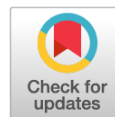


DOI: <https://doi.org/10.17816/uroved58899>

Formation dynamics of phase and elemental composition of the oxalate-calcium nephrolithes



Pavel S. Plugin^{1, 2}, Dmitriy Yu. Troitskii³, Alexander I. Gubanov³, Alphiya R. Tsygankova³, Irina B. Troitskaya³, Igor V. Feofilov²

¹ City Clinical Hospital of the Emergency Care No. 2, Novosibirsk, Russia;

² Novosibirsk State Medical University, Novosibirsk, Russia;

³ Nikolaev Institute of Inorganic Chemistry of Siberian Branch of Russian Academy of Sciences, Novosibirsk, Russia

BACKGROUND: Fundamental investigation of the issue how various factors influence on origin and behavior of the nephrolithiasis is very actual because of necessity of the information about of early diagnostic methods as well as a prognostication.

So, the information about of formation dynamics of phase and elemental composition of oxalate-calcic nephrolithes pending of lifetime of one patient is useful.

AIM: The aim of the investigation is to obtain the information about of elemental composition as well as phase composition of the one patient nephrolithes formed pending of lifetime.

MATERIALS AND METHODS: In the paper the data of the careful investigation of the elemental and phase composition of the two nephrolithes ablated from one patient at different times are presented. First nephrolith had been ablated from the right kidney in the March of 2002 (patient was 41 years old), subsequently second that had been did from the left kidney in the December of 2019 (patient was 58 years old; the nephrolith was found in 2012). The study was carried out using mass spectrometry and atomic adsorption spectrometry with inductively coupled plasma, infrared spectroscopy, X-ray phase analysis, CHN/S analysis.

RESULTS: Both calculi were calcium oxalate, predominantly Veveelite structures. The chemical composition of the both nephrolithes is alike. They contain microimpurities of all essential as well as conditionally essential elements. Quantities of the toxic elements in the nephrolithes are identical too. Microquantities of the nitrogen and sulphur indicate a presence of amino acids and proteins in the nephrolithes structure.

CONCLUSIONS: The results indicate that the nephrolithes with invariable phase and elemental composition would be forming in the different kidneys of one patient pending of lifetime.

Keywords: oxalate-calcic nephrolithes; nephrolithiasis; elemental composition of the nephrolithes; essential elements; conditionally essential elements; mass spectrometry; atomic adsorption spectrometry; infrared spectroscopy; X-ray phase analysis; CHN/S analysis.

To cite this article:

Plugin PS, Troitskii DY, Gubanov AI, Tsygankova AR, Troitskaya IB, Feofilov IV. Formation dynamics of phase and elemental composition of the oxalate-calcium nephrolithes. *Urology reports (St. Petersburg)*. 2021;11(2):133-139. DOI: <https://doi.org/10.17816/uroved58899>

DOI: <https://doi.org/10.17816/uroved58899>

Динамика формирования фазового и элементного состава оксалатно-кальциевых конкрементов

П.С. Плугин^{1, 2}, Д.Ю. Троицкий³, А.И. Губанов³, А.Р. Цыганкова³, И.Б. Троицкая³, И.В. Феофилов²

¹ Городская клиническая больница скорой медицинской помощи № 2, Новосибирск, Россия;

² Новосибирский государственный медицинский университет, Новосибирск, Россия;

³ Институт неорганической химии им. А.В. Николаева СО РАН, Новосибирск, Россия

Введение. Фундаментальные исследования влияния различных факторов на возникновение и течение мочекаменной болезни (МКБ) весьма актуальны ввиду острой востребованности информации о методах ее ранней диагностики и прогнозирования течения. С этих позиций информация о динамике формирования кристаллической структуры (фазового состава) и элементного состава оксалатно-кальциевых конкрементов у одного пациента на протяжении жизни может быть полезна.

Цель — получение информации об элементном составе и кристаллической структуре оксалатно-кальциевых уролитов, формирующихся у одного пациента на протяжении жизни.

Материалы и методы. В статье приведены данные подробного исследования элементного состава и кристаллической структуры почечных камней, удаленных у одного и того же пациента в марте 2002 г. из правой почки (возраст пациента составлял 41 год) и в декабре 2019 г. из левой почки (возраст 58 лет, камень был обнаружен в 2012 г.). Исследование проводили с помощью масс-спектрометрии и атомно-адсорбционной спектрометрии с индуктивно-связанной плазмой, инфракрасной спектроскопии, рентгенофазового анализа, CHN/S-анализа.

