

## Organ Distribution of Heavy Metals in Autopsy Material from Normal Korean

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To obtain the usual value of aluminum, arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury, molybdenum, nickel, selenium, silicon, tin, vanadium and zinc in the normal human body, the amounts of these 16 metals were determined in 89 male and 61 female Korean cadavers, whose ages ranged from 12 to 87 years. Inductively coupled plasma atomic emission spectrometry was used for analysis of heavy metals in 9 autopsied human organs (liver, kidney, cerebrum, heart, spleen, lung, bone, hair and nail). Distribution of arsenic, nickel, selenium, lead and vanadium in the human body were almost uniform. Cadmium, mercury, manganese, molybdenum, tin and zinc were found in large quantities in the metabolic organs, whereas the concentrations of aluminum, chromium and silicon were greatest in the tissues exposed to the exterior.

**Key words** — Korean, tissue, heavy metal, concentration, ICP-AES, microwave digestion

### INTRODUCTION

As the human body is exposed to such environmental media as water, air and soil, the ingestion of heavy metals generally takes place. The ingested heavy metals do not remain in the living body easily. However, if organic or inorganic compound has

been formed by the metals, this could influence its movement in the body. The effect of heavy metals on the human body varies according to each metal's characteristics and based on the affinity of special tissues.<sup>1-3)</sup>

Therefore, trace metals in human body tissues create interests as to their role in the body, from the point of view of virulence, their relationship with diseases, and the relationship between environmental pollution and the heavy metal. In addition, the estimate of the normal range of heavy metals in human body tissue has an important role as baseline data. Many investigations have been done so far in developed countries to determine these values, and the monitoring has been continued through several decades.<sup>4-14)</sup>

Compared to this, in Korea, the normal range of concentration of heavy metal in Korean tissues has scarcely been investigated. For our country, where industrial development has been rapid, the amount of heavy metal accumulated in the human body from the polluted environment is expected to increase. So, basic data like the normal range of heavy metals in the human body as a basis for recommending changes in living conditions such as the environment and diet need to be determined immediately. Thus, the normal ranges of heavy metal concentration in Korean tissues were investigated in cadavers undergoing forensic medical examinations in National Institute of Scientific Investigation of Korea

### MATERIALS AND METHODS

**Preparation of Samples** — From July 1997 to March 2000, we collected and examined body tissue parts (liver, kidney, cerebrum, spleen, lung, bone, hair and nail) from 150 dead bodies (89 males, 61 females) who had lived in Seoul and Kyonggi Province and died prematurely, from trauma, traffic accident, hanging, strangulation, etc. As a result of our histological examination, we obtained samples without special diseases. The tissue samples collected from autopsy were kept in -40°C and used for an experiment. The distribution by age group is shown in Table 1.

**Decomposing the Sample and Measuring the Recovery** — After leaving each tissue alone until it reached room temperature, the blood which stained their surface was removed and the tissues were decomposed with microwave digestion system (Milestone s.r.l., mls 1200 mega, Italy) according to the

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**Table 1.** Distribution of Age and Gender of Individual Subjects

Age group	Female	Male	Total
Teens	9	3	12
Twenties	14	14	28
Thirties	16	25	41
Forties	11	21	32
Fifties	5	16	21
Sixties	3	7	10
Over seventies	3	3	6
Total	61	89	150

reported procedure described earlier.<sup>15)</sup> Next, using the ICP (Thermo Jarrel Ash Co., Atomscan 25, U.S.A.) for recovery, the concentration of the heavy metals in tissues was measured. The analytical condition of the ICP is shown in Table 2.

**Statistical Analysis** — The concentration of heavy metals of each tissue by different sexes was expressed as an average, standard deviation, range of concentration and 95% confidence interval using an SAS program from the concentration measured from each part of the body.

## RESULTS AND DISCUSSION

### Standard Curve and Measuring the Recovery

As it has been reported in a previous study,<sup>15)</sup> the results of a standard curve of about 16 metallic elements in standard solution, Al, As, Cd, Cr, Cu, Fe, Hg, Mn, Mo, Ni, Pb, Se, Sn, V and Zn using ICP, were plotted in a straight line in which the values of  $r$  were more than 0.999. The recovery of all

metals except Si was more than 79%, and the relative standard deviation (RSD) was less than 5% in all heavy metals.

### Concentration of Heavy Metals in Tissues

The heavy metal concentration in each tissue by gender, the average concentration of total samples, standard deviation, the range of concentration and the number of samples from the sample of 150 dead bodies (89 males, 61 females) which do not have special disease is shown in Table 3.

