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Childhood Arsenic Exposure and Health Risk Assessment from Rice Cultivated Near the Mining Areas in Korea

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ABSTRACT – Domestic studies for identification of causality between children exposure to toxic chemicals, such as arsenic (As) and resulted hazardous effects were not implemented. This study was conducted to probabilistically estimate dietary As intake and health risk assessment for young children and all age-specific populations from the consumption of As-contaminated rice of Korea. Arsenic intakes for young children (1 to 6 years old) from As-contaminated rice were higher than other age-specific groups, based on a dose-per-body weight basis. Based on the current EPA cancer slope factor for As, estimated cancer risks (to the skin cancer) associated with dietary intake of As-contaminated rice for 1 to 2 years old group and 3 to years old group are 1.76 per 10,000 and 3.16 per 10,000, respectively, at the 50th percentile. Based on possible reference levels (0.005 mg/kg/day) for children, mean and 95th percentile value of HQ from rice for young children are very below 1.0, which is a regulatory limit of non-carcinogenic risks for human.

Key words: arsenic, childhood, exposure, rice, risk assessment

Arsenic (As), classified as group A (human carcinogen) form IRIS, have shown statistically significant increment in skin cancer with oral exposure[1]. Dietary intake can be a significant source of exposure to As for most individuals. However, it is difficult to estimate the true extent of the impact of As in food on human health. Especially because health in childhood may be due to the long latency periods that may occur between As exposure and outcome, it is difficult to prove an association[2,3].

Currently, the Codex committee noted the clear understanding that the margin between the provisional tolerable weekly intake (PTWI) for As and intakes reported to have toxic effects in epidemiological studies was narrow and therefore was no longer appropriate, and the Committee withdrew the previous PTWI[4]. U.S. EPA also reported As intake for infants through diet may approach the Provisional Tolerable Daily Intake (PTDI)[5]. However, until recently, domestic studies for identification of causality between children exposure to chemicals, such as arsenic (As) and resulted hazardous effects have not been implemented[6]. Therefore, it is necessary to accurately estimate subchronic exposure and human health risk assessment of As for childhood in Korea.

On the one hand, because prevalence of non-cancer health effects for subchronic to chronic exposure is related to daily dose combined with length of exposure, a subchronic reference level should be higher than the chronic reference level for lifetime exposure. Therefore, EPA has evaluated and developed a subchronic reference level of As, 0.005 mg/kg/day, for short-term exposure (i.e., preferably 6 years or less), which is compared with 0.0003 mg/kg/day for long-term exposure (i.e., over 7 years)[7]. Therefore, a subchronic reference level should be used to accurately calculate non-carcinogenic risk of As for young children (1 to 6 years old).

This study was schemed to assess probabilistic health risks of As intake for young children (1 to 6 years old) and all age-specific populations from the consumption of rice, the primary dietary source in Korea. We used the rice cultivated near the mining areas in Korea to consider human risk assessment of a high-risk group in this probabilistic approach. There are still a few reports on inorganic As speciation data of rice cultivated in Korea. Therefore, in this study, we estimated dietary As intake and calculated the human health risk assessment, such as noncarcinogenic and cancer risk (to the skin cancer), for Korean young children (1 to 6 years old) and all age-specific populations, using the total As concentration data of rice cultivated near the mining areas of Korea in previous study.

Material and Methods

Exposure assessment

Using previous results for total As concentration data of

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Table 1. Summary of Monte Carlo parameter assumptions and inputs

