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Severe lead contamination among children of samurai families in Edo period Japan

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ABSTRACT

This paper presents evidence for severe lead contamination among children of samurai families living in a castle town in Edo period Japan (1603–1867). Excavated rib bones were analyzed by atomic absorption, and soft X-ray roentgenograms of long bones were taken. The median values of lead concentration in the bones of children 3 years of age and under(1241.0 μg Pb/g dry bone) and 4–6 years of age (462.5 μg Pb/g dry bone) were significantly higher than those of adult males (14.3 μg Pb/g dry bone) and females (23.6 μg Pb/g dry bone) ($p < 0.001$). In addition, that of children over 6 years of age (313.0 μg Pb/g dry bone) was significantly higher than those of adult males ($p < 0.01$) and adult females ($p < 0.05$). The median value of lead in the bones of children 3 years of age and under was over fifty times higher than that of their mothers (adult females). Hypertrophy was seen in the long bones of five samurai children. In this area, lead lines or lead bands were distinguished by soft X-ray roentgenogram. Samurai children suffered from severe lead contamination in Edo period Japan. When the mothers were nursing their children, the children might have ingested their mother's white lead non-selectively.

1. Introduction

Lead is found widely in the environment as a natural substance and a contaminant. Lead is used in many types of industry. Air contaminated with lead in workshops may be discharged into the environment. The total amount of global environmental lead was estimated from the ice of the Arctic (Murozumi et al., 1969). The lead concentration in ice today is two hundred times higher than that in 800 B.C. in Arctic ice sheets, with the sharpest rise occurring in 1940. The increase in lead with time in Arctic ice is ascribed mainly to lead smeltries before 1940 and the burning of lead alkyls after 1940. Imai (2005) reported a geochemical map of Japan for 53 elements that evaluated the distribution and natural background levels of toxic elements. About 3000 fine stream sediments are collected from river and the sampling density is one sample/10 × 10 km. The average value of lead in the sediment of the whole country was 23.1 ppm (3024 samples, Max. 7594 ppm, Min. 4.07 ppm, SD = 11.8). Higher lead concentrations are attributed to mineral deposits.

Since Japanese modernization began in 1868 (Meiji Reformation), lead (Pb) pollution in our overall environment has greatly increased, especially with industrialization, urbanization and motorization. Before the modern period, Japan was an agricultural country, which was ruled by samurai warriors during the Edo period (1603–1867). In a previous study, we showed that although people in Edo period Japan lived under less contaminated conditions than the modern atmosphere and environment, populations with extremely high lead contamination lived in a castle town (Kokura; Kitakyushu City) in West Japan. Samurai and merchant class people living in the castle town showed extremely high levels of lead contamination (Nakashima et al., 1998, 2007).

Lead is a devastating, debilitating poison that has harmed industrial workers for centuries, but lead has also been among the most devastating poisons of children (Rosner and Markowitz, 2007). In the 1990s, lead paint poisoning in children was recognized, and childhood lead poisoning is now well documented and persists as a major public health problem throughout the world (Lanphear et al., 1996a,b). The clinical features of acute lead poisoning include cramp, colicky abdominal pain and constipation in the early stage. Headache and fatigue are common complaints. The more severe neurologic manifestations of lead encephalopathy, confusion, coma and seizures are more common in children than in adults (Lewis, 2007). In severe cases, renal failure and convulsions can occur, and extremely high levels may lead to coma and death (Meyer et al.,

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2003). The early signs of chronic lead poisoning include fatigue, apathy, irritability and vague gastrointestinal symptoms. Arthralgias (articular gouts) and myalgias may be involved in the extremities of axial structures. As exposure continues, central nervous system symptoms progress, with insomnia, confusion, impaired concentration and memory problems. Long-term exposure can lead to distal motor neuropathy presenting with wrist drop (Lewis, 2007).

This paper presents evidence of lead contamination of children of samurai living in a castle town in a highly polluted environment.

