# MORPHOSTRUCTURAL AND MINERALOGICAL FEATURES OF CALCIUM UROLITHS IN PATIENTS FROM THE DNIPROPETROVSK REGION

***K.S. Barannik, R.V. Duka, R.M. Molchanov, S.L. Malinovskyj, Y.V. Pilin***

Dnipro State Medical University, Dnipro, Ukraine

***Objective*** *– to determine morphostructural and mineralogical features of calcium urolith formation in residents of an industrially developed region of the Dnipropetrovsk oblast (Ukraine), and to compare uroliths with the prevalence of monohydrate- and dehydrate calcium oxalate.*

***Material and methods.*** *stones, removed without assistance following lithotripsy, or surgically, were examined by stereoscopic and polarization microscopy. A subgroup of 54 patients (24 monohydrate-, 30 dihydrate-predominant) was compared by 24-hour urine biochemistry and AP(CaOx) index EQ(s).*

***Results.*** *Nearly 2/3 of oxalate calculi had weddellite and whewellite in their composition, accounting for 96.7±3.3%. The ratio of whewellite to weddellite was 4:1. Other substances accounted for a minor percentage (<2%). One-third of oxalate calculi contained a significantly higher proportion of other substances. Their oxalate content constituted 78.4±21.6%, with a whewellite-to-weddellite ratio of 2:3. They also contained 10% to 30% uric acid crystals. The optical petrography revealed the presence of 15 mineral species, predominantly oxalate and urate compounds. Quantitative comparison confirmed that urate content in the urolith was significantly higher in the monohydrate-predominant group than in the dihydrate-predominant group (16.3±23.3% vs 0.0%, p<0.001); differences in 24-hour urine calcium, oxalate, citrate, magnesium and the AP(CaOx) crystallization index did not reach statistical significance at the available sample size (p>0.05 for all).*

***Conclusions.*** *Calcium urolith formation occurs in stages, combining crystallization and recrystallization dependent on urinary pH and stabilizing resources. Progressive incorporation of uric acid dihydrate into monohydrate-predominant stones coordinates with their higher urate content, supporting a shared metabolic background relevant to metaphylaxis.*

***Key words****: urolithiasis, calcium uroliths, morphological genesis of uroliths, whewellite, weddellite, AP(CaOx) index, lithogenicity.*

Clinical and experimental pathology 2026. Vol. 25, № 3 (97). P. 136-143.

DOI 10.24061/1727-4338.XXV.3.97.2026.18

E-mail: *k.barannik1984@gmail.com*

**МОРФОСТРУКТУРНІ ТА МІНЕРАЛОГІЧНІ ОСОБЛИВОСТІ КАЛЬЦІЄВИХ УРОЛІТІВ У ПАЦІЄНТІВ ДНІПРОПЕТРОВСЬКОЇ ОБЛАСТІ**

***К.С. Баранник, Р.В. Дука, Р.М. Молчанов, С.Л. Малиновський, Є.В. Пілін***

***Дніпровський державний медичний університет, м. Дніпро, Україна***

***Мета роботи*** *– визначити морфоструктурні та мінералогічні особливості формування кальцієвих уролітів у мешканців промислово розвиненого регіону Дніпропетровської області (Україна) та порівняти уроліти з переважанням моногідрату і дигідрату оксалату кальцію.*

***Матеріал і методи.*** *камені, що відійшли самостійно, після літотрипсії або видалені хірургічно, досліджували стереоскопічною та поляризаційною мікроскопією. Підгрупу з 54 пацієнтів (24 моногідрат-, 30 дигідрат-переважаючих) порівнювали за біохімією добової сечі та індексом AP(CaOx) EQ(s).*

***Результати.*** *майже 2/3 оксалатних каменів містили веделіт і вевеліт у своєму складі, що в сумі становило 96,7±3,3%. Співвідношення вевеліту до веделіту становило 4:1. Інші речовини становили незначну частку (<2%). Третина оксалатних каменів містила значно вищу частку інших речовин: вміст оксалату в них становив 78,4±21,6% при співвідношенні вевеліт:веделіт 2:3, а також від 10% до 30% кристалів сечової кислоти. Оптична петрографія виявила 15 мінеральних видів, переважно оксалатні та уратні сполуки. Кількісне порівняння підтвердило, що вміст урату в уроліті був значно вищим у групі з переважанням моногідрату порівняно з групою переважання дигідрату (16,3±23,3% проти 0,0%, p<0,001); відмінності за показниками добової сечі (кальцій, оксалат, цитрат, магній) та індексом кристалізації AP(CaOx) не досягли статистичної значущості за наявного обсягу вибірки (p>0,05 для всіх показників).*

***Ключові слова:*** *сечокам'яна хвороба, кальцієві уроліти, морфологічний генез уролітів, вевеліт, веделіт, індекс AP(CaOx), літогенність.*

Клінічна та експериментальна патологія. 2026; Т.25, № 3 (97). С. 136-143.