Parameters	Distribution type	Assumption			Basis for selection
		Values		Reference	
As concentration of rice	Lognormal	Mean = 92.8 μg/kg 95th percentile = 303.4		8	(a)Using the As concentrations of rice as results analyzed in previous study (b)Values below limit of detection (LOD) was put as one half of LOD.
Ingestion rate of rice	Lognormal	1 to 2 years old	Mean = 73.3 g/day 95th percentile = 203.6	9	
		3 to 6 years old	Mean = 135.3 g/day 95th percentile = 289.6		
		7 to 12 years old	Mean = 176.8 g/day 95th percentile = 349.6		
		13 to 19 years old	Mean = 205.3 g/day 95th percentile = 450.9		
		20 to 29 years old	Mean = 212.4 g/day 95th percentile = 449.5		
		30 to 49 years old	Mean = 240.7 g/day 95th percentile = 479.9		
		50 to 64 years old	Mean = 258.6 g/day 95th percentile = 500.7		
		≥ 65 years old	Mean = 230.7 g/day 95th percentile = 426.5		
Bioavailability	Point	0.33		11	(a) As gut bioavailability, particularly for inorganic As, from rice grain for swine was is 33 ± 3%
Body weight	Point	1 to 2 years old	Mean = 12.7 kg	11	
		3 to 6 years old	Mean = 19.2 kg		
		7 to 12 years old	Mean = 37.6 kg		
		13 to 19 years old	Mean = 59.9 kg		
		20 to 29 years old	Mean = 61.4 kg		
		30 to 49 years old	Mean = 63.5 kg		
		50 to 64 years old	Mean = 62.4 kg		
		≥ 65 years old	Mean = 56.5 kg		
CSF	Point	1.5		13	
RfD	Point	1 to 6 years old	0.005 mg/kg/day	12	(a)Subchronic exposure for young children
	Point	Over 7 years old	0.0003 mg/kg/day	13	(a)Chronic exposure, near lifetime, for over 7 years

OCSF = Cancer Slope Factor
RfD = Reference Dose

300 rice samples cultivated near the mining areas in Korea, we calculated the dietary intake of As for young children (1 to 6 years old) and age-specific population in Korea. Mean total As concentrations of rice samples analyzed in previous study was 92.8 μg/kg (303.4 μg/kg at 95th percentile)[8] and lognormal distribution model was set for probabilistic estimation by Crystal ball® program (Table 1). Dietary intakes of rice for Korean young children and other age-specific populations were based on Korea Health and Nutrition Examination Survey[9].

To estimate As exposure for young children and other age-specific populations from rice, the following basic exposure algorithm was developed.

$$ADD = \frac{AC \times IR \times BF}{BW} \quad (1)$$

where ADD is arsenic daily dose from *via* ingestion of rice, AC is arsenic concentration in rice (μg/kg), IR is ingestion rate of rice (kg/day), BF is relative bioavailability factor for As[10], considering the ingestion of cooked rice, BW is body weight (kg)[11]. The input assumptions of As are summarized in Table 1.

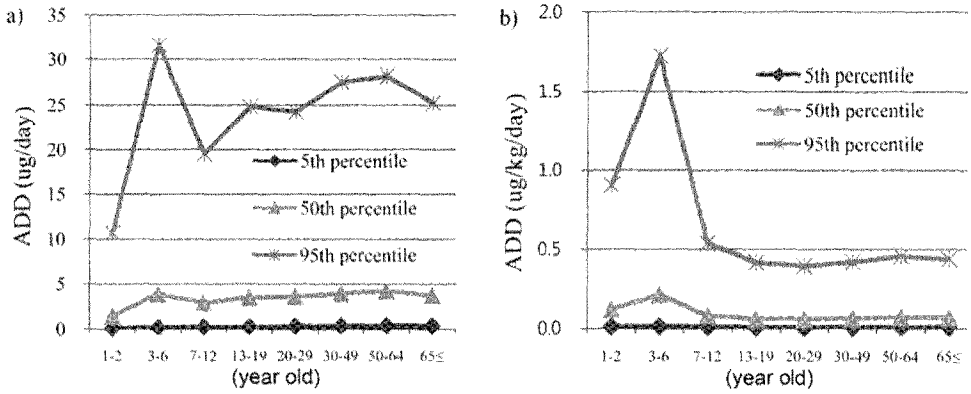

Fig. 1. Results of probabilistic analysis of ADD (arsenic daily dose) values, based on a μg/day unit (a) and on a μg/kg/day unit (b) from the consumption of rice cultivated near the mining areas of Korea.

