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Research article

Physico-biochemical parameters of urine and blood and biomineralogy of urinary bladder stones in patients with bladder outlet obstruction

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BACKGROUND: Bladder outlet obstruction is one of the main factors leading to the formation of stones in the urinary bladder. Understanding of the physico-biochemical processes in urine and blood, as well as the biomineralogy of urinary bladder stones, will make it possible to determine the pathogenetically justified treatment of such patients.

AIM: The aim of the study was to identify and study the relationship between the physico-biochemical parameters of urine and blood and the biomineralogical composition of urinary bladder stones in patients with bladder outlet obstruction.

MATERIALS AND METHODS: A comprehensive examination of 76 patients at the age of 37 to 89 years with urinary bladder stones occurred against the background of bladder outlet obstruction was carried out. A comprehensive diagnosis, including an assessment of the physico-biochemical parameters of urine and blood, bacteriological urine tests, radiological diagnostics, as well as biomineralogical studies of concretions, was carried out.

RESULTS: The data obtained show that not all physicochemical parameters of blood and urine of the subjects are comparable with the data of patients with nephrolithiasis. In the vast majority of the studied kidney calculi were not detected, in addition, blood biochemical parameters, including the level of stone-forming substances were within the reference values. In urine tests an increase in some lithogenic substances is detected. Urinary stones in patients with bladder outlet obstruction had a mixed composition, more often phosphates and uric acid salts were detected (75 and 54% of cases, respectively). Considering the nature of metabolism and the increase in uric acid excretion with age, as well as the presence of residual urine in case of bladder outlet obstruction, it can be assumed that uric acid is the primary matrix in cystolithiasis. The data obtained indicate a connection between the infectious process in the bladder and the composition of urinary stones. Against this background, there is a more intensive process of cystolithogenesis.

CONCLUSIONS: The algorithm for the diagnosis of urinary bladder stones secondary to bladder outlet obstruction should include not only the collection of anamnesis and the performance of routine blood and urine tests, but also specific physical and biochemical studies, as well as assess the biomineralogy of urinary stones, which will make it possible to choose an adequate tactics for the pathogenetic treatment of patients and effective metaphylaxis of stone formation.

Keywords: cystolithiasis; lithogenesis; bladder outlet obstruction; biomineralogy; urate lithiasis; phosphates.

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Научная статья

Физико-биохимические показатели мочи и крови и биоминералогия камней мочевого пузыря у пациентов с инфравезикальной обструкцией

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Актуальность. Инфравезикальная обструкция — один из основных факторов, приводящих к образованию камней в мочевом пузыре. Понимание физико-биохимических процессов в моче и крови, а также биоминералогии камней мочевого пузыря позволит определить патогенетически обоснованное лечение пациентов с инфравезикальной обструкцией.

Цель — выявить и изучить связь между физико-биохимическими показателями мочи и крови и биоминералогическим составом камней мочевого пузыря у пациентов с инфравезикальной обструкцией.

Материалы и методы. Проведено комплексное обследование 76 пациентов в возрасте от 37 до 89 лет с камнями мочевого пузыря, возникших на фоне инфравезикальной обструкции. Проведена комплексная диагностика, включающая оценку физико-биохимических показателей мочи и крови, бактериологические анализы мочи, лучевую диагностику, а также биоминералогические исследования конкрементов.

Результаты. Полученные данные показывают, что не все физико-химические параметры крови и мочи исследуемых сопоставимы с данными пациентов с нефролитиазом. У абсолютного большинства больных конкременты в почках выявлены не были, а биохимические показатели крови, в том числе уровень камнеобразующих веществ, в пределах референсных значений. В анализах мочи выявлено повышение некоторых литогенных веществ. Мочевые камни у пациентов с инфравезикальной обструкцией имели смешанный состав, чаще выявляли фосфаты и соли мочевой кислоты (75 и 54 % случаев соответственно). Учитывая характер метаболизма и повышение экскреции мочевой кислоты с возрастом, а также наличие остаточной мочи при инфравезикальной обструкции, можно предположить, что мочевая кислота является первичным матриксом при цистолитиазе. Полученные данные свидетельствуют о влиянии инфекционного процесса в мочевом пузыре на состав мочевых камней и на интенсивность цистолитогенеза.