The heavy metal concentration that was gained from each tissue is expressed in  $\mu\text{g/g}$  wet weight. Arsenic (As) is distributed quite evenly in each tissue, though it was a little high in the liver. As it was found in a high concentration, especially in bones, hair, and nails, it can be concluded that arsenic is accumulated in these parts. In the case of Cadmium (Cd),  $35 \pm 18 \mu\text{g/g}$  was detected in the kidney and  $2.8 \pm 1.8 \mu\text{g/g}$  was detected in the liver, but in other tissues,  $0.10\text{--}1.67 \mu\text{g/g}$  of the mean value was detected. Compare to the Japanese's average of Cd concentration in the kidney and liver, the concentration in Korean kidney and liver was very low.<sup>5,6,16)</sup> However it was high in comparison with the Chinese<sup>13)</sup> and Europeans.<sup>8)</sup> Livingstone *et al.*<sup>17)</sup> and Elinder *et al.*<sup>18)</sup> reported that the Cd concentration in the kidney is related to age and the smoking habit, whereas the concentration of Cd in non-smokers comes from the diet. There was a significant difference at  $p < 0.01$  between the kidney concentration of Cd and age (Pearson's correlation coefficient = 0.419). Chromium (Cr) was detected in large quantity in the lung, spleen and liver compared with other tissues. From

**Table 2.** Analytical Conditions of ICP

Gas flow rate
Torch gas: High flow
Auxiliary gas: Medium (1.0 l/min)
Nebulizer gas: On (PSI): 30.1
Approximate RF power (w): 1350
Slit height (mm): 3
Observation height (mm): 14.9
Peristaltic pump parameters
Pump rate (RPM): 100
Relaxation time (sec): 10
Pump tubing type: EP-19
Wavelength (nm): Al (396.152), As (189.042), Cd (228.802), Cr (267. 716), Cu (324.754), Fe (259.940), Hg (184.950), Mn (257.610), Mo (202.030), Ni (231.604), Pb (220.353), Se (196.090), Si (251.612), Sn (189.989), V (309.311), Zn (213.856)

**Table 3.** Concentration of Heavy Metals in Korean Human Tissues

Unit: $\mu\text{g/g}$ -wet weight											
Tissue	Sex	Arsenic					Cadmium				
		Mean	S.D.	Range	95%CI	(No.)	Mean	S.D.	Range	95% CI	(No.)
Liver	M	0.77	1.0	$\leq 5.0$	0.56–0.99	87	2.2	1.2	0.12–5.4	2.0–2.5	85
	F	0.25	0.33	$\leq 1.3$	0.16–0.34	56	3.7	2.2	0.41–9.4	3.1–4.3	58
	Total	0.57	0.86	$\leq 5.0$	0.43–0.71	143	2.8	1.8	0.12–9.4	2.5–3.1	143
Kidney	M	0.44	0.46	$\leq 2.0$	0.34–0.55	77	34	14	7.1–67	31–37	84
	F	0.35	0.33	$\leq 1.2$	0.26–0.44	57	36	23	8.9–102	30–42	56
	Total	0.40	0.41	$\leq 2.0$	0.33–0.47	134	35	18	7.1–102	32–38	140
Heart	M	0.51	0.51	$\leq 2.1$	0.40–0.63	80	0.16	0.17	$\leq 0.76$	0.12–0.20	83
	F	0.35	0.30	$\leq 1.1$	0.26–0.43	56	0.25	0.21	$\leq 0.77$	0.19–0.30	56
	Total	0.44	0.44	$\leq 2.1$	0.37–0.52	136	0.20	0.19	$\leq 0.77$	0.16–0.23	139
