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POSSIBILITIES OF MULTISLICE COMPUTED TOMOGRAPHY IN ASSESSING THE STRUCTURAL AND COMPOSITIONAL FEATURES OF CALCIUM-CONTAINING URINARY STONES

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Abstract. The aim: *to study the X-ray density index (HU) in calcium-containing urinary stones with different structural and compositional features.*

The structural and compositional features of 118 samples of calcium-containing urinary stones, which were obtained as a result of extracorporeal shock wave lithotripsy, percutaneous nephrolithotripsy and ureteroscopic lithotripsy in patients with kidney and ureteral stones were studied. The structural features of the stones were evaluated by conducting a crystal-optical analysis, during which the linear dimensions, shape, color and degree of transparency of crystalline elements were estimated, and the volume fractions of the amorphous and crystalline phases in the sample structure were calculated. The compositional features of kidney stones were studied on the basis of a qualitative and quantitative assessment of their mineral composition by infrared spectroscopy. X-ray density of calcium-containing kidney stones was assessed based on the data of computed tomography without contrast, which was performed in all patients in the preoperative period.

Structural and compositional features of calcium-containing urinary stones are characterized by the presence in their composition of calcium oxalate compounds in the form of vewellite and weddelite, as well as calcium phosphate in the form of apatite, hydroxylapatite, fluorapatite, carbonate apatite, which, depending on the stage of crystallization, can be in amorphous, amorphous-crystalline or crystalline state. The X-ray density of this type of urinary stones, according to multislice computed tomography, corresponds to the range of 1090-1785 HU. There is a direct correlation between the level of X-ray density of the stone and the volume fraction of the crystalline phase in its structure.

МОЖЛИВОСТІ МУЛЬТИСПІРАЛЬНОЇ КОМП'ЮТЕРНОЇ ТОМОГРАФІЇ В ОЦІНЦІ СТРУКТУРНО-КОМПОЗИЦІЙНИХ ОСОБЛИВОСТЕЙ КАЛЬЦІЄВМІСНИХ СЕЧОВИХ КОНКРЕМЕНТІВ

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Ключові слова:
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Резюме. Мета *– вивчити показники рентгенівської щільності (HU) кальцієвмісних сечових конкрементів із різними структурно-композиційними особливостями.*

У роботі вивчено структурно-композиційні особливості 118 зразків кальцієвмісних сечових конкрементів, які отримані в результаті проведення екстракорпоральної ударно-хвильової, перкутанної та уретроскопічної літотрипсії у пацієнтів із конкрементами нирок та сечоводів. Структурні особливості конкрементів оцінені шляхом проведення кристалооптичного аналізу, в процесі якого оцінені лінійні розміри, форма, колір та ступінь прозорості кристалічних елементів, розраховано показники об'ємної частки аморфної та кристалічної фаз у структурі зразка. Композиційні особливості ниркового конкремента вивчені на підставі якісної та кількісної оцінки їх мінерального складу методом інфрачервоної спектроскопії. Рентгенівська щільність (HU) кальцієвмісних ниркових конкрементів оцінювалася на підставі даних комп'ютерної томографії без контрастування, яка виконувалася всім пацієнтам у передопераційному періоді.

Структурно-композиційні особливості кальцієвмісних сечових конкрементів характеризуються наявністю в їх складі сполук оксалату кальцію у вигляді вевеліту і веделіту, а також фосфату кальцію у вигляді апатиту, гідроксилапатиту, фторапатиту, карбонатапатиту, які, залежно від стадії *кристалізації, можуть бути на кристалічному стані. Рентгенівська щільність даного виду сечового конкремента, за даними мультиспіральної комп'ютерної томографії, відповідає діапазону 1090-1785 HU. Є пряма кореляційна залежність рівня рентгенівської щільності конкремента та об'ємної частки кристалічної фази у його структурі.*

Introduction. Urolithiasis is a global health burden with a high economic cost to health systems. Its prevalence in the modern population, according to various epidemiological studies, is 5 -13% [1].

Currently, a wide range of non-invasive and minimally invasive treatment methods based on stone fragmentation - extracorporeal shock wave lithotripsy (ESWL), percutaneous nephrolithotripsy (PNL), ureteroscopic lithotripsy (URL) are used for these patients treatment [2]. The correct choice of lithotripsy in each specific case determines its further effectiveness and patient satisfaction with the treatment [3]. According to the recommendations of the European Association of Urology (EAU), the main criteria that determine the choice of the appropriate treatment method are the size and localization of the calculus in the urinary system [4]. An additional parameter that influences the results of treatment, especially when performing SWL, is the hardness of the calculus, which is determined by its mineral composition. Stones consisting of uric acid salts easily give in to fragmentation, cystine stones are the hardest and most resistant [5]. Calcium-containing urinary stones in practice often show different susceptibility to shock wave effects [6]. A possible reason for this phenomenon may be the features of the stones, which are determined by the different structural state of the inorganic components that make up their composition. Evaluation of the structural and compositional features of the urinary calculi at the stage of choosing the method of lithotripsy is appropriate in terms of predicting its results.