Заключение. В алгоритм диагностики камней мочевого пузыря, вторичных к инфравезикальной обструкции, необходимо включать не только сбор анамнеза и рутинные исследования крови и мочи, но и проводить специфические физико-биохимические исследования, а также оценивать биоминералогию мочевых камней, что позволит выбрать адекватную тактику патогенетического лечения больных и эффективную метафилактику камнеобразования.

Ключевые слова: цистолитиаз; литогенез; инфравезикальная обструкция; биоминералогия; уратный литиаз; фосфаты.

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ЭКО•ВЕКТОР

BACKGROUND

Infravesical obstruction currently represents an urgent problem of modern urology. This term refers to the impairment of the physiological patency of the vesicourethral segment of the urinary system [1]. Infravesical obstruction can be functional or organic. Functional infravesical obstruction is mainly associated with neurogenic dysfunctions, whereas organic infravesical obstruction combines a number of pathologies, such as benign prostatic hyperplasia (BPH), urethral stricture, sclerosis of the bladder neck, and malignant neoplasms of the prostate, bladder, and urethra and urethral valves [2, 3]. Infravesical obstruction can cause numerous complications, including cystolithiasis [4]. The latter is understood as the formation of stones in the bladder. The term "urolithiasis" is understood as a chronic systemic disease resulting from metabolic disorders and the influence of environmental factors, manifested by lithogenesis in the kidneys and urinary tract. Most often, stones are localized in the kidney and ureter but can also be detected in the bladder [5, 6]. Cystolithiasis affects 7%–15% of men with infravesical obstruction, especially in the Middle East and North Africa [7]. In Russia, the proportion of patients with bladder stones is about 5% of all patients with the presence of calculi [8]. Based on the literature data, cystolithogenesis is facilitated by an impairment of urine outflow from the bladder, altered anatomy, metabolic disorders, and the presence of foreign bodies in the lower urinary system [9]. Most treatment issues of patients with cystolithiasis associated with infravesical obstruction and metaphylaxis of lithogenesis are currently the subject of discussion given that a number of aspects of the pathogenesis of this condition are still unclear [10, 11].

The presence of infravesical obstruction not only causes the occurrence of calculi in the entire urinary system but also affects the intensity of lithogenesis [12]. According to the study by V. Yu. Ivanova et al. [13], bladder stones are detected in 87.4% of cases in patients with infravesical obstruction. Given the presence of combined pathology, a thorough examination of such patients and the development of adequate approach for their treatment are required. The understanding of the mineralogical composition of urinary stones is important because it will influence the process of lithogenesis in this group of patients. To date, indirect methods are used to determine the composition of uroliths using clinical and biochemical analyses of urine and blood and dual-energy computed tomography [14, 15]. The accurate determination of the mineralogical composition of urinary calculi is possible only after their removal from the urinary system organs using contemporary methods for the identification of the composition of stones, namely, infrared spectroscopy, X-ray fluorescence analysis, and scanning electron microscopy of the calculus cut [16]. Correlations should be made between the physical and biochemical analyses of blood and urine and the composition of uroliths, which will enable the prescription of pathogenetic treatment of patients [17, 18].

The study aimed to identify and analyze the relationship between the physical and biochemical parameters of urine and blood and the biomineralogical composition of bladder stones in patients with infravesical obstruction.

MATERIALS AND METHODS

From 2015 to 2020, at the Department of Urology of the Mechnikov North Western State Medical University, calculi were removed from the bladder of 76 patients with infravesical obstruction. In 25 (33%) patients, a suprapubic urinary catheter was installed at the prehospital stage. The size of calculi varied from 2.2 cm to 6 cm (average 3.8 cm). The average age of patients was 64 years (37–89 years). Bladder calculi were detected using radiographic diagnostic methods, such as plain radiography, ultrasound examination, or multislice computed tomography. In addition to routine clinical and biochemical analyses (including urine culture for microflora, blood levels of uric acid, and total and ionized calcium, magnesium, and phosphorus), specific studies of the physical and biochemical parameters of blood and urine were performed to determine the osmolarity of urine and blood, the daily excretion of urinary acid, calcium, phosphorus, magnesium, and citrate, and kinematic viscosity and crystal-inhibiting activity of urine [16].

