Effect of Population Distribution on Estimating Lifetime Attributable Risk of Thyroid Cancer Incidence for Korean population

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1. Introduction

As a part of level 3 Probabilistic Safety Analysis (PSA), it is necessary to estimate lifetime cancer risk due to radiation exposure. Based on the Biological Effects of Ionizing Radiation (BEIR) VII report [1], Lifetime Attributable Risk (LAR) can be calculated using population distribution, baseline cancer incidence and mortality rates, and survival function of target population.

Regarding the population distribution, two (2) types of data are available in the Korean statistical database (KOSIS) [2]: general and stationary distributions. The former indicates a real-time data describing the present status, and is primarily used for estimating LARs despite limitation of its variability. And, the latter is regarded as a hypothetical value, and assumes that there is no population growth and migration.

In this study, for comparing the effect of population distribution on cancer incidence risk induced by radiation exposure, we performed estimation for LARs of thyroid cancer in accordance with the general and stationary distribution, respectively. The thyroid cancer is selected as the representative case since the high incidence rate in Korea results in the obvious difference. Among the widely-used thyroid cancer risk models, three (3) kinds of models were applied to this study.

2. Methods

2.1 Thyroid cancer risk models

As mentioned above, LARs of thyroid cancer were estimated using Biological Effects of Ionizing Radiation (BEIR) VII [1], U.S. Environmental Protection Agency (EPA) (2011) [3], and Preston et al. (2007) [4], respectively. More detailed description for each model is as follows.

2.1.1 BEIR VII

In the BEIR VII model, Excess Relative Risk (ERR) of thyroid cancer is estimated as the formula below:

$$ERR_{Male} = 0.53D \times exp[-0.083(e-30)]$$
$$ERR_{Female} = 1.05D \times exp[-0.083(e-30)]$$

where D is exposure dose and e is exposure age.

2.1.2 U.S. EPA (2011)

Thyroid cancer risk model in the U.S. EPA (2011) is expressed as follows:

$$ERR_{Male} = 10.7D \times A(e) \times T(t)$$

where D is exposure dose, e is age at exposure , and t is time since exposure. Table 1 summarizes functions (i.e. A(e) and T(t)), which are included in the formula above.

Table 1. Functions incorporated into thyroid cancer risk model in EPA (2011)

Function	Range	Value
A(*e*)	e < 5	1.0
	5 ≤ e ≤ 9	0.6
	10 ≤ e ≤ 14	0.2
	15 ≤ e	0.2 · exp[-0.083(e-15)]
T(*t*)	t < 5	0
	5 ≤ t ≤ 14	1.15
	15 ≤ t ≤ 19	1.9
	20 ≤ t ≤ 24	1.2
	26 ≤ t ≤ 29	1.6
	30 ≤ t	0.47

2.1.3 Preston et al. (2007)

In the cancer risk model developed by Preston et al. (2007), ERR and Excess Absolute Risk (EAR) is estimated as the formula below:

$$ERR(D,e,a,g) \text{ [per Gy] or}$$
$$EAR(D,e,a,g) \text{ [per } 10^4 \text{ person·year·Gy]}$$
$$= \beta_g D \times exp\left[\left(\frac{e-30}{10}\right) \times ln(1+\gamma)\right] \times \left(\frac{a}{70}\right)^{\eta}$$

where D is exposure dose, e is exposure age, and a is attained age. Values of coefficients included in this formula are tabulated in Table 2.

Table 2. Values of coefficients for thyroid cancer risk model developed by Preston et al. (2007)

	β_M*	β_F*	γ	η
ERR	0.49	0.65	-0.31	-1.5
EAR	0.5	1.9	-0.46	0.6

* M: male, F: female.

2.2 Lifetime risk estimation

As provided in BEIR VII, LAR for target population can be calculated by the formula below:

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

$$M_{EAR}(D,e,a,g) = EAR(D,e,a,g)$$

$$M_{ERR}(D,e,a,g) = ERR(D,e,a,g) \times \lambda_i(a,g)$$

$$LAR_{pop}(D) = \frac{1}{N_{total}} \times \int_{0}^{100-L} N(e,g) \times LAR(D,e,g)\, de$$

where g (i.e. male or female) is gender, L is latency period (= 5 year) of thyroid cancer, $\lambda_i(a,g)$ is the baseline cancer incidence for age a and gender g, S(e) is survival function for age at e, and $N(e,g)$ is the number of person with age of e and gender g.