Результаты. Оба конкремента представляли собой оксалат кальция, преимущественно структуры вевеллита. Химический состав камней очень близок, конкременты содержат весь спектр эссенциальных и условно-эссенциальных элементов на уровне микропримесей. Состав и содержание токсичных элементов в обоих камнях также значительно не изменяется. Наличие микроколичеств азота и серы в составе камней свидетельствует о присутствии аминокислот и белка в их структуре.

Заключение. Полученные результаты свидетельствуют, что на протяжении жизни в разных почках у пациента формировались конкременты постоянного фазового и химического состава.

Ключевые слова: оксалатно-кальциевые конкременты; мочекаменная болезнь; элементный состав конкрементов; эссенциальные элементы; условно-эссенциальные элементы; масс-спектрометрия; атомно-адсорбционная спектрометрия; инфракрасная спектрометрия; рентгенофазовый анализ; CHN/S-анализ.

Как цитировать:

Плугин П.С., Троицкий Д.Ю., Губанов А.И., Цыганкова А.Р., Троицкая И.Б., Феофилов И.В. Динамика формирования фазового и элементного состава оксалатно-кальциевых конкрементов // Урологические ведомости. 2021. Т. 11. № 2. С. 133–139. DOI: <https://doi.org/10.17816/uroved58899>

INTRODUCTION

Urolithiasis is one of the most critical problems of contemporary medicine, which is associated with its high prevalence, chronic and recurrent course, and frequent development of severe complications. Its causes are associated with improper nutrition, environmental factors, physical inactivity, and metabolic disorders [1, 2]. Taking into account the urgency of the problem and critical demand for information on the methods of early diagnosis and prognosis of urolithiasis, as well as on methods of preventing relapse, fundamental studies have examined the influence of various factors on the occurrence and course of urolithiasis [3–6].

Since the course of urolithiasis is often unpredictable, information on the changes over time of the formation of the crystal structure and elemental composition of calcium oxalate calculi is very useful. This paper presents data from a detailed study of the composition of nephroliths removed from the same patient in March 2002 from the right kidney and in December 2019 from the left kidney. This paper also presents the possibility of a complex of contemporary mutually complementary analytical methods for a detailed study of the chemical and phase compositions of calculi.

MATERIALS AND METHODS

We examined the calculi removed from the same patient (at age 41) in March 2002 from the right kidney and in December 2019 from the left kidney (at age 58, and this stone was detected in 2012). For analysis, the stones were ground in an agate mortar. The resulting powders were used in the X-ray phase analysis (XPA), double-jet arc plasma atomic emission spectrometry (DAP-AES), and elemental CHN/S analysis. For analyses by inductively coupled plasma mass spectrometry (ICP-MS) and inductively coupled plasma atomic emission spectrometry (ICP-AES), the ground stone samples were dissolved in aqua regia (a mixture of hydrochloric and nitric acids in the proportion of 3HCl : 1HNO₃).

The mineral composition of the calculi was analyzed by the ICP-MS method using an Agilent 8800 Quadrupole Mass Spectrometer (Japan) with a collision and reaction cell to eliminate spectral overlaps, using oxygen and helium as reaction gases [7, 8]. The ICP-AES method was performed on an ICAP 6500 Spectrometer (Thermo Fisher Scientific, Waltham, MA, USA) with a cyclone-type spray

chamber and a SeaSpray-type pneumatic nebulizer, with a recorded wavelength range of 166–847 nm and with an axial method for recording an analytical signal [9, 10] and by the DAP-AES method [11].

The organic composition was examined by CHN/S analysis on a Euro EA 3000 Analyzer according to the optimized technique [12] and by IR spectroscopy using an FT-801 Spectrometer (Simex, Novosibirsk).

The phase composition was determined by powder XPA on a DRON-3M diffractometer [13].

