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Original Research

The Application of Principal Component Analysis to Interpretation of Occurrence of Metals in the Femur Head

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Abstract

Principal components analysis is one of the modern mathematical-statistic methods and it enables the reduction and organization of the results in order to indicate important implicit features. In such an analysis the components, correlated with each other, are shown on the basis of the matrix correlation of many variables. The examined materials were femur heads of hip joints which had various degenerative-deforming changes and came from people who lived on the industrial area. The examined population of 103 femur heads came from 64 women and 39 men.

The determination of the content of 12 metals in samples of femur heads was made using atomic absorption spectrophotometry (AAS) by the means of the Pye Unicam SP-9 in the flame acetylene-air. The principal components analysis in most examined groups showed that the first factor describes the change of the Cr, Ni, Cu, Zn, Na and Ca contents. Other main components emphasized variously the meaning of a given parameter. The results of PCA analysis are in accordance with the results of correlative analysis.

Keywords: femur head, heavy metals, principal components analysis

Introduction

The estimation of the changes in the natural environment caused by toxic substance emissions is conducted by determination of their concentration in three basic elements of the environment: air, soil and water. The results of such research do not usually fulfill the condition of the necessary amount and specificity of environmental conditions. That is why it is currently believed that the application of modern mathematical-statistic methods, e.g principal components analysis or analysis of group similarity, are necessary to interpret the level of chemical pollution of the natural environment and the risk of exposure arising from it. These methods enable us to estimate the exposure of the population on the basis of variability of chosen chemical compound contents in separate important elements of human life settlement, including behavioral and environmental factors [1-5].

Femur heads are one of the biological samples which are rarely used as a biomarker of exposure. The reasons for it are the difficulties in obtaining it, because they are obtained in an intraoperational way. Bone tissue is a very important and worthy biomarker of exposure and due to the long time of regeneration it stores many metals that may be released in case of illness of the tissue, acidity of an organism, etc. [6-9].

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The growth of content metals in femur heads may be influenced by many factors such as age, place of living, smoking – active and passive. In order to describe the roles of these factors objectively, the method of principal components analysis was used.

Principal components analysis is one of the modern mathematical-statistic methods. It consists of the reduction and organization of results in such a way that it enables us to find and define important implicit features. The aim of Components Analysis is to show – on the basis of correlation matrix of many variables – the relationships among a large amount of uncorrelated variables. It comes down to the relationships among several components, usually uncorrelated to each other [10-13].

Principal components analysis is often used as a method of data reduction, which is believed to have specific components meaning. It enables us to learn the meaning of components and to make a sensible interpretation of them. In the correlation matrix a few relatively independent components are chosen. At first, correlation between variables and marked components is investigated. It should be emphasized that the first component reproduces the most important correlations between components. The components are distinguished one by one and they explain smaller and smaller total variance.

The values of the components may be drawn on the distribution chart, the axes may be rotated in any direction, relatively not changing the standing of the points toward each other, at the same time the values of the components undergo a change. There are various strategies of rotation but the aim of all of them is to get a clear system, so-called principal components, which are clearly singled out by big values for some variables and small values for others. Typical strategies of rotation are varimax, quartimax and equamax. The varimax rotation of normalized components values is the most frequently used method and it consists of dividing raw values of components by square roots of appropriate stores of common variability. The aim of this rotation is to maximize variance of normalized component charges, variable for each component. It is also simultaneous to the maximization of normalized component charges matrix variances. As a result, we obtain such a system of charges at each component that possibly reflects the biggest variability, making the simple interpretation possible. The values of components are interpreted as correlations between given variables and components. Only these components are interesting, the value of which is bigger than 1. However, exceptions are possible because the assumption of components analysis is explaining 75% of variability by the principal components. For clearly marked parameters of the influence on given phenomena of e.g. a physiological, ecotoxicological character, and for the interpretation of results, there should not be too many principal components [14-18].

The aim of the conducted research was to apply principal components analysis for an explanation of co-occurring metals in the femur head.

Table 1. Concentration of metals (arithmetic mean, geometric mean and range of changes) in male and female femur heads.

	Metals	Arithmetic mean	Geometric mean	Range of changes
Women	Cd	0.56	0.33	0.02-8.27
	Mn	2.41	1.49	0.06-19.46
	Cu	4.22	3.19	0.20-26.80
	Ni	7.02	5.71	0.62-70.72
	Pb	11.46	7.73	0.37-70.46
	Cr	14.24	8.79	0.15-230.35
	Zn	85.10	72.49	7.57-828.96
	Fe	118.36	63.45	2.97-2,563.96
	K	1,081.72	756.36	124.27-10,642.34
	Mg	1,352.49	979.94	150.31-10,997.14
	Na	8,066.31	6,431.07	788.22-24,377.88
	Ca	28,512.42	26,298.89	10,022.51-76,758.48
Men	Cd	0.46	0.27	0.02-2.39
	Mn	2.52	1.57	0.09-17.86
	Cu	3.73	2.63	0.17-35.32
	Ni	6.30	5.02	1.00-70.50
	Pb	10.99	7.69	0.81-53.33
	Cr	12.15	6.75	0.05-256.37
	Zn	88.63	71.50	16.80-917.22
	Fe	145.13	54.64	2.79-5,520.62
	K	1,025.99	744.44	134.77-9,736.75
	Mg	1,818.91	1,166.75	196.97-9,596.01
	Na	7,510.03	6,181.31	1,046.74-24,556.47
	Ca	29,099.37	26970.33	10663.20-79179.78

