Phase and Elemental Composition and Distribution of Urinary Calculi in Patients from Novosibirsk and Omsk Regions

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Abstract

Investigation of endemic features of urolithiasis taking into account local factors, both natural and technology-related ones, allows one to obtain additional information about one of the reasons of this disease. Mineral composition and distribution of urinary calculi in patients from Novosibirsk and Omsk Regions are investigated. A common feature of urolithiasis in the regions under comparison is noticeable predominance of oxalate urinary calculi. However, at the conservation of the general trend of distribution with respect to the prevailing component, patients from Novosibirsk Region exhibit an increase in phosphate and decrease in urate urolithiasis. Noticeable differences in paragenesis of minerals comprising multicomponent urinary calculi and in the composition of single-component concretions are observed. In the Novosibirsk samples, single-mineral concretions are more frequently composed of whwellite, while in the Omsk samples it is anhydrous uric acid. Comparative analysis of the mineral composition and distribution of urinary calculi in other regions according to literature data was carried out.

INTRODUCTION

The formation of calculi in human urinary organs is a result of very complicated and diverse metabolic disorders in organism functioning. Even within the same group of patients with identical diagnosis and disorder of exchange processes, the formation of calculi occurs in different ways or does not occur at all. On the other hand, different diseases can be complicated by the formation of calculi with identical composition and similar structures. The authors of [1] having analyzed 2000 calculi from medical museums all over the world stressed rather clear dependence of incidence of disease on occupations (sedentary life style and hard physical work increase the percentage of disease), sex (nephrolithiasis is more frequently observed in women, while in men calculi in urinary bladder are more often), rural or urban residence (urban population suffers from this disease 30 times more frequently). Urolithiasis is widely spread, especially in industrially developed countries [2]. This disease had been known long ago; non-uniformity of its geographic distribution over the world had been noted. At present, endemia for urolithiasis remains typical (Yu. S. Rubtsov, 1993), which is explained by differences in environmental status: quality of drinking water, soil, unfavourable combination of other ecological factors; non-uniformity of the distribution of this disease is observed not only within a separate country but also within a district [3–5]. Some authors report results of investigation of the composition, morphology and texture-structural features of urinary calculi demonstrating that the formation of calculi is caused by a number of reasons including dysbolism and functional disorders in urinary organs, hereditary susceptibility, *etc*., as well as regional ecological situation [6, 7]. Carrying out comparative analysis of the mineral composition of concretions in patients from different regions (taking into account geographical positions and ecological situation), one can obtain additional information on the reasons of formation and progress of pathogenous organomineral concretions in human organism.

Omsk and Novosibirsk Regions are unfavourable from the ecological point of view; an increase in the number of urolithiasis cases is observed. The highest incidence of the disease was found in the regions with the developed industrial activities and in the regions with poor drinking water quality [8, 9]. The largest number of patients in the Novosibirsk Region Clinic suffering from urolithiasis came from the regions which are certainly unfavourable from the ecological point of view: Iskitim and Novosibirsk Rural Districts.

According to the data of the State Committee for Ecology (Goskomekologiya), for the years 1998–1999, Novosibirsk and Omsk are within the list of 33 cities with the highest air pollution level; total emission from stationary sources and automobiles puts Omsk into the 7th place among the cities and Novosibirsk occupies the 11th place. Pollution of drinking water is also a problem for these districts. The worst situation is in the rural regions of the Omsk Region, in which 24.1 % of samples from public water supply pipelines did not meet the requirements of State Standard GOST 2874–82 with respect to bacteriological characteristics and 42.7 % with respect to chemical ones; for non-departmental pipelines, 25.0 % of samples are unsatisfactory for their bacteriological characteristics and 46.7 % for chemical ones. On the basis of the data obtained during processing the information about the patients who were undergoing a course of remote lithotripsy in the Omsk Region Clinic (1992–2000), regions with the largest urolithiasis rates can be revealed. These regions are situated mainly in the southern part of the Omsk Region: Kalachinskiy, Maryanovskiy, Omskiy, Lubinskiy and Isilkulskiy. The trend of an increase in urolithiasis rate in the Omsk Region can be observed in the data shown in Table 1.

The goal of the present work is investigation of endemic features of urolithiasis, revelation and comparison of elemental and mineral composition, and parageneses in concretions extracted from patients in the Omsk and Novosibirsk Regions.