Lung	M	0.45	0.47	$\leq 1.9$	0.35–0.56	77	0.28	0.20	$\leq 0.79$	0.24–0.33	81
	F	0.37	0.33	$\leq 1.3$	0.28–0.46	56	0.37	0.35	$\leq 1.6$	0.28–0.46	56
	Total	0.42	0.42	$\leq 1.9$	0.35–0.49	133	0.32	0.27	$\leq 1.6$	0.27–0.37	137
Spleen	M	0.57	0.61	$\leq 2.4$	0.43–0.71	79	0.27	0.15	$\leq 0.76$	0.23–0.30	83
	F	0.28	0.31	$\leq 1.3$	0.20–0.36	56	0.48	0.32	$\leq 1.3$	0.39–0.56	56
	Total	0.45	0.53	$\leq 2.4$	0.36–0.54	135	0.35	0.26	$\leq 1.3$	0.31–0.39	139
Cerebrum	M	0.61	0.71	$\leq 2.8$	0.46–0.77	84	0.09	0.11	$\leq 0.49$	0.07–0.11	86
	F	0.24	0.30	$\leq 1.2$	0.16–0.32	56	0.11	0.13	$\leq 0.67$	0.07–0.15	55
	Total	0.46	0.61	$\leq 2.8$	0.36–0.57	140	0.10	0.12	$\leq 0.67$	0.08–0.12	141
Bone	M	3.0	1.6	$\leq 6.9$	2.6–3.3	86	0.13	0.12	$\leq 0.56$	0.10–0.15	85
	F	2.6	1.3	$\leq 4.8$	2.3–3.0	54	0.12	0.11	$\leq 0.47$	0.09–0.15	55
	Total	2.8	1.5	$\leq 6.9$	2.6–3.1	140	0.12	0.11	$\leq 0.56$	0.11–0.14	140
Hair	M	2.5	2.6	$\leq 9.3$	1.9–3.1	81	0.13	0.17	$\leq 0.72$	0.09–0.16	78
	F	0.89	0.88	$\leq 3.6$	0.65–1.1	57	0.09	0.10	$\leq 0.35$	0.06–0.12	58
	Total	1.8	2.2	$\leq 9.3$	1.4–2.2	138	0.11	0.14	$\leq 0.72$	0.09–0.13	136
Nail	M	12	15	$\leq 58$	8.2–15	79	0.70	0.96	$\leq 3.9$	0.48–0.92	78
	F	8.4	8.8	$\leq 28$	5.9–11	53	0.62	0.89	$\leq 3.0$	0.37–0.86	53
	Total	10	13	$\leq 58$	8.1–12	132	0.67	0.93	$\leq 3.9$	0.51–0.83	131
Tissue	Sex	Chromium					Copper				
		Mean	S.D.	Range	95%CI	(No.)	Mean	S.D.	Range	95	(No.)
Liver	M	0.39	0.26	$\leq 0.97$	0.33–0.44	88	5.3	2.0	1.1–11	4.9–5.8	83
	F	0.24	0.19	$\leq 0.71$	0.19–0.29	60	6.1	2.8	0.73–13	5.4–6.8	59
	Total	0.33	0.25	$\leq 0.97$	0.29–0.37	148	5.7	2.4	0.73–13	5.3–6.0	142
Kidney	M	0.20	0.15	$\leq 0.63$	0.17–0.23	84	2.0	0.58	0.48–3.3	1.9–2.1	86
	F	0.15	0.11	$\leq 0.39$	0.11–0.18	55	2.2	0.64	0.82–3.7	2.1–2.4	57
	Total	0.18	0.14	$\leq 0.63$	0.15–0.20	139	2.1	0.61	0.48–3.7	2.0–2.2	143
Heart	M	0.19	0.14	$\leq 0.61$	0.16–0.22	84	2.7	0.62	1.4–3.9	2.5–2.8	87
	F	0.14	0.11	$\leq 0.39$	0.11–0.17	56	2.9	0.66	1.4–4.2	2.7–3.0	59
	Total	0.17	0.13	$\leq 0.61$	0.15–0.19	140	2.7	0.64	1.4–4.2	2.6–2.8	146
Lung	M	0.48	0.35	$\leq 1.4$	0.40–0.55	83	0.94	0.41	$\leq 2.2$	0.85–1.0	82
	F	0.31	0.24	$\leq 0.93$	0.24–0.37	57	1.1	0.33	0.32–1.9	0.97–1.1	58
	Total	0.41	0.32	$\leq 1.4$	0.35–0.46	140	0.99	0.38	$\leq 2.2$	0.93–1.1	140
Spleen	M	0.48	0.35	$\leq 1.5$	0.41–0.56	85	0.85	0.24	$\leq 1.5$	0.80–0.90	83
	F	0.28	0.21	$\leq 0.77$	0.22–0.33	57	0.97	0.22	0.43–1.4	0.91–1.0	56
	Total	0.40	0.32	$\leq 1.5$	0.35–0.45	142	0.90	0.24	$\leq 1.5$	0.86–0.94	139
Cerebrum	M	0.18	0.12	$\leq 0.50$	0.15–0.21	84	3.6	1.1	0.99–6.0	3.3–3.8	86
	F	0.14	0.12	$\leq 0.42$	0.11–0.18	58	3.6	1.1	0.54–6.1	3.3–3.8	59
	Total	0.17	0.12	$\leq 0.50$	0.15–0.19	142	3.6	1.1	0.54–6.1	3.4–3.7	145