Materials and Methods

The issue of the possibility of PCA use is based on the example of femur head examination, with the various degenerative-deforming changes of hip joint coming from people living on the industrial area – Upper Silesia (Górny Śląsk). Femur heads were obtained during hip replacement operations, conducted in Town Hospital in Siemianowice Śląskie on the basis of an agreement witch the Bioethical Commission at the Medical University of Silesia in Katowice (No. NN-6501-160/I/06, 22nd of November 2006).

The femur samples were cut into several sections, from which fragments of articular cartilage, cortical bone and trabecular bone were distinguished. The examined population of 103 femur heads was obtained from 69 women and 39 men. The average age of patients was 71.6 years.

Samples of bones, with a known mass, were gradually reduced to ashes to solid mass in a muffle furnace in a temperature of 100ºC, and then 420ºC. The obtained sample of ash was dissolved in 2 ml of spectrally pure HNO_3 (V) (Supra pure) from Merck. The obtained solution was put into a 25 cm^3 flask, and then filled with double distilled water to the line.

The determination of metals content in femur heads was conducted by atomic absorption spectrophotometry (AAS) using apparatus Pye Unicam SP-9 in an acetylene-air flame. The contents of the following elements: Cr, Ni, Mn, Cu, Cd, Zn, Fe, Pb, Ca, Mg, Na, and K were determined.

In dust pm10 is the following amount of toxic elements: Pb 96 ng/m^3, Cd 2.9 ng/m^3, Mn 44 ng/m^3, Cr 9.9 ng/m^3, Ni 6.5 ng/m^3, Cu 220 μg/m^3 [19].

The research results were subjected to statistical analysis using the program Statistica 7.1 Pl.

Results

Trace elements to research were chosen on purpose in support about noticed character co-occurrence in changes between them. Among them were essential correlations Pb from Mn, Cd; Cd from Mn, Cu, Pb, Na; Cr from Ni, Zn, Cu. These correlations characterize the coefficients of correlation 0.51-0.85 [20].

The differences in 12 metal contents in femur heads of women in comparison to men were statistically significant ($p<0.05$). Bigger contents of cadmium, copper, nickel, lead, chromium, potassium and sodium were determined in women's femur head than in men. On the other hand, there was more manganese, zinc, iron, magnesium and calcium – Table 1. In case of separate parts of femur head, the biggest contents of 12 metals (with the exception of magnesium) occurred in articular cartilage: the biggest content of magnesium was in trabecular bone. The contents at the lowest level, with the exception of potassium and magnesium, were characteristic of trabecular bone (Table 2).

The conducted Principal Components Analysis includes the following variables: the sort of morphological part of the femur head (articular cartilage, trabecular bone, cortical bone), age of a patient, sex, place of living (in the meaning of the sum of Pb, Cd, Mn, Ni Cr, Zn, Fe occurrence in the dust in the air), smoking and the content of the roots: Cd, Mn, Cu, Cr, Ni, Pb, Fe, Zn, K, Mg, Na, Ca in examined bone tissues.

In the whole examined population of 8 significant components, the values of which are higher than 1 and their total variance 80.36%, were defined (Table 3). The first component denotes first-rate meaning of nickel, copper, chromium, zinc, calcium and sodium in the hydroxyapatite, and the second component emphasizes the role of Mn, Cd, Pb, big values of the third component show the meaning of smoking and the age of a patient. The fourth component indicates the meaning of the morphological parts of bones and the content of Na and K. The fifth component emphasizes the role of the place of living, corrected by sex.

Table 2. Concentration of metals (arithmetic mean, geometric mean and range of changes) in selected femur head parts.

