Letter

Comparison of Concentrations of Lead and Cadmium in Various Parts of The Femur Head in Patients after Arthroplasty of The Hip Joint in Northwest Poland*

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Abstract

Objective To determine the concentrations of lead (Pb) and cadmium (Cd) in three kinds of materials (cartilage, cortical bone, and cancellous bone) of the femur head obtained from patients in the process of operation.

Methods Concentrations of Pb and Cd were determined in selected parts of the femur head of 30 patients after total hip arthroplasty, using ICP-AES (atomic absorption spectrophotometry).

Results Pb contained the highest concentration in cortical bone, while Cd did so in cancellous bone. There were statistically significant differences in the concentrations of both elements between the cartilage and cortical bone, and also differences in the concentration of Pb between the cartilage and cancellous bone. There were no significant differences in the concentrations of Pb or Cd between cortical and cancellous bone.

Conclusion Comparative studies on toxic metals should take into account both analogous bones and their fragments, as even if they come from the same kind of bones (e.g. femur head), clear differences exist in concentrations of heavy metals related to the sampling site and type of tissue (cartilage, cortical bone, and cancellous bone).

Key words: Femur head; Heavy metals; Cartilage; Cortical bone; Cancellous bone

Biomed Environ Sci, 2012; 25(5):577-582 doi: 10.3967/0895-3988.2012.05.012 ISSN:0895-3988

www.besjournal.com(full text) CN: 11-2816/Q

INTRODUCTION

The properties of bones and their long recovery time make them an ideal indicator for chronic exposure to certain metals, and a basis for indirect assessment on the degree of environmental exposure[1-3]. As technological progress has resulted in increasing environmental pollution of anthropogenic origin, including heavy metals, we are challenged by an increasing necessity of monitoring not only environmental pollution, but also concentrations of heavy metals in human tissues.

Human bones may provide a wealth of valuable

*This paper was financed as research project no. NN 404507738 by the Polish Ministry of Education from the resources for years 2010-2011.

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Received: November 7, 2011; Accepted: April 19, 2012

information as they reflect long-term processes in the environment, and the influence of generally low concentrations of heavy metals, including Pb and Cd. These elements accumulate in the skeleton of humans and other mammals throughout their lives[4].

Until recently, significant amounts of Pb have been introduced into the environment from car exhausts. Poland banned the use of lead compounds in gasoline only in 2004. In European Union countries, such lead-containing substances are no longer used, but intensified development of the automotive industry has resulted in increasing amount of cadmium in the air and road dust due to abrasion of tires where Cd is used as a hardener[5-6]. Currently, lead is introduced into mammalian organisms primarily with food, and the process and the degree of accumulation are relatively well documented. Lead has a different affinity for bone and cartilage components; it accumulates more intensively and for longer periods in cortical bone than in cancellous bone. This metal accumulation is shortest in the bones of the skull, and longest, up to 25 years, in the metatarsal bones[7].

Although Cd has a distinctly lower affinity for hard tissues and is rarely determined there, its toxic effect mainly on bones of humans and laboratory animals has been shown in various reports. Cadmium might promote skeletal demineralization, which may in turn increase bone fragility and risk to fractures. The human itai-itai disease observed in Japan 50 years ago entails a mixed pattern of bone diseases, as well as kidney damage[8]. Despite the number of various studies on heavy metals in humans, knowledge of their concentrations and effects on bones and joints remains incomplete.

Although the marked differences in the concentrations of Pb and Cd, were reported, depending on the type of elements of the femur head, and type of tissues (cartilage, cortical and cancellous bones), they usually concern only Tarragona County (Spain)[9] and southern part of Poland, a heavily industrialized region of the country[1-2]. This study was aimed to determine the concentrations of Cd and Pb in the cartilage, cortical, and cancellous bones of the femur head obtained from patients after arthroplasty living in northwestern Poland.