2. Materials and methods

2.1. Sohgenji site

The bone samples from the samurai class used in this study consisted of ribs that were excavated at the Sohgenji Temple site (Zen Buddhist temple established in 1632 and burned down in 1866 in a civil war) in Kitakyushu, Japan. This was the temple of the retainer of the Ogasawara clan. Ogasawara was the daimyo (feudal lord) of Kokura in Kitakyushu, Japan. The bones buried at this site were all from people of the samurai class. All samurai bones were placed in large, uncolored earthen pots. Burial in an earthen pot was peculiar to the samurai class. Owing to this custom, the bones are very well preserved. All the samples studied are shown in Table 1. Two samples were distinguished by the names in an epitaph on the pot. The age of the adults was classified into prime (21–39 years), middle (40–59 years) and old (over 60 years) ages by anatomical observations. The age of the children was classified into 3 years of age and under (milk teeth were erupting), 4–6 years of age (eruption of milk teeth was complete) and over 6 years of age (permanent teeth had begun to erupt).

Table 1
Specimens of samurai class in this study (Sohgenji site).

Adult Males ($n = 11$)		Adult Females ($n = 12$)	
Sample ID	Age	Sample ID	Age
35	middle	21	76[b]
91	old	39	middle
104	prime	78	middle
107	69[a]	113	old
142	old	139	old
168	prime	144	middle
174	middle	169	middle
180	unknown	196	old
207	middle	222	prime
337	middle	290	middle
371	prime	333	middle
		641	old
Children ($n = 38$)			
44	under 3 years	205	under 3 years
22–4	under 3 years	26	under 3 years
36–2	under 3 years	75	under 3 years
89	under 3 years	155	under 3 years
156[c]	under 3 years	158[c]	under 3 years
165	under 3 years	167[c]	under 3 years
297	under 3 years	299	under 3 years
330	under 3 years	335[c]	under 3 years
348	under 3 years	355	under 3 years
392	under 3 years	461	under 3 years
636	under 3 years	34	4–6 years
58	4–6 years	93–1	4–6 years
108–2	4–6 years	111	4–6 years
143	4–6 years	157[c]	4–6 years
191	4–6 years	209	4–6 years
295	4–6 years	298	4–6 years
300	4–6 years	315	4–6 years
369	4–6 years	125	over 6 years
208	over 6 years	360	over 6 years

[a] Niki Kan-Emon (1639–1708), chief retainer of the Ogasawara.
[b] Ogasawara Sada (1790–1866), daughter of the 6th feudal lord of the Ogasawara.
[c] Hypertrophy was seen.

2.2. Atomic absorption spectrometry

The bone samples were treated with 1% NaOH and then dried at 105 °C for 24 h. Approximately 200 mg of rib bone was taken, and the precisely weighed samples were transferred into a 100-ml Kjeldahl flask and digested with a mixture of 15 ml of nitric acid and 2 ml of sulfuric acid. The residual sample was made up to 100 ml with distilled water. The sample solution was analyzed by atomic absorption spectrometry with a Hitachi Model 180-80 spectrometer equipped with a graphite atomizer. The concentration of the sample was calculated from the calibration curve derived from standard solutions for each run.

2.3. Soft X-ray roentgenogram

Soft X-ray roentgenograms of long bones of upper and lower extremities were taken by Softex type CMB-S (Sofron Co., Ltd., Tokyo).

2.4. Statistical analysis

Measurement values were expressed as median and range (max. and min.) values of each population. Statistical comparisons between two groups were performed using Mann–Whitney test and those within each age group were performed using Kruskal–Wallis test.

3. Results

3.1. Lead concentrations in bones

The lead concentrations in the rib bones of children and adults of the samurai class are shown in Table 2. Thirty-eight rib bones of children were analyzed from among the bones of 47 excavated children. The median values of lead concentration in the children 3 years of age and under (1241.0 μg Pb/g dry bone) and 4–6 years of age (462.5 μg Pb/g dry bone) were significantly higher than those of the adult males (14.3 μg Pb/g dry bone) and females (23.6 μg Pb/g dry bone) ($p < 0.001$). In addition, that of children of over 6 years of age (313.0 μg Pb/g dry bone) was significantly higher than those of adult males ($p < 0.01$) and adult females ($p < 0.05$). The median value for the children 3 years of age and under was over fifty times higher than that of their mothers (adult females). The median value of the children 3 years of age and under was also significantly higher than that of the children 4–6 years of age ($p < 0.001$). Statistical analysis of each age group of samurai children was performed by Kruskal–Wallis test (Fig. 2). A significant difference in lead contamination was found between 3 years of age and under and 4–6 years of age in the samurai children. The lead concentration in the soil at the Sohgenji site was 21.7 μg lead/g dry soil. As this value is sufficiently lower than that of the children's bones, and was positioned between those of adult males and females, we concluded that there were no contaminational relationships between these values.