	Metals	Arithmetic mean	Geometric mean	Range of changes
Articular cartilage	Cr	16.56	8.94	1.15-256.37
	Ni	9.63	7.82	1.37-70.72
	Mn	4.08	3.24	0.49-17.86
	Cd	1.06	0.91	0.12-4.16
	Cu	6.29	5.00	0.37-35.32
	Pb	16.31	12.92	0.91-68.11
	Zn	105.07	85.75	8.77-917.22
	Fe	227.70	124.60	9.77-5,520.62
	Na	12,904.29	11,621.14	1,687.65-24,556.47
	K	1,608.67	1,334.70	431.08-10,589.96
	Mg	1,357.79	1,069.52	175.40-10,373.82
	Ca	30,917.40	27,983.26	10,146.52-79,179.78
Trabecular bone	Cr	10.42	6.67	0.05-109.40
	Ni	4.56	3.82	0.73-38.99
	Mn	1.27	0.74	0.06-7.59
	Cd	0.26	0.13	0.02-8.27
	Cu	2.63	1.97	0.20-20.42
	Pb	6.22	4.02	0.49-45.48
	Zn	61.48	53.63	7.57-441.46
	Fe	64.04	36.44	2.79-1,285.81
	Na	4,745.47	3,877.18	788.22-23,448.80
	K	828.80	557.24	124.27-10,489.55
	Mg	1,650.85	1,027.55	150.31-9,859.38
	Ca	25,244.65	23,328.79	10,022.51-63,345.78
Cortical bone	Cr	14.99	10.45	0.75-59.13
	Ni	6.86	6.20	1.04-16.25
	Mn	2.18	1.60	0.15-19.46
	Cd	0.36	0.30	0.05-2.82
	Cu	3.73	3.13	0.17-17.68
	Pb	12.27	9.69	1.03-70.46
	Zn	94.72	86.09	10.42-337.05
	Fe	93.89	54.49	7.77-2,337.06
	Na	6,790.35	6,165.03	897.95-22,579.38
	K	767.11	594.60	161.82-10,642.34
	Mg	1,376.14	982.13	175.83-10,997.14
	Ca	30,216.83	28,749.80	10,711.41-62,337.06

Table 3. Results of principal component analysis for femur head.

	Components						
Parameter	1	2	3	4	5	6	7
part of bone	-0.06	0.17	0.03	**0.82**	-0.07	0.07	-0.06
sex	-0.08	0.03	**0.57**	-0.05	**-0.41**	-0.11	**0.57**
age	-0.07	0.03	-0.04	-0.05	-0.19	0.04	**-0.90**
place of living	0.05	0.04	0.17	-0.04	**0.92**	-0.02	0.14
cigarette smoking	-0.10	0.08	**-0.87**	0.02	-0.25	0.01	-0.04
Cr	**0.94**	-0.14	0.03	0.06	0.00	-0.05	0.00
Ni	**0.90**	0.18	0.04	0.17	0.04	-0.08	-0.01
Mn	0.13	**0.64**	0.03	0.25	-0.07	0.01	0.06
Cd	0.28	**0.79**	0.01	0.33	0.03	0.00	-0.08
Cu	**0.73**	0.36	0.06	0.23	0.08	0.02	-0.05
Pb	0.09	**0.78**	-0.12	-0.09	0.04	-0.10	0.01
Zn	**0.82**	0.15	0.02	-0.05	0.02	-0.14	0.07
Fe	0.06	0.27	0.05	0.04	-0.02	0.04	-0.02
Na	**0.43**	0.38	0.06	**0.58**	0.03	0.07	0.00
K	0.28	-0.11	-0.19	**0.62**	0.05	-0.22	0.22
Mg	0.07	0.06	0.04	-0.01	0.01	**-0.96**	0.06
Ca	**0.57**	0.32	-0.08	-0.16	-0.01	0.23	0.28

The sixth component shows the antagonistic properties of magnesium in relation to other heavy metals. The meaning of age is defined by the seventh component, and the changes of iron content- by the eighth one, which is also important for mineral content changes. It is characteristic that the meaning of sex is denoted by three principal components, the third one – 0.57, the fifth one – 0.41, the seventh – 0.57; it strongly emphasizes changes in the physiology of the roots mentioned in the first component. The result is, for example, osteopenia.

Changes in mineral content in the femur head of women are described by 6 significant principal components, the total variance of which is 72.32%. The first component is representing the change of the contents of: Cr, Ni, Zn, and also Na, Ca and Cu, and in the second order there are changes of content of Mn, Cd, Pb, Fe in women as well as