***Висновки:*** *формування кальцієвих уролітів відбувається стадійно, поєднуючи кристалізацію та рекристалізацію, залежні від pH сечі. Прогресуюче включення дигідрату сечової кислоти в моногідрат-переважаючі уроліти узгоджується з вищим вмістом урату в цій групі, підтримуючи гіпотезу спільного метаболічного фону, значущого для метафілактики.*

**Introduction**

Urolithiasis is one of the most common diseases of the urinary system and remains a major medical and socioeconomic challenge in modern urology. According to contemporary epidemiological studies, its global prevalence is approximately 2–3% of the general population and exceeds 10% in certain geographic regions due to the changes in lifestyle, dietary habits, climatic conditions, and the increasing prevalence of metabolic disorders [1–3]. Urolithiasis predominantly affects individuals of the working age and frequently is presented with acute renal colic. The disease may be complicated by urinary tract obstruction, urinary tract infection, acute kidney injury, and chronic kidney disease, resulting in substantial morbidity, reduced quality of life, and considerable healthcare costs.

Despite significant advances in understanding the etiology and pathophysiology of urinary stone disease, as well as the widespread implementation of minimally invasive treatment modalities, recurrent stone formation remains a major unresolved clinical problem. Approximately 40–50% of patients experience recurrent stone episodes, with recurrence rates approaching 50% within five years and 80–90% within ten years after the initial episode [1–3]. Consequently, the current European Association of Urology (EAU) Guidelines emphasize not only complete stone removal but also reliable stone composition analysis, comprehensive metabolic evaluation, and individualized metaphylaxis aimed at preventing recurrent stone formation [1].

Although contemporary endoscopic and extracorporeal stone removal techniques provide excellent immediate stone-free rates, they do not eliminate the underlying lithogenic mechanisms responsible for recurrent urolithiasis. Likewise, currently available metaphylactic strategies remain only partially effective in preventing recurrence. Therefore, further investigation of the mechanisms underlying urinary stone formation, pathological biomineralization, crystal growth, and stone maturation, together with the development of personalized preventive approaches, remains highly relevant and of considerable clinical importance [4–7].

Kidney stone formation represents a complex multistep process of pathological biomineralization involving urinary supersaturation, crystal nucleation, crystal growth, aggregation, retention within the renal collecting system, and continuous remodeling of the organic–mineral matrix. Calcium oxalate constitutes the predominant component of most urinary calculi; however, the term calcium oxalate stone alone does not adequately describe its pathogenesis. Calcium oxalate monohydrate (whewellite) and calcium oxalate dihydrate (weddellite) are formed under different physicochemical conditions and may reflect distinct pathways of lithogenesis. Furthermore, the sequential deposition of calcium phosphate, urate, and organic matrix components preserves a morphological record of changes occurring within the urinary microenvironment during stone development [8-11]. Consequently, detailed morphological analysis should complement validated analytical techniques for stone characterization, including Fourier-transform infrared (FTIR) spectroscopy and X-ray diffraction, as recommended by the European Association of Urology Guidelines [12].

**Objective**

The aim of this study was to identify specific morphostructural and mineral characteristics of calcium-containing urolith formation in residents of an industrially developed region of the Dnipropetrovsk oblast (Ukraine), and to compare quantitatively the mineral composition, 24-hour urine biochemistry and the calculated lithogenicity index between uroliths predominantly composed of calcium oxalate monohydrate (whewellite) and those predominantly composed of calcium oxalate dihydrate (weddellite).

**Material and methods**

To achieve the study objective, a comparative morphostructural analysis was performed in a cohort of 54 patients with calcium oxalate urolithiasis from the industrially developed Dnipropetrovsk region of Ukraine.

In this study, the term “industrial region” is used solely to characterize the geographic and socioeconomic setting. The Dnipropetrovsk region has a diversified heavy-industrial profile dominating by mining and mineral processing, ferrous metallurgy, coke-chemical and chemical production, and mechanical engineering. However, the present study did not assess ambient concentrations of specific pollutants, individual occupational exposure, residential proximity to industrial facilities, or biomarkers of exposure, and it did not include a comparison cohort from a non-industrial region. Therefore, regional industrialization was not treated as an exposure variable, and the study was not designed to attribute the observed morphostructural characteristics of uroliths to any particular industrial sector or pollutant. The designation is descriptive, and no causal relationship between industrial activity and urolith formation can be inferred from the present findings.

Inclusion criteria were: age 18–70 years; a confirmed diagnosis of urolithiasis with an available stone sample suitable for macro- and microscopic (petrographic) examination; for the quantitative subgroup, a semi-quantitative urolith mineral composition report showing unambiguous predominance of either monohydrate (whewellite) or dihydrate (weddellite) calcium oxalate; and signed informed consent to participate. The population under study included 21 women and 33 men. Exclusion criteria were: age under 18 years; urolith of non-calcium composition or with an equal proportion of monohydrate and dihydrate components; insufficient

stone material for thin-section preparation; incomplete clinical or laboratory documentation; and refusal to provide informed consent. The study included stones that passed spontaneously during conservative treatment, those fragmented after contact or extracorporeal lithotripsy, and those removed surgically. The dimensions of the examined stones ranged from 5 to 67 mm in length, from 4 to 54 mm in width, and from 3 to 31 mm in thickness; some stones were larger. The shape of the stones was variable. Morphostructural observations and mineralogical studies at the macro level were performed using an MBS-9 stereoscopic binocular microscope. All samples were photographed, measured, and weighed. At this stage, mineralogical investigations were also carried out, including assessment of the general color of each calculus, its shape, surface morphology, hardness according to the Mohs scale, streak color, macrostructure of the sample, and other mineralogical features. Petrographic studies of urolith thin sections were performed using a POLAM R-312 optical polarization microscope in transmitted plane-polarized and polarized light. Identification of individual minerals was based on comparison of known crystal-optical characteristics with those determined in the thin sections.