The study included patients with infravesical obstruction and the presence of calculi in the bladder. The criteria for exclusion from the study were ligature-fixed calculi due to previous surgeries and the presence of functional infravesical obstruction.

BPH was the cause of infravesical obstruction in 49 patients, of which 11 also had urethral stricture, 19 were diagnosed with a malignant neoplasm of the prostate (prostate cancer), and 8 had bladder neck stenosis. An important aspect was the presence of an organic cause of infravesical obstruction. Transurethral cystolithotripsy was performed on 48 patients, including 21 patients with BPH, 19 patients with prostate cancer, and 8 patients with bladder neck stenosis. Cystolithotomy with simultaneous transvesical adenomectomy was performed on 17 patients with BPH. Eleven patients with BPH and urethral stricture underwent lithotripsy in accordance with our method of percutaneous cystolithotripsy with lithoextraction (priority for the invention of the Russian Federation "Method of percutaneous cystolithotripsy in patients with infravesical obstruction" No. 2021121779 dated 07/22/2021).

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A total of 59 patients underwent stage 1 treatment in the form of cystolithotripsy and cystolithoextraction only during one hospitalization. Hospitalization after 2–4 weeks was recommended to 49 patients with BPH as the stage 2 of treatment to eliminate infravesical obstruction. To date, 42 patients from this group have been treated. All these patients underwent bipolar or plasma ablation of the prostate. Exactly 19 patients with prostate malignant tumors underwent stage 2 treatment at the Oncourology Department. A total of 10 out of 11 patients with urethral stricture were operated on using various methods of urethral reconstruction. Six patients with bladder neck stenosis underwent transurethral plasma vaporization of the bladder neck. Three patients temporarily refrained from the proposed methods of treatment.

The reason for the two-stage choice of treatment for patients with bladder stones was the presence of bladder infections in patients and age-related concomitant somatic diseases. Patients were referred to the stage 2 of treatment to eliminate infravesical obstruction, which was the main cause of the development of cystolithiasis. This approach was fully justified given that surgical complications during and after surgery are minimal.

During intravesical imaging using endovideosurgical technique, calculi were mainly observed, and they had a rounded shape and a smooth surface. The colors of the stones were diverse, with predominant light-yellow and light-gray colors. During the crushing of calculi, the prevailing majority had a loose structure and pronounced layering predominantly.

Contrary to popular belief, visual examination of the calculi removed from the bladder cannot suggest their composition, as evidenced by further biomineralogical analysis. Occasionally, a macroscopic assessment enables doctors to "guess," for example, a phosphate stone. However, in general, conclusions about the mineral composition during visual examination of uroliths are often erroneous [17, 18].

Table 1. The structure of urine microflora in examined patients with cystolithiasis (*n* = 76)

Таблица 1. Структура микрофлоры мочи у обследуемых больных цистолитиазом (*n* = 76)

Type of microorganism	Number of patients	
	n	%
Mixed flora (microorganisms of different species)	17	22.3
Staphylococcus spp.	15	19.7
Streptococcus spp.	13	17.2
Enterobacter spp.	12	15.7
Clostridium perfringens	10	13.2
Escherichia coli	6	7.9
Klebsiella spp.	3	4.0
Total	76	100

Stone fragments after cystolithotripsy or whole stones after cystolithotomy were sent for examination, which included scanning electron microscopy of the stone cut and X-ray fluorescence analysis. Using X-ray phase analysis, the chemical composition of the urolith was determined. For this purpose, automated powder diffractometers ADP-2 and Dron-3 were used. Scanning electron microscopy of urolith cuts was performed on a CamScan MX2500 device equipped with an energy dispersive analytical attachment INCA Energy [19, 20].