S.D.: standard deviation, M: male, F: female, (No.): number of specimens. 95% CI: 95% Confidence Interval.

Table 3. Continued

Tissue	Sex	Chromium					Copper				
		Mean	S.D.	Range	95%CI	(No.)	Mean	S.D.	Range	95	(No.)
Bone	M	1.7	0.77	≤ 3.4	1.6–1.9	85	0.51	0.34	≤ 1.5	0.43–0.58	84
	F	2.3	0.91	≤ 4.2	2.0–2.5	58	0.62	0.36	≤ 1.6	0.53–0.72	57
	Total	2.0	0.87	≤ 4.2	1.8–2.1	143	0.55	0.35	≤ 1.6	0.49–0.61	141
Hair	M	0.72	0.62	≤ 2.3	0.58–0.86	79	8.6	3.4	0.24–18	7.8–9.4	82
	F	0.41	0.35	≤ 1.2	0.31–0.51	54	15	12	0.41–55	12–18	56
	Total	0.60	0.55	≤ 2.3	0.50–0.69	133	11	8.4	0.24–55	9.9–13	138
Nail	M	3.1	2.8	≤ 9.9	2.5–3.8	76	9.6	7.7	≤ 29	7.9–11	79
	F	2.6	3.0	≤ 11	1.7–3.4	50	7.8	5.7	≤ 24	6.3–9.4	52
	Total	2.9	2.9	≤ 11	2.4–3.4	126	8.8	7.0	≤ 29	7.7–10	131
Tissue	Sex	Iron					Mercury				
		Mean	S.D.	Range	95%CI	(No.)	Mean	S.D.	Range	95% CI	(No.)
Liver	M	207	84	40–431	189–224	88	0.19	0.16	≤ 0.62	0.15–0.22	84
	F	114	51	28–242	101–128	55	0.21	0.17	≤ 0.71	0.16–0.25	59
	Total	171	86	28–431	157–185	143	0.20	0.17	≤ 0.71	0.17–0.22	143
Kidney	M	88	33	30–168	81–95	88	0.25	0.16	≤ 0.70	0.22–0.29	82
	F	78	33	14–149	69–86	61	0.32	0.23	≤ 0.94	0.26–0.39	56
	Total	84	34	14–168	78–89	149	0.28	0.20	≤ 0.94	0.25–0.31	138
Heart	M	52	11	5.2–75	50–55	82	0.11	0.14	≤ 0.54	0.08–0.14	84
	F	51	13	15–90	48–55	56	0.12	0.14	≤ 0.51	0.08–0.15	56
	Total	52	12	5.2–90	50–54	138	0.11	0.14	≤ 0.54	0.09–0.13	140
Lung	M	254	113	61–497	229–278	85	0.14	0.17	≤ 0.68	0.11–0.18	81
	F	213	95	59–410	188–237	59	0.15	0.13	≤ 0.48	0.11–0.18	55
	Total	237	108	59–497	219–255	144	0.15	0.15	≤ 0.68	0.12–0.17	136
Spleen	M	312	133	106–694	283–341	84	0.15	0.16	≤ 0.56	0.12–0.19	85
	F	229	94	75–475	205–253	61	0.16	0.14	≤ 0.46	0.12–0.19	58
	Total	277	125	75–694	257–297	145	0.16	0.15	≤ 0.56	0.13–0.18	143
Cerebrum	M	52	11	4.2–77	50–54	88	0.11	0.13	≤ 0.49	0.08–0.14	87
	F	49	12	7.4–73	46–53	58	0.11	0.11	≤ 0.45	0.08–0.14	56
	Total	51	11	4.2–77	49–53	146	0.11	0.12	≤ 0.49	0.09–0.13	143
Bone	M	70	35	1.2–153	63–78	87	2.5	1.1	≤ 4.4	2.3–2.8	84
	F	41	23	6.2–102	34–47	56	3.2	1.6	≤ 6.6	2.8–3.6	59
	Total	59	34	1.2–153	53–64	143	2.8	1.4	≤ 6.6	2.6–3.1	143
Hair	M	88	94	7.3–410	66–109	77	1.1	0.68	≤ 2.7	0.95–1.3	80
	F	30	22	≤ 90	24–36	52	0.88	0.51	≤ 1.9	0.75–1.0	57
	Total	64	79	≤ 410	51–78	129	1.0	0.62	≤ 2.7	0.91–1.1	137
Nail	M	161	115	29–527	133–188	71	1.3	2.5	≤ 10	0.75–1.9	77
	F	114	64	16–310	96–132	53	3.0	4.9	≤ 25	1.7–4.3	57
	Total	141	99	16–527	123–158	124	2.0	3.8	≤ 25	1.4–2.7	134
Tissue	Sex	Manganese					Molybdenum				
		Mean	S.D.	Range	95%CI	(No.)	Mean	S.D.	Range	95% CI	(No.)
Liver	M	1.4	0.40	0.02–2.3	1.3–1.5	85	0.68	0.36	≤ 1.4	0.60–0.75	86
	F	1.6	0.57	≤ 2.5	1.4–1.7	60	0.80	0.38	≤ 1.8	0.70–0.90	60
	Total	1.5	0.49	≤ 2.5	1.4–1.5	145	0.73	0.37	≤ 1.8	0.67–0.79	146
Kidney	M	0.98	0.28	0.05–1.7	0.92–1.0	87	0.26	0.15	≤ 0.60	0.23–0.29	82
	F	1.0	0.34	≤ 1.8	0.95–1.1	61	0.28	0.13	≤ 0.54	0.25–0.32	60
	Total	1.0	0.30	≤ 1.8	0.95–1.1	148	0.27	0.14	≤ 0.60	0.25–0.30	142
Heart	M	0.28	0.09	≤ 0.49	0.26–0.30	83	0.09	0.10	≤ 0.42	0.07–0.11	81
	F	0.29	0.09	≤ 0.46	0.27–0.32	55	0.08	0.10	≤ 0.38	0.05–0.10	55
	Total	0.29	0.09	≤ 0.49	0.27–0.30	138	0.09	0.10	≤ 0.42	0.07–0.10	136