MATERIAL AND METHODS

The study group comprised of 20 women aged from 32 to 82 years (70.1±10.56) and 10 men aged from 46 to 78 years (60.41±9.51) living in the Szczecin, West Pomeranian Voivodeship (northwestern Poland), hospitalized due to degeneration of the hip or femoral fractures after total hip arthroplasty. In most cases, the indication for this treatment was the degeneration of the left and/or right hip joint (15 and 14 patients, respectively), or fracture of the left femur (1 patients). The study included 30 patients treated with arthroplasty of the femoral head due to osteoarthritis and 3 patients due to fracture (osteoporosis).

All patients were interviewed using a questionnaire to collect data on demography, health status, and occupational exposure to specific heavy metals. None of the patients were ever occupationally exposed to Pb or Cd. The study was approved by the Bioethics Committee of the Pomeranian Medical University in Szczecin (BN/001/111/08). From the prepared bones, cartilage, cortical bone, and cancellous bone were obtained. Articular cartilage underwent advanced pathological changes. Bones were separated in sterile conditions from the every examined femoral head. In total, 90 samples were collected, including 30 samples of cortical bone, 30 samples of cancellous bone and 30 samples of cartilage surface. The bone and cartilage samples were ashed in the glass vessels of a Velp Scientifica, mineralised in a mixture of 65% nitric acid (HNO_3) and 70% perchloric acid ($HClO_4$) (Suprapur Merck®). Two metals (Pb, Cd) were assayed in the human bones with inductively coupled plasma-atomic emission spectrometry (ICP-AES) in an Elmer Optima 2000 DV spectrometer at the laboratory of the West Pomeranian University of Technology in Szczecin. The limit of detection of that apparatus for Pb and Cd is 1.0 and 0.1 μg/L, respectively.

The metal concentrations were expressed in mg/kg dry weight (dw) and more detail of analytical procedures is given by Kalisińska et al.[10]. The standard reference materials NIST-SRM 1486 (Bone meal) and Fish Tissue IAEA-407 were used in the study to validate the analytical technique (Table 1). The Mann-Whitney nonparametric *U*-test, the Kruskal-Wallis one-way analysis of variance and Spearmans rank-order correlation were used for statistical analysis. The results were processed using the statistical program Statistica for Windows ver. 8.0.

Table 1. Analysis of NIST-SRM 1486 (Bone meal) and Fish Tissue IAEA-407 by ICP-AES

Metal	Bone Meal SRM NIST 1486 (mg/kg dw)		Recovery (%)	Fish Tissue IAEA-407 (mg/kg dw)		Recovery(%)
	Certified	Measured *n*=7		Certified	Measured *n*=8	
Pb	1.335±0.014	1.190±0.306	89.1	0.120	0.11±0.03	91.7
Cd	0.003*	0.0020±0.0002	66.7	0.189	0.176±0.010	93.1

Note. All values given as mg/kg in dry weigth (arithmetic mean±standard deviation) *non-certified.

RESULTS

The values of the concentration of Pb in the head of the femur were arranged in the following descending series: cortical bone>cancellous bone>cartilage (means decreasing from 0.60 to 0.40 Pb mg/kg dw, respectively), while the concentration of Cd had a slightly different arrangement: cancellous bone>cortical bone>cartilage (means decreasing from 0.03 to 0.02 Cd mg/kg dw,respectively).

There were also statistically confirmed differences in the concentrations of both elements between the cartilage and the cortical bone, and in the concentrations of Pb between the cartilage and cancellous bone ($P<0.05$). The average concentrations of Pb and Cd in the cartilage and cortical bone were 46% and 36% higher than in that of the cortical bone. The concentration of Pb in the cartilage was 0.41 mg/kg dw and was 19% less than in cancellous bone (0.49 mg/kg dw) (Table 2).

There were no significant differences in the concentrations of Pb or Cd between cortical and cancellous bones.

In this study, a separate analysis was performed for each of the femoral head components (cartilage, cancellous bone, and cortical bone). In all three components, the highest Spearmans rank-order correlation coefficient r_s, ($P<0.0001$) was found between Pb and Cd (r_s=0.713 for cartilage, r_s=0.764 for cortical bone and r_s=0.736 for cancellous bone).