For the quantitative part of the study, a subgroup of 394 patients with urolithiasis, for whom prospectively collected clinical and laboratory data (semi-quantitative urolith mineral composition and 24-hour urine biochemistry) were available in the departmental database, was screened. Patients whose urolith mineral composition report indicated a clear predominance of one calcium oxalate hydrate form over the other were stratified into two comparison groups: a monohydrate (whewellite)-predominant group (n=24) and a dihydrate (weddellite)-predominant group (n=30); patients with an equal proportion of both components were excluded from between-group comparison. Within these groups, 24-hour urinary excretion of calcium, oxalate, citrate, magnesium, urate and phosphate, where available, was compared between groups. The relative risk of calcium oxalate crystallization was estimated using the standardized AP(CaOx) index EQ(s) of Tiselius [6]: AP(CaOx) = 1.9 × Ca^0.84 × Ox × Mg^-0.12 × Cit^-0.22 × V^-1.03, where Ca, Ox, Mg and Cit are the 24-hour urinary excretion of calcium, oxalate, magnesium and citrate (mmol/24h) and V is the urine volume (L/24h), standardized to 1.5 L because the actual 24-hour urine volume was not systematically recorded; this index could therefore be calculated only for patients with a complete set of the four required parameters (n=6 monohydrate-predominant, n=4 dihydrate-predominant), and its results should be regarded as preliminary. Group comparisons were performed using the Mann–Whitney U test (two-tailed, appropriate given the small sample sizes and non-normal distribution of several variables); Welch's t-test is reported for reference. A value of $p<0.05$ was considered statistically significant. Statistical analysis was performed in Python 3 (SciPy 1.17).

All patients signed a written informed consent to participate in the study. The study was conducted in accordance with the principles of the Declaration of Helsinki and received approval from the Bioethics Committee of Dnipro State Medical University (Dnipro, Ukraine), protocol №3, of 16.11.2022.

The study was conducted within the framework of the research project of the Department of Surgery and Urology, Dnipro State Medical University, entitled "Optimization of Therapeutic and Preventive Strategies in Patients with Surgical and Urological Diseases" (State Registration No. 0125U002385; 2025–2028).

**Results and Discussion**

Our petrographic studies of the structure of calcium-containing uroliths, which accounted for 74.2% of all urinary stones, were therefore focused specifically on this group. According to the existing classification based on the pH of the environment, calcium phosphate and calcium oxalate stones belong to different groups. Monomineral formations were exceedingly rare (<1%). Among them, uric acid (urate) stones constituted 14.5%, struvite – 11.3%, calcium phosphates – 11.3%, calcium phosphates + oxalates – 29%, and calcium oxalates – 33.9%. However, the study of the morphogenetic features of calcium-containing uroliths indicates certain contradictions to previously reported data [4].

To complement the qualitative petrographic findings above, 54 patients with an unambiguous predominance of either whewellite or weddellite in the urolith (24 and 30 patients, respectively) were compared for mineral composition, 24-hour urine biochemistry, and the estimated AP(CaOx) crystallization index (Table 1). As expected from the group definition, the monohydrate- and dihydrate-predominant groups differed strongly in their respective mineral content ($p<0.001$ for both). Notably, the urate content of the urolith was also significantly higher in the monohydrate-predominant group (16.3±23.3% vs 0.0%, $p<0.001$), whereas the phosphate content did not differ significantly between groups ($p=0.148$).

Among 24-hour urine parameters, patients with monohydrate-predominant uroliths showed a numerically higher mean urinary calcium excretion (5.35 vs 3.81 mmol/24h) and lower citrate excretion (2.37 vs 3.98 mmol/24h) compared with the dihydrate-predominant group, consistent with a relatively more hypercalciuric and hypocitraturic metabolic profile; however, neither difference reached statistical significance ($p=0.114$ and $p=0.127$, respectively) at the available sample sizes (n=8–13 per group). Urinary oxalate, magnesium, urate, phosphate and creatinine excretion likewise did not differ significantly between groups (Table 1).

The AP(CaOx) index EQ(s), calculable only in the subset of patients with a complete panel of calcium, oxalate, citrate and magnesium excretion (n=6 monohydrate-predominant, n=4 dihydrate-predominant), was similar between groups (1.28±0.40 vs 1.30±1.00, $p=0.762$), with wide variability in the dihydrate-predominant subgroup (range 0.26–2.65). Given the very small subgroup sizes for this analysis and the necessary assumption of a standardized 1.5 L/24h urine volume, this result should be regarded as preliminary and hypothesis-generating rather than conclusive.