Given the lack of normative data on the physicochemical parameters of urine and blood, we examined 35 healthy men aged 35–80 years from the comparison group [21].

Statistical processing of the results was performed using the statistical software package Statistica. Differences were considered significant at p lower than 0.05

RESULTS AND DISCUSSION

According to the ultrasound examination of the kidneys, 5 (7%) of the 76 patients had calculi in the kidneys (one kidney in 2 patients and in both kidneys in 3 patients). In 93% of patients, no stones were found in the upper urinary tract. According to the survey radiography, bladder calculi were visualized in 50 (66%) patients, whereas radiolucent calculi were detected in the remaining 26 patients who underwent multislice computed tomography. According to clinical and biochemical analyses of blood and urine at the time of hospitalization, all patients had leukocyturia of varying degrees, and erythrocyturia was registered in 59 (78%) patients. According to the urine culture in the patients examined, in most cases, Gram-positive bacteria, such as *Staphylococcus, Streptococcus, Enterococcus*, and *Clostridium*, were detected. Pathogens, such as *Escherichia coli* and *Klebsiella pneumoniae*, were detected in less than 15% of patients (Table 1).

Among microorganisms, mixed flora (22.3%) and *Staphylococcus* spp. (19.7%) prevailed. Table 1 shows no significant difference in the number of pathogens. The share of *Escherichia coli*, the main causative agent of cystitis, accounted for 7.9%, and the share of *Staphylococcus* was 2.5 times more. Based on these data, lithogenesis in the bladder is related to infectious agents that enter the bladder through a suprapubic urinary catheter.

Differences were registered between the group of patients with cystolithiasis and healthy people from the comparison group in terms of urine parameters, whereas the values of blood parameters did not differ significantly (Table 2). The level of daily excretion of uric acid in the urine in patients with cystolithiasis varied from 775.8 mg to 914.8 mg (mean 911.42 ± 1.79 mg), and this finding may be associated with the excessive synthesis of uric acid in older people [22]. In our study,

Table 2. Physico-biochemical parameters of urine and blood of patients with cystolithiasis and healthy people from the comparison group (*M* ± *m*)

Таблица 2. Физико-биохимические показатели мочи и крови больных цистолитиазом и здоровых людей из группы сравнения (*M* ± *m*)

Parameter	Patients with cystolithiasis, *n* = 76	Healthy people from the comparison group, *n* = 35	*p*
	Urine		
Daily excretion of uric acid, mg per day	911.42 ± 1.79 (775.8–914.8)	532.43 ± 3.46 (489.9–576.5)	<0.001
Daily excretion of calcium, mg per day	302.39 ± 2.64 (194.4–321.4)	225.91 ± 1.29 (210.9–240.4)	<0.001
Daily excretion of phosphorus, mmol per day	43.39 ± 0.38 (33.1–47.1)	32.31 ± 0.51 (26.7–38.1)	<0.001
Daily excretion of magnesium, mg per day	50.96 ± 0.33 (44.5–56.2)	50.2 ± 0.36 (45.7–54.6)	<0.001
Osmolarity, mOsmol/l	853.18 ± 3.07 (575.5–910.7)	–	–
Excretion of citrate, mg per day	271.54 ± 1.46 (246.4–290.1)	350.71 ± 0.49 (344.9–356.5)	<0.001
Kinematic viscosity of urine, cSt	1.25 ± 0.01 (1.12–1.75)	–	–
Crystal-inhibiting activity of urine, U	1.18 ± 0.01 (0.16–1.19)	–	–
	Blood		
Uric acid, mmol/l	454.42 ± 2.42 (192.9–517.6)	409.5 ± 3 (184.2–478.5)	0.05
Calcium total, mmol/l	2.36 ± 0.01 (2.10–2.61)	2.34 ± 0.01 (2.2–2.5)	0.05
Ionized calcium, mmol/l	1.26 ± 0.02 (1.13 ÷ 1.31)	1.25 ± 0.01 (1.1–1.4)	0.05
Phosphorus, mmol/l	1.35 ± 0.03 (0.97–1.49)	1.15 ± 0.01 (1.1 ± 1.6)	0.05
Magnesium, mmol/l	1.09 ± 0.02 (0.78–1.26)	0.93 ± 0.01 (0.8–1)	0.05
Osmolarity, mmol/kg	298.87 ± 1.36 (290.4–340.6)	290.03 ± 0.41 (284.1–295)	0.05

an increase in the daily excretion of uric acid in the urine was noted in 15 patients. The average content of uric acid in the blood of patients was 454.42 ± 2.42 mmol/l (192.9–517.6 mmol/l), and three of them exceeded the upper limit of the norm (reference value: 150–480 mmol/l). The daily excretion of calcium in urine in patients with cystolithiasis averaged 302.39 ± 2.64 mg (194.4–321.4 mg), whereas the levels of total and ionized calcium in the blood did not differ from the values observed in healthy people from the comparison group and were within the reference values (2.2–2.55 and 1.15–1.27 mmol/l, respectively). The concentration of ionized calcium is an important parameter that reflects most reliably the amount of calcium ions per unit volume of blood. In the case of impaired calcium metabolism, stones in the urinary system are often manifested in the form of calcium salts that oversaturate the urine [23]. The urine concentrations of phosphorus and magnesium also differed from the norm. The daily excretion of phosphorus varied from 33.1 mmol to 47.1 mmol (average 43.39 ± 0.38 mmol) at a rate of up to 42 mmol per day. The level of magnesium in daily urine ranged from 44.5 mg to 56.2 mg (mean 50.96 ± 0.33 mg) at a norm of less than 50 mg. The increased urinary excretion of these elements significantly affects the process of lithogenesis in the urinary system. Urinary osmolarity ranged from 575.5 mOsmol/l to 910.7 mOsmol/l (average 853.18 ± 3.07 mOsmol/l) and was within the reference range (300–900 mOsmol/l). Osmolarity reflects the processes of energy conversion that occurs inside the cells and is associated with electrolyte, water, and protein homeostasis, and with its increase, the probability

of stones in the urinary system increases. The kinematic viscosity of urine ranged from 1.12 cSt to 1.75 cSt (average 1.25 ± 0.01 cSt) at a norm of 1.13 ± 0.05 cSt. The value of this indicator is determined by the value of internal friction that occurs between colloid particles. The increase in viscosity is due to an increase in the number and size of crystals in the urine, increasing the likelihood of the formation of a urolith core. The crystal-inhibiting activity of urine reflects its capability to inhibit the formation of crystals. Its value in the patients with cystolithiasis whom we monitored was 1.18 ± 0.01 U (0.16–1.19 U), and it was lower than the reference values (1.45 ± 0.05 U) [12].

The results of the physical and biochemical analyses of urine and blood obtained by our group indicate that not all patients with bladder stones initially had a tendency to develop lithogenesis. Infravesical obstruction was the main trigger for stone formation. Several patients had a history of comorbidities, such as hypertension, diabetes mellitus, gout, and osteoporosis. Other patients were examined by an endocrinologist on an outpatient basis, including an examination to determine the level of parathyroid hormone. One patient was diagnosed with hyperparathyroidism, and stone formation was associated with primary hyperparathyroidism. Parathyroidectomy enabled the stabilization of the level of parathyroid hormone and calcium–phosphorus metabolism in this patient.

Distinct differences were observed in the biomineralogical properties of stones removed from patients with and without a suprapubic urinary catheter. A total of 90% of all stones of patients with suprapubic urinary catheter had a phosphate composition and included hydroxyapatite, struvite, and carbonate apatite, and 10% had a mixed urate and phosphate composition. In addition, urinalysis showed alkaline urine (pH above 7.5) in 90% of these patients. Probably, these patients had concomitant infection due to the presence of cystostomy drainage; microbiological examination of urine often revealed *Enterobacter* spp. in them. In patients without the history of surgeries on the organs of the urinary system, urate calculi, consisting of uric acid and sodium urate, were detected. Among the 76 patients, 19 had a history of repeated catheterizations due to urinary retention.