Table 3. Continued

Tissue	Sex	Manganese					Molybdenum				
		Mean	S.D.	Range	95%CI	(No.)	Mean	S.D.	Range	95% CI	(No.)
Lung	M	0.19	0.11	≤ 0.47	0.16–0.21	84	0.11	0.12	≤ 0.52	0.08–0.13	82
	F	0.18	0.10	≤ 0.42	0.15–0.21	56	0.09	0.11	≤ 0.40	0.06–0.11	57
	Total	0.18	0.11	≤ 0.47	0.17–0.20	140	0.10	0.11	≤ 0.52	0.08–0.12	139
Spleen	M	0.16	0.06	≤ 0.37	0.15–0.18	79	0.09	0.10	≤ 0.44	0.07–0.11	83
	F	0.18	0.07	≤ 0.36	0.16–0.20	56	0.06	0.09	≤ 0.30	0.04–0.08	55
	Total	0.17	0.07	≤ 0.37	0.16–0.18	135	0.08	0.10	≤ 0.44	0.06–0.10	138
Cerebrum	M	0.28	0.08	≤ 0.52	0.27–0.30	86	0.06	0.08	≤ 0.31	0.04–0.08	80
	F	0.28	0.08	≤ 0.42	0.26–0.30	57	0.04	0.07	≤ 0.30	0.02–0.06	54
	Total	0.28	0.08	≤ 0.52	0.27–0.30	143	0.05	0.07	≤ 0.31	0.04–0.06	134
Bone	M	0.07	0.06	≤ 0.23	0.06–0.08	79	0.09	0.12	≤ 0.45	0.06–0.12	77
	F	0.07	0.07	≤ 0.25	0.06–0.09	54	0.10	0.15	≤ 0.55	0.06–0.14	56
	Total	0.07	0.06	≤ 0.25	0.06–0.08	133	0.09	0.14	≤ 0.55	0.07–0.12	133
Hair	M	3.5	5.4	≤ 32	2.4–4.7	87	0.29	0.32	≤ 0.67	0.22–0.36	75
	F	0.99	0.74	≤ 2.8	0.79–1.2	56	0.19	0.23	≤ 0.69	0.13–0.25	57
	Total	2.5	4.4	≤ 32	1.8–3.3	143	0.25	0.28	≤ 0.69	0.20–0.29	132
Nail	M	3.4	3.1	≤ 12	2.7–4.1	74	1.9	2.5	≤ 9.9	1.3–2.5	78
	F	2.3	2.4	≤ 12	1.7–2.9	57	2.0	2.5	≤ 7.8	1.3–2.7	53
	Total	2.9	2.8	≤ 12	2.4–3.3	131	1.9	2.5	≤ 9.9	1.5–2.4	131
Tissue	Sex	Nickel					Lead				
		Mean	S.D.	Range	95%CI	(No.)	Mean	S.D.	Range	95% CI	(No.)
Liver	M	0.09	0.17	≤ 0.72	0.05–0.12	79	0.32	0.34	≤ 1.2	0.25–0.34	84
	F	0.04	0.07	≤ 0.27	0.02–0.06	55	0.16	0.23	≤ 0.85	0.09–0.22	54
	Total	0.07	0.14	≤ 0.72	0.04–0.09	134	0.26	0.32	≤ 1.2	0.20–0.31	138
Kidney	M	0.10	0.18	≤ 0.84	0.06–0.14	78	0.29	0.30	≤ 1.2	0.22–0.36	82
	F	0.08	0.10	≤ 0.33	0.05–0.10	52	0.22	0.24	≤ 0.94	0.16–0.28	55
	Total	0.09	0.15	≤ 0.84	0.07–0.12	130	0.26	0.28	≤ 1.2	0.22–0.31	137
Heart	M	0.11	0.18	≤ 0.74	0.07–0.15	78	0.18	0.20	≤ 0.92	0.14–0.23	83
	F	0.11	0.15	≤ 0.55	0.07–0.15	55	0.40	0.58	≤ 2.4	0.25–0.55	60
	Total	0.11	0.17	≤ 0.74	0.08–0.14	133	0.27	0.42	≤ 2.4	0.20–0.34	143
Lung	M	0.10	0.15	≤ 0.58	0.07–0.14	72	0.25	0.24	≤ 0.89	0.20–0.30	81
	F	0.13	0.15	≤ 0.55	0.09–0.17	56	0.36	0.31	≤ 1.1	0.28–0.44	56
	Total	0.12	0.15	≤ 0.58	0.09–0.14	128	0.30	0.27	≤ 1.1	0.25–0.34	137
Spleen	M	0.11	0.21	≤ 0.87	0.07–0.16	79	0.21	0.24	≤ 1.0	0.15–0.26	81
	F	0.06	0.10	≤ 0.34	0.03–0.09	51	0.16	0.21	≤ 0.72	0.10–0.22	54
	Total	0.09	0.18	≤ 0.87	0.06–0.12	130	0.19	0.23	≤ 1.0	0.15–0.23	135
Cerebrum	M	0.07	0.13	≤ 0.52	0.04–0.10	80	0.29	0.47	≤ 2.8	0.19–0.39	89
	F	0.04	0.07	≤ 0.27	0.02–0.06	52	0.13	0.20	≤ 0.67	0.07–0.18	57
	Total	0.06	0.11	≤ 0.52	0.04–0.08	132	0.23	0.40	≤ 2.8	0.16–0.29	146
Bone	M	0.08	0.16	≤ 0.64	0.04–0.11	77	1.6	0.93	≤ 3.9	1.4–1.8	85
	F	0.09	0.17	≤ 0.55	0.05–0.14	52	1.4	0.99	≤ 3.3	1.1–1.7	56
	Total	0.08	0.17	≤ 0.64	0.05–0.11	129	1.5	0.96	≤ 3.9	1.4–1.7	141
Hair	M	0.54	0.72	≤ 2.6	0.38–0.71	76	3.0	2.3	≤ 9.8	2.4–3.5	76
	F	0.75	0.76	≤ 2.5	0.55–0.95	58	2.0	1.5	≤ 5.6	1.6–2.4	55
	Total	0.63	0.74	≤ 2.6	0.51–0.76	134	2.5	2.1	≤ 9.8	2.2–2.9	131
Nail	M	5.8	6.2	≤ 24	4.4–7.2	78	10	8.1	≤ 31	8.5–12	79
	F	5.0	5.1	≤ 19	3.6–6.5	51	14	13	≤ 44	9.9–17	55
	Total	5.5	5.8	≤ 24	4.5–6.5	129	12	11	≤ 44	9.8–13	134