The central part of calcium-containing uroliths was examined at the boundary between the organic core and the surrounding inner stone (Fig. 1A). Collophane and

whewellite inclusions were present in the core in 29% of cases; two whewellite crystal apices were almost entirely saturated with fine organic inclusions (Fig. 1B). A polymineral aggregate dominated by cystine grains with minor weddellite, enveloped by organic matter, was also observed (Fig. 1C). Adjacent to the core, a whewellite aggregate with a pseudo-oolitic texture and organic-filled fractures was noted nearby (Fig. 1D).

**Table 1**

**Quantitative comparison of the monohydrate- and dihydrate-predominant groups**

| Parameter | Monohydrate- predominant group | Dihydrate- predominant group | p-value (Mann–Whitney U) |
|---|---|---|---|
| ***Urolith composition, %*** | | | |
| Monohydrate (whewellite) | 61.2 ± 24.0 (n=24) | 15.3 ± 12.7 (n=30) | <0.001 |
| Dihydrate (weddellite) | 7.7 ± 12.6 (n=24) | 53.5 ± 18.6 (n=30) | <0.001 |
| Phosphate | 24.0 ± 19.9 (n=23) | 32.8 ± 21.3 (n=29) | 0.148 |
| Urate | 16.3 ± 23.3 (n=16) | 0.0 ± 0.0 (n=10) | <0.001 |
| ***24-h urine biochemistry*** | | | |
| Calcium, mmol/24h | 5.35 ± 2.64 (n=13) | 3.81 ± 2.32 (n=10) | 0.114 |
| Oxalate, mmol/24h | 3.21 ± 8.00 (n=8) | 7.77 ± 18.08 (n=6) | 1.000 |
| Citrate, mmol/24h | 2.37 ± 3.61 (n=8) | 3.98 ± 2.58 (n=5) | 0.127 |
| Magnesium, mmol/24h | 2.95 ± 1.57 (n=11) | 2.22 ± 0.91 (n=8) | 0.272 |
| Urate, µmol/24h | 1530.6 ± 2000.1 (n=12) | 2313.0 ± 2327.1 (n=8) | 0.297 |
| Phosphate, mmol/24h | 33.2 ± 17.5 (n=13) | 29.5 ± 13.4 (n=10) | 0.733 |
| Creatinine, mmol/24h | 27.5 ± 21.3 (n=5) | 10.9 ± 2.8 (n=3) | 0.071 |
| AP(CaOx) index EQ(s)* | 1.28 ± 0.40 (n=6) | 1.30 ± 1.00 (n=4) | 0.762 |

***Note:*** **AP(CaOx) index EQ(s): standardized Tiselius index calculated with a fixed urine volume of 1.5 L/24h [6]; calculable only for patients with a complete Ca/oxalate/citrate/Mg panel. Bold/shaded p-values indicate p<0.05*

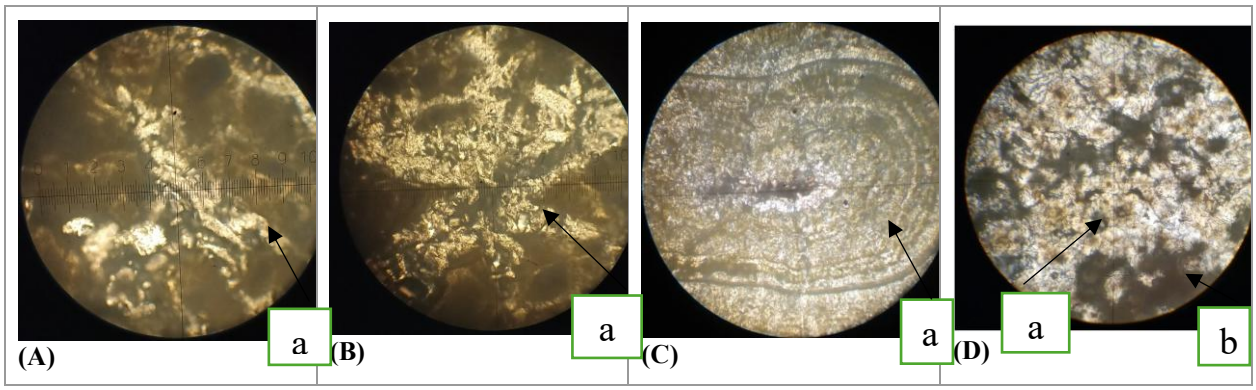



**Fig. 1.** Structural features of the central part of calcium-containing uroliths. Transmitted light. Magnification (×110). **(**A) Numerous inclusions of collophane with “impurities” and whewellite inclusions are observed in the “organic core” (a); (B) A region of the urolith showing the apices of two whewellite crystals (a); (C) A polymineral aggregate predominantly composed of cystine grains with minor impurities of weddellite (a); (D) An aggregate of whewellite grains (a). In the lower part of the image, a pseudo-oolitic aggregate is present (b)

Thus, the central part forms under continuously fluctuating pH and repeated crystallization/recrystallization, reflecting opposing crystallization promoters and inhibitors within the renal microenvironment [4,5,13].