3.2. Lead line or lead band

Forty-seven excavated bones of samurai children were studied from an anatomical point of view. During the entire growth period, epiphyses or secondary centers of ossification were separated from the primary center of ossification, which forms the diaphysis, or body. A large long bone has at least two epiphyses, one at each end. A peculiar pathological change was seen in one end of the diaphysis of the long bones in the upper and lower extremities, namely,

Table 2
Lead concentrations in rib bones in children and adults of samurai class.

Bone lead level (μg lead/g dry bone)				
	Number	Range		Median
		max.	min.	
Children				
3 years of age and under (Milk teeth were erupting)	21	5140.0	148.0	1241.0
4 to 6 years of age (Eruption of milk teeth was complete)	14	964.0	104.0	462.5
Over 6 years of age (Permanent teeth had begun to erupt)	3	644.0	115.0	313.0
Adult males	11	33.0	4.4	14.3
Adult females	12	945.5	5.6	23.6
Soil at the Sohgenji site				21.7 #
3 years of age and under	Adult males		p=0.0000	***
4 to 6 years of age	Adult males		p=0.0000	***
Over 6 years of age	Adult males		p=0.0055	**
3 years of age and under	Adult females		p=0.0003	***
Over 6 years of age	Adult females		p=0.0308	*
3 years of age and under	4 to 6 years of age		p=0.0002	***
4 to 6 years of age	Over 6 years of age		p=0.4324	NS
Adult males	Adult females		p=0.0564	NS

Mann–Whitney test: ***: $p < 0.001$, **: $p < 0.01$, *: $p < 0.05$ significant, NS: not significant, #; μ g Pb/g dry soil.

hypertrophy (peculiar enlargement) of the metaphyseal part.A photograph and soft X-ray roentgenogram of the femurs of child No. 335 are shown in Fig. 1. This hypertrophy was seen in the metaphyseal part of both right and left femurs (Fig. 1, Left). At the same time, a few lines were seen in the same part in the soft X-ray roentgenogram (Fig. 1, Right). These lines are called lead lines (Leone, 1968; Sachs, 1981) or lead bands (Blickman et al., 1986).

At the Sohgenji site, this hypertrophy was seen in the specimens of five children, as shown in Table 1. The overall prevalence of hypertrophy was 10.6% (5 specimens among 47 children). We separated the specimens into two groups: those with hypertrophy and those without hypertrophy. The lead concentrations in the bones are shown in Table 3. The median value of the group with hypertrophy (1486.0 μg Pb/g dry bone) was higher than that of the group without hypertrophy (726.0 μg Pb/g dry bone), but the difference was not significant.

4. Discussion

4.1. Upper ranks of society suffered higher lead poisoning

Gilfillan (1965) stated that lead poisoning (plumbism) is considered a major influence in the fall of the Roman Empire. Ancient well-to-do Romans exposed themselves to the risk of ingesting considerable quantities of lead from their food and drink, especially from wine, grape syrup and preserved fruit. Nriagu (1983) estimated the amount of lead exposure among people during the Roman Empire. Estimates of the average lead intakes were 250 μg of lead per day (range: 160–1520) by aristocrats, 35 μg of lead per day (range: 35–350) by plebeians, and 15 μg of lead per day (range: 15–77) by slaves. There is a strong suggestion that a large number of Roman aristocrats ingested more than enough lead with their food and drink each day to put them at risk of lead poisoning. The coexistence of widespread plumbism and gout during the Roman Empire seems to have been an important feature of the aristocratic lifestyle. In a study of specimens from a colonial (1630–1730) plantation cemetery in Virginia, Aufderheide et al. (1981) reported that plantation proprietors (185 ppm bone ash) were found to have skeletal lead levels more than five-fold greater than those of the plantation labor force (35 ppm bone ash). In a study of merchant and samurai populations living in a castle town in the Edo period (1603–1867), where samurai were the ruling class and merchants were the wealthy class, these classes suffered markedly more contamination than farmer class people living in the suburbs of the feudal domain (Nakashima et al., 1998, 2007).