Thus, in most patients with bladder stones that occurred in presence of infravesical obstruction, no changes were detected in the blood characteristic of patients with stones in the upper urinary tract, whereas typical changes of increased lithogenicity were noticed in the urine. We associated this phenomenon with the presence of an infectious inflammatory process in the bladder of such patients.

The results of the biomineralogical study of calculi showed that in 66 (86.8%) patients, the composition of bladder calculi was mixed (polymineral). Uric acid salts were detected in 41 (53.9%) cases, phosphates in 57 (75%) cases, and oxalates and other salts in 11 (14.5%) cases. Ten (13.2%) patients had monomineral uroliths consisting of uric acid. Figures 1–5 present five stone samples; two were composed of uric acid, and three were composed of phosphate. Urates are usually of the spherulitic type, whereas phosphates are of the granular type [13]. The samples presented had a loose and layered structure, which is characteristic of urates (Figs. 1 and 2). X-ray fluorescence analysis established the crystal chemical composition of stones [22].

Different types of samples were present in the phosphate stones of the bladder, namely, a stone of granular structure (Fig. 3), a stone with a complex concentric-layered structure with a zonal pattern (Fig. 4), and a stone with a loose porous structure interspersed with phosphates (Fig. 5).

Correlations between the mineralogical composition of bladder stones and the physicochemical properties of urine and blood were found in 14 (18.5%) patients monitored. Thus, given the purpose of this work, metabolism has a direct effect on lithogenesis in the bladder only in certain cases. The main role is played by the presence of residual urine in the bladder due to obstruction and the presence of infection. The entry of infection during bladder catheterization, in turn, can affect the stabilizing factors of lithogenesis in the bladder. In this case, in patients with infravesical obstruction, the process of cystolithogenesis is more intense. Given the nature of the metabolism of uric acid, in some patients, especially the elderly, its excretion in the urine increases, and owing to infravesical obstruction, it is not evacuated from the bladder in time, which causes the formation of primary stones.

CONCLUSIONS

Infravesical obstruction as the main cause of a number of urological pathologies attracts great attention from specialists. Cystolithiasis occupies a special place among these nosologies. This study revealed the relationship between the physical and biochemical parameters of urine and blood and the biomineralogical composition of bladder stones in patients with infravesical obstruction. The data obtained demonstrated a possible connection between the infectious process in the bladder and the composition of urinary calculi. The algorithm for diagnosing bladder stones secondary to infravesical obstruction should include not only the history taking and performing routine blood and urine tests but also specific physical and biochemical studies and assessment of the biomineralogy of urinary stones for the selection of an adequate approach of pathogenetic treatment of patients and effective metaphylaxis of lithogenesis.

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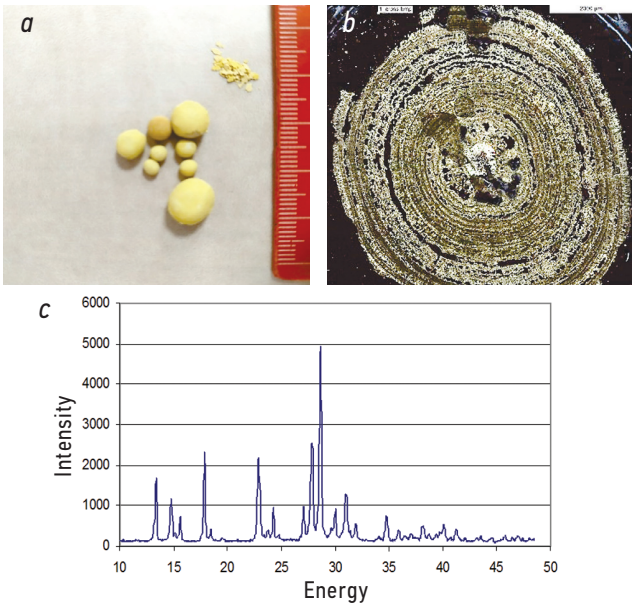