Table 3. Continued

Tissue	Selenium						Silicon				
	Sex	Mean	S.D.	Range	95%CI	(No.)	Mean	S.D.	Range	95% CI	(No.)
Liver	M	0.90	0.44	≤ 2.3	0.77–1.0	49	6.9	7.6	≤ 29	5.1–8.6	79
	F	0.74	0.37	≤ 1.7	0.63–0.85	48	7.9	7.4	≤ 24	6.0–9.9	57
	Total	0.82	0.41	≤ 2.3	0.74–0.90	97	7.3	7.5	≤ 29	6.0–8.6	136
Kidney	M	1.2	0.32	0.56–2.0	1.1–1.3	51	8.6	10.0	≤ 47	6.3–11	82
	F	1.3	0.35	0.54–1.9	1.2–1.4	46	8.4	7.6	≤ 24	6.3–10	55
	Total	1.2	0.33	0.54–2.0	1.2–1.3	97	8.5	9.4	≤ 47	6.9–10	137
Heart	M	0.63	0.29	≤ 1.1	0.55–0.71	52	9.0	12.0	≤ 52	6.4–12	83
	F	0.68	0.37	≤ 1.5	0.57–0.79	48	10.0	9.3	≤ 37	7.8–13	56
	Total	0.66	0.33	≤ 1.5	0.57–0.72	100	9.5	11.0	≤ 52	7.7–11	139
Lung	M	0.88	0.57	≤ 2.1	0.72–1.0	51	37	27	≤ 112	31–44	77
	F	0.88	0.46	≤ 2.1	0.74–1.0	45	26	19	≤ 83	20–31	53
	Total	0.88	0.52	≤ 2.1	0.78–0.98	96	33	25	≤ 112	28–37	130
Spleen	M	1.2	0.58	≤ 2.4	1.0–1.3	51	8.7	9.6	≤ 38	6.5–11	80
	F	0.90	0.37	0.36–2.3	0.79–1.0	46	7.5	6.2	≤ 18	5.8–9.3	50
	Total	1.0	0.51	≤ 2.4	0.94–1.2	97	8.2	8.5	≤ 38	6.8–9.7	130
Cerebrum	M	0.50	0.28	≤ 0.97	0.42–0.58	50	5.8	6.6	≤ 22	4.2–7.3	72
	F	0.50	0.33	≤ 1.2	0.41–0.60	50	6.3	6.5	≤ 24	4.5–8.1	53
	Total	0.50	0.30	≤ 1.2	0.44–0.56	100	6.0	6.5	≤ 24	4.8–7.1	125
Bone	M	0.71	0.87	≤ 2.8	0.47–0.96	52	74	75	≤ 278	57–90	82
	F	0.48	0.67	≤ 2.0	0.29–0.68	47	98	89	≤ 320	75–122	56
	Total	0.60	0.79	≤ 2.8	0.45–0.76	99	84	82	≤ 320	70–97	138
Hair	M	1.5	1.2	≤ 3.6	1.2–1.9	47	174	156	≤ 559	140–208	84
	F	0.90	0.83	≤ 2.4	0.65–1.1	45	172	131	5.1–592	136–209	51
	Total	1.2	1.1	≤ 3.6	1.0–1.4	92	174	147	≤ 592	149–198	135
Nail	M	6.4	7.3	≤ 23	4.3–8.6	48	335	308	≤ 1118	264–405	75
	F	7.5	8.6	≤ 24	4.8–10	43	446	350	≤ 1187	351–542	54
	Total	6.9	7.9	≤ 24	5.3–8.6	91	381	329	≤ 1187	324–439	129
Tissue	Tin						Vanadium				
	Sex	Mean	S.D.	Range	95%CI	(No.)	Mean	S.D.	Range	95% CI	(No.)
Liver	M	0.39	0.37	≤ 1.5	0.31–0.47	85	0.49	0.17	≤ 0.86	0.45–0.53	81
	F	0.30	0.37	≤ 1.3	0.21–0.40	59	0.49	0.16	0.10–0.78	0.45–0.53	59
	Total	0.36	0.37	≤ 1.5	0.29–0.42	144	0.49	0.16	≤ 0.86	0.47–0.52	140
Kidney	M	0.22	0.24	≤ 0.79	0.16–0.27	82	0.46	0.21	≤ 0.92	0.41–0.50	84
	F	0.12	0.18	≤ 0.54	0.07–0.16	56	0.38	0.14	≤ 0.68	0.34–0.42	56
	Total	0.18	0.23	≤ 0.79	0.14–0.21	138	0.43	0.19	≤ 0.92	0.40–0.46	140
Heart	M	0.19	0.24	≤ 0.78	0.14–0.24	85	0.65	0.25	≤ 1.3	0.59–0.70	83
	F	0.08	0.15	≤ 0.52	0.04–0.12	56	0.61	0.23	≤ 1.1	0.55–0.67	60
	Total	0.15	0.22	≤ 0.78	0.11–0.18	141	0.63	0.24	≤ 1.4	0.59–0.67	143
Lung	M	0.23	0.29	≤ 1.1	0.17–0.29	82	0.39	0.21	≤ 0.91	0.34–0.43	80
	F	0.09	0.17	≤ 0.58	0.05–0.14	56	0.34	0.18	≤ 0.76	0.29–0.38	58
	Total	0.17	0.25	≤ 1.1	0.13–0.22	138	0.37	0.20	≤ 0.91	0.33–0.40	138
Spleen	M	0.23	0.25	≤ 0.95	0.18–0.29	83	0.44	0.16	≤ 0.78	0.40–0.47	81
	F	0.13	0.21	≤ 0.58	0.08–0.19	58	0.46	0.15	≤ 0.82	0.42–0.50	57
	Total	0.19	0.24	≤ 0.95	0.15–0.23	141	0.44	0.16	≤ 0.82	0.42–0.47	138
Cerebrum	M	0.15	0.19	≤ 0.70	0.11–0.19	84	0.45	0.16	≤ 0.79	0.41–0.48	82
	F	0.04	0.10	≤ 0.38	0.02–0.07	55	0.41	0.14	0.07–0.66	0.38–0.44	59
	Total	0.11	0.17	≤ 0.70	0.08–0.13	139	0.43	0.15	≤ 0.79	0.41–0.46	141