4.2. Females are more contaminated than males in the upper ranks of society

In the samurai class (Nakashima et al., 1998), the mean value of lead contamination of females (30.5 μg Pb/g dry bone) was higher than that of males (15.6 μg Pb/g dry bone) and, moreover, in the merchant class (Nakashima et al., 2007), the mean value of females (90.8 μg Pb/g dry bone) was significantly higher than that of males (39.9 μg Pb/g dry bone; $p < 0.01$). In view of the higher contamination in female bone than male, we assumed that facial cosmetics (white lead) were one of the main sources of lead exposure. During the Edo period, cosmetics became popular and the vogue was usually introduced by Kabuki actors, courtesans and geisha through ukiyoe prints and popular literature, and by beauticians who helped establish fashions. The white face powders used in those days were keifun (mercury chloride) and empaku (white lead). Mercury chloride was imported mainly from China, and white lead was popular in Japan, although the toxic nature of lead cosmetics was not recognized. Ikutarou Hirai, the first professor of the Department of Pediatrics at Kyoto University, revealed in 1923 that “so-called tentative meningitis” of infants was actually caused by lead-containing face powder used by mothers (Horiguchi, 2006).

4.3. Highly contaminated mothers would strongly affect their children

As the relationship between mother and child is very close, highly contaminated samurai mothers would strongly affect their children through their lead-containing face powder. As shown in Table 2, the lead concentrations in children 3 years of age and under and 4–6 years of age were significantly higher than those in adult males and

Fig. 1. Photograph and soft X-ray roentgenogram of No. 335 child femur (R: right side), under 3 years of age. Four lead lines are shown by arrows (→). Minimum scale is 1 mm.

females ($p < 0.001$). As the median value of the children under 3 years of age was over fifty times higher than that of their mothers (adult females), samurai children might have been contaminated more than their mothers. In terms of present lead exposure among mothers and their newborn children in Toronto, the mean maternal blood lead levels were found to be almost invariably higher than the neonatal levels, and it was indicated that the maternal burden contributed 35% to the variability in fetal lead levels (Koren et al., 1990). In the First Nation Cree in Mushkegowuk territory of Northern Ontario, Canada, breast milk Pb and maternal blood lead were significantly correlated (Hanning et al., 2003). There were no reports that children's contamination was significantly higher than that of their mothers. As the difference in the median values among age groups was significant (Fig. 2), we can infer that the younger children were more vulnerable to lead exposure. When a mother was nursing her child, the child might have ingested the mother's white lead non-selectively. Older children could avoid the ingestion of foreign substances other than foods.

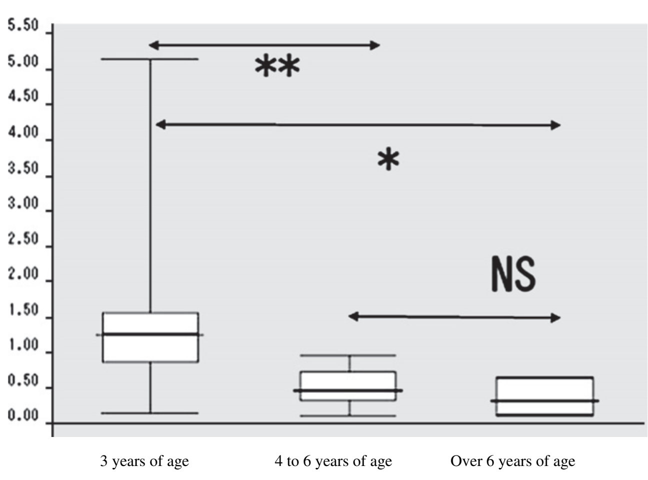

Fig. 2. Kruskal–Wallis test of each age group of samurai children. **: $p < 0.01$, *: $p < 0.05$ significant, NS: not significant ($p = 0.0003$ after correction of the same rank).

4.4. Possibility of diagenesis

Lead, atomic number 82, is one of the most abundant non-essential trace elements in the human body. Bone contains approximately 91% of the total body burden of lead (Schroeder and Tipton, 1968). The lead level in human beings is measured by blood lead and bone lead concentrations. Although the blood lead level is recognized as an important index of lead exposure and accumulation in populations, it captures only a short time frame of previous exposure limited to 21–30 days (Rosen et al., 1993). Bone lead levels serve as a cumulative dosimeter of lead exposure over many years, because of lead's long residence time in bone (Hu, 1998;

Table 3
Lead concentrations in groups of children with and without hypertrophy.