The most acceptable methods for studying the physicochemical parameters of a stone are infrared spectroscopy and X-ray diffraction [7]. Their significant drawback is that stones are analyzed only after they have been removed, so the search for possible methods for determining the mineral composition of the stone, as well as the structural state of its components at the stage of treatment planning is of great practical importance.

The purpose: to study the X-ray density index (HU) in calcium-containing urinary calculi with different structural and compositional features.

Materials and methods. 118 samples of calcium-containing urinary calculi obtained after ESWL, percutaneous nephrolithotripsy and ureteroscopic lithotripsy in patients with kidney and ureteroliths were studied. All the patients under exanimation were treated at Regional Medical Clinical Center of Urology and Nephrology n.a. V.I. Shapoval (Kharkiv, Ukraine).

Structural features of urinary calculi were assessed by crystal optical analysis on a polarizing microscope POLAM (LOMO), using immersion liquids. Based on the principles of quantitative analysis of microscopic images [8], using the microscope eyepiece grid, the volume fraction of the amorphous phase (VFAP) and the volume fraction of the crystalline phase (VFCP) in the calculus were calculated. The linear dimensions, shape, color and degree of transparency of crystalline elements were also evaluated.

The compositional features of renal calculi were studied by qualitative and quantitative assessment of their mineral composition by infrared spectroscopy (IRS) on an infrared spectrophotometer IKS-29 (LOMO), in the spectral range of 4000 - 400 cm^{-1}. The mineral composition of the calculi was estimated based on the identification of absorption bands characteristic of certain mineral compounds in the infrared range [9].

The density of calcium-containing renal calculi was assessed in Hausfield units (HU) by computed tomography without contrast, which was performed in all patients in the preoperative period. Toshiba Aquilion 16 multislice computed tomography was used. This indicator was calculated as the arithmetic mean of calculi density values in the central and peripheral zones, measured in the plane corresponding to its maximum dimensions.

Statistical data processing was carried out using Microsoft Excel 2016 spreadsheets and Statistica 12 software (StatSoft, USA). Quantitative data are presented as $M \pm \delta$, where M is the sample mean, δ is the standard deviation. An intergroup comparison of four independent samples was performed using Kruskal-Wallis' test. The direction and strength of the relationship between the indicators were assessed using Spearman's correlation coefficient.

The research protocol was approved by the ethics committee of the Regional Medical Clinical Center of Urology and Nephrology named after V.I. Shapoval. Before the start of the study, all patients were informed about the aims, objectives and method of the study, after which they voluntarily signed the informed consent.

Results and its discussion. Preoperative prediction of the calculi's chemical composition is important for choosing the optimal treatment method. The issue of the possibility of using imaging diagnostic methods to identify the mineral components of renal calculi is vividly discussed in modern literature [10,11]. Computed tomography (CT) makes it possible to differentiate calculi composed of uric acid and calcium compounds (calcium oxalate, calcium phosphate) based on differences in their X-ray density [12]. However, the differentiation of calcium minerals among themselves on the basis of this indicator is difficult, due to the fact that calcium-containing renal calculi often have a mixed composition [13].

In our study, infrared spectroscopy of kidney stone samples resulted in the identification of a wide spectrum of calcium-containing compounds composition: calcium oxalate in the form of monohydrate (wevellite) and dihydrate (weddelite), as well as calcium phosphate in the form of apatite, hydroxyapatite, fluorapatite, carbonate apatite (Table 1).

In most cases - 83 (70.3%) stones had a mixed mineral composition, represented by two or more mineral components. Most often - 72 (61%) - there were samples

Table 1

The frequency of occurrence of calcium-containing mineral compounds in the composition of kidney stones

Type of mineral	Number of samples N, %
Whewellite	89 (75.4%)
Weddelite	30 (25.4%)
Apatite	31 (26.2%)
Hydroxyapatite	36 (30.5%)
Fluorapatite	21 (17.8%)
Carbonate apatite	15 (12.7%)

consisting of vellite and apatite in various percentages. Depending on the quantitative presence of mineral components in the samples under analysis, urinary stones were divided into the following mineral types:

I. Monocomponent calcium – oxalate calculi;

II. Monocomponent calcium phosphate calculi;

III. Mixed, with a predominant content of the oxalate-calcium component (more than 50% of the sample.) calculi;

IV. Mixed, with a predominant content of the phosphate-calcium component (more than 50% of the sample).

The X-ray density of stones was studied with multislice computed tomography performed at the preoperative period. Its value varied from 1090 to1785 HU in the samples under analysis.