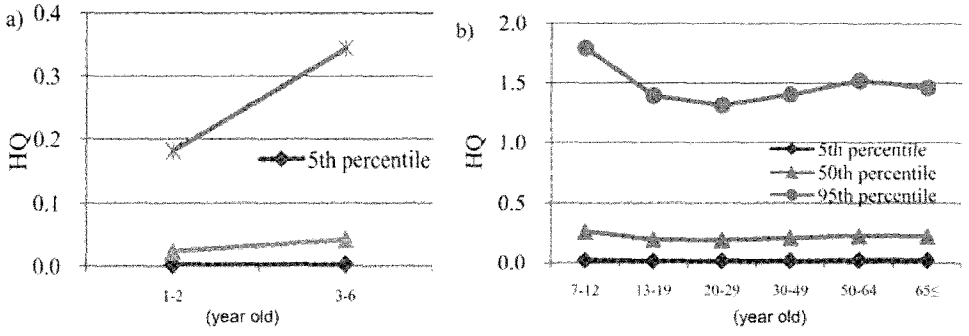

Fig. 2. Results of probabilistic analysis of arsenic HQ (hazard quotient), assessed for young children (1 to 6 years old) by the higher reference level (0.005 mg/kg/day) (a) and for other age groups (over 7 years old) by the lower reference lever (0.0003 mg/kg/day) (b) from the consumption of rice cultivated near the mining areas of Korea.

Health risk assessment

The noncarcinogenic hazard quotient (HQ) and cancer risk (CR) from rice were calculated using the equations.

$$CR = ADD \times CSF \quad (2)$$

$$HQ = ADD/RfD \quad (3)$$

where SCF was the cancer slope factor and RfD was the reference dose (mg/kg/day). The parameters used in calculating the HQs and CRs were based on standard EPA assumed values (Table 1). The higher reference level (0.005 mg/kg/day) could be applied to subchronic exposures for young children (i.e., less than 6 years)[12] and the lower reference level (0.0003 mg/kg/day) to chronic exposures for other age-specific population (i.e., over 6 years)[13].

Results and Discussion

Exposure assessment

The ADD values for young children and other age-specific population are shown in Fig. 1. The ADD on a μg/day basis shown at Fig. 1 a means As daily intake from the consumption of rice, without considering the bodyweight for each group. The ADD values, on a μg/day basis, of all age-specific populations ranged from 1.41 μg/day to 4.16 μg/day for 50th percentile (mean) estimates. 1 to 2 years old population had the lowest ADD value based on a μg/day. However, the ADD, based on a μg/day, of 3 to 6 years old group was higher than those of other age-specific groups (Fig. 1(a)). The older population gets, the more the ADD values on a μg/day basis increase for all groups above young childhood, but except above 65 years old group. In other words, there is little difference between young children and other age-specific group from As daily intake from consumption of rice, when considering the bodyweight for each group.

However, these results on a μg/day basis didn't show similarly at the results of ADD on a μg/kg/day basis. The ADD, on a μg/kg/day basis, of all age-specific populations ranged from 0.06 μg/kg/day to 0.21 μg/kg/day for 50 percentile estimates (Fig. 1(b)). Median of 3 to 6 years old group of dietary As intake estimate for rice was 0.21 μg/kg/day with a range of 0.01 to 1.72 μg/kg/day for the 5th and 95th percentiles, respectively, which is the highest value among other age-specific group in Korea. And also, median of ADD, on a μg/kg/day basis, of 1 to 2 years old group was 0.12 μg/

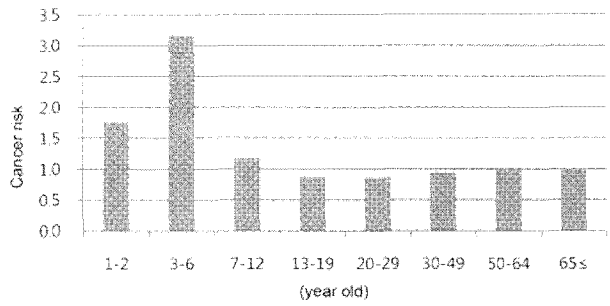

Fig. 3. Arsenic cancer risk, expressed as chance per 10,000, at the 50 percentiles for age-specific groups from the consumption of rice cultivated near the mining areas of Korea.

kg/day, showing the second highest value. Whereas, median of ADDs for populations over 7 years old were ranged from 0.06 μg/kg/day to 0.08 μg/kg/day. That is, As daily intakes for young children (1 to 6 years old) were lower overall than Korean adolescents from 13 to 19 and adults over 20 years old, if considered As intake just throughout a consumption of rice.