Further growth occurs under more stabilized conditions. The middle part is composed of druse-like aggregates of larger whewellite crystals, in contrast to the concentric organomineral layering of the outer zone (Fig. 2A). Moving toward the periphery, composition transitions from whewellite to weddellite and is ultimately replaced by uric acid dihydrate at the surface, with fine rhythmic mineral-organic layering (Fig. 2B). A penetration twin of whewellite shows numerous inclusions and a distinct zoned microblock structure (Fig. 2C). Large, well-zoned weddellite crystals predominate in some areas, with whewellite present only in minor amounts (Fig. 2D).

Structural variations from this pattern were observed in 18% of samples. In several cases, a small, later-formed urolith was incorporated during growth of an earlier "primary" calculus, showing a zonal structure that transitions from whewellite at the center to fine-grained weddellite at the periphery (Fig. 3A). Droplet-like cystine inclusions enclosed in organic sheaths formed simple or compound "cystine necklaces" (Fig. 3B). In simpler cases, the outer layer consisted of a vein-like structure dominated by uric acid dihydrate, with fine septa-like weddellite aggregates (Fig. 3C).

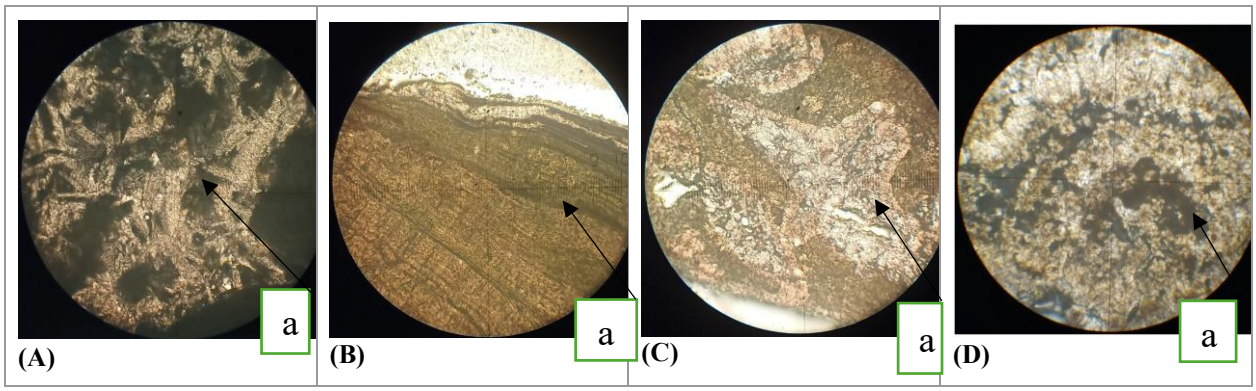



**Fig. 2.** Structural features of the peripheral part of calcium-containing uroliths. Transmitted light. (Magnification ×110). (A) The middle part of the urolith is represented by druse-like aggregates of relatively large whewellite crystals (a); (B) A transition is observed from calcium oxalate monohydrate—whewellite—to calcium oxalate dihydrate—weddellite—which at the surface of the urolith is replaced by uric acid dihydrate (a); (C) A twinned intergrowth (penetration twin) of calcium oxalate monohydrate—whewellite (a); (D) An aggregate of relatively large weddellite crystals with well-developed zoning and a microblock structure is visible (a). (Magnification ×180)

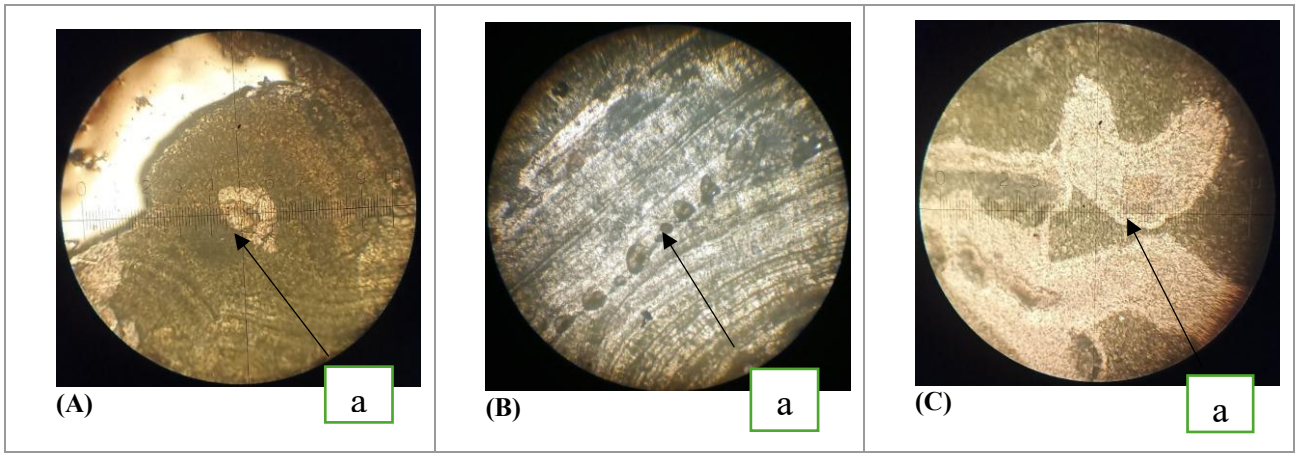



**Fig. 3.** Unusual structural features of calcium-containing uroliths. Transmitted light. (Magnification ×110). (A) At the intersection of the crosshairs, the central part of a small, later-formed urolith (a) is visible, which was incorporated during the growth of an earlier, "primary" calculus; (B) Within the field of view, along a layer of organic matter, a series of droplet-like inclusions of cystine crystal aggregates enclosed in an "organic sheath" (a) can be seen, forming a "cystine necklace"; (C) Within the field of view, an area of the outer layer formed predominantly by a vein-like structure with a predominance of uric acid dihydrate (a) is visible