Fig. 1. Uric acid calculi of the urinary bladder. *a* – The appearance of the calculi; *b* – photo of a thin section of a calculus in crossed nicols, the layered structure of the calculi is visible; *c* – X-ray fluorescence analysis of the calculus: crystalline phases are detected – wevellite (calcium oxalate monohydrate $CaC_2O_4 \cdot H_2O$) – 10%, and uric acid – dihydrate ($C_5H_4O_3N_4 \cdot 2\ H_2O$) – 90%

Рис. 1. Уратные камни мочевого пузыря. *a* — Внешний вид конкрементов; *b* — фото шлифа конкремента в скрещенных николях, видно слоистое строение камня; *c* — рентгенофлуоресцентный анализ камня: выявляются кристаллические фазы — вевеллит (оксалат кальция моногидрат $CaC_2O_4 \cdot H_2O$) — 10 %, мочевая кислота — дигидрат ($C_5H_4O_3N_4 \cdot 2\ H_2O$) — 90 %

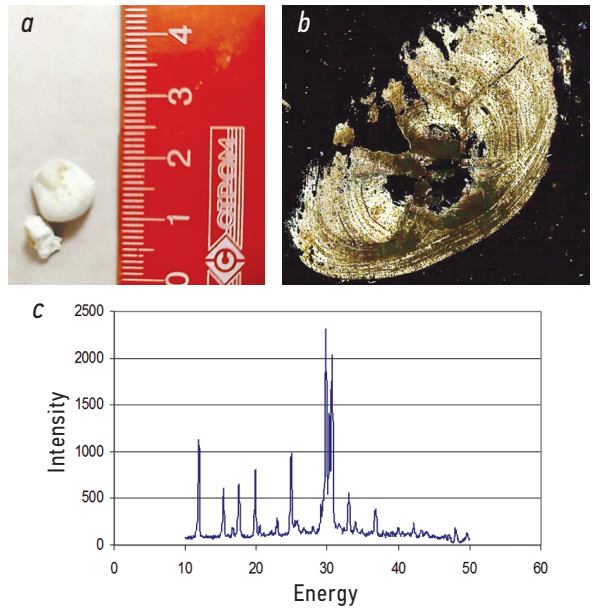

Fig. 2. Uric acid calculi of the urinary bladder. *a* – The appearance of the calculi; *b* – photo of a thin section of a calculus in crossed nicols, the layered structure of the calculi is visible; *c* – X-ray fluorescence analysis of the calculus: the crystalline phase is detected – uric acid ($C_5H_4N_4O_3$) – 100%

Рис. 2. Уратные камни мочевого пузыря. *a* — Внешний вид конкрементов; *b* — фото шлифа конкремента в скрещенных николях, видно слоистое строение камня; *c* — рентгенофлуоресцентный анализ камня: выявляется кристаллическая фаза — мочевая кислота ($C_5H_4N_4O_3$) — 100 %

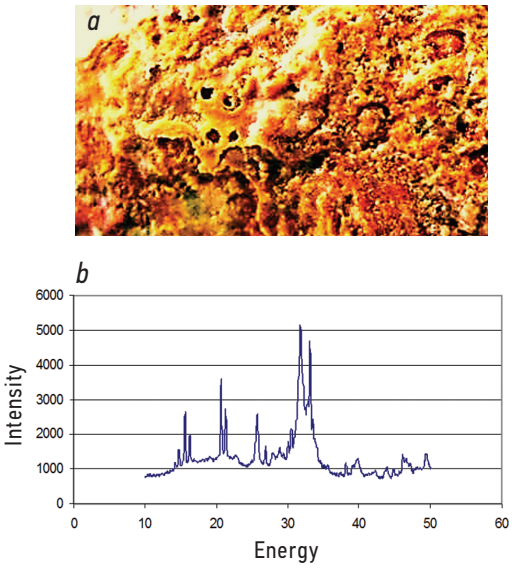

Fig. 3. Phosphate calculus of the urinary bladder. *a* – The granular structure of the calculus; *b* – X-ray fluorescence analysis of the calculus: crystalline phases are revealed – struvite ($MgNH_4PO_4 \cdot 6\ H_2O$) – 60% and hydroxylapatite [$Ca_5(PO_4)_3OH$] – 40%