When comparing the concentration of metals between gender, the concentration of Pb in the cortical bone of males was 0.83 mg/kg dw and was 66% higher than in that of females (0.50 mg/kg dw). Differences between them were statistically insignificant. The average concentration of Cd in the cortical bone of males was 0.037 mg/kg dw and was 37% higher than in that of females (0.027 mg/kg dw). These means differed significantly (Mann-Whitney *U*-Test=45.0; $P<0.04$). The mean content of Cd (0.037 mg/kg dw) in female cancellous bones was higher than in that of male bones (0.026 mg/kg dw), but these differences were statistically insignificant (Table 3). Furthermore, the concentration of Cd in cortical bone was correlated with gender (r_S=0.40; $P<0.04$).

DISCUSSION

In humans, the biological half-life of Pb in bones is about 30 years, for Cd it is 20 years[2]. In hard tissues they are deposited for a long time and/or accumulate throughout life. The toxic effects of these metals on health status of people are not immediate and often become apparent many years later. Femoral heads are biological material that is rarely used as a biomarker of exposure for scientific research due to the poor availability. The results of this study in the West Pomeranian Voivodeship clearly document differences in the concentrations of Pb and Cd in different type of element of the femoral head.

Table 2. The Contents of Lead and Cadmium in Cartilage, Cortical, and Cancellous Parts of the Femur Head (mg/kg dw)

Metal	Parameter	Cartilage	Cortical Bone	Cancellous Bones	Significant K-W Test
Pb	AM±SD	0.41±0.11	0.60±0.44	0.49±0.14	*P*<0.05
	Med	0.41	0.49	0.47	
	range	0.21-0.65	0.15-2.54	0.29-0.79	
	CV	27.1	74.5	132.9	
Cd	AM±SD	0.022±0.005	0.030±0.012	0.035±0.046	*P*<0.05
	Med	0.021	0.031	0.024	
	range	0.013-0.034	0.002-0.054	0.014-0.269	
	CV	23.1	39.6	132.9	

Note. AM, arithmetic mean; SD, standard deviation; Med, median; CV, coefficient of variation in %; K-W, Kruskal-Wallis one-way analysis of variance; *P*, significant value.

Table 3. Toxic Metal Concentrations in the Femur Head (mg/kg dw) According to Gender and Significance of Differences

Material	Parameter	Cartilage	Cortical Bone	Cancellous Bones
		Women, *n*=20		
Pb	AM±SD	0.41±0.11	0.49±0.24	0.47±0.14
	Med	0.38	0.46	0.44
	range	0.25-0.64	0.15-0.99	0.29-0.79
	CV	31.7	47.8	30.3
Cd	AM±SD	0.022±0.005	0.027±0.0017	0.037±0.055
	Med	0.021	0.027	0.024
	range	0.014-0.033	0.002-0.049	0.014-0.270
	CV	22.6	43.4	148.0
		Men, *n*=10		
Pb	AM±SD	0.40±0.13	0.83±0.69	0.49±0.22
	Med	0.39	0.54	0.49
	range	0.21-0.65	0.32-2.54	0.25-0.75
	CV	31.7	83.3	44.8
Cd	AM±SD	0.022±0.006	0.037±0.009	0.026±0.012
	Med	0.022	0.032	0.025
	range	0.013-0.035	0.021-0.054	0.019-0.042
	CV	25.3	25.7	47.8
		Women *vs* Men		
Pb	U	NS	NS	NS
Cd	U	NS	45.0	NS

Note. AM, arithmetic mean; SD, standard deviation; Med, median; CV; coefficient of variation in %; U, M-W, Mann-Whitney test; NS, non-significant.

Jurkiewicz et al.[1] examined the femur head of people (inhabitants of Silesia and Cracow, the most industrialized and heavy metal polluted regions in Poland) and found that Cd concentrations reach 0.05 mg/kg dw in Silesia, and 0.06 mg/kg dw in Cracow, which are 25% and 50% higher than those obtained in cortical bones in the current study.

The concentrations of Pb in the patients from Silesia and Cracow were 1.90 and 2.98 mg/kg dw, and were 216% and 400% higher than in those of the cortical bones of patients after total hip arthroplasty (0.60 mg/kg) from northwestern Poland, respectively. It seems that environmental conditions contributed greatly to the accumulation of Pb and Cd in human bones.