SUBJECTS AND PROCEDURES OF INVESTIGATION

Urinary calculi from patients in the Omsk and Novosibirsk Regions were investigated (100 and 102 samples, respectively) after removal by surgical intervention and remote lithotripsy. The remote lithotripsy procedure involves

TABLE 1

Statistical data on urolithiasis in Omsk Region

Parameter	Year			
	1997	1998	1999	2000
Number of patients	2313	2581	5237	6759
Urolithiasis rate per 100 thousand persons	338	371	416	427
First detected urolithiasis cases per 100 thousand persons	122	124	106	104

the action of a focused wave on calculus resulting in its fragmentation, followed by discharge of its separate parts through urinary tracts.

In order to reveal phase composition and structural state of minerals and their quantitative relations, X-ray diffraction analysis and IR spectroscopy (Specord-75 IR) were used. The latter method allows one to identify not only crystalline compounds but also amorphous ones. The IR spectra were solved by comparing with the spectra of pure components and their mixtures shown in the atlas of calculi [10]. The samples were prepared by pressing of tablets with KBr. Diffraction patterns were obtained with DRON-3 diffractometer using CuK_α and CoK_α radiation. Mean composition of the samples was analyzed. The analysis of some samples was carried out in zones from the centre to the surface. The features of morphology of the minerals comprising calculi were studied by means of scanning electron microscope (BS-350 instrument of Tesla company), which helped obtaining high-quality micrographs of particles with a resolution of 0.1 mm. The surface of samples was investigated using X-ray electron spectroscopy with VG ESCA LAB 5 HP instrument. Emission spectral analysis was carried out with STE-1 spectrograph, the atlas of spectral bands [11], spectroprojector (SPP-2M) and a measuring spectral microphotometer (MF-4).

RESULTS AND DISCUSSION

According to the accepted notion, three main groups of urinary calculi are distinguished: urates, composed mainly of uric acid and its salts; phosphates, composed mainly of the salts of orthophosphoric acid; and oxalates, composed of the salts of oxalic acid. Much more rare calculi are cystine, protein, *etc*. Attribution of the calculi of mixed to one group or another was carried out on the basis of the prevailing component.

Phase analysis of the sampled concretions shows that in both districts the most widely spread minerals of urinary calculi are oxalates: whewellite and weddellite, then phosphate minerals: hydroxyl apatite and struvite, followed by urates. However, at the conservation of the general trend in the distribution with respect to the predominant component, we observe a decrease in urate urolithiasis in the patients from the Novosibirsk Region (Table 2). One can also see in Table 2 that oxalate and phosphate urolithiasis cases are similarly spread in both districts as a fist approximation.

We carried out a comparative analysis of the results obtained by us with the investigations of composition and distribution of urinary calculi in Moscow, Berlin and Kyrgyzstan [4]. According to the data of these authors, oxalate calculi are predominant in Moscow, Berlin and Kyrgyzstan, too, but the incidence of calcium oxalates in urinary calculi was the highest in the samples from Berlin and the lowest in the samples from Moscow. In Omsk, Novosibirsk districts and Kyrgyzstan, oxalate urolithiasis occurs at approximately the same rate. Phosphates in urinary concretions are most frequent in Moscow (up to 39 %), then come Omsk and Novosibirsk Regions and Kyrgyzstan with approximately the same level of their occurrence, and in Berlin they are more rare (see Table 2). Urate urolithiasis is more widely

TABLE 2

Occurrence rate of concretions of different composition with respect to the prevailing component in patients from Omsk and Novosibrisk Regions in comparison with the data of [6] for other regions, %

Composition of urinary calculi	Omsk Region (n = 100)	Novosibrisk Region (n = 102)	Moscow (n = 546)	Berlin (n = 10 000)	Kyrgyzstan (n = 106)
Oxalate	61.4	68.7	45.4	72.4	60.4
Phosphate	22.9	20.5	39.0	14.1	20.1
Urate	15.7	10.8	15.2	11.8	19.5
Cystine	0.0	0.0	0.0	0.0	0.0
Protein	0.0	0.0	0.0	0.0	0.0

TABLE 3

Occurrence rate of different minerals in urinary calculi in regions under comparison, %

Mineral	Omsk Region (n = 100)	Novosibrisk Region (n = 102)	Moscow (n = 325)	Berlin (n = 1000)	Kyrgyzstan (n = 127)
Whewellite, $CaC_2O_4 \cdot H_2O$	89	74.5	33.8	80.9	59.8
Weddellite, $CaC_2O_4 \cdot 2H_2O$	36	40.2	24	51.7	32.3
Struvite, $NH_4MgPO_4 \cdot 6H_2O$	13	13.7	41.2	17.3	20.5
Apatite, $Ca_5(PO_4)_3OH$	54	57.8	52.3	49.8	52.8
Whitlockite $Ca_3(PO_4)_2$	3	3.1	9.2	0.2	0.0
Uric acid (anhydrous), $C_5H_4N_4O_3$	18	14.7	17.2	8.4	19.7
Uric acid (dihydrate), $C_5H_4N_4O_3 \cdot 2H_2O$	2		1.2	3.7	2.4
SiO_2	2	0.0	0.0	0.0	0.0
NH_4 urate	0.0	1	7.4	1.7	2.4
Brushite	0.0	1	0.3	1	0.8
Cystine	0.0	0.0	0.0	0.2	0.0

spread in Kyrgyzstan and more rare in Novosibirsk Region and in Berlin.