RESULTS AND DISCUSSION

The phase composition of nephroliths was examined by X-ray phase powder analysis. The 2002 stone was composed of 75% whewellite and 25% weddellite, and the 2019 stone was 100% whewellite. Both phases represented crystalline modifications of calcium oxalate, with a difference in the content of water of crystallization. Whewellite is calcium oxalate monohydrate CaC₂O₄ · H₂O, and weddellite is calcium oxalate dihydrate CaC₂O₄ · 2H₂O. However, an increase in the content of water of crystallization in the 2002 stone could have occurred during the stone storage for 18 years under ambient conditions.

The mineral composition was investigated by complementary spectral analysis methods. The ICP-MS method with a collision and reaction cell determined most accurately the content of heavy elements, and the ICP-AES method with an axial signal registration method determined lightweight elements. As an advantage, the DAP-AES method allows the analysis of solid objects, excluding the dissolution stage. As a summary, Table 1 presents the results of the analyses of these three methods.

Table 1 shows that the elemental compositions of the 2002 and 2019 stones were comparable and represented by all essential and conditionally essential elements [14–18]. The mineral base of both stones was calcium. Moreover, the stones contain toxic elements that are often technogenic in nature and enter the body through the skin, lungs, or food [17]. It is believed that heavy elements such as mercury, cadmium, and lead are the calculi centers of crystallization [19]. However, mercury, cadmium, uranium, and thorium were not found in the stones. Trace amounts of lead were detected in both stones. Interestingly, the 2002 stone contains indium, whereas the 2019 stone does not contain this element, and the patient worked with this substance in 2000–2002.

Table 1. Results of the analysis of the mineral composition of uroliths, mass percentage**Таблица 1.** Результаты анализа минерального состава уролитов, мас%

Element	Calculus 2002			Calculus 2019		
	ICP-MS	ICP-AES	DAP-AES	ICP-MS	ICP-AES	DAP-AES
1. Macronutrients, essential elements						
Ca	–	24	–	–	21	–
Na	–	$2 \cdot 10^{-1}$	–	–	$1 \cdot 10^{-1}$	–
K	–	$7 \cdot 10^{-2}$	–	–	$3 \cdot 10^{-2}$	–
Mg	–	$6 \cdot 10^{-2}$	$6 \cdot 10^{-2}$	–	$3 \cdot 10^{-2}$	$4 \cdot 10^{-2}$
Zn	$1 \cdot 10^{-2}$	$1 \cdot 10^{-2}$	$1 \cdot 10^{-2}$	$2 \cdot 10^{-3}$	$2 \cdot 10^{-3}$	$2 \cdot 10^{-3}$
Cu	$1 \cdot 10^{-3}$	$7 \cdot 10^{-4}$	$1 \cdot 10^{-3}$	$2 \cdot 10^{-3}$	$5 \cdot 10^{-3}$	$4 \cdot 10^{-4}$
Fe	–	$6 \cdot 10^{-3}$	$2 \cdot 10^{-3}$	–	$2 \cdot 10^{-3}$	$1 \cdot 10^{-3}$
Mn	–	$1 \cdot 10^{-3}$	$5 \cdot 10^{-4}$	–	$4 \cdot 10^{-3}$	$3 \cdot 10^{-4}$
Co	$4 \cdot 10^{-4}$	$6 \cdot 10^{-4}$	$2 \cdot 10^{-3}$	$1 \cdot 10^{-4}$	$3 \cdot 10^{-4}$	$3 \cdot 10^{-4}$
P	$3 \cdot 10^{-1}$	1,3	$9 \cdot 10^{-1}$	$5 \cdot 10^{-2}$	$3 \cdot 10^{-1}$	$2 \cdot 10^{-1}$
2. Conditionally essential elements						
Ni	$7 \cdot 10^{-5}$	–	$5 \cdot 10^{-4}$	$1 \cdot 10^{-4}$	–	$2 \cdot 10^{-4}$
I	$2 \cdot 10^{-3}$	–	–	$1 \cdot 10^{-3}$	–	–
Br	$2 \cdot 10^{-4}$	–	–	$4 \cdot 10^{-4}$	–	–
Si	–	–	$2 \cdot 10^{-2}$	–	–	$3 \cdot 10^{-2}$
Cr	$2 \cdot 10^{-5}$	–	$5 \cdot 10^{-4}$	$2 \cdot 10^{-5}$	–	$4 \cdot 10^{-4}$
W	$6 \cdot 10^{-5}$	–	$3 \cdot 10^{-5}$	$3 \cdot 10^{-5}$	–	$3 \cdot 10^{-5}$
Sr	$1 \cdot 10^{-2}$	$5 \cdot 10^{-3}$	$7 \cdot 10^{-3}$	$7 \cdot 10^{-3}$	$4 \cdot 10^{-3}$	$6 \cdot 10^{-3}$
Zr	$5 \cdot 10^{-5}$	–	–	$4 \cdot 10^{-5}$	–	–
Rare earth elements	not detected ($5 \cdot 10^{-6}$)	–	–	not detected ($5 \cdot 10^{-6}$)	–	–
3. Toxic elements						
Hg, Cd	not detected ($5 \cdot 10^{-6}$)	–	–	not detected ($5 \cdot 10^{-6}$)	–	–
Pb	$3 \cdot 10^{-3}$	–	$6 \cdot 10^{-3}$	$4 \cdot 10^{-4}$	–	$1 \cdot 10^{-3}$
Al	$5 \cdot 10^{-2}$	$6 \cdot 10^{-1}$	$2 \cdot 10^{-2}$	$1 \cdot 10^{-1}$	$1 \cdot 10^{-1}$	$7 \cdot 10^{-2}$
Ti	$1 \cdot 10^{-3}$	–	–	$2 \cdot 10^{-4}$	–	–
In	$2 \cdot 10^{-5}$	–	–	not detected ($5 \cdot 10^{-6}$)	–	–
Sn	$5 \cdot 10^{-5}$	–	–	$2 \cdot 10^{-4}$	–	–
Ba	$2 \cdot 10^{-4}$	$1 \cdot 10^{-4}$	$8 \cdot 10^{-4}$	$2 \cdot 10^{-4}$	$4 \cdot 10^{-5}$	$5 \cdot 10^{-4}$
Th, U	not detected ($3 \cdot 10^{-7}$)	–	–	not detected ($3 \cdot 10^{-7}$)	–	–