An intergroup comparison of the average value of X-ray density among calcium-containing stones belonging to different mineral types, no significant difference was found, which does not allow to use this indicator as an indicator of the calculi mineral type at the preoperative period (Table 2).

Table 2

Comparative analysis of X-ray density indicators of various mineral types of calcium-containing urinary stones (P-Kruskal-Wallis)

Mineral type of a stone	I, n = 21	II, n=14	III, n=45	IV, n = 38	P
X-ray stone density (HU)	1476±123 (1123-1766)	1383±293 (976 - 1730)	1598±130 (1387-1785)	1499±118 (1097-1654)	0.07

Crystal-optical analysis of urinary calculi showed that regardless of the stone's mineral type the inorganic components included in its composition were in an amorphous or crystalline state, which corresponds to various stages of the mineral crystallization process (Fig. 1).

According to modern concepts, the amorphous phase in the structure of the calculus is a sign of an incomplete crystallization process and indicates a relatively young age of the stone [14]. In our study, urinary stone samples had an amorphous, amorphous-crystalline, and crystalline structure. To assess the degree of crystallinity of the sample, the volume fraction of the crystalline phase (VFCP) in its structure was calculated. When conducting a correlation analysis of the dependence of the X-ray density index (HU) and VFCP, a statistically significant dependence of a positive direction was revealed ($p<0.05$; $r=0.77$), i.e. with an increase in the quantitative presence of the crystalline phase in the structure of the calculus, the value of the densitometric index of its X-ray density increases (Fig. 3).

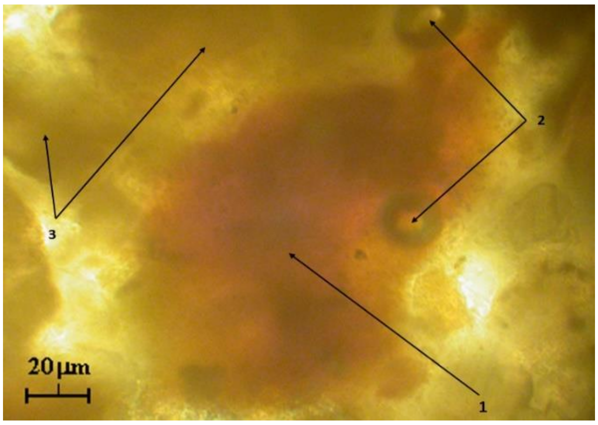

Fig. 1. Micrograph of a kidney stone in an immersion preparation. Incomplete crystallization process: amorphous wevellite in the form of an orange mass (1) with single spherical centers of crystallization (2) surrounded by an amorphous phosphate mass (3)

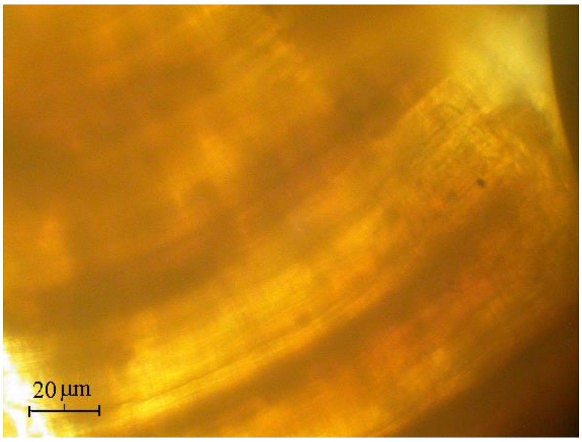

Fig. 2. Micrograph of a renal stone in an immersion preparation. Completed crystallization process: large grains of crystalline wevellite with a characteristic banded texture

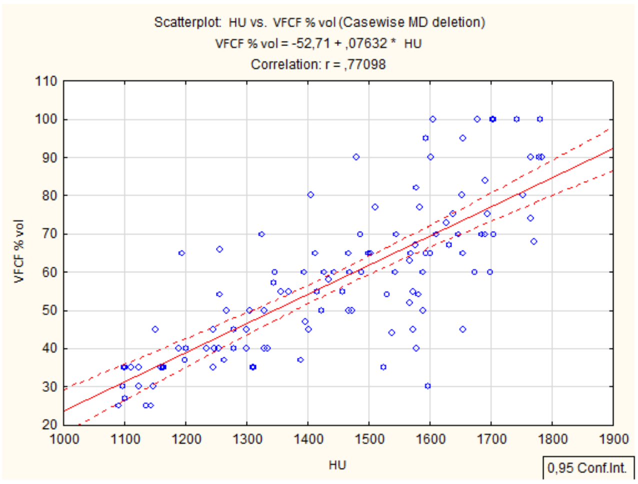

Fig. 3. Correlation dependence of the X-ray density of urinary stones (HU) on the indicator of the volume fraction of the crystalline phase (VFCF)

Conclusions

1. Structural and compositional features of calcium-containing urinary stones are characterized by the presence in their composition of calcium oxalate compounds in the form of vewellite and weddelite, as well as calcium phosphate in the form of apatite, hydroxylapatite, fluorapatite, carbonate apatite, which, depending on the stage of crystallization, can be in amorphous, amorphous-crystalline or crystalline state.