In 5% of samples no clear structural organization could be traced, with mixed layered/clumped whewellite textures, uric acid dihydrate veins, and organic-whewellite spherulites. The organic content associated with the mineral phase consistently decreases in the sequence: collophane → whewellite → weddellite → uric acid dihydrate.

The findings support the concept that calcium nephrolithiasis is not a single homogeneous entity. Identification of calcium oxalate and/or calcium phosphate in a stone provides essential compositional information, but stones with similar bulk composition may arise through different sequences of nucleation, growth and secondary deposition. Contemporary models describe kidney stones as dynamic biomineral structures in which crystalline phases interact with proteins, lipids and other organic constituents; this interaction contributes to the marked spatial heterogeneity demonstrated in the present thin sections [14-17].

Microscopic analysis showed a predominantly layered and microblock architecture, with organic material concentrated along crystal surfaces, intergranular fissures and boundaries between successive mineral generations. Such interfaces may represent zones of reduced mechanical strength. From a clinical perspective, this heterogeneity is relevant because stone structure, not merely mean chemical composition, can influence fragmentation behavior during shock-wave or endoscopic lithotripsy. Morphological and compositional characterization may therefore provide complementary information when interpreting treatment response and planning recurrence prevention [18-20].

The quantitative comparison added a metabolic dimension to the morphological observations. Urate content was significantly higher in monohydrate-predominant stones than in dihydrate-predominant stones. This agrees with the petrographic finding of progressive uric-acid deposition during later stages of stone growth and suggests that a whewellite-dominant scaffold may coexist with urinary conditions favoring urate crystallization. Persistently low urine pH, reduced citrate activity and increased calcium oxalate supersaturation are biologically plausible links between these phases [5,21].

Urinary calcium was numerically higher and citrate lower in the monohydrate-predominant group, although neither difference reached statistical significance. These trends are compatible with established mechanisms of calcium oxalate stone formation, in which hypercalciuria increases supersaturation and citrate deficiency reduces complexation of calcium and inhibition of crystal growth [5]. The absence of statistical significance should not be interpreted as proof of equivalence, because biochemical data were available only for small subgroups.

The AP(CaOx) index was similar between groups, but it could be calculated in only ten patients and required standardization of urine volume. Tiselius developed this index as an estimate of calcium oxalate crystallization risk based on urinary calcium, oxalate, magnesium, citrate and volume [6,17]. In the present dataset, the index should therefore be regarded as exploratory. Prospective collection of complete 24-hour urine profiles, including measured volume and pH, is required before firm conclusions can be drawn.

**Limitations**

The study has several limitations. Mineral composition was recorded semi-quantitatively; patients with equal proportions of whewellite and weddellite were excluded from the comparison; complete 24-hour urine panels were available for only a minority of participants; and measured urine volume was unavailable for calculation of AP(CaOx). Urinary pH was not measured, so the proposed role of pH fluctuations in driving the observed mineral zonation remains an inference from the petrographic pattern and the literature rather than a directly demonstrated mechanism. Comparisons across multiple urinary parameters were not corrected for multiple testing, which increases the risk of false-positive findings. In addition, the framing of the cohort as originating from an industrially developed region was not accompanied by environmental exposure data or comparison with a non-industrial cohort, and this aspect should be interpreted as descriptive rather than causal. These factors reduce statistical power and increase the possibility of type II error. Nevertheless, the combination of detailed petrography with preliminary biochemical comparison generates a clinically testable hypothesis: monohydrate-predominant stones with urate incorporation may represent a distinct phenotype requiring careful assessment of urine pH, urate, calcium and citrate. Such phenotype-based evaluation is consistent with guideline-supported individualized metaphylaxis [1,8,9].

**Conclusions**

1. The structural formation of calcium-containing uroliths is consistent with a staged combination of crystallization and recrystallization processes, presumed to reflect dynamic changes in urinary pH as described in the literature [4,5], together with the stabilizing resources of the urinary system; gradual depletion of inhibitory processes stabilizes the direction of further urolith growth.

2. The progressive incorporation of uric acid dihydrate into the structure of monohydrate-predominant uroliths may be regarded as evidence of conditions favorable for its crystallization; this study additionally demonstrates, quantitatively, that monohydrate-predominant uroliths contain significantly more urate than dihydrate-predominant uroliths ($p<0.001$), directly supporting this morphological observation.

3. Differences in 24-hour urine calcium, oxalate, citrate and magnesium excretion, and in the AP (CaOx) crystallization index, trended in a biologically plausible direction (more hypercalciuric/hypocitraturic profile in the monohydrate-predominant group) but did not reach statistical significance given the limited sample size available for these analyses, and warrant confirmation in a larger, prospectively characterized cohort with complete 24-hour urine collection.