In previous study[8], the ADD value for general population in Korea was 0.07 μg/kg/day, ranging from 0.01 μg/kg/day for the 5th percentile to 0.47 μg/kg/day for the 95th percentile estimate. As daily intake estimated in this paper for all groups who are over 13 years old were near the previous values of As intakes for general population from same rice, which indicate that there is no difference for dietary As intake, based on body weight basis, among adolescents, adults and senescent. However, this study showed that young children who are 1 to 6 years old are susceptible to more As exposure throughout a consumption of rice than other age-specific populations above 12 years old. These results may be due to the application of bodyweight for each group in this estimation. Zaldivar also reported the similar presumption with this paper, interpreting that older age groups receive more cumulative exposure over their lifetime, but younger children receive a higher daily dose of As per-unit-body-weight than older age groups at the same As concentration levels because of their lower bodyweight[14].

Health risk assessment

Fig. 2 shows HQ values that indicate the non-carcinogenic risk of As by consumption just the rice cultivated near the mining areas in Korea. HQ values estimated in this study were based on possible reference levels, which are 0.005 mg/kg/day for subchronic exposure of young children (less than 6 years old) and 0.0003 mg/kg/day for chronic exposure over 7 years[12].

HQs of all groups above 7 years old ranged from 0.19 to 0.26 for the 50 percentile estimates, which were below 1.0, a regulatory limit of non-carcinogenic risks for human by EPA (Fig. 2(b))[15]. In addition, median and even the 95 percentile estimates of HQs for young children (both 1 to 2 years old and 3 to 6 years old group) were very below 1.0, indicating a low risk for childhood heath, if considering that all dietary intake consists of the only consumption of rice cultivated near the mining areas of Korea.

The types of effects considered for subchronic reference criteria do not include cancer. Some evidence indicates that healthy dysfunction such as skin signs is a sensitive indicator of later developing cancer in individuals and populations of subsequent health risk[16,17]. The risk of cancer is closely related with HQ value, non-carcinogenic risks. However, there are the few studies available on shorter-term exposure, mostly of chronic exposure for adults.

In this assessment, CR values for skin cancers were generated using the standard default value of 1.5 mg/kg/day, which is listed currently in the USEPA's IRIS database[13]. Fig. 3 showed median values of CR for age-specific groups, based on chance per 10,000. Median CRs for all age-specific populations by consumption of rice cultivated near the mining areas in Korea ranged from 0.86×10^{-4} to 3.16×10^{-4}. Especially, CRs of young children such as 1 to 2 years and 3 to 6 years age group were higher than other age-specific groups, showing 1.76×10^{-4} and 3.16×10^{-4} for the 50 percentiles, respectively.

In other words, risks of young children associated with the consumption of rice cultivated near the mining areas of Korea are slightly above EPA's upper target risk goal of 1 in 10,000[15], based on the current As slope factor of 1.5 per mg/kg/day. Tsuji *et al.* also reported similar results with this estimation that symptoms of chronic arsenic poisoning may be more severe in children (ages 0-15 years) compared to adults[18]. However, additional examination or specific health effects of As in young children (ages 6 years and younger) is also needed to address uncertainties in health effects. In addition, development of health-protective reference levels and cancer slope factors by regulatory agencies makes it possible to induce more exact the health risk of As for young children.

요 약

우리나라 유아들이 비소에 노출된 경우의 인체위해성에 대한 상관관계 연구가 미비한 실정이다. 본 연구는 우리나라 광산인근 지역에서 생산된 백미의 섭취를 통한 비소의 노출을 유아기(1-6세)와 타 연령군으로 나누어 평가하고 해당 연령군의 인체위해성 평가를 확률적 접근법을 이용해 실시하였다. 우리나라 광산인근 지역에서 생산된 백미 섭취를 통한 유아기의 비소 노출량은 체중을 기준으로 했을 때 타 연령군에 비해 높게 나타났다. 피부암에 대한 초과발암위해의 경우 1-2세 군과 3-6세 군의 50% percentile 값이 각각 만명 당 1.76명과 3.16명으로 나타났다. 어린이와 같은 아만성기간 동안의 비소 노출에 대한 비발암 기준

참고치(0.005 mg/kg/day)를 적용한 결과 비발암위해도의 평균값 뿐 아니라 고섭취군을 나타내는 95% percentile 값 또한 규제수치인 1.0 이하로 나타났다.

