Research Square

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Epidemiological Characteristics and Composition Analysis of Urinary Stones by Fