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Health Risk Assessment of Lead Ingestion Exposure by Particle Sizes in Crumb Rubber on Artificial Turf Considering Bioavailability

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Objectives: The purpose of this study was to assess the risk of ingestion exposure of lead by particle sizes of crumb rubber in artificial turf filling material with consideration of bioavailability.
Methods: This study estimated the ingestion exposure by particle sizes (more than 250 um or less than 250 um) focusing on recyclable ethylene propylene diene monomer crumb rubber being used as artificial turf filling. Analysis on crumb rubber was conducted using body ingestion exposure estimate method in which total content test method, acid extraction method and digestion extraction method are reflected. Bioavailability which is a calibrating factor was reflected in ingestion exposure estimate method and applied in exposure assessment and risk assessment. Two methods using acid extraction and digestion extraction concentration were compared and evaluated.
Results: As a result of the ingestion exposure of crumb rubber material, the average lead exposure amount to the digestion extraction result among crumb rubber was calculated to be 1.56×10^{-4} mg/kg-day for low grade elementary school students and 4.87×10^{-5} mg/kg-day for middle and high school students in 250 um or less particle size, and that to the acid extraction result was higher than the digestion extraction result. Results of digestion extraction and acid extraction showed that the hazard quotient was estimated by about over 2 times more in particle size of lower than 250 um than in higher than 250 um. There was a case of an elementary school student in which the hazard quotient exceeded 0.1.
Conclusions: Results of this study confirm that the exposure of lead ingestion and risk level increases as the particle size of crumb rubber gets smaller.

Key words: Artificial turf, Bioavailability, Crumb rubber, Exposure assessment, Lead

INTRODUCTION

Toxic substances contained inside of artificial turf, who's utility has recently been increasing, and its negative effect on children's health are on the rise as a social issue. In particular, for heavy metals, polycyclic aromatic hydrocarbon and, volatile organic compounds contained inside of artificial turf filling, there is a fear that ingestion exposure could happen through direct absorption of rubber powder or indirect flow into the human body when rubber-stained hands are moved to the mouth. The hazard to humans and to the environment, when rubber powder is used as artificial turf filling, is still uncertain, but doubts and interest in its potential dangers have been growing in various countries in and out of Korea. In the case of the U.S.A., the research presented by the Office of Environmental Health Hazard Assessment claimed, after toxicity assessment results related to ingestion of rubber ingestion based on research into children's gastro-intestinal tract digestion, in the case of rubber powder being ingested for a short period of time, it was possible to confirm the danger level of some heavy metal materials [1]. National Broadcasting Company of U.S.A. reported absorption of lead according to the simulation [2].

It is known that lead has a strong toxicity even when just a small amount of lead enters inside the human body. In the case that the human body is exposed to lead, the smaller the particle size and the younger the age of the exposure group, the higher the absorption rate inside the body, and it is

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known that only a portion of lead that is not absorbed is discharged from the human body. In addition, lead that enters the body is absorbed instead of calcium. Thus, children who need a lot of calcium, even when exposed to the same amount of lead as adults, an even larger amount of lead that exceeds the level of adults is absorbed inside by the children's body. Also, compared to the adults, children have a more active metabolism, which leads to 3-7 times quicker absorption of lead than in adults. Since the absorption rate or the latency period of lead is big among children, children have a bigger body load than adults. In the case of children, they are more sensitive to the toxicity of lead, and because lead induces damages to the kidney, liver, nerves and immune system, management of lead is very important.

Bioavailability is a value which shows how much pollutant can negatively affect humans and living organisms, and it is used to show how much is absorbed after the chemical substance enters the human body, is absorbed and is circulated. Most of the time, experiments about bioavailability are used to assess the heavy metals inside the soil, and Netherlands Rijksinstitut voor Volksgezondheid en Milieu (RIVM) is suggesting various methods of experiment. Following this, based on artificial digestion simulation research, research that applies the potential bioavailability of the ingestion exposure inside rubber powder is in progress [3-5].

Until now, examples of exposure and risk assessment examples related to rubber powder used for artificial turf are mostly inhalation exposure, skin exposure, and ingestion exposure. Among these exposure examples, research about ingestion exposure is a supposition about direct ingestion, and there is research in progress that estimates the exposure claim that states that rubber powder may be swallowed from artificial turf during exercise [6]. However, this estimate only supposes the worst condition. It is necessary to consider the possibility that small-sized particles, that exist in the powder state due to deterioration of rubber powder, can be unconsciously inhaled in the case that a person is exposed to hazardous substances while doing activities on the artificial turf. In the case of hazardous substances being exposed to the human body, the absorption rate inside the body can show differences in absorption rate according to the particle size. Researche done to compare the difference between the particle sizes due to ingestion exposure in soil or in food, and according to the in vitro digestive fluid extract experiment related to the particle size of the soil, the smaller the particle size, the higher the concentration [7,8]. Compared to the particles that are big, particles that have a small grain diameter, by increasing the unit surface area per mass, obtain characteristics that are more usable, biologically [9,10].

According to the content method and elution test method of artificial turf filling per each particle size, various age groups who used playgrounds with artificial turf were investigated, and the purpose of this study was to estimate the human risk level through lead ingestion exposure assessment.

MATERIALS AND METHODS

I. Research Object Sample

Based on artificial turf filling of recycled ethylene propylene diene monomer (EPDM) that is being universally used, ingestion exposure amount of each grain diameter of rubber powder (more or less than 250 um) was presumed. When a particle size of lower than 250 um inside the soil from the soil testing method is stained on children's hands, that size is suggested to be the standard size that could be ingested unconsciously, and it can be referred to as the form similar to rubber powder [11].

II. Exposure Route and Revision of Testing Method

Out of all heavy metals, lead was assessed as a target substance. Out of various routes of exposure to the human body, for the purpose of assessing ingestion exposure to the polluted rubber powder when doing exercises or playing games on the artificial turf, this research tried to assess the effect of rubber powder that could be ingested unconsciously (below 250 um) and consciously (more than 250 um) through the particle size and elution test method. The method used a process which revises the content concentration through ingestion exposure compensating method through bioavailability, and it compared and assessed the instance of using the acid extraction method and digestive fluid solution elution concentration. Among EPDMs, the entire content experiment used a method which tests and sees whether there are hazardous substances inside rubber powder, an acid extraction experiment used "autonomy safety assessment industrial products" safety standard that chose hazardous element elution testing method, and a digestive extraction experiment applied a testing method that was suggested by RIVM.

III. Sample Extraction and Analysis Method

A) Analysis method

A test piece was classified as below 250 um and above 250 um in order to compare the particle size of rubber powder. A test piece that is below 250 um was prepared by grinding recycled EPDM rubber powder using a hand-grinder and by filtering it using a strainer. In order to assess the applied ingestion exposure characteristics of lead, the content inside the rubber powder of artificial turf filling, it is analyzed in three ways: total content, acid extraction, and artificial digestive extract methods (Figure 1).

The first total content test method consulted "analysis

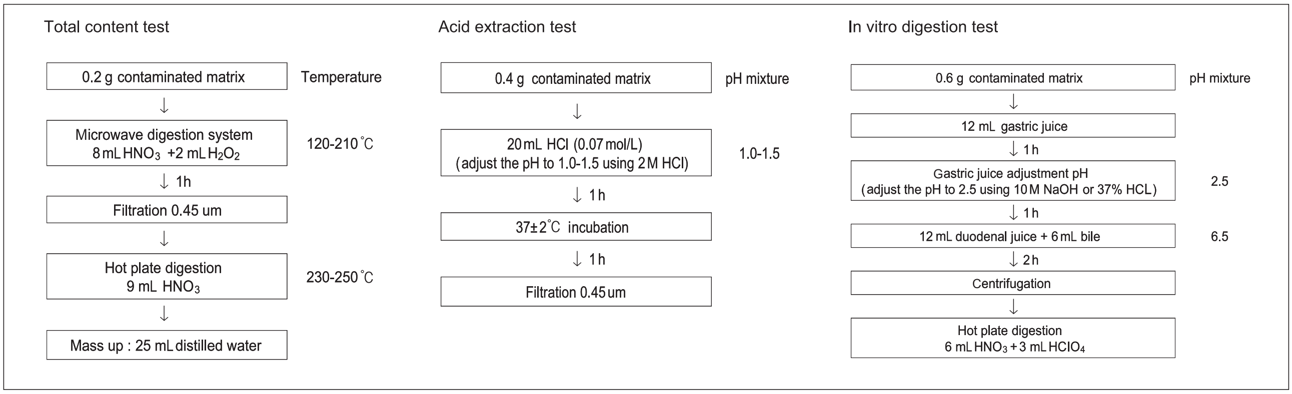

Figure 1. Procedures of extraction methods.

method of hazardous substances inside recycled rubber powder" (US EPA 3052 method) of industrial standards suggested by the Korean Industrial Standard. The test piece of rubber powder (0.2 g) was put in a teflon container, 8 mL of nitric acid and, 2 mL of hydrogen peroxide were added, then it was decomposed by heating in a microwave digestion system, and then the diluted solution was extracted and decomposed by heating on a hot plate.

The second acid extraction experiment consulted the "hazardous element elution test method" from "quality control and industrial products safety supervision law from autonomy confirmation subject industrial product safety standards" suggested by the Agency for Technology and Standards. In a conical flask, 0.07 mol/L of hydrochloric aqueous solution (20 mL) and 0.4 g of test piece was mixed and was shaken for 1 minute, then after confirming the pH of the mixture, the mixture was extracted (rpm: 200) at 37±2˚C for one hour in the concussor. After extraction, the mixture was left to stand for one hour at 37±2˚C, filtered with filter paper (pore size: 0.45), and then this solution was used as a test solution.

The third artificial digestive extraction testing method consulted the report about the children's toy experiment reported by RIVM and Oomen's report about soil test [7,12]. Using ready-made artificial digestive juice, the first step was done by blending 0.6 g of the test piece and 12 mL of ready-made artificial gastric juice and extraction for one hour. The pH level was fixed to be 2.5, and then it was extracted again for one hour. In the second step, 12 mL of artificial duodenal juice and 6 mL of artificial bile was mixed, its pH level was fixed to be 6.5, and it was reacted for 2 more hours, centrifuged and its supernatant was extracted. The extracted solution was decomposed by heating on a hot plate using acid and was extracted.

For sample analysis, the preprocessed sample was analyzed through an inductively coupled plasma mass spectrometer DRC ICP-MS (Perkin-Elmer Inc., Massachusetts, MA, USA).

B) Quality control of analysis

The researchers, using two kinds of certified standard substances, ERM-EC680k (low-density polyethylene) and ERM-EC681k (low-density polyethylene), performed the wet process acid separation method and microwave separation method in order to assess the quality control of the preprocess methods. The wet process acid separation method was done by putting 0.2 g of sample into a conical beaker, dissembling using sulfuric acid and nitric acid, and then, using nitric acid and perchloric acid, the researchers did total decomposition. The microwave separation method was done using nitric acid and perchloric acid, and then was decomposed by heating in a microwave digestion system. For sample analysis, the sample whose preprocess was done was analyzed through an induction coupled mass spectrometer DRC ICP-MS. After drawing the calibration curve, most substances demonstrated a correlation coefficient higher than 0.99, which is a good straight line type. The limit of detection was shown to be 0.005 ng/mL, microwave separation method was 0.041 ng/ml, acid extraction testing method was 0.127 ng/mL, and artificial digestive juice extraction testing method was shown to be 0.019 ng/mL. Certified standard substance ERM-EC680k and ERM-EC681k went through total content analysis after applying the preprocess method using wet process acid decomposition and microwave decomposition, then it was analyzed through ICP-MS. Analysis was done through comparison with the standard analysis value and recovery rate. Following this, the recovery rate of the certified standard material, in the case of the wet process acid decomposition method was ERM-EC680k 107.7%, ERM-EC681k 101.4%, microwave decomposition method ERM-EC680k 102.2%, and ERM-EC681k 120.3%.

C) Assessment of bioavailability

The extraction analysis result of digestive organs based on human digestion simulation could be assessed through calibrating constant bioavailability and, in addition, it could be classified as an acid extraction method (1) and artificial digestive extraction method (2) and the result could be

Table 1. Exposure factors of survey group

Exposure factor	Symbol	Age groups (y)			Source
		Elementary school students		Middle and high school students (13-18)	
		Younger (7-9)	Older (10-12)		
Body weight (kg)	BW	28	40	56	[13]
Ingestion rate (g/d)	IR	200	200	100	[14,15]
Period and Time					
Exposure period (y)	ED	3	3	3	Survey
No. of standard time exposure (d)	AT	1095	1095	1095	Survey
No. of year exposure (d/y)	EF	134.4 (48, 336)	177.6 (48, 336)	168 (96, 228)	Survey

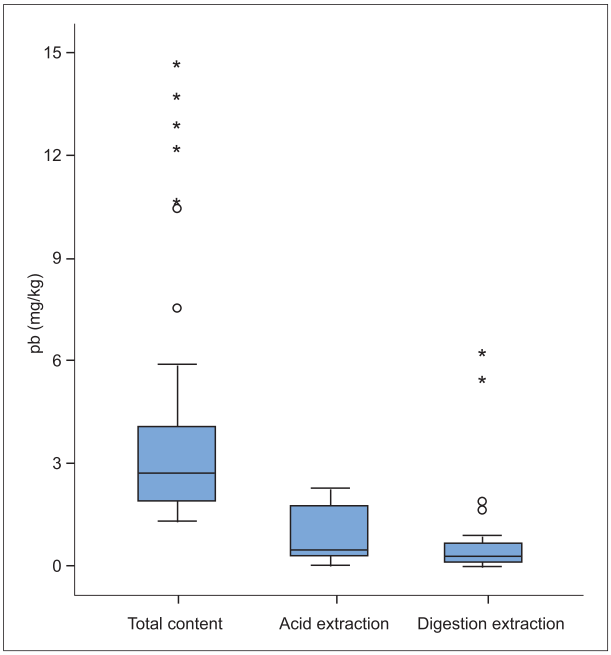

Figure 2. Comparison of extracted Pb levels by test methods in crumb rubber material.

calculated. This research, using the formula that shows the extraction level of heavy metals contained within the rubber powder inside human digestive organs, and this research calculated the result as follows:

- Bioavailability formula using acid extraction experiment result

(1) Bioavailability(%) = (content of elements inside rubber powder extracted by acid extraction experiment) / (total content of elements inside rubber powder extracted by acid extraction) × 100

- Bioavailability formula using artificial digestive extraction experiment result

(2) Bioavailability(%) = (content of elements inside rubber powder extracted by digestive fluid experiment) / (total content of elements inside rubber powder extracted by digestive fluid experiment) × 100

D) Health exposure assessment

Out of all routes of exposure, during exercise or play on the artificial turf, ingesting polluted rubber powder non-purposely (below 250 um) or purposely (above 250 um) and the particle size and its exposure amount per elution test method are assessed. Age of the subjects of the experiment varied from elementary school students (low-level, high-level classified), to middle and high school students. In order to perform the exposure assessment, the researchers calculated human exposure level through rubber powder ingestion amount, exposure frequency, and period which are all characteristics of exposure characteristics and exposure variable.

Among exposure factors according to subjects' age in order to do ingestion exposure assessment, "Korean exposure coefficient and management system construction" was consulted to find biological variable-related factors [13], and survey (275 people) of artificial turf playground school and park was consulted to find time-related variables. Both methods were used to deduct exposure frequency and exposure period values (Table 1). In order to find the average rubber powder ingestion, based on soil ingestion basic values suggested by the exposure factors handbook of Environmental Protection Agency (EPA) values of children 0.2 g/day, and youths 0.1 g/day were used [14]. Thus, based on the determined exposure coefficient, based on ingestion exposure characteristics and testing method, lifetime average daily dose (LADD) was calculated.

- In case of ingesting rubber powder when using artificial turf

$$LADD\ (mg/kg/day) = (C \times IR \times EF \times ED)/(BW \times AT) \times B$$

LADD (mg/kg/d): lifetime average daily dose,
C (mg/kg): content concentration inside rubber powder,
B (%): bioavailability,
IR (mg/d): daily rubber powder ingestion dose,
EF (d/y): yearly average exposure frequency,
ED (y): average usage period,
BW (kg): average weight of exposed population,
AT (d): average exposed days of exposed population.

E) Risk calculation

Lead, which is the subject matter of this research, in the

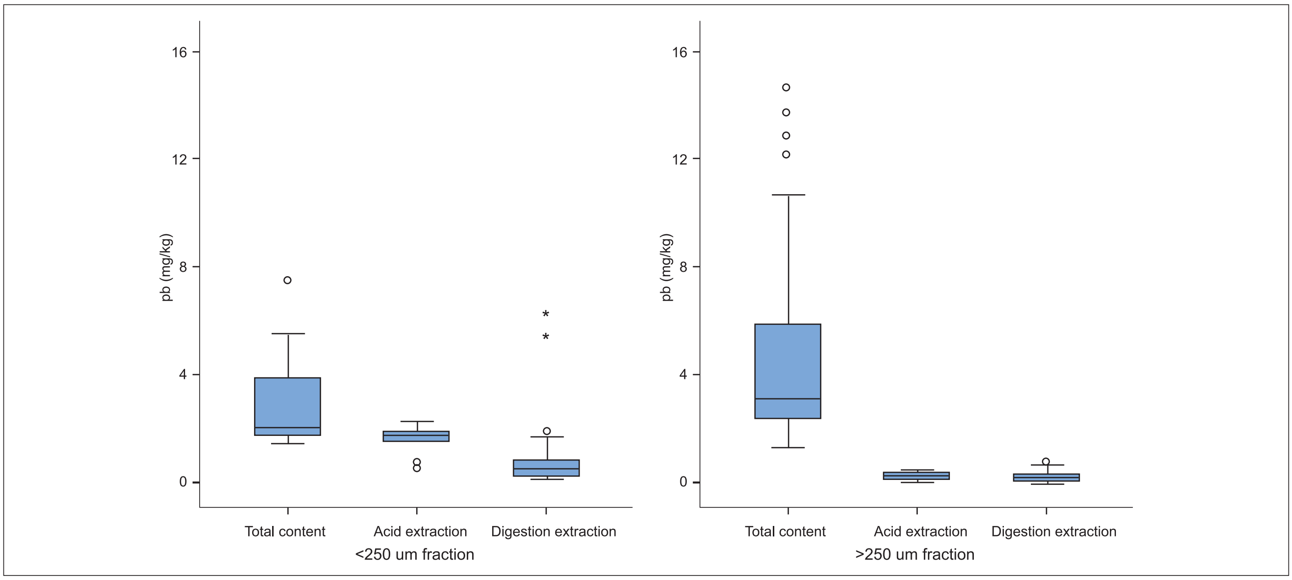

Figure 3. Pb levels by particle size fractions in crumb rubber.

Table 2. Bioavailability of Pb by particle size fractions in crumb rubber

Size	Bioaccessibility value (%)						Ratio[a]	*p*-value[b]
	Acid extraction			Digestion extraction				
	n	GM (GSD)	Range	n	GM (GSD)	Range		
<250 um	30	58.0 (1.5)	29.7, 96.2	30	21.9 (2.3)	6.3, 98.0	2.7	<0.001*
>250 um	30	4.0 (7.4)	0.0, 29.6	30	4.2 (3.0)	0.3, 29.1	0.9	0.284

GM, geometric mean; GSD, geometric standard deviation.
[a] Acid extraction / digestion extraction.
[b] Wilcoxon rank sum test.
*$p<0.01$

case of chronic exposure in early childhood, can induce cell necrosis, nerve behavioral abnormalities and developmental disability, and in the case of long-term exposure it can induce cell necrosis, blood pressure, cancer, and kidney tumor [16,17].

In the process of exposure assessment calculated exposure dose and after effect evaluation result was compared, hazard quotient was calculated from US EPA integrated risk information system and children's tolerable daily intake of lead non-carcinogenic reference dose value (0.001 mg/kg-day) was consulted [18]. The researchers used human hazard probability distribution 5%th relevant value, 50%th relevant value and 95%th relevant value were used, hazard quotient was judged to be hazardous when it exceeded 1 according to hazard quotient judgment standard suggested by Environmental Health Law. Elementary school students were considered to be a sensitive group, and even when the average value exceeded 0.1, it was considered to have hazard possibility.

$$HQ = LADD / RfD$$

HQ: hazard quotient
LADD: lifetime average daily dose
RfD: reference dose

RESULTS

1. Result of Sample Analysis

In order to verify similar shape method on human body out of all rubber powder testing methods, the researchers, using three methods such as total content method, acid extraction, and artificial digestive extraction method, compared the results (Figure 2). Each testing method concentration distribution showed asymmetrically big deviation and in order to decrease the gap, the researchers showed results through geometric values. While testing the three methods, when the total content method was applied (3.00 mg/kg), it showed a higher result, and compared to the digestive extraction method (0.29 mg/kg) the result showed a 10 times bigger difference. After acid extraction value and digestive extraction, the result showed a similar aspect, and showed a relatively lower extraction rate compared to the total content method.

In consideration of the possibility of inhaling rubber powder, according to particle size that is below 250 um and above 250 um, the researchers applied three testing methods and then compared the results (Figure 3). According to the

Table 3. Result of ingestion exposure of Pb by particle sizes of bioavailability

Size fraction (mg/kg-day)	Digestion extraction (y)						Acid extraction (y)					
	Elementary school students				Middle and high school students (13-18)		Elementary school students				Middle and high school students (13-18)	
	Younger (7-9)		Older (10-12)				Younger (7-9)		Older (10-12)			
	Normal	Worst	Normal	Worst	Normal	Worst	Normal	Worst	Normal	Worst	Normal	Worst
<250 um												
5th	2.95×10^{-5}	7.38×10^{-5}	2.73×10^{-5}	5.16×10^{-5}	9.22×10^{-6}	1.25×10^{-5}	1.22×10^{-4}	3.06×10^{-4}	1.13×10^{-4}	2.14×10^{-4}	3.82×10^{-5}	5.19×10^{-5}
Mean	1.56×10^{-4}	3.89×10^{-4}	1.44×10^{-4}	2.73×10^{-4}	4.87×10^{-5}	6.61×10^{-5}	4.13×10^{-4}	1.03×10^{-3}	3.82×10^{-4}	7.23×10^{-4}	1.29×10^{-4}	1.75×10^{-4}
95th	1.20×10^{-3}	2.99×10^{-3}	1.11×10^{-3}	2.10×10^{-3}	3.74×10^{-4}	5.08×10^{-4}	1.33×10^{-3}	3.32×10^{-3}	1.23×10^{-3}	2.32×10^{-3}	4.15×10^{-4}	5.63×10^{-4}
>250 um												
5th	2.32×10^{-6}	5.81×10^{-6}	2.15×10^{-6}	4.07×10^{-6}	7.26×10^{-7}	9.85×10^{-7}	1.40×10^{-7}	3.49×10^{-7}	1.29×10^{-7}	2.44×10^{-7}	4.37×10^{-8}	5.92×10^{-8}
Mean	5.58×10^{-5}	1.40×10^{-4}	5.16×10^{-5}	9.77×10^{-5}	1.74×10^{-5}	2.37×10^{-5}	5.26×10^{-5}	1.31×10^{-4}	5.16×10^{-5}	9.77×10^{-5}	1.74×10^{-5}	2.37×10^{-5}
95th	8.90×10^{-4}	2.22×10^{-3}	8.23×10^{-4}	1.56×10^{-3}	2.78×10^{-4}	3.77×10^{-4}	9.11×10^{-4}	2.28×10^{-3}	8.43×10^{-4}	1.59×10^{-3}	2.85×10^{-4}	3.86×10^{-4}

Table 4. Hazard quotient of Pb by particle size of bioavailability

Size fraction (mg/kg-day)	Digestion extraction (y)						Acid extraction (y)					
	Elementary school students				Middle and high school students (13-18)		Elementary school students				Middle and high school students (13-18)	
	Younger (7-9)		Older (10-12)				Younger (7-9)		Older (10-12)			
	Normal	Worst	Normal	Worst	Normal	Worst	Normal	Worst	Normal	Worst	Normal	Worst
<250 um												
5th	0.049	0.123	0.046	0.086	0.015	0.021	0.204	0.510	0.189	0.357	0.064	0.087
Mean	0.260	0.649	0.240	0.454	0.081	0.110	0.689	1.723	0.637	1.206	0.215	0.292
95th	1.996	4.991	1.847	3.494	0.624	0.847	2.211	5.527	2.045	3.869	0.691	0.938
>250 um												
5th	0.004	0.010	0.004	0.007	0.001	0.002	0.001	0.001	0.001	0.001	0.001	0.001
Mean	0.093	0.233	0.086	0.163	0.029	0.040	0.088	0.219	0.086	0.163	0.029	0.040
95th	1.483	3.708	1.372	2.595	0.463	0.629	1.519	3.797	1.405	2.658	0.475	0.644

comparison of particle sizes that are below 250 um and above 250 um, the results showed that the lead concentration of EPDM rubber powder's total content, acid extraction, and digestive fluid turned out to be 2.42 mg/kg, 1.40 mg/kg, and 0.53 mg/kg, respectively, all of which are assessed to be considerably high lead concentrations compared to the content and elution concentration of big particles that are above 250 um. As a whole, test results showed higher extraction rates from particle sizes above 250 um, but from the total content method the geometric mean was 3.73 mg/kg, and this result is a higher value than the value from particle sizes above 250 um. In addition, in the case of the digestive extraction method and acid extraction method, there were statistically significant differences per every particle size ($p<0.01$). When comparing the elution extent according to the particle size, a particle size less than 250 um showed a higher result in the acid extraction test (1.40 mg/kg) compared to the digestive extraction test (0.53 mg/kg), but a particle size above 250 um showed a higher result in the digestive elution test (0.16 mg/kg). The reason for such a result was because, while doing preprocessing of the digestive extraction method and when the organism was being decomposed on the hot plate, white refractory precipitate was left during 200˚C and above heating process and the lead analysis was difficult.

The result which was an analysis of rubber powder through a digestive simulation process similar to the human body digestive system, using the extracted amount as a ratio, was used by the, researchers to analyze bioavailability (Table 2). Bioavailability was analyzed and classified according to particle size, the differences in size were as follows: below 250 um resulted in 58.0% of acid extraction and 21.9% of digestive extraction and these results showed more bioavailability than a particle size of 250 um. In addition, compared to the digestive extraction method, it showed a greater bioavailability result in the acid extraction method. It also showed that, according to the particle size, there was a statistically significant difference between acid extraction and digestive extraction ($p<0.01$). In particular, the bioavailability from acid extraction in particles with a diameter less than 250 um was 58.0%, which was approximately 2.7 times greater different, and particle size above 250 um was investigated to be at the similar level.

II. Ingestion Exposure Assessment

The researchers confirmed the level of exposure in the case of polluted rubber powder is either purposely or non-purposely ingested during exercising or playing on artificial turf. The researchers made an exposure scenario by differentiating the normal condition from the worst exposure condition that has the most extreme exposure form, and assessed human hazard probability distribution values of the average exposure level per each age group (Table 3). Comparing the bioavailability results using the elution method, was observed, after having used the acid extraction method, that bioavailability was at a higher level than when using the digestive extraction method, and the result showed a significant difference in particle size that is less than 250 um. The average exposure scenario in relation to the digestive extraction method of rubber powder and after assessing the particle size of less than 250 um, for elementary lower grades was 1.56×10^{-4} mg/kg-day, elementary school higher grades was 1.44×10^{-4} mg/kg-day, middle and high school was 4.87×10^{-5} mg/kg-day, and 95th percentile value for elementary lower grades was 1.20×10^{-3} mg/kg-day, for elementary higher grades was 1.11×10^{-3} mg/kg-day, and for middle and high school was calculated to be 3.74×10^{-4} mg/kg-day.

The average exposure scenario in relation to the acid extraction method of rubber powder and after assessing the particle size of less than 250 um, for elementary lower grades was 4.13×10^{-4} mg/kg-day, elementary school higher grades was 3.82×10^{-4} mg/kg-day, middle and high school was 1.29×10^{-4} mg/kg-day, and 95th percentile value for elementary lower grades was 1.33×10^{-3} mg/kg-day, for elementary higher grades was 1.23×10^{-3} mg/kg-day, and for middle and high school was calculated to be 4.15×10^{-4} mg/kg-day. When compared between each particle size, the digestive extraction result and acid extraction result both showed that daily ingestion dose was calculated to be about twice as high in particle sizes less than 250 um compared to those above 250 um.

III. Health Risk Assessment

The level of hazard in human body, in the case of purposeful and non-purposeful ingestion of polluted rubber powder during exercising or playing on artificial turf, was estimated. Hazard index was calculated by comparing children's daily intake dose and average exposure dose values (Table 4).

Index of hazard according to average exposure scenario in the acid extraction method and the digestive extraction method both showed a calculated level of hazard in the order: elementary lower grades > elementary higher grades > middle and high school. The index of hazard according to the average exposure scenario of elementary, middle and high school was 0.01-0.1, and in the case of elementary school students most of the indexes of hazard exceeded 0.1. There was a case where an elementary school child exceeded the index of hazard of 0.1, and the digestive extraction result, from particle sizes less than 250 um, showed that the index of hazard was at the 0.01-0.1 level. Results from the digestive extraction method of the hazard index showed a 0.01-0.1 level and there was a case where an elementary school student exceeded the 0.1 level of hazard index. From the acid extraction result, the particles with a size less than 250 um demonstrated a 0.1-1 hazard index, and there was a case where an elementary school student exceeded the hazard index of 1 from the worst exposure scenario, and this result was calculated to be higher level than the digestive extraction method. Comparing each particle size, both the digestive extraction method and acid extraction method showed that, more from a particle size above 250 um than from a particle size below 250 um, the hazard index was assessed to be twice as high. Based on the acid extraction method, a particle size of less than 250 um the average hazard index, from elementary school average exposure scenario and the worst exposure scenario was 0.689 and 1.723, respectively. At a particle size of above 250 um, the elementary school student's average exposure scenario and the worst exposure scenario was 0.088 and 0.219, respectively, and there was as much as 7.9 times difference.

DISCUSSION

Until now, there has been much interest in research that examined children's exposure to hazardous materials in soil or children's products and so on. For example, it has been discovered that soil and in children's toy paint, which can contain lead, can be a serious hazard to children's normal development and health, and there have been many efforts to manage this serious matter. Moreover, recently there has been much research reporting about hazardous substances in the school playground, physical education facilities or in artificial turf playgrounds [19].

This research aimed to investigate ingestion exposure of lead found inside artificial turf filling. The researchers, along with a former content measuring method, tried to examine what happens when lead enters the human body and it is absorbed through the stomach pipe. The researchers tried to apply the acid extraction method and digestive extraction method that reflect conditions that are characterized to have hazardous materials contained in the products melted and absorbed into body. As a result, lead concentration inside of EPDM rubber powder was 3.0 mg/kg, the acid extraction method result was 6.5 times higher than content concentration, and digestive extraction was 10.3 times higher. The acid extraction result and digestive extraction result showed similar aspects.

In order to assess the possibility of exposure of humans to heavy metals contained within rubber powder, research about the total content method and elution method are being carried out. The acid extraction method is a method used when testing several kinds of Korean toy types' hazardous substances assessment, and is an elution method applied according to the standard of ISO 3696 (1987, water for analytical laboratory use - specification and test methods), and is a testing method that extracts hazardous substances according to the elution testing method and based on toy types that children can suck, lick, or swallow. For the two extraction methods, when doing preprocessing, the acid extraction method uses sulfuric acid, and digestive extraction method uses prescribed stomach, intestine, and bile. The typical digestive extraction test method is the in vitro extract test method, suggested by RIVM, and this is reported to have the most efficiency [20]. Some of the ways in which the researchers could use the digestive extraction testing method are temperature, elution time period, pH condition, separation method, etc. Out of those methods, this study also applied the method and used the in vitro digestive extract testing method suggested by RIVM. However, the digestive extraction method which is currently being used, even though such method can very well reflect digestion process similar to the human body, its flows are that the method requires many procedures of extract processes, it requires a lot of time, cost, and effort, and it leads to a big deviation for the researcher.

Comparison according to particle sizes of below 250 um and above 250 um shows, that the EPDM rubber powder lead concentration of particle sizes below 250 um is considerably higher than content and elution concentration of particle size above 250 um. Therefore, due to long use of artificial turf filling and when the grain diameter of rubber powder becomes smaller, there was a fear that elution volume inside the body might become big. In the case of soil, for example, research about the exposure of small particle size rubber powder are being conducted [21,22]. In research that studies extraction experiments outside of the body and its bioavailability, the particle size below 250 um is being used as the standardized particle size [23]. In addition, a particle size of less than 250 um has been used as the general size that a child could ingest when it adheres to the fingers [24-26]. From this research, the researchers were able to confirm the differences of the concentration according to the particle size, and they were able to discover high exposure volume from small particle sizes. This was the result because small particles, compared to big particles, have increased surface area and their solubility is significantly higher than the big particles.

In the case of the content method, considering the fact that the sample is entirely melted during the acid decomposition process, there is a possibility that the hazardous substance human body transition rate of the actual ingested rubber powder could be overestimated. Thus, assessment using bioavailability, using total content concentration values, and the results of acid extraction and digestive extraction results were revised in order to estimate suitable human exposure quantity. Bioavailability, which is a calibrating constant for estimating human exposure volume and risk level using content concentration of lead within rubber powder, showed a difference in results based on the digestive extraction method, and the acid extraction result showed a 2 times bigger difference in the outcome in the case of particle sizes of less than 250 um. For the small grain diameter of artificial turf filling, the bioavailability was considerably high. When the researchers compared the results of two elution methods in order to verify the credibility, the acid extraction method had an elution rate which was twice as high as the digestive elution result in the case of the particle size being less than 250 um, whereas there was not a huge difference in cases in which the particle size was above 250 um. Following this, it was obvious that when comparing particle sizes, there was high deviation between the two elution methods.

The most similar method in assessing hazardous substances induced by inflow of rubber powder inside the human body is an elution method using digestive extraction. However, due to complications of testing methods and due to the many kinds of organic substances contained within the digestive extraction, the base value revision is difficult, it is determined that this digestive extraction method has restrictions as an universal standard testing method. In contrast, the acid extraction method is a much shortened and standardized testing method which can minimize the deviation, compared to the digestive extraction, which is composed of digestive enzymes which help various digestive absorbing actions, and the researchers are restricted to assess the elution from the stomach based on hydrochloric acid extraction. Despite the fact that the acid extraction method is a limitative extraction method, it is judged to be more suitable than the digestive extraction method.

Ingestion exposure assessment of rubber powder was used to assess exposure volume similar to the human body, and according to the result which examined the applicability of the digestive extraction method and acid extraction method, out of all EPDM rubber powders with a particle size of less than 250 um, it was found that the highest value of ingestion result was calculated in the elementary school lower grades students who used artificial turf that contained EPDM rubber powder with the particle size of less than 250 um. However, the calculated result was inferior to the daily ingestion dose of 0.004 mg/kg-day related to children from Bundesinstitut fur Risikobewertung. The World Health Organization recommends a daily intake dose of lead for children to be 0.035 mg/kg-day, and EPA of Denmark suggests 0.001 mg/kg-day [27-29].

According to the estimation result of rubber powder conducted by this research, the hazard index due to the elementary school and middle and high school average exposure scenario was 0.01-0.1, and it was calculated that most elementary school students' hazard index exceeds 0.1. Californian research stated that if, a child ingested 10 g of rubber powder, the child's acid extraction hazard index of lead was 0.226, and digestive extraction result was 0.174. Both results showed index results higher than 0.1, a potential for hazard [1]. In addition, in the research where the researcher compared ingestion of hazardous substances in soil from not artificial turf fields through to playground floor materials, it was found that the hazard index of lead among heavy metals ingested in the apartment or neighbor playground soil floor materials is at a level of 7×10^{-5} level, and this result is assessed to be a lower hazard index value compared to the rubber powder, which was the subject matter of this research [30].

For artificial turf filling, many kinds of rubber powder are used, but the one in which is used the most in this research was recycled EPDM materials. The characteristics of EPDM were applied in the results of this research, trial products not the site samples were analyzed, and since it is practically difficult to accurately grasp the ingestion volume of rubber powder in the playground, this limits the interpretations of the results of this research.

The results of this research, out of various types of rubber powder, are results which used only the recycled EPDM rubber powder prototype to assess and to calculate, and thus, there is uncertainty as to whether the result could represent the entire artificial turf or not. Therefore, from now on, research about the multiple routes and substances related to children°Øs exposure in the artificial turf playground as well as various methods of elution test should be conducted.

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CONFLICT OF INTEREST

The authors have no conflict of interest to declare on this study.

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