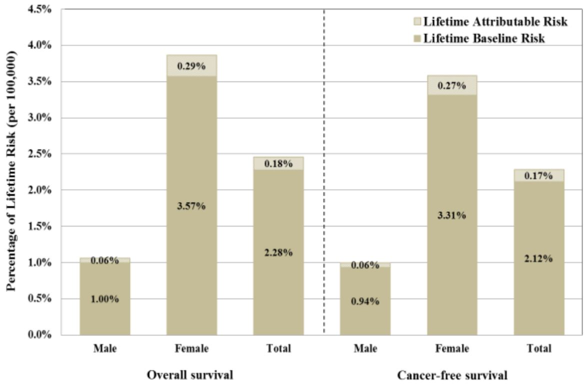

Fig. 2. The percentage of lifetime risk from 0.1 Gy exposure applying overall or cancer-free survival for Korean population in 2016

LARs for male were both 0.06% and LARs for female and total population applying cancer-free survival were slightly lower than those applying overall survival. Moreover, as LBRs were further reduced because of cancer-free survival, the total lifetime risks (i.e. sum of LAR and LBR) of thyroid cancer incidence were also decreased.

Table 1 tabulates the calculation result of LFR from 0.1 Gy exposure when using overall or cancer-free survival.

Table. 1. The lifetime fractional risk from 0.1 Gy exposure applying overall or cancer-free survival for Korean population in 2016

Thyroid cancer	**LFR (%)**	
	Overall survival	**Cancer-free survival**
Male	6.49	6.58
Female	8.24	8.28
Total	7.85	7.88

As shown in Table 1, in contrast with the decrease of LARs and LBRs, LFRs were larger when applying cancer-free survival. However, this was probably caused by the change of the reference value (i.e. LBR).

4. Conclusion

WHO firstly applied cancer-free survival instead of overall survival to estimating of excess cancer incidence from radiation. In this study, similar to the health risk assessment by WHO, LARs of thyroid cancer incidence were estimated applying overall and cancer-free survival to comparing differences due to the survival function. As a result, it was found that using overall survival resulted in overestimation of LAR even though the differences were small.

Accordingly, it is necessary to apply cancer-free survival to the risk assessment of cancer incidence along with using overall survival for estimation of cancer mortality risk.

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