Рис. 3. Фосфатный конкремент мочевого пузыря. *a* — Зернистое строение конкремента; *b* — рентгенофлуоресцентный анализ камня: выявляются кристаллические фазы — струвит ($MgNH_4PO_4 \cdot 6\ H_2O$) — 60 % и гидроксилапатит [$Ca_5(PO_4)_3OH$] — 40 %

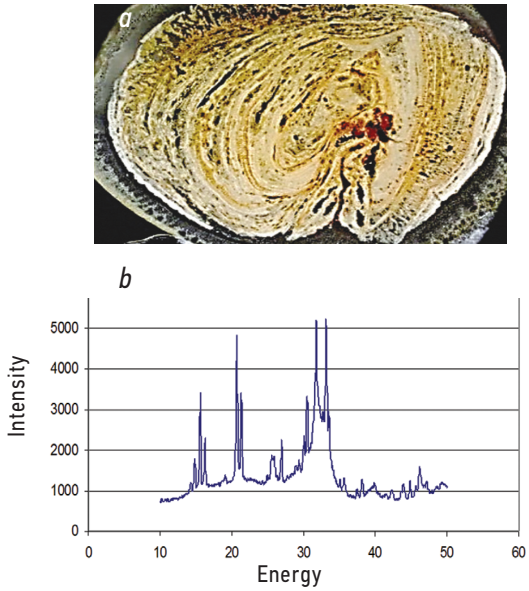

Fig. 4. Phosphate calculus of the urinary bladder. *a* – Cut of phosphate calculus: a concentric-layered structure with a zonal structure is revealed, struvite-hydroxylapatite layers are detected; *b* – X-ray fluorescence analysis of the stone: the crystalline phase is revealed – struvite ($MgNH_4PO_4 \cdot 6\ H_2O$) – 100%

Рис. 4. Фосфатный конкремент мочевого пузыря. *a* — Спил фосфатного конкремента: выявляется концентрически-слоистая структура с зональным строением, определяются струвит-гидроксилапатитовые слои; *c* — рентгенофлуоресцентный анализ камня: выявляется кристаллическая фаза — струвит ($MgNH_4PO_4 \cdot 6\ H_2O$) — 100 %

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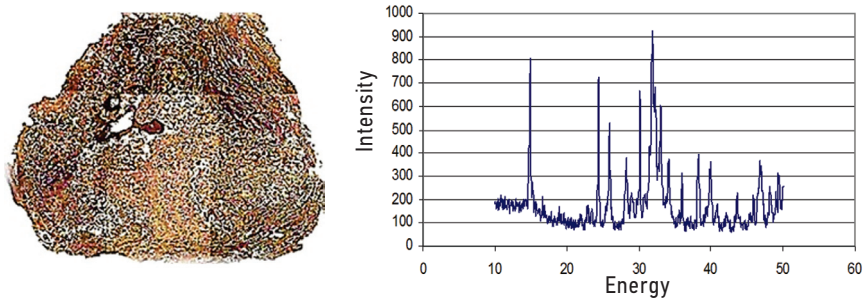

a *b*

Fig. 5. Phosphate calculus of the urinary bladder. *a* – Cut of phosphate calculus: loose porous structure; *b* – X-ray fluorescence analysis of the calculus: crystalline phases are revealed – wevellite (calcium oxalate monohydrate $CaC_2O_4 \cdot H_2O$) – 60% and hydroxylapatite $[Ca_5(PO_4)_3OH]$ – 40%

Рис. 5. Фосфатный конкремент мочевого пузыря. *a* — Спил фосфатного конкремента: заметна рыхлая пористая структура; *b* — рентгенофлуоресцентный анализ камня: выявляются кристаллические фазы — вевеллит (оксалат кальция моногидрат $CaC_2O_4 \cdot H_2O$) — 60 % и гидроксилапатит $[Ca_5(PO_4)_3OH]$ — 40 %

ADDITIONAL INFORMATION

Author contributions. All authors confirm that their authorship complies with the international ICMJE criteria (all authors have made a significant contribution to the development of the concept, research, and preparation of the article; they read and approved the final version before its publication).

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