Note. ICP-MS, inductively coupled plasma mass spectrometry; ICP-AES, inductively coupled plasma atomic emission spectrometry; DAP-AES, double-jet arc plasma atomic emission spectrometry.

According to the XPA data, the presence of various elements (Table 1) does not affect the crystal structure of the calculi. The possible cause was that the elements were captured during growth and incorporated into the structure of growing crystals.

The organic composition of stones was evaluated by the CHN/S method, and the results are presented in Table 2.

Table 2 shows that the CHN/S-compositions of the stones were slightly different. The 2002 stone contains more hydrogen, which is consistent with the XPA data that this stone contains 25% weddellite. The sulfur content could be due to the presence of protein in the stones in the composition of both their hormones and bacteria. The presence of nitrogen could be attributed to the content of amino acids [20, 21]. To confirm this assumption, the IR spectroscopy method was used. The IR spectra of the stone samples are presented in the figure.

The figure shows that the IR spectra of the 2002 stone (curve 1) and 2019 stone (curve 2) are identical, the relief of the curves is absolutely equal, and only minor differences exist in the intensities of the absorption bands. The spectra show absorption bands in the range of 1000–1200 cm^{-1} . These bands are attributed to the absorption of amino acids [20]. Indeed, in the IR spectrum of calcium oxalate synthesized in the laboratory, no absorption bands were found in this region [21]. Thus, both spectra corresponded to the calcium oxalate formed in the presence of amino acids.

CONCLUSION

The above results of a comprehensive study of the phase and chemical compositions of calcium oxalate calculi removed from the same patient in March 2002 from the right kidney (at age 41) and in December 2019

REFERENCES

1. Prosyannikov MYu, Golovanov SA, Konstantinova OV, et al. Study of the urolithiasis problem in the scientific research institute of urology: history, present and prospects (actual speech of the head of the urolithiasis department 21.12.2018). *Experimental & clinical urology*. 2019;(1):70–76. (In Russ.) DOI: 10.29188/2222-8543-2019-11-1-70-76
2. Prosiannikov MY, Anokhin NV, Golovanov SA, et al. Urine stones of different chemical composition occurrence depending on the level of uricuria. *Urology reports (St. Petersburg)*. 2020;10(2):107–113. (In Russ.) DOI: 10.17816/uroved102107-113

Table 2. Data of CHN / S analysis of uroliths, mass percentage
Таблица 2. Данные CHN/S-анализа уролитов, мас%