Table 3. Continued

Tissue	Tin						Vanadium				
	Sex	Mean	S.D.	Range	95%CI	(No.)	Mean	S.D.	Range	95% CI	(No.)
Bone	M	0.84	0.57	≤ 2.3	0.71–0.97	77	3.8	1.3	≤ 6.5	3.5–4.1	85
	F	0.81	0.73	≤ 2.5	0.61–1.00	56	4.3	1.4	0.74–7.2	4.0–4.7	59
	Total	0.83	0.64	≤ 2.5	0.72–0.94	133	4.0	1.3	≤ 7.2	3.8–4.2	144
Hair	M	0.67	0.81	≤ 3.0	0.49–0.84	82	0.84	0.73	≤ 2.8	0.68–1.0	77
	F	0.66	0.68	≤ 2.1	0.48–0.84	59	0.92	0.75	≤ 2.8	0.73–1.1	59
	Total	0.66	0.75	≤ 3.0	0.54–0.79	141	0.88	0.74	≤ 2.8	0.75–1.0	136
Nail	M	2.9	4.4	≤ 17	1.9–3.9	80	3.0	3.0	≤ 12	2.3–3.7	75
	F	1.0	2.8	≤ 13	0.3–1.8	57	2.3	2.5	≤ 9.3	1.6–3.0	50
	Total	2.1	3.9	≤ 17	1.5–2.8	137	2.7	2.8	≤ 12	2.2–3.2	125
Tissue	Zinc						Aluminum				
	Sex	Mean	S.D.	Range	95%CI	(No.)	Mean	S.D.	Range	95% CI	(No.)
Liver	M	44	13	9.7–76	41–47	81	2.6	1.6	≤ 6.7	2.1–3.2	35
	F	50	18	10–91	45–55	58	3.1	1.2	≤ 5.6	2.7–3.5	36
	Total	47	16	9.7–91	44–49	139	2.9	1.4	≤ 6.7	2.5–3.2	71
Kidney	M	43	12	18–72	40–46	86	2.9	1.5	≤ 6.0	2.4–3.4	36
	F	42	15	11–84	37–46	55	2.9	1.3	≤ 5.4	2.5–3.4	33
	Total	42	13	11–84	40–45	141	2.9	1.4	≤ 6.0	2.6–3.3	69
Heart	M	22	4.1	12–32	22–23	82	2.2	1.4	≤ 5.7	1.8–2.7	37
	F	25	5.8	10–44	23–26	56	3.0	1.1	≤ 4.8	2.6–3.3	36
	Total	23	4.9	10–44	22–24	138	2.6	1.3	≤ 5.7	2.3–2.9	73
Lung	M	10	2.6	5.1–16	9.4–11	83	36	32	3.4–115	25–47	36
	F	12	3.6	3.3–22	11–13	55	16	12	3.8–57	12–20	36
	Total	11	3.2	3.3–22	10–11	138	26	26	3.4–115	20–32	72
Spleen	M	15	3.0	4.3–21	14–15	83	2.5	1.6	≤ 8.3	1.9–3.0	35
	F	15	2.6	6.9–20	15–16	54	2.9	1.6	≤ 8.4	2.3–3.4	36
	Total	15	2.8	4.2–21	15–16	137	2.7	1.6	≤ 8.4	2.3–3.0	71
Cerebrum	M	11	2.1	4.4–16	10–11	84	2.6	1.9	≤ 7.0	2.0–3.2	37
	F	11	2.4	4.3–17	10–11	53	2.6	1.8	≤ 7.6	2.0–3.2	36
	Total	11	2.2	4.3–17	10–11	137	2.6	1.8	≤ 7.6	2.1–3.0	73
Bone	M	43	13	5.5–69	40–45	84	194	68	84–361	171–218	32
	F	47	15	16–79	43–51	56	245	88	82–395	216–275	34
	Total	44	14	5.5–79	42–47	140	221	83	82–395	201–241	66
Hair	M	140	41	6.9–254	131–149	83	72	68	14–267	49–96	33
	F	142	59	46–308	126–158	56	44	31	6.6–123	34–54	37
	Total	141	49	6.9–308	133–149	139	57	54	6.6–267	45–70	70
Nail	M	96	36	18–208	88–104	79	187	96	58–407	154–220	32
	F	97	42	12–237	85–109	51	166	91	48–432	135–197	34
	Total	97	38	12–237	90–103	130	176	94	48–432	154–199	66