4. Understanding the combined morphological and biochemical stages of stone formation may contribute to improved strategies for early detection of lithogenesis and optimization of individualized metaphylaxis in patients with urolithiasis.

**Prospects for further research.** Further research will focus on improving personalized approaches to the treatment and prevention of urolithiasis through a comprehensive analysis of the morphological characteristics of uroliths, their mineral composition, metabolic risk factors, and lithogenicity indices. The findings of this study may provide a basis for developing algorithms for the early prediction of disease recurrence, optimizing individualized metaphylaxis, and improving treatment outcomes in patients with urolithiasis.

**Author Contributions. K.S. Barannik:** Investigation, Data Curation, Formal analysis, Writing – original draft, Project administration; corresponding author. **R.V. Duka, R.M. Molchanov**: Conceptualization, Methodology, Supervision, Writing – review & editing. **S.L. Malinovskyj**: Investigation, Data Curation, Formal analysis, Writing – review & editing. **Y.V. Pilin**: Investigation, Data Curation, Writing – review & editing. All authors reviewed and approved the final manuscript.

**Ethics approval and consent to participate.** The study was conducted in accordance with the principles of the Declaration of Helsinki. The study protocol was approved by the Bioethics Committee of Dnipro State Medical University (Dnipro, Ukraine), protocol №3, of 16.11.2022.Written informed consent was obtained from all participants included in the study.

**Conflict of interest.** The authors declare no conflict of interest.

**Financing resources:** Self-financing.

**Generative AI disclosure.** No Generative AI tools were used in the preparation of this manuscript.

**References**

1. Skolarikos A. Davis NF, Gambaro G, Geraghty R, Jung H, Kamphuis GM, et al. EAU Guidelines on Urolithiasis. European Association of Urology; 2026. 130 p.
2. Romero V, Akpinar H, Assimos DG. Kidney stones: a global picture

of prevalence, incidence, and associated risk factors. Rev Urol. 2010;12(2-3):e86-96.
3. Khan SR, Pearle MS, Robertson WG, Gambaro G, Canales BK, Doizi S, et al. Kidney stones. Nat Rev Dis Primers. 2016;2:16008. https://doi.org/10.1038/nrdp.2016.8
4. Sivaguru M, Saw JJ, Wilson EM, Lieske JC, Krambeck AE, Williams JC, et al. Human kidney stones: a natural record of universal biomineralization. Nat Rev Urol. 2021;18(7):404-32. https://doi.org/10.1038/s41585-021-00469-x
5. Worcester EM, Coe FL. Clinical practice. Calcium kidney stones. N Engl J Med. 2010;363(10):954-63. https://doi.org/10.1056/nejmcp1001011
6. Tiselius HG. Aspects on estimation of the risk of calcium oxalate crystallization in urine. Urol Int. 1991;47(4):255-9. https://doi.org/10.1159/000282232
7. Williams JC Jr, Lingeman JE, Daudon M, Bazin D. Using micro computed tomographic imaging for analyzing kidney stones. C R Chim. 2022;25(Suppl 2):10.5802/crchim.89. https://doi.org/10.5802/crchim.89
8. Rule AD, Lieske JC, Li X, Melton LJ 3rd, Krambeck AE, Bergstralh EJ. The ROKS nomogram for predicting a second symptomatic stone episode. J Am Soc Nephrol. 2014;25(12):2878-86. https://doi.org/10.1681/asn.2013091011
9. Pearle MS, Goldfarb DS, Assimos DG, Curhan G, Denu-Ciocca CJ, Matlaga BR, et al. Medical management of kidney stones: AUA guideline. J Urol. 2014;192(2):316-24. https://doi.org/10.1016/j.juro.2014.05.006
10. Ishkov VV, Koziy ES, Trufanova MO. Osoblyvosti ontohenezu urolitiv zhyteliv Dnipropetrovs'koi oblasti [Peculiarities of ontogenesis of uroliths of residents of Dnipropetrovsk region]. Mineralogical Journal (Ukraine). 2020;42(4):50-9. https://doi.org/10.15407/mineraljournal.42.04.050 (in Ukrainian)
11. Tiselius HG. Stones: Guidelines reignite interest in medical treatment of stones. Nat Rev Urol. 2014 Sep;11(9):490-2 https://doi.org/10.1038/nrurol.2014.206
12. Tasian GE, Copelovitch L. Evaluation and medical management of kidney stones in children. J Urol. 2014 Nov;192(5):1329-36. https://doi.org/10.1016/j.juro.2014.04.108
13. Colleran GC, Callahan MJ, Paltiel HJ, Nelson CP, Cilento BG Jr, Baum MA, Chow JS. Imaging in the diagnosis of pediatric urolithiasis. Pediatr Radiol. 2017 Jan;47(1):5-16. https://doi.org/10.1007/s00247-016-3702-z
14. Davis R, Jones JS, Barocas DA, Castle EP, Lang EK, Leveillee RJ, Messing EM, Miller SD, Peterson AC, Turk TM, Weitzel W; American Urological Association. Diagnosis, evaluation and follow-up of asymptomatic microhematuria (AMH) in adults: AUA guideline. J Urol. 2012 Dec;188(6 Suppl):2473-81. https://doi.org/10.1016/j.juro.2012.09.078
15. Auge BK, Maloney ME, Mathias BJ, Pietrow PK, Preminger GM. Metabolic abnormalities associated with calyceal diverticular stones. BJU Int. 2006 May;97(5):1053-6. https://doi.org/10.1111/j.1464-410X.2006.06134.x
16. Stoller ML, Chi T, Eisner BH, Shami G, Gentle DL. Changes in urinary stone risk factors in hypocitraturic calcium oxalate stone formers treated with dietary sodium supplementation. J Urol. 2009 Mar;181(3):1140-4. https://doi.org/10.1016/j.juro.2008.11.020
17. Ekeruo WO, Tan YH, Young MD, Dahm P, Maloney ME, Mathias BJ, Albala DM, Preminger GM. Metabolic risk factors and the impact of medical therapy on the management of nephrolithiasis in obese patients. J Urol. 2004 Jul;172(1):159-63. https://doi.org/10.1097/01.ju.0000128574.50588.97
18. Balawender K, Łuszczki E, Mazur A, Wyszyńska J. The Multidisciplinary Approach in the Management of Patients with Kidney Stone Disease-A State-of-the-Art Review. Nutrients. 2024 Jun 18;16(12):1932. https://doi.org/10.3390/nu16121932
19. Salem SM, Sultan MF, Badawy A. Oral dissolution therapy for renal radiolucent stones, outcome, and factors affecting response: A prospective study. Urol Ann. 2019 Oct-Dec;11(4):369-373. https://doi.org/10.4103/UA.UA_20_19
20. Cong X, Huang L, Wang X, Li L, Zhang X, Chen X, Xu Y. Comparison of the bone mineral density status of patients with kidney stones stratified by stone composition. World J Urol. 2024 Jan 20;42(1):42. https://doi.org/10.1007/s00345-023-04727-y
21. Zheng Z, Cao X. Association of dietary live microbe intake with kidney stone disease in US adults: a real-world cross-sectional study. Front Nutr. 2024 Oct 21;11:1463352. https://doi.org/10.3389/fnut.2024.1463352