Element	Calculus 2002	Calculus 2019
C	17.6	18.0
N	1.1	0.8
H	2.5	2.0
S	0.1	0.1

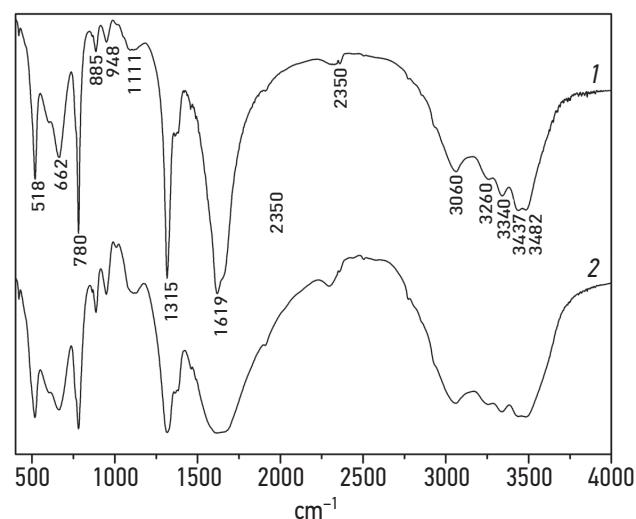


Figure. Infrared spectra of urinary calculi. 1 – calculus in 2002, 2 – calculus in 2019

Рисунок. Инфракрасные спектры мочевых конкрементов. 1 – конкремент 2002 г., 2 – конкремент 2019 г.

from the left kidney (at age 58, the stone was found in 2012) indicate that throughout life, stones with a constant phase and chemical composition were formed in either kidney of the patients. The calculi were represented by calcium oxalate, predominantly of whewellite structure. Concrements contained the entire range of essential and conditionally essential elements at the level of trace impurities. The composition and amounts of toxic elements also did not change significantly. Trace amounts of nitrogen and sulfur found in nephroliths indicate the presence of amino acids and protein in their structure.

3. Golovanov SA, Sivkov AV, Drozhzheva VV, Anokhin NV. Metabolic risk factors and urinary stone formation. The first study: role of calciuria and uricuria. *Experimental & clinical urology*. 2017;(1): 52–57. (In Russ.)
4. Golovanov SA, Sivkov AV, Drozhzheva VV, Anokhin NV. Metabolic risk factors and formation of urinary stones. Study II: effects of phosphaturia and magnesium. *Experimental & clinical urology*. 2017;(2):40–46. (In Russ.)
5. Golovanov SA, Sivkov AV, Polikarpova AM, et al. Metabolic risk factors and formation of urinary stones. Study III: effect of urine pH.