It is interesting to observe the occurrence of separate minerals in the calculi in patients from Novosibirsk and Omsk Regions in comparison with that in Moscow, Berlin and Kyrgyzstan (Table 3). It follows from Table 3 that among calcium oxalates, whewellite is observed much more frequently than weddellite; among phosphates, hydroxylapatite is more widely spread than struvite. In all the indicated regions, hydroxylapatite occurs with almost the same frequency in urinary calculi. Only in the samples from Moscow the highest rate of whitlockite and struvite occurrence is observed, as well as the rate of one-component calculi composed of struvite, the formation of which is closely of connected with the vital activity of microorganisms. Hydroxylapatite occurs at higher rate in Novosibirsk Region. In the opinion of some authors [4, 12], the occurrence rate of phosphate urolithiasis is mainly connected with coccus microflora, which is an evidence of low efficiency of antibacterial treatment of patients from Moscow and Novosibirsk Region. Urate concretions are represented mainly by anhydrous uric acid in all the regions except samples from Berlin, among which uric acid dehydrate also occurs rather frequently in urate calculi. Among the salts of uric acid, only ammonium hydtogen urate occurs, which is prevailing in calculi in the patients from Moscow.

Analysis of the mineral composition of urinary calculi showed that one-component concretions are most frequent in Moscow (38.1 %), somewhat rarer in Berlin (29.8 %) and are less widespread in Omsk and Novosibirsk Regions (24.3 and 17.8 %, respectively). In Novosibirsk, Omsk Regions and in Berlin the largest fraction of one-component concretions is represented by whewellite crystals, while the samples from Moscow are distinguished by higher rate of monomineral calculi composed of anhydrous uric acid, hydroxylapatite, struvite. In the calculi of complicated composition from Novosibirsk Region, most frequent were associations of whewellite, weddellite and apatite (up to 20 %), the associations of whewellite with apatite and struvite with apatite were of approximately similar frequency (up to 13 %), and then whewellite with weddellite (up to 11 %). For the Omsk Region, the following groupings of minerals were most typical: whewellite with weddellite and apatite, whewellite with weddellite (15.4 %), and whewellite with uric acid (9.1 %). In calculi from Moscow, struvite with hydroxylapatite, as well as hydroxylapatite with whitlockite and whewellite were frequent. In the samples from Berlin, combinations of whewellite with weddellite, whewellite with weddellite and hydroxy apatite were most frequent (3-4 times more frequent than in the samples from Moscow and from Kyrgyzstan).

Generalizing the results shown in Table 3 we may stress that in Novosibirsk Region whewellite and hydroxy apatite occur in urinary calculi with the same frequency, while in Omsk Region whewellite is more widespread than apatite. Struvite is more frequently detected in urinary calculi of patients from Moscow. Weddellite occurs rather uniformly in the calculi of patients over the territories studied in the present paper and those described in [4]. Other compounds (for example, organic pigment, carpathite, *etc.*) and minerals are very rare in the indicated regions, unlike Chelyabinsk Region, where matrix and organic urinary calculi occur with the same frequency as urate and apatite-containing ones [9].

Urinary calculi are diverse in shape, character of surface, colour and size. Their shape can be globular, often slightly flattened, sometimes very complicated coral-like. The latter is usually typical of the calculi formed in kidneys and consisting of the main calculus and its multiple extensions. The colouring of concretions (from white and light-gray to brownish-yellow and dark-brown) depends on the penetration of urinary pigments (urochrome, uroerythrin, *etc.*) into the organic substance. The size of pathological formations in the urinary system varied in our collection from 2 to 67 mm along the maximal section. The internal structure of urinary calculi is most often zonal layered and is characterized by alteration of the layers of similar [13] or different composition, because each compound gets crystallized under definite environmental parameters and pH [12].