**Відомості про авторів:**
**Баранник К.С. –** к. мед. н., асистент кафедри хірургії та урології Дніпровського державного медичного університету, м. Дніпро, Україна.
E-mail: k.barannik1984@gmail.com
ORCID: https://orcid.org/0000-0002-1009-4990
**Дука Р.В. –** професор, д. мед. н., завідувач кафедри хірургії та урології Дніпровського державного медичного університету, м. Дніпро, Україна.
E-mail: rusduka@gmail.com
ORCID: https://orcid.org/0000-0003-3962-8746
**Молчанов Р.М. –** професор, д. мед. н., професор кафедри хірургії та урології Дніпровського державного медичного університету, м. Дніпро, Україна.
E-mail: rob_molch@yahoo.com
ORCID: https://orcid.org/0000-0002-9589-8364
**Малиновський С.Л. –** доцент, к. мед. н., доцент кафедри хірургії та урології Дніпровського державного медичного університету, м. Дніпро, Україна.
E-mail: proct.surg@gmail.com
ORCID: https://orcid.org/0000-0002-5554-836X
**Пілін Є.В.** – к. мед. н., асистент кафедри хірургії та урології Дніпровського державного медичного університету, м. Дніпро, Україна.
E-mail: evgeniypilin@gmail.com
ORCID: https://orcid.org/0000-0002-7542-919x
**Information about the authors:**
**Barannik K.S.** – Assistant, Candidate of Medical Sciences (PhD), Department of Surgery and Urology, Dnipro State Medical University, Dnipro, Ukraine.
E-mail: K. barannik1984@gmail.com
ORCID https://orcid.org/0000-0002-1009-4990.
**Duka R.V.** – Prof., DM Sienc., Head of the Department of Surgery and Urology, Dnipro State Medical University, Dnipro, Ukraine.
E-mail: rusduka@gmail.com
ORCID: https://orcid.org/0000-0003-3962-8746.
**Molchanov R.M. –** Prof., DM Sienc., Department of Surgery and Urology, Dnipro State Medical University, Dnipro,

Ukraine.
E-mail: rob_molch@yahoo.com
ORCID: https://orcid.org/0000-0002-9589-8364
**Malinovskyj S.L. –** Associate Professor, Candidate of Medical Sciences (PhD), Research Assistant, Department of Surgery and Urology, Dnipro State Medical University; Dnipro, Ukraine.
E-mail: proct.surg@gmail.com.
ORCID: https://orcid.org/ 0000-0002-5554-836X
**Pilin Y.V.** – Assistant, Candidate of Medical Sciences (PhD), Department of Surgery and Urology, Dnipro State Medical University; Dnipro, Ukraine.
E-mail: evgeniypilin@gmail.com
ORCID: https://orcid.org/0000-0002-7542-919x

*Дата першого надходження рукопису до видання: 21.07.2026*
*Дата прийнятого до друку рукопису після рецензування: 22.08.2026*
*Дата публікації: 28.09.2026*