- Experimental & clinical urology*. 2018;(1):84–91. (In Russ.) DOI: 10.29188/2222-8543-2018-9-1-84-90.
6. Golovanov SA, Sivkov AV, Prosyannikov MYu, Drozhzheva VV. Metabolic risk factors and urinary stone formation. Study IV: prediction of the chemical composition of the stone in vivo according to metabolic parameters. *Experimental & clinical urology*. 2018;(4): 54–63. (In Russ.)
 7. Bortnikova S, Yurkevich N, Devyatova A, et al. *Transfer of chemical elements in vapor-gas streams at the dehydration of secondary sulfates*. Proceedings of the 16th International symposium on water-rock interaction, WRI 2019 and 13th International symposium on applied isotope geochemistry, 1st IAGC International conference. Tomsk, 2019 July 21–26 P. 05004. DOI: 10.1051/e3sconf/20199805004.
 8. Artamonova SYu, Ushnitskii VE, Troitsky DYu, et al. *Chemical composition of surface water of the "crystal" site and uranium content in it in 2019*. XVI Mezhdunarodnaya nauchnaya konferentsiya "Interehkspo Geo-Sibir. Nedropol'zovanie. Gornoe delo. Napravleniya i tekhnologii poiska, razvedki i razrabotki mestorozhdenii poleznykh iskopayemykh. Ehkonomika. Geohkologiya". Novosibirsk, 2020 April 20–24, 298–310 p. (In Russ.) DOI: 10.18303/B978-5-4262-0102-6-2020-030
 9. Shaverina AV, Tsygankova AR, Saprykin AI. A procedure of ICP-AES analysis of silicon using microwave digestion and preconcentration. *Journal of Analytical Chemistry*. 2015;70(1):26–29. (In Russ.) DOI: 10.7868/S004445021501017X.
 10. Tsygankova A, Lundovskaya O, Aleksandrova A, et al. Kidney stones analysis by ICP-OES. *J of Physics: Conference series*. 2020;1611(1):012055. DOI: 10.1088/1742-6596/1611/1/012055
 11. Zaksas NP, Sultangazieva TT, Korda TM. Using a two-jet arc plasmatron for determining the trace element composition of powdered biological samples. *Journal of Analytical Chemistry*. 2006;61(6):632–637. (In Russ.) DOI: 10.1134/S1061934806060128
 12. Koshcheeva OS, Zubareva AP, Saprykin AI. CHN analysis of functional materials and their precursors. *Journal of Structural Chemistry*. 2010;51(S7):178–181. (In Russ.) DOI: 10.1007/s10947-010-0209-6
 13. Tsygankova AR, Korolkov IV, Gubanov AI, et al. Phase and Microelement Composition of the Kidney Stones of Ob' River Watershed Residents. *J Pharm Sci Res*. 2019;11(5):1721–1726.
 14. Takaev RM, Kondrova NS, Stepanov EG, et al. Influence of doctors & surgeons professional factors on chemical composition of their blood. *Bashkir chemical journal*. 2010;17(5):116–120. (In Russ.)
 15. Notova SV, Kiyayeva EV, Marshinskaya OV, et al. Mineral balance in athletes with physical disabilities (exemplified by sledge hockey players). *Journal of medical and biological research*. 2018;6(2): 147–155. (In Russ.) DOI: 10.17238/issn2542-1298.2018.6.2.147
 16. Okuneva GN, Karas'kov AM, Chernyavskii AM, et al. Zavisimost' kontsentratsii khimicheskikh ehlementov ot atomnoi massy v miokarde kardiokhirurgicheskikh patsientov. *Trace elements in medicine (Moscow)*. 2012;13(1):11–19. (In Russ.)
 17. Skal'nyi AV, Grabeklis AR, Demidov VA, et al. Svyaz' ehlementnogo statusa naseleniya tsentral'nogo federal'nogo okruga s zabolevaemost'yu. Chast' 1. Toksichnye khimicheskie ehlementy: Al, As, Be, Cd, Hg, Pb, Sn. *Trace elements in medicine (Moscow)*. 2011;12(1–2):23–26. (In Russ.)
 18. Skal'nyi AV, Grabeklis AR, Demidov VA, et al. Svyaz' ehlementnogo statusa naseleniya tsentral'nogo federal'nogo okruga s zabolevaemost'yu. Chast' 2. Ehsentsial'nye i uslovno ehsentsial'nye khimicheskie ehlementy. *Trace elements in medicine (Moscow)*. 2012;13(2):1–7. (In Russ.)
 19. Samokhina NA, Tret'yakova EV. Pokazateli izmeneniya mikroehlementnogo statusa v patogeneze metallonefropatii. *Trace elements in medicine (Moscow)*. 2012;13(2):1–7. (In Russ.)
 20. Golovanova OA, Korol'kov VV. Thermodynamics and Kinetics of Calcium Oxalate Crystallization in the Presence of Amino Acids. *Crystallography Reports*. 2017;62(5):787–796. DOI: 10.1134/S1063774517050078
 21. Šter A, Šafranko S, Bilic' K, et al. The effect of hydrodynamic and thermodynamic factors and the addition of citric acid on the precipitation of calcium oxalate dehydrate. *Urolithiasis*. 2018;46: 243–256. DOI: 10.1007/s00240-017-0991-0