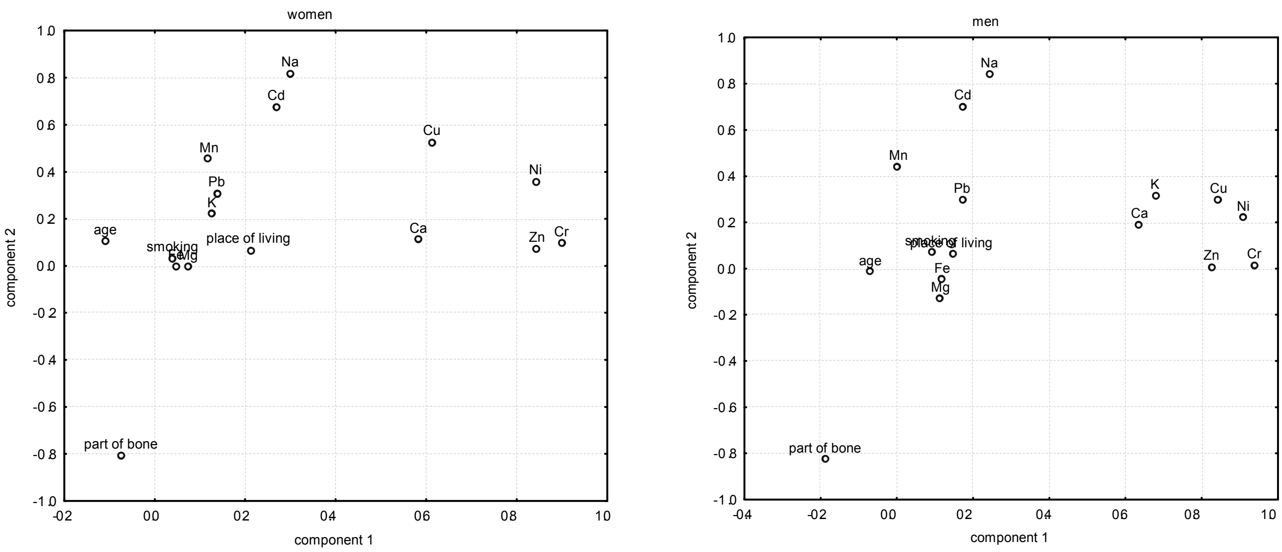

Fig. 1. The graphic illustration Principal Components Analysis for women and men's femur head.

Table 4. Results of principal component analysis for male and female femur heads.

	Women						Men					
	Components											
Parameter	1	2	3	4	5	6	1	2	3	4	5	6
part of bone	-0.13	0.06	-0.08	**0.83**	-0.01	0.11	0.04	0.19	**0.83**	0.01	0.03	-0.04
age	-0.13	0.00	-0.40	0.08	-0.06	-0.64	-0.13	0.13	-0.05	**-0.79**	0.10	-0.14
place of living	0.10	-0.09	**0.82**	0.01	0.06	0.11	-0.09	0.13	-0.02	0.01	0.01	**0.96**
cigarette smoking	-0.04	-0.03	**-0.77**	0.03	0.00	-0.01	-0.19	0.25	-0.11	0.68	0.15	-0.17
Cr	**0.90**	-0.16	0.01	0.03	0.04	0.15	**0.94**	-0.13	0.01	-0.09	0.08	-0.09
Ni	**0.89**	0.14	0.04	0.21	0.10	0.08	**0.93**	0.12	0.19	-0.04	0.08	0.02
Mn	0.20	**0.79**	-0.04	0.25	-0.01	0.14	0.02	**0.83**	0.40	0.07	-0.02	0.03
Cd	0.37	0.55	0.07	0.51	0.10	-0.25	0.19	0.50	0.69	0.02	-0.20	0.05
Cu	0.69	0.23	0.13	0.38	0.03	-0.13	**0.85**	0.08	0.28	-0.06	-0.08	-0.01
Pb	0.16	**0.79**	0.02	0.03	0.20	-0.22	0.13	**0.78**	0.17	0.20	-0.11	0.16
Zn	**0.82**	0.25	0.01	-0.08	0.18	0.18	**0.82**	0.49	-0.02	-0.03	0.11	0.00
Fe	-0.01	**0.78**	-0.07	-0.03	-0.14	0.33	0.12	**0.87**	-0.04	-0.14	0.08	0.00
Na	0.49	0.11	0.05	0.67	-0.04	0.03	0.30	-0.02	**0.77**	-0.06	-0.06	0.01
K	0.10	0.15	-0.10	0.43	0.11	0.62	0.67	-0.01	0.36	0.27	0.38	-0.01
Mg	0.05	0.05	0.06	0.00	**0.95**	0.09	0.10	0.00	-0.09	0.02	**0.92**	0.00
Ca	0.60	0.16	0.12	-0.09	-0.16	-0.05	0.63	0.28	0.10	0.22	-0.36	-0.06

in men (Table 4, Fig. 1). The third component for women and fourth component for men indicate that the above-mentioned changes are influenced by the place of living and smoking. The bigger content of these metals in the air dust is, the more of them may be found in the bone tissue. The meaning of differences in the metals content in examined morphological parts of femur head is indicated by the fourth component. The same in women as in men, the fifth component concerns the role of magnesium content. The age as a determinant of metal occurrence changes was emphasized together with the meaning of potassium by the sixth component.

The physiological meaning of examined roots in the femur head in men according to behavioral parameters is explained by six principal components that describe 80% of all changes. Their variance is higher in comparison to women. The first component also represents the change of contents of Cr, Cu, Ni, Zn, K, and Ca. It may be noticed that the strong position of Ca results in the smaller presence of Pb – 0.134 and Cd 0.186. The second component denotes common changes of Mn, Pb, Fe, Cd, and Zn contents. Moreover, the third component indicates the important meaning of separate morphological parts of femur head – 0.795 and the Na, Cd contents, and it shows the role of K, Cu, and Mn. The values of the fourth component indicate that the older a person is, the smaller the presence of Ca in the tissue (Ca 0.223), which is additionally corrected by the strong meaning of smoking (0.681). The fifth component emphasizes the role of magnesium content change. The last parameter, which influences the occurrence of metals, is the place of living in the meaning of presence of those metals that remain in interactions in a given natural environment.

The differences of metals physiology in femur head between smoking and non-smoking people were described by the data in Table 5, Fig. 2.