Bone lead level (μg lead/g dry bone)					
	Number	Range		Median	
		max.	min.		
Samurai children					
Group with hypertrophy	5	5140.0	373.0	1486.0	NS
Group without hypertrophy	33	2698.0	104.0	726.0	
Mann–Whitney test: NS; not significant					
Group with hypertrophy	–	group without hypertrophy	$p = 0.0556$	NS	

Hu et al., 1998). The lead content of archeologically recovered skeletal tissue may accurately reflect the lifetime lead ingestion of individuals. Now, we intend to evaluate the total amount of lead exposure and accumulation in a population using human bones excavated at an archeological site. However, a confounding problem could be that the bones might have undergone post-mortem absorption of lead in the ground or its surrounding environment (Waldron, 1981; Reinhard and Ghazi, 1992; Ghazi et al., 1994). In Japanese burial services, coffins were usually made of wood and pottery as an uncolored earthen pot, and the face of the dead person was not painted heavily. The lead concentration in the soil at the Sohgenji site was 21.7 μg Pb/g dry soil weight (Table 2). This value nearly agreed with that reported by the Geochemical Survey of Japan (Imai, 2005). The concentration of lead in Kokura, Japan was 33.3 ppm. Judging from the lead concentration in the soil at the site, diagenesis was not considered to be responsible for the extremely high concentrations of lead found in the samurai children.

4.5. Anatomical features of severely contaminated children's skeletons

From the anatomical point of view, there were five cases in which anomalies of bone were seen (Fig. 1). These were hypertrophy of the long bones and a few lead lines or lead bands. These roentgenographic pictures of dense metaphyseal bands seen in the growing long bones of children with lead poisoning are familiar to radiologists (Leone, 1968). These anomalies were seen in all the long bones of the upper and lower extremities in the five cases. Sachs (1981) reported that the appearance of a lead line required a minimum blood lead concentration (PbB) of 70–80 μg/dL. The blood lead concentrations in these samurai children might have been over these values. Bouchard et al. (2009) reported that, in young adults with low levels of lead exposure, higher blood lead levels were associated with increased odds of major depression and panic disorders. As the mean blood lead level was 1.61 μg/dL (range, 0.3–37.3 μg/dL), the lead level of samurai children might have been far higher than these values. The lead concentrations in the bones of the groups of children with and without hypertrophy are shown in Table 3. The median value of the group with hypertrophy (1486.0 μg Pb/g dry bone) was considerably higher than that of the group without hypertrophy (726.0 μg Pb/g dry bone), but the difference was not significant.

4.6. Discrepancy in cerebral palsy of severely contaminated samurai children

There are reports about a strong association between lead exposure and intellectual impairment in children (Needleman et al., 1979; Canfield et al., 2003; Lanphear et al., 2005). Lanphear et al. (2000) described that deficits in cognitive and academic skills associated with lead exposure occurred at blood concentrations lower than 5 μg/dL. The severe contamination of samurai children of the Edo period might have left them with severe intellectual impairments (cerebral palsy) when they grew up. Partly because of the high lead contamination in samurai children, severe political insecurity could develop in the Edo period when highly lead-contaminated samurai children grew up. From historical documents (Cosenza and Harris, 1930; Suzuki, 1985), intellectual impairments (cerebral palsy) were seen in the Tokugawa Shogunate, particularly Tokugawa Ieshige (1712–1761), the 9th Shogun, and Tokugawa Iesada (1824–1858), the 13th Shogun, in the Edo period. The former had no impact on politics on account of the peace of the period, but the latter had a serious impact on Japanese politics. In 1853, United States Commodore Matthew Perry (1794–1858) entered Uraga harbor, Kanagawa, Japan, with four battleships (gunboat diplomacy). Japan entered the period of Bakumatsu (1853–1867; the final years of the Edo period when the Tokugawa Shogunate came to an end). The high lead concentrations in the samurai children of the Edo period may have left them intellectually incapable of dealing with the political crisis, resulting in the downfall of the Shogunate. Whether or not lead exposure is related to children's intellectual impairment will be the focus of a prospective epidemiologic study (Koller et al., 2004).

5. Conclusion

There was severe lead contamination among children of samurai families living in a castle town in the Edo period (1603–1867). As the relationship between mother and child is very close, contamination of samurai children by white lead is more serious than that of their mothers. The median value for the children 3 years of age and under was over fifty times higher than that of their mothers. The bones of five children showed lead lines or lead bands. This shows that lead contamination deeply affected bone growth. As samurai were the ruling class, severe political insecurity could develop when highly lead-contaminated samurai children grew up.

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