СПИСОК ЛИТЕРАТУРЫ

1. Просянников М.Ю., Голованов С.А., Константинова О.В., и др. Изучение проблемы мочекаменной болезни в НИИ урологии: история, настоящее и перспективы (Актовая речь заведующего отделом мочекаменной болезни 21.12.2018) // Экспериментальная и клиническая урология. 2019. № 1. С. 70–76. DOI: 10.29188/2222-8543-2019-11-1-70-76.
2. Просянников М.Ю., Анохин Н.В., Голованов С.А., и др. Встречаемость мочевых камней различного химического состава в зависимости от уровня урикурии // Урологические ведомости. 2020. Т. 10, № 2. С. 107–113. DOI: 10.17816/uroved102107-113
3. Голованов С.А., Сивков А.В., Дрожжева В.В., Анохин Н.В. Метаболические факторы риска и формирование мочевых камней. Исследование I: влияние кальцийурии и урикурии // Экспериментальная и клиническая урология. 2017. № 1. С. 52–57.
4. Голованов С.А., Сивков А.В., Дрожжева В.В., Анохин Н.В. Метаболические факторы риска и формирование мочевых камней. Исследование II: влияние фосфатурии и магнийурии // Экспериментальная и клиническая урология. 2017. № 2. С. 40–46.
5. Голованов С.А., Сивков А.В., Поликарпова А.М., и др. Метаболические факторы риска и формирование мочевых камней. Исследование III: влияние рН мочи // Экспериментальная и клиническая урология. 2018. № 1. С. 84–91. DOI: 10.29188/2222-8543-2018-9-1-84-90
6. Голованов С.А., Сивков А.В., Просянников М.Ю., Дрожжева В.В. Метаболические факторы риска и формирование мочевых камней. Исследование IV: Прогнозирование химического состава камня *in vivo* по метаболическим показателям // Экспериментальная и клиническая урология. 2018. № 4. С. 54–63.
7. Bortnikova S., Yurkevich N., Devyatova A., et al. Transfer of chemical elements in vapor-gas streams at the dehydration of secondary sulfates. Proceedings of the 16th International symposium on water-rock interaction, WRI 2019 and 13th International symposium on applied isotope geochemistry, 1st IAGC International conference. Tomsk, 2019 July 21–26. P. 05004. DOI: 10.1051/e3sconf/20199805004.
8. Артамонова С.Ю., Ушницкий В.Е., Троицкий Д.Ю., и др. Химический состав поверхностных вод объекта «Кристалл» и содержание в них урана в 2019 г. Материалы конференции: XVI Международная научная конференция «Интерэкспо Гео-Сибирь. Недропользование. Горное дело. Направления и технологии

поиска, разведки и разработки месторождений полезных ископаемых. Экономика. Геоэкология». Новосибирск, 20–24 апреля 2020 г. С. 298–310. DOI: 10.18303/B978-5-4262-0102-6-2020-030.

9. Шаверина А.В., Цыганкова А.Р., Сапрыкин А.И. Методика ИСП-АЭС анализа кремния с микроволновым разложением и концентрированием // Журнал аналитической химии. 2015. Т. 70, № 1. С. 26–29. DOI: 10.7868/S004445021501017X.

10. Tsygankova A., Lundovskaya O., Aleksandrova A., et al. Kidney stones analysis by ICP-OES // J of Physics: Conference series. 2020. Vol. 1611. No. 1. ID012055. DOI: 10.1088/1742-6596/1611/1/012055

11. Закас Н.П., Султангазиева Т.Т., Корда Т.М. Использование двухструнного дугового плазматрона для определения микроэлементного состава порошковых биологических проб // Журнал аналитической химии. 2006. Т. 61, № 6. С. 632–637. DOI: 10.1134/S1061934806060128

12. Кощеева О.С., Зубарева А.П., Сапрыкин А.И. CHN-анализ функциональных материалов и их прекурсоров // Журнал структурной химии. 2010. Т. 51, № S7. С. 178–181. DOI: 10.1007/s10947-010-0209-6

13. Tsygankova A.R., Korolkov I.V., Gubanov A.I., et al. Phase and Microelement Composition of the Kidney Stones of Ob' River Watershed Residents // J Pharm Sci Res. 2019. Vol. 11. No. 5. P. 1721–1726.

14. Такаев Р.М., Кондрова Н.С., Степанов Е.Г., и др. Влияние профессиональных факторов на химический состав крови врачей-хирургов // Башкирский химический журнал. 2010. Т. 17, № 5. С. 116–120.

15. Нотова С.В., Кияева Е.В., Маршинская О.В., и др. Элементный баланс спортсменов с ограниченными физическими возможностями (на примере следж-хоккеистов) // Журнал меди-

ко-биологических исследований. 2018. Т. 6, № 2. С. 147–155. DOI: 10.17238/issn2542-1298.2018.6.2.147

16. Окунева Г.Н., Караськов А.М., Чернявский А.М., и др. Зависимость концентраций химических элементов от атомной массы в миокарде кардиохирургических пациентов // Микроэлементы в медицине. 2012. Т. 13, № 1. С. 11–19.