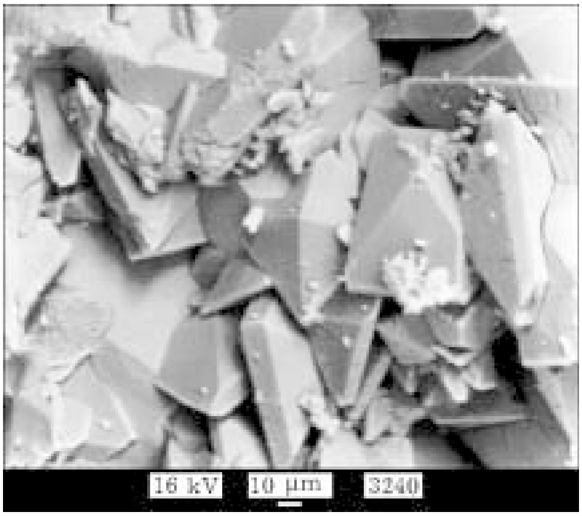

Fig. 1. Microphotograph of the surface of oxalate calculus.

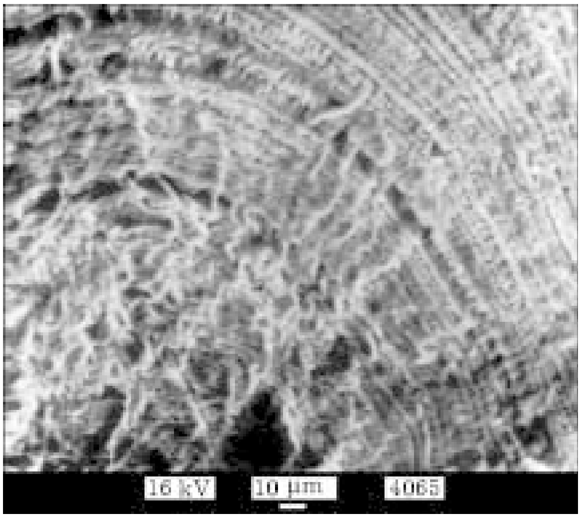

Fig. 2. Microphotograph of the surface of weddellite with the spherulite internal structure.

The mcirostructure of minerals comprising urinary calculi can be substantially different even within one sample, though a preferable morphology is observed for each mineral. Bipyramidal, mainly well-faced crystals are more characteristic of oxalate calculi (Fig. 1). whewellite usually occurs in the form of bipyramidal, less frequently arrow-like crystals with a size up to 20−100 mm, as well as in the form of the thinnest plates overlapping each other and parallel to the calculus surface. Weddellite occurs as both spherulites (Fig. 2) and well-faced flattened bipyramidal envelope-shaped crystals. For the morphology of phosphates, more friable structure is typical than that of oxalates; it is composed of many loosely adjacent spherulites with a size up to 10−15 μm (Fig. 3). Hydroxylapatite forms gel-like ball-shaped aggregates 1−2 μm in diameter and sometimes clearly faced thinnest plates or needle-like crystals. Calcium orthophosphate forms thin disc-like crystals which grow to give shapeless twisted fibrous aggregates. Uric acid is observed in the form of prismatic or needle-like crystals (Fig. 4).

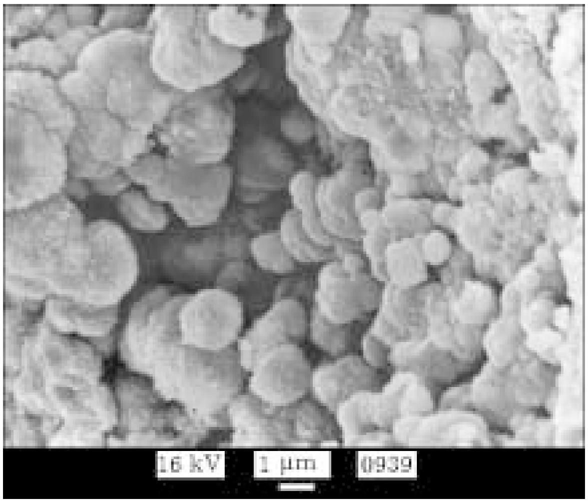

Fig. 3. Microphotograph of the surface of phosphate calculus.

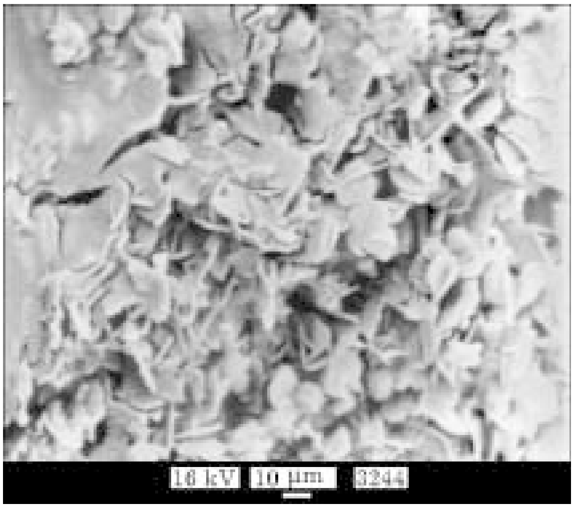

Fig. 4. Microphotograph of the surface of urate calculus.