Pääkko *et al.*'s report<sup>19)</sup> that the concentration of Cr in the lung increases according to the age and the period of smoking, we surmise that smoking influences the concentration of heavy metals in tissues. Copper (Cu) was detected at a relatively high level in the order of the liver, cerebrum, heart and kidney. Compared with the other heavy metals, Cu was accumulated at a high concentration especially in the cerebrum. The highest level of iron (Fe) was detected in the spleen, which is the tissue of hematopoiesis,

and it was also detected in the order of lung, liver and kidney. The high concentration of Fe detected in these organs was influenced of blood. Mercury (Hg) was detected in a large amount in the kidney and liver compared to the other tissues, but its mean concentration was below 0.28  $\mu\text{g/g}$ , which was lower than the concentration in Japanese.<sup>5,6,20)</sup> However, 2.8  $\mu\text{g/g}$  of mean value was detected in the bone: thus Hg accumulates in the bones. Manganese (Mn) was detected significantly in the kidney and liver.

The concentration of Mn in Korean tissues was similar to Tipton's report,<sup>21)</sup> and it was detected in a high level in the hair and nails. Molybdenum (Mo) was detected in a high level in the order of liver, kidney and lung, but the difference in the concentration was not large in the lung, heart, spleen, cerebrum and bone. Nickel (Ni) was detected to a great extent in the lung, with a mean value of 0.12  $\mu\text{g/g}$ , but its level was similar in the other tissues, 0.06–0.12  $\mu\text{g/g}$ , except in the nails, where the mean value was 5.5  $\mu\text{g/g}$ . Lead (Pb) was detected in the order of the lung, heart, liver, kidney and cerebrum, and 1.5  $\mu\text{g/g}$  was detected in bone. Also 2.5  $\mu\text{g/g}$  and 12  $\mu\text{g/g}$  was detected in the hair and nails, so we determined that it accumulates in bone, nail and hair. Selenium (Se) was distributed evenly in all tissues in the range of 0.50–1.2  $\mu\text{g/g}$ , though 6.9  $\mu\text{g/g}$  was detected in the nails. Silicon (Si) was detected in the amount of 33  $\mu\text{g/g}$  from the lung, which was 3–5 times higher than in other tissues. This is due to the Si which is included in the dust of air and thus accumulated in the lung. The lung concentration of Si increased with age (Pearson's correlation coefficient = 0.459,  $p < 0.01$ ). Also, Si was highly accumulated in the hair and nails. Tin (Sn) was distributed evenly in every tissue except for bone, in the range of 0.11–0.36  $\mu\text{g/g}$ , which was similar to Hamilton's report.<sup>22)</sup> Vanadium (V) was also distributed evenly in every tissue except for bone, and it can be seen that bone was the accumulative tissue because 4.0  $\mu\text{g/g}$  was detected in bone. Zinc (Zn) was highly detected in the liver and kidney, and the concentration of Zn in Korean tissues was lower than in American<sup>21)</sup> and English.<sup>22)</sup> Aluminum (Al) was detected with a mean value of 26  $\mu\text{g/g}$  in the lung, and 2.6–2.9  $\mu\text{g/g}$  was detected evenly in the liver, kidney, heart and cerebrum which was similar to Yugawa's report.<sup>6)</sup> The accumulation of aluminum in the lung is thought to be the result of breath of air dust which contains aluminum.

From the above results, heavy metals such as Cd, Mn, Hg, Mo, Sn and Zn in Korean tissues were detected from the tissues related to metabolism, and the heavy metals Cr, Si and Al were highly detected from tissues exposed to ambient air, such as the lung. Major differences in the distribution of the heavy metals, as with As, Ni, Se, Pb and V, in tissues were rarely seen.

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