2. The X-ray density of this type of urinary stones, according to multislice computed tomography, corresponds to the range of 1090-1785HU.

3. There is a direct correlation between the stone's X-ray density and the volumetric fraction of the crystalline phase in its structure.

References

1. Sorokin I, Mamoulakis C, Miyazawa K, Rodgers A, Talati J, Lotan Y. Epidemiology of stone disease across the world. World J Urol. 2017;35(9):1301-20. DOI: 10.1007/s00345-017-2008-6.

2. Zanetti SP, Talso M, Palmisano F, Longo F, Gallioli A, Fontana M, et al. Comparison among the available stone treatment techniques from the first European Association of Urology Section of Urolithiasis (EULIS) Survey: Do we have a Queen? PLoS One [Internet]. 2018[cited 2022 Nov 11];13(11):e0205159. Available from: https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0205159 DOI:10.1371/journal.pone.0205159.

3. Nouri AI, Hassali MA, Allayla TH. Satisfaction and perceptions of patients toward kidney stones disease management: A review of literature. Malay J Pharm Sci. 2018;16(1):55-60. DOI:10.21315/mjps2018.16.1.5.

4. Turk C, Neisius A, Petřík A, Seitz C, Skolarikos A, Thomas K, et al. EAU Guidelines on Urolithiasis 2020. Edn. presented at the EAU Annual Congress Amsterdam 2020. Publisher: The European Association of Urology Guidelines Office. Available from: https://uroweb.org/guideline/urolithiasis.

5. Chaussy CG, Tiselius HG. How can and should we optimize extracorporeal shockwave lithotripsy? Urolithiasis. 2018;46(1):3-17. DOI: 10.1007/s00240-017-1020-z.

6. Williams JC Jr, Saw KC, Paterson RF, Hatt EK, McAteer JA, Lingeman JE. Variability of renal stone fragility in shock wave lithotripsy. Urology. 2003;61(6):1092-7. DOI:10.1016/s0090-4295(03)00349-2.

7. Serkan Yalçın M, Tek M. Analysis of urinary stones collected from some patients with X-ray diffraction, Fourier transform infrared spectroscopy, and scanning electron microscopy. J ApplSpectrosc. 2019;85:1050-7. DOI: 10.1007/s10812-019-00758-9.

8. Lee JH, Woo SH, Kim ET, Kim DK, Park J. Comparison of patient satisfaction with treatment outcomes between ureteroscopy and shock wave lithotripsy for proximal ureteral stones. Korean J Urol. 2010;51(11):788-93. DOI: 10.4111/kju.2010.51.11.788.

9. Sekkoum K, Abdelkrim C, Taleb S, Belboukhari N. FTIR spectroscopic study of human urinary stones from El Bayadh district (Algeria). Arab J Chem. 2016;9(3):330-34. DOI: 10.1016/j.arabjc.2011.10.010.

10. Kawahara T, Miyamoto H, Ito H, Terao H, Kakizoe M, Kato Y, et al. Predicting the mineral composition of ureteral stone using non-contrast computed tomography. Urolithiasis. 2016;44(3):231-9. DOI: 10.1007/s00240-015-0823-z.

11. Silva TR, Lima ML. Correlation between Hounsfield unit value and stone composition in nephrolithiasis. Medical Express [Internet]. 2016[cited 2022 Nov 11];3(3):M160303. Available from: https://www.scielo.br/j/medical/a/Nb5dR6vthfVGpNYYM9XXYDL/?format=pdf&lang=en DOI:10.5935/MedicalExpress.2016.03.03.

12. Jendeberg J, Thunberg P, Popiolek M, Lidén M. Single-energy CT predicts uric acid stones with accuracy comparable to dual-energy CT-prospective validation of a quantitative method. Eur Radiol. 2021;31(8):5980-9. DOI: 10.1007/s00330-021-07713-3.

13. Stewart G, Johnson L, Ganesh H, Davenport D, Smelser W, Crispen P, et al. Stone size limits the use of Hounsfield units for prediction of calcium oxalate stone composition. Urology. 2015;85(2):292-5. DOI: 10.1016/j.urology.2014.10.006.

14. Prywer J, Mielniczek-Brzóska E. Formation of Poorly Crystalline and Amorphous Precipitate, a Component of Infectious Urinary Stones: Role of Tetrasodium Pyrophosphate. Cryst. Growth Des. 2019;19(2):1048-56. DOI: 10.1021/acs.cgd.8b01581.

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