The changes in femur head between smoking and non-smoking people are described by 7 important components, the total variance of which is 80.42 %. The first component indicates, the same as above, the presence of Cr, Ni, Zn, and Cu in the structure of hydroxyapatite. The meaning of Mn, Pb, and Fe in ion exchange is characterized by the second component, which additionally remains in the interaction with Cd, Zn, and K. The sex and age are emphasized by the third component. The fourth component shows the meaning of the differences in metals occurrence in separate morphological parts and in accumulating during a long period of time, the role of Cd and K is also important. The place of living as an important parameter is indicated by the fifth principal component, and the sixth one denotes the physiological meaning of calcium content together with the changes of Cu, Pb, and Cd. Just like the previous time, the seventh component shows the role of magnesium content's changes.

People who have smoked in the past are described by six principal components, the total variance is 74.30% -

Table 5, Fig. 2. In this case the first component indicates only the meaning of Cr, Ni, Na, Cd and Ca. The meaning of sex, age, place of living and Fe and Mn contents is denoted by the second principal component, and the third component shows the meaning of the morphological part of the bone. The fourth component emphasizes common origin of lead and cadmium and their proportional changes over a long period of time. Moreover, Mg also is described by the fifth component – 0.86, and the last roots undergoing the changes were copper and zinc with the changes of Ca, Na and Cd.

Changes in the mineral content of the femur head of smoking people are described by 6 important principal components, total variance of which 76.59% (Table 6). The first component emphasizes the role of content changes of Cr, Ni, Cu, and Zn, and the second one denotes the accumulation of Mn, Pb, Fe, and Cd in the bone tissue and its presence in the processes of ion exchange. The third component concerns the sex and place of living and the fourth one – as in the previous examples – confirms the meaning of separate parts of femur head, but the presence of Mn, Cd, Pb and K is not unimportant. The fifth component needs to be taken into consideration when examining the role of age and the sixth one, as in most cases, confirms the role of magnesium. The role of smoking consists in the change of the importance of separate roots in the concurrence about the place in hydroxyapatite and interactions in it.

The physiology of root content changes in the articular cartilage is described by 7 important component groups, and in trabecular bone and in the cortical one – 6 principal components (Table 6, Fig. 3). Total variance, describing the principal components for the trabecular bone and articular cartilage were described as likely 77%, and for the cortical bone – 74.63%. For the trabecular bone the content change of Cr, Ni, Cu, and Zn are of the first-rate meaning, for the cortical bone – Cr, Ni, Cu, and Na, and for the articular cartilage – Cr, Ni, Zn, and Mg. The second component emphasizes the meaning of Mn content in all 3 morphological parts of femur head, and additionally Cd and Pb in trabecular bone, Cd, Pb, and Fe in cortical bone, and Fe in articular cartilage. The third component is different in every part of femur head. For cortical bone it is age and sex, for articular cartilage – smoking, for trabecular bone – the change of magnesium content. The fourth component is also very different for parts of femur head, in cortical bone – it is Mg, in trabecular bone – sex, in articular cartilage – lead and sodium content. The sixth component emphasizes the place of living for cortical bone and trabecular bone, and accumulation of cadmium – for articular cartilage. The seventh component occurs only in the case of articular cartilage and it describes the role of age as the last influencing component.