The average concentration of Cd (0.02 mg/kg dw) in cartilage was similar to that assayed by Brodziak-Dopierala et al.[11] in cortical bones, and several times higher than that found by Kuo et al.[12] and Brodziak-Dopierala et al.[13] in cartilage (0.70 mg/kg dw).

In addition to the femur, the concentration of toxic metals has been examined in the ribs[9,14-15]. Literature shows very high differences among the inhabitants of Western Europe in terms of highly toxic element concentrations. For instance, Garcia et al.[14] and Bocio et al.[9] examined concentrations of Pb and Cd in the ribs of patients from the area of Tarragona in Spain. The concentration of Pb in the bones was approximately 2 mg/kg dw. In the subjects from Tarragona, inhabiting an area near the waste incinerator, the concentration of Pb in the ribs was over 110% higher than that in people from outside the area of impact[9]. The concentration of Cd in the bones of the inhabitants of Tarragona, observed in both research groups, was low, or 0.05 mg/kg dw[9,14]. Also in the case of residents of West Pomerania, the three tested materials had small bone concentrations of Cd, which did not exceed 0.03 mg/kg dw (Table 2).

Concentrations of this metal in human ribs were observed in people from Obninsk in Russia[3] and Pb and Cd concentrations were found to be 2.24 and 0.04 mg/kg dw, higher than in cartilage of patients from northwestern Poland (0.41 and 0.022 mg/kg dw, respectively).

In people not occupationally exposed to Pb and Cd in various Asian countries including South Korea and Taiwan, there was a much higher concentration of these xenobiotics in comparison with those of people in northwestern Poland[12,16]. In Asians, Pb concentrations ranged from 1.9 to 7.1 mg/kg dw and Cd concentrations ranged from 0.11 to 1.2 mg/kg dw. It seems that in these regions of the world the general environmental exposure to heavy metals is higher than in northwestern Poland.

European scientific literature is full of information on occupational exposure to Pb and Cd among workers in various industries. For people working in the steel industry in Sweden, the concentration of Pb in bone was on average 40 to 100 mg/kg dw, from 3 to 9 times higher than that in the control group. Also, in workers employed in the production of nickel-cadmium batteries, Pb concentration was greater than in those not occupationally exposed to the heavy metals[17-18]. The concentration of Cd in the femoral heads of Swedish oil refinery and mill workers was strikingly high: (1.28 mg/kg dw). Such a high concentration of this metal in these individuals was directly associated with occupational exposure[19]. Among patients undergoing hip replacement surgery at a hospital in Szczecin, there were people occupationally exposed to Pb and Cd, but the concentrations of these metals were often many times lower.

Gender has been found to influence the concentration of metal elements in bone. The mean content of Cd in female cancellous bones from northwestern Poland was higher than in male bones. In general, the internal Cd dose is higher in women than in men due to a higher gastrointestinal absorption at low iron stores. This was probably the major reason why itai-itai disease affected mostly the women[13]. The effect of gender on Cd in rib bone (consisting mainly of cartilage) of 80 apparently healthy people from Russia was examined by Zaichick et al.[3]. In the ribs of men they reported higher concentration of Pb (2.36 mg/kg dw) compared to women (2.10 mg/kg dw), but these differences were not statistically confirmed. In our analysis of patients from Szczecin, there were no significant differences between genders in the concentration of Pb in the tested materials (Table 3).

The average concentration of Cd (0.044 mg/kg dw) in males was 50% higher that obtained in male cortical bones in this paper (0.022 mg/kg dw), but these differences were statistically insignificant.

It can be seen that concentrations of both metals were the smallest in the cartilage. Cartilage, compared with cancellous bone, has a less mineralized intercellular substance and a very low rate of metabolism. Comparative studies on toxic metals should therefore take into account both analogous bones and their fragments, as even if they come from the same kind of bones (e.g. femur head). Clear differences exist in concentrations of heavy metals related to the sampling site and type of tissue (cartilage, cortical bone, and cancellous bone).

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