In addition, Lifetime Baseline Risk (LBR) was calculated for providing risk without radiation exposure. LBR for a certain population can be calculated by below formula:

$$LBR(e,g) = \int_{e+L}^{100} \lambda_i(a,g) \times \frac{S(a)}{S(e)} da$$

$$LBR_{pop} = \frac{1}{N_{total}} \times \int_{0}^{100} N(e,g) \times LBR(e,g)\, de$$

In this study, two (2) types of population distribution were used for identifying the effect of distribution applied to the estimation of LAR. All of the latest data (i.e. as of 2016) on Korean population used for estimation were obtained from KOSIS [2].

3. Results

For Korean population, two (2) types of distribution are schematized in Figure 1. In case of general distribution, the number of younger person (about 0 to 10 years old) is smaller than older person (about 20 to 50 years old). It is expected that the number of older person in the future will be decreased to the level of number of younger person of the present state. As a result, the overall demographics will change over time. On the other hand, in the stationary distribution, the population would be consistent even when time goes.

To identify the effect of population distribution, LARs were individually calculated based on each type of distribution. The results of LAR_{pop} for thyroid cancer incidence when exposed to radiation of 0.1 Gy are summarized in Table 3.

LARs of thyroid cancer incidence applying stationary distribution were larger than those of general distribution. Since LARs of younger person were larger than those of older person, estimation with stationary distribution resulted in higher LARs.

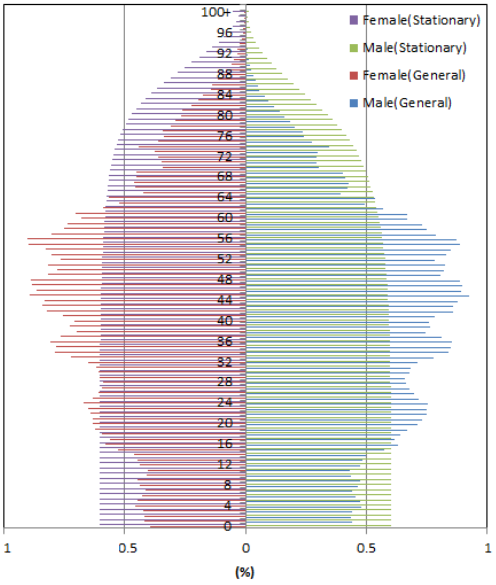

Fig 1. Graphs for general and stationary population distribution in Korea

Table 3. The results of LAR_{pop} for 0.1 Gy exposure scenario with two population distributions

Population Distribution	Gender	LAR (per 100,000)			LBR (per 100,000)
		BEIR VII*	US. EPA (2011)*	Preston et al. (2007)*	
General	Male	79	85	43	998
	Female	555	296	196	3570
	Average	316	190	119	2280
Stationary	Male	96	101	48	953
	Female	676	352	221	3380
	Average	397	231	138	2210

* For low dose exposure scenario (exposure dose is lower than 0.1 Gy), DDREF (Dose and Dose Rate Effectiveness Factor) of 1.5 is applied.

Consequently, the type of population distribution data applied to calculation should be determined according to the purpose of estimation. If LAR estimation for present distribution is needed, the general population distribution would be proper. On the other hand, if it is required to exclude changes in population distribution, the stationary population distribution would be more appropriate to apply.

4. Conclusion

The effect of general and stationary distributions of Korean population on LAR estimates was evaluated in this study. Population data applied probably would affect LARs differently, especially due to a portion of younger age person.

Even though LAR estimation with general distribution can reflect real population structure of Korea, the distribution is so unstable that the overall appearance will be changed in future, and estimates will be different correspondingly. On the other hand, as the stationary population distribution seems to be more

stable than general distribution, variability of LAR resulted from temporal changes of general population distribution could be avoided in case of using this distribution. In conclusion, it is suggested to use proper distribution depending on the purpose of estimation.

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