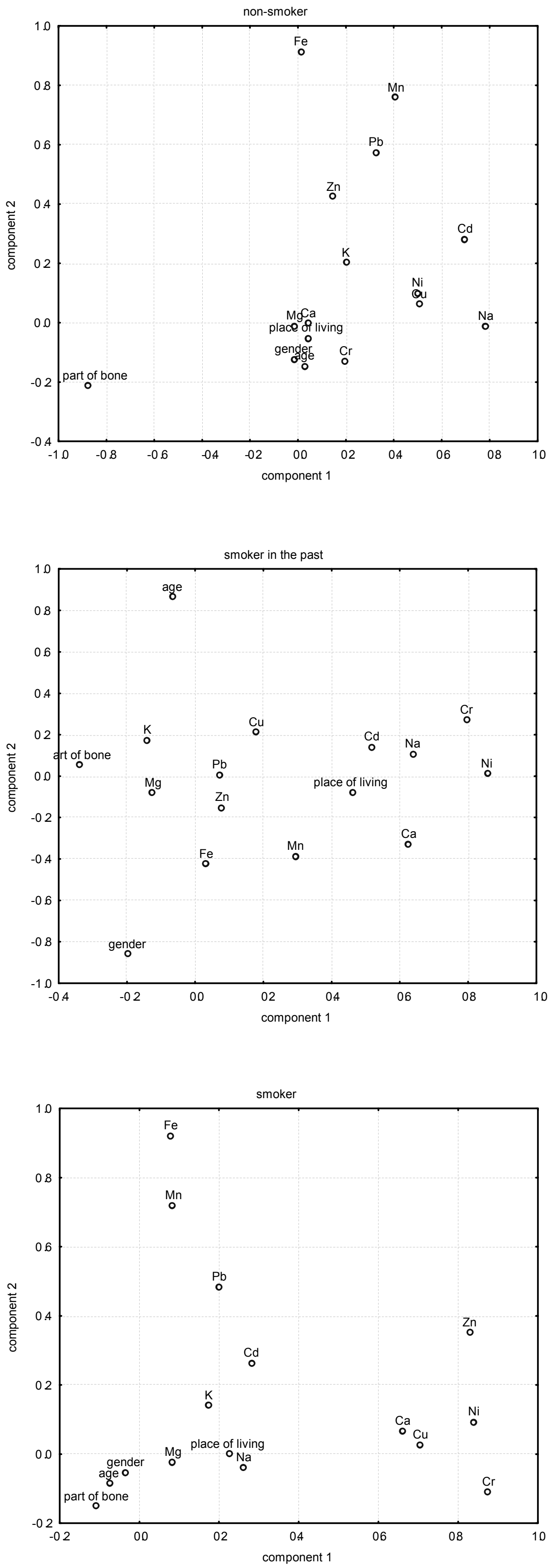

Fig. 2. A graphic illustration of principal components analysis in according cigarette smoking for femur head.

Discussion of Results

The obtained results of PCA, which considers various combinations of parameters, confirms the usefulness of this method for interpretation of interactions (Tables 3-6 and Figs. 1-3). In particular the obtained results by the method

Table 5. Results of principal component analysis in accordance with cigarette smoking for femur head.

	Non-smoker							Smoker in the past						Smoker					
	Components																		
Parameter	1	2	3	4	5	6	7	1	2	3	4	5	6	1	2	3	4	5	6
part of bone	-0.04	0.03	0.04	**0.90**	-0.01	0.09	0.01	0.05	0.02	**0.81**	-0.02	0.13	0.04	-0.03	0.16	-0.12	**0.81**	-0.05	0.06
sex	-0.08	-0.05	**-0.81**	0.00	-0.20	0.14	0.19	-0.20	**0.85**	-0.14	0.13	-0.08	-0.13	-0.13	0.06	**-0.83**	-0.02	0.17	0.07
age	0.11	-0.10	**0.84**	-0.02	-0.17	0.04	-0.07	-0.09	**-0.86**	0.05	0.33	0.05	-0.01	-0.20	0.06	-0.06	-0.04	**-0.90**	0.11
place of living	0.03	-0.05	0.00	0.00	**0.98**	0.05	0.03	-0.13	0.50	-0.27	0.11	0.52	0.20	-0.05	0.08	**0.82**	-0.04	0.28	0.14
Cr	**0.91**	-0.14	0.12	-0.11	0.01	0.05	-0.15	**0.79**	-0.28	-0.24	-0.22	0.13	0.19	**0.93**	-0.10	0.00	0.06	0.05	0.21
Ni	**0.88**	0.19	0.13	0.10	0.01	0.21	0.03	**0.93**	0.06	0.04	0.09	0.02	0.19	**0.90**	0.16	0.07	0.21	0.03	0.17
Mn	0.21	**0.83**	-0.05	0.20	-0.11	0.11	0.06	0.44	0.50	0.44	0.29	-0.18	0.10	0.13	**0.80**	-0.03	0.35	0.05	-0.06
Cd	0.39	0.46	0.12	0.45	-0.02	0.46	0.17	0.60	-0.04	0.33	0.49	0.06	0.34	0.26	0.56	0.16	0.45	-0.17	-0.20
Cu	0.55	0.18	0.11	0.21	0.09	0.56	0.11	0.26	-0.10	0.10	0.09	0.30	**0.82**	**0.82**	0.14	0.08	0.35	0.01	-0.02
Pb	-0.05	**0.73**	-0.02	0.03	0.03	0.52	0.13	0.11	0.01	-0.03	**0.95**	0.04	0.12	0.18	**0.77**	0.12	0.11	-0.22	0.06
Zn	0.61	0.49	-0.15	-0.25	0.05	0.32	-0.04	0.13	0.08	-0.14	0.11	-0.14	**0.71**	**0.82**	0.38	0.01	0.01	0.04	0.27
Fe	-0.01	**0.87**	0.01	0.04	0.01	-0.11	-0.11	0.14	0.54	0.37	0.15	0.14	0.06	0.06	**0.81**	-0.13	-0.11	0.13	0.17
Na	**0.72**	0.07	0.01	0.49	-0.01	0.07	0.08	**0.71**	-0.01	0.37	0.18	-0.10	0.36	0.36	0.10	0.11	**0.71**	0.10	-0.13
K	0.20	0.35	-0.28	0.56	0.05	-0.26	-0.07	-0.07	-0.07	0.64	0.00	-0.12	-0.08	0.44	-0.04	0.03	0.47	0.19	0.44
Mg	-0.02	0.00	-0.24	0.00	0.03	-0.08	**0.91**	-0.11	0.08	-0.06	-0.01	**-0.86**	0.03	0.17	0.10	0.05	-0.06	-0.14	**0.84**
Ca	0.33	0.02	-0.18	-0.06	0.03	**0.70**	-0.24	0.60	0.22	-0.20	0.18	0.15	-0.36	0.71	0.24	0.02	-0.04	0.20	-0.21

Table 6. Results of principal component analysis for selected parts of femur head.