17. Скальный А.В., Грабеклис А.Р., Демидов В.А., и др. Связь элементного статуса населения центрального федерального округа с заболеваемостью. Часть 1. Токсичные химические элементы: Al, As, Be, Cd, Hg, Pb, Sn // Микроэлементы в медицине. 2011. Т. 12, № 1–2. С. 23–26.

18. Скальный А.В., Грабеклис А.Р., Демидов В.А., и др. Связь элементного статуса населения центрального федерального округа с заболеваемостью. Часть 2. Эссенциальные и условно эссенциальные химические элементы // Микроэлементы в медицине. 2012. Т. 13, № 2. С. 1–7.

19. Самохина Н.А., Третьякова Е.В. Показатели изменения микроэлементного статуса в патогенезе металлонефропатий // Микроэлементы в медицине. 2011. Т. 12, № 3–4. С. 59–63.

20. Golovanova O.A., Korol'kov V.V. Thermodynamics and Kinetics of Calcium Oxalate Crystallization in the Presence of Amino Acids // Crystallography Reports. 2017. Vol. 62. No. 5. P. 787–796. DOI: 10.1134/S1063774517050078

21. Šter A., Šafranko S., Bilic' K., et al. The effect of hydrodynamic and thermodynamic factors and the addition of citric acid on the precipitation of calcium oxalate dehydrate // Urolithiasis. 2018. Vol. 46. No. 243–256. DOI: 10.1007/s00240-017-0991-0

AUTHORS' INFO

***Dmitrij Yu. Troitskii**, Leading engineer-technologist; address: 3, Academician Lavrentiev av., Novosibirsk, 630090, Russia; ORCID: <https://orcid.org/0000-0002-4406-3543>; eLibrary SPIN: 6996-4028; e-mail: dmitroitsk@ngs.ru.

Pavel S. Plugin, Urologist; eLibrary SPIN: 1883-7451; e-mail: pavelplugin@mail.ru.

Alexander I. Gubanov, Cand. Sci. (Chem.), associate-professor; ORCID: <https://orcid.org/0000-0002-6966-3844>; eLibrary SPIN: 6444-5032; e-mail: gubanov@niic.nsc.ru.

Alphiya R. Tsygankova, Cand. Sci. (Chem.); eLibrary SPIN: 6619-9694; e-mail: alphiya@yandex.ru.

Irina B. Troitskaya, Cand. Sci. (Chem.); eLibrary SPIN: 4507-0783; e-mail: troitskaia@niic.nsc.ru.

Igor V. Feofilov, Dr. Sci. (Med.), associate-professor; ORCID: <https://orcid.org/0000-0001-8938-2479>; eLibrary SPIN: 8384-2431; e-mail: fil_urolog@mail.ru

ОБ АВТОРАХ

***Дмитрий Юрьевич Троицкий**, ведущий инженер-технолог; адрес: Россия, 630090, Новосибирск, пр. Академика Лаврентьева, д. 3; ORCID: <https://orcid.org/0000-0002-4406-3543>; eLibrary SPIN: 6996-4028; e-mail: dmitroitsk@ngs.ru

Павел Сергеевич Плагин, врач-уролог; eLibrary SPIN: 1883-7451; e-mail: pavelplugin@mail.ru

Александр Иридиевич Губанов, канд. хим. наук, доцент; ORCID: <https://orcid.org/0000-0002-6966-3844>; eLibrary SPIN: 6444-5032; e-mail: gubanov@niic.nsc.ru

Альфия Рафаэльевна Цыганкова, канд. хим. наук; eLibrary SPIN: 6619-9694; e-mail: alphiya@yandex.ru

Ирина Баязитовна Троицкая, канд. хим. наук; eLibrary SPIN: 4507-0783; e-mail: troitskaia@niic.nsc.ru

Игорь Викторович Феофилов, д-р мед. наук, доцент; ORCID: <https://orcid.org/0000-0001-8938-2479>; eLibrary SPIN: 8384-2431; e-mail: fil_urolog@mail.ru