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Reference

1. Integrated Risk Information System (IRIS), US EPA: Arsenic, Inorganic (1997) http://cfpub.epa.gov/ncea/iris/index.cfm?fuseaction =iris.showQuickView&substance_nmbr=0278.
2. World Health Organization (WHO): Toxicological evaluation of certain food additives and contaminants. WHO Food Additives Series, No. 24 (1989).
3. Yost, L.J., Tao, S.-H., Egan, S.K., Barraj, L.M., Smith, K.M., Tsuji, J.S., Lowney, Y.W., Schoof, R.A. and Rachman, N.J.: Estimation of dietary intake of inorganic arsenic in U.S. children. *Hum. Ecol. Risk Assess.* **10**, 473-483 (2004).
4. Joint FAO/WHO food standard programme codex committee on contaminants in foods: Matters of interest arising from FAO and WHO and from the 72th meeting of the Joint FAO/WHO expert committee on food additives (JECFA), 4th session, Izmir, Turkey (2010).
5. U.S. EPA: Development of arsenic speciation methodology for determining background exposure levels of inorganic arsenic in dietary samples and application to *in vitro* bioaccessibility studies (2009).
6. Lee, H.M. and Jung, K.H.:. Chemical risk factors for children's health and research strategy. *J. FD. Hyg. Safety* **23(3)**, 276-283 (2008).
7. U.S. EPA: Derivation of acute and subchronic oral reference doses for inorganic arsenic. U.S. Environmental Protection Agency Superfund Technical Support Center, National Center for Environmental Assessment, Cincinnati, OH, and U.S. EPA Region VIII, Denver, CO (2002).
8. Paik, M.K., Kim, W.I., Yoo, J.HI, Kim, J.K., Im, G.J. and Hong, M.K.: A probabilistic assessment of human health risk from arsenic-contaminated rice grown near the mining areas of Korea. *J. FD. Hyg. Safety*. In pressing .
9. KCDC: In-depth Analysis on the 3rd (2005) Korea Health and Nutrition Examination Survey -Nutrition survey- (2007).
10. Juhasz, A.L., Smith, E., Weber, J., Rees, M., Rofe, A., Kuchel, T., Sansom, L. and Naidu, R.: *In vivo* assessment of arsenic bioavailability in rice and its significance for human health risk assessment. *Environ. Health Persepct.* **114**, 1826-1831 (2006).
11. Korea Food and Drug Administration Agency(KFDA): Food Ingestion Factors for Dietary Exposure -: 2001 NHNS (2005).
12. Tsuji, J.S., Benson, R., Schoof, R.A. and Hook, G.C.: Response to additional support for derivation of an acute/subchronic reference level for arsenic. *Regul. Toxicol. Pharmacol.* **40**, 372 (2004).
13. Integrated risk information system (IRIS), U.S. EPA: record for arsenic (2007).
14. Zaldivar, R.: Ecological investigations on arsenic dietary intake and endemic chronic poisoning in man: Dose-response curve. *Zentrabl. Bakt. Hyg. I. Abt. Orig. B.* **164**, 481-484 (1977).
15. U.S. EPA: Exposure factors handbook (EPA/600/8-89/043), Environmental Protection Agency, Office of Research and Development, OH, USA (1989).
16. Tsuda T, Inoue T and Kojima M.: Market basket and duplicate portion estimation of dietary intakes of cadmium, mercury, arsenic, copper, manganese, and zinc by Japanese adults. *J AOAC Intl.* **78**, 1363-1368 (1995).
17. Tucker, S.B., Lamm, S.H., Zhendong, L., Zhao, H.X., Li, F.X. and Polkanov, M.: Relationship between consumption of arsenic contaminated well water and skin disorders in Huhhot, Inner Mongolia. University of Texas, Houston, Texas, and Inner Mongolia Cooperative Arsenic Project (2001).
18. Tsuji, J.S., Yost, L.J., Barraj, L.M., Scrafford, C.G. and Mink, P.J.: Use of background inorganic arsenic exposure to provide perspective on risk assessment results. *Reg. Toxicol. Pharmacol.* **48**, 59-63 (2007).