	Articular cartilage							Trabecular bone						Cortical bone					
	Components																		
Parameter	1	2	3	4	5	6	7	1	2	3	4	5	6	1	2	3	4	5	6
sex	-0.05	-0.06	0.55	0.09	-0.25	-0.04	-0.62	-0.11	0.05	0.06	**-0.90**	-0.13	-0.07	-0.13	-0.09	**0.83**	0.19	-0.19	-0.13
age	-0.08	0.05	0.03	0.05	-0.19	0.04	**0.90**	-0.17	0.02	-0.36	**0.55**	-0.21	-0.13	-0.13	-0.01	**-0.74**	0.21	-0.27	-0.24
place of living	0.05	0.10	0.17	0.06	**0.91**	0.02	-0.08	0.10	0.08	0.05	0.08	**0.89**	-0.03	0.09	-0.03	-0.02	0.04	**0.93**	0.05
smoking cigarette	-0.11	0.04	**-0.87**	0.05	-0.25	0.06	0.03	-0.08	0.03	0.14	**0.51**	**-0.59**	-0.06	-0.07	0.00	-0.44	-0.19	-0.49	0.41
Cr	**0.91**	0.05	0.07	-0.20	-0.05	0.01	0.00	**0.93**	-0.23	-0.12	0.02	0.06	-0.01	**0.88**	-0.27	-0.02	-0.09	-0.02	-0.11
Ni	**0.87**	-0.10	0.09	-0.24	0.01	0.18	0.02	**0.94**	0.13	0.01	0.02	0.07	0.08	**0.91**	0.17	-0.06	-0.04	0.08	-0.05
Mn	0.05	**-0.81**	0.00	-0.14	-0.14	0.36	-0.10	0.07	**0.87**	0.04	-0.08	-0.01	0.27	0.03	**0.91**	0.08	0.06	0.00	0.14
Cd	0.16	-0.23	-0.09	-0.08	-0.01	**0.87**	0.05	0.37	**0.70**	0.07	0.05	0.15	-0.23	0.37	**0.75**	-0.22	-0.01	0.04	-0.07
Cu	0.64	0.06	0.04	-0.06	0.11	0.44	0.02	**0.90**	0.20	-0.08	0.02	0.16	-0.05	**0.86**	0.08	-0.06	-0.05	0.01	-0.12
Pb	0.14	-0.22	-0.06	**0.71**	0.09	0.49	0.05	0.14	**0.92**	0.05	0.01	0.00	0.04	-0.17	**0.83**	-0.10	-0.10	-0.01	0.05
Zn	**0.85**	-0.27	0.13	0.17	0.02	0.05	-0.02	**0.87**	0.30	0.02	-0.09	0.00	0.14	0.68	0.37	0.08	-0.11	-0.01	0.15
Fe	0.09	**-0.85**	0.05	0.31	0.00	-0.03	0.01	0.03	**0.53**	**-0.41**	-0.03	0.03	**0.58**	0.08	**0.79**	0.06	0.04	-0.04	0.06
Na	0.17	0.04	-0.02	**-0.83**	0.00	0.28	0.03	**0.70**	0.22	0.28	0.01	0.12	0.20	**0.75**	-0.15	0.01	0.23	0.07	0.14
K	0.58	-0.17	-0.21	-0.22	0.23	-0.13	-0.25	0.14	0.04	0.21	-0.01	-0.01	**0.84**	0.02	0.14	0.03	0.12	0.02	**0.84**
Mg	**0.71**	0.02	-0.08	0.29	0.03	0.08	-0.04	-0.10	0.11	**0.83**	-0.16	-0.05	0.11	-0.09	0.03	0.05	**0.92**	0.09	0.10
Ca	0.47	0.16	0.13	0.14	-0.20	0.33	-0.34	**0.60**	0.15	**-0.40**	-0.06	-0.11	-0.01	0.53	0.20	0.13	-0.24	0.14	0.13

of PCA showed first of all the group of roots that take part in the changes of mineral content in hydroxyapatite. The first component most often showed the change of Cr, Ni, Cu, Zn, Na and Ca contents. The higher content of Cr, Ni, Cu, and Zn in the environment is strictly connected with the smelting industry. And a big content of calcium and sodium in the bone tissue results from the character of this tissue. A comparison of the results according to sex and smoking were clearly emphasized by consecutive principal components, but usually sex and age are shown by the third component and the meaning of morphological parts in respect to distribution of 12 examined metals – the fourth component. The place of living, in which the examined roots occur in air dust in various quantities, is described by only a fifth component due to the big migration of patients. Although strongly emphasized, antagonistic features of calcium and magnesium in respect to lead and cadmium are the last components that determine the complicated process of the mineral content change of hydroxyapatite over a long period of time, because earlier research showed that femur head may be a biomarker of exposure for the Cr, Ni, Cd, Mn, and Pb presence in the natural environment of a patient.

The applications of PCA method for the analysis of metals content in human tissue samples were known before. This method was used to analyze the content of chosen metals in women's placenta, in umbilical cord blood of infants, and in teeth of adults. In the umbilical cord blood samples the first component included Cd, Cu and Fe, the second one – Pb, Mn, and Zn. The source of those metals in the environment is anthropogenic activity. In the umbilical cord blood the first component is characterized by a high participation of Pb, Cd, Ni and Fe, and the second one – Cd and Zn. In teeth of adults the first component was characterized by high participation of Pb, Fe, and Mn, and the second component – Cd and Zn [21-24].

The results of correlative analysis confirm the results obtained by the PCA method. The correlative analysis in the group of women and men showed similar quantity of correlations between roots, but in men the rate of correlation of most cases had higher values, e.g. Ni-Cr in men (0.90), in women (0.84). It was similar in the case of the Cd-Mn relation: in men this rate was (0.70), in women (0.56). Additionally, in men the correlations of Ca with Ni and Cu with Zn was noticed (0.53-0.55). Interpretation of the meaning of age in the case of women is strongly emphasized by the occurrence of osteoporosis.

In cases of correlative analysis for separate parts of femur heads, the biggest quantity of observed correlations occurred in the trabecular bone, then in cortical bone and articular cartilage. In all three parts of femur head the highest rate of correlation was for Ni-Cr, in articular cartilage it was 0.89; for the trabecular bone – 0.8; and for the cortical bone 0.78. There was also big correlation in all parts between Zn and Ni (0.76-0.89). In the trabecular and cortical bone there was correlation of a synergistic character between Pb-Mn, in the trabecular bone it was (0.77), and in the cortical one (0.67).

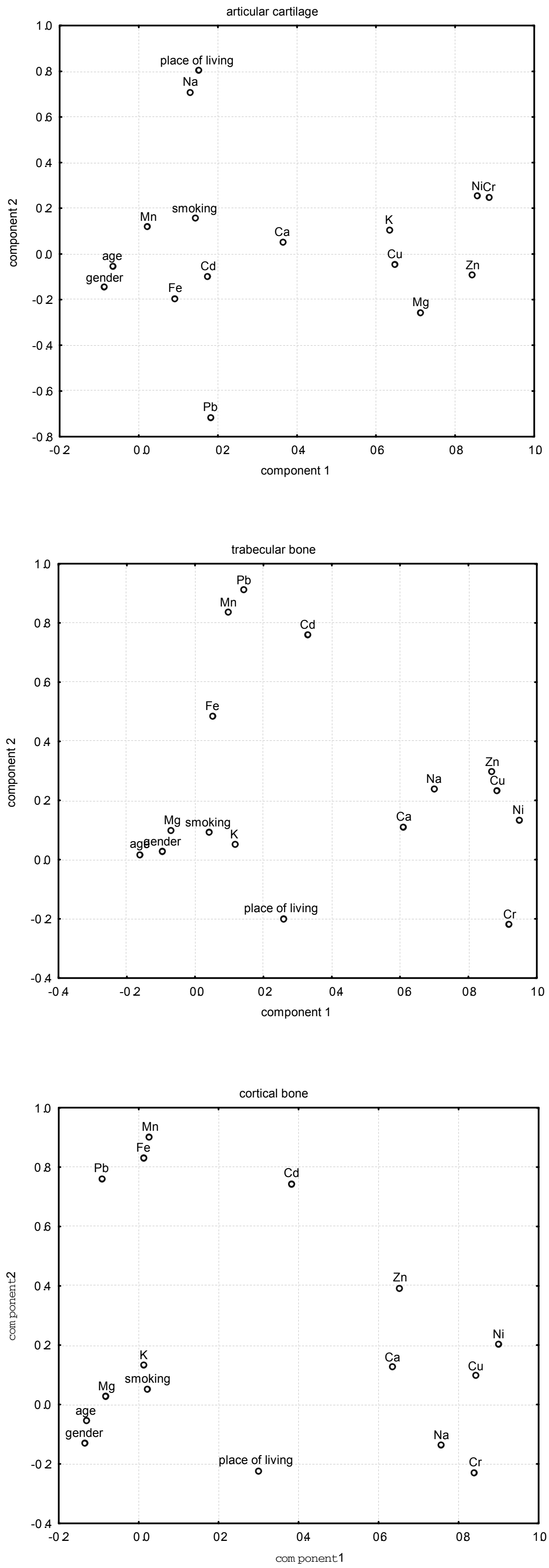

Fig. 3. The graphic illustration Principal Components Analysis for selected parts of femur head.

Conclusions

Principal components analysis enables us to notice the differences in physiological features of separate roots depending on behavioral factors (sex, place of living, age).

The interpretation of the results obtained by PCA is not only in accordance with the results of correlative analysis, but it also enables us to extend our knowledge about the method of occurrence and interactions between them in separate parts of the femur head.

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