The internal structure of urinary calculi can be granular and spherulite, or mixed, containing both these structures. As a rule, granular internal structure is observed in oxalate samples and sometimes in phosphate ones (struvite). Spherulite structures are more typical for the pathological formations of phosphate and urate types; as a rule, a sample is represented by one coarse spherulite in the centre of which there is a clot of organic substance.

Microelemental composition of oxalate, phosphate and urate calculi of patients from Omsk and Novosibirsk Regions was determined by means of emission spectral analysis. It was established that in the concrements from Omsk Region Fe, Ti, Al, Cu, Mg are present in all the calculi of mineral types; urate calculi do not contain Ca, Zn, Pb, Si, but Mn was detected only in this type of calculi. Another distribution of microelements is typical for the samples from Novosibirsk: oxalate and phosphate calculi contain Ca, Fe, Si, Pb, Cu, Ti, Zn, Sr, Ba, Rb, As, Cd, Mo, Nd, Ag, Sn, Sb. It was established that the samples comprised by minerals the structure of which is able to sustain isomorphous substitutions (for example, apatite) contain larger amount of microelements than the calculi represented only by uric acid $C_5H_4N_4O_3$. The urate calculi investigated by us contained the lowest concentration of microelements which are likely to be sorbed from solution only by the porous organic component. Apatite-containing calculi are the richest in microelements. In the urinary calculi composed of calcium oxalate (whewellite and/or weddellite), in spite of imperfect crystal structure and limited capacity toward isomorphous substitutions, substantial amounts and diversity of microelements were detected, which is due to the fact that the positions of

TABLE 4

Urolithiasis occurrence rate in age groups in Novosibirsk and Omsk Regions

Age, years	Morbidity, %	
	Omsk	Novosibirsk
10–20	2.8	4.2
20–30	7.6	9.2
30–40	28.1	24.2
40–50	27.1	25.0
50–60	21.3	20.8
60–70	11.2	13.3
70–80	1.9	3.3

Ca can be occupied by Pb, Sr, *etc*. because of close ion radii. Apatite often occurs in association with oxalates. In struvite calculi, substitutions of Mg by Cu, Zn, Ni, Fe^{2+} and of NH_4 by Rb, K are probable; this is the case when higher Rb content is observed.

When processing the data about patients who were treated from urolithiasis in Omsk and Novosibirsk Regions (1992–2000), we categorized the cases to reveal the ages most prone to this disease (Table 4). Patients aged 30 to 50 account for 50 % of all urolithiasis patients. One can see that in Novosibirsk Region, unlike Omsk Region, younger (10–30 years) and older (60–80 years) patients are observed at higher frequency.

CONCLUSIONS

Comparative analysis of the composition and distribution of urinary calculi in patients from different regions showed that oxalate urolithiasis is prevailing in all the regions, which points to the leading role of metabolic factors in the formation of calculi in urolithiasis patients. A characteristic feature of oxalate urolithiasis is high frequency of one-component calculi composed of whewellite. Weddellite is spread almost uniformly in all the regions. In Moscow, oxalate urolithiasis is only slightly more widespread than phosphate one. The frequency of occurrence of hydroxylapatite in the calculi of patients from Novosibirsk and Omsk Regions, Kyrgyzstan, Berlin and Moscow is approximately the same. Struvite and whitlockite are more widespread in the urinary calculi of patients from Moscow. Struvite urinary calculi are typical for the infection route urolithiasis. It should be stressed that there are noticeable differences in the composition of one-component concretions. One-mineral formations are more frequently composed of whewellite in the samples from Novosibirsk, Kyrgyzstan and Berlin, while in Omsk it is whewellite and anhydrous uric acid, while in Moscow it is hydroxylapatite, struvite and anhydrous uric acid. The formation of urate calculi is connected in most cases with disorders in exchange processes and incorrect regulation of pH of urine.

Results of elemental analysis showed that the samples composed of the minerals which are able to sustain isomorphous substitutions (for example, apatite) contain larger amount of diverse microelements that those represented only by uric acid.

Revelation of the mineral composition and structural features of pathogenic mineralization in human organism provides additional information about aetiology and pathogenesis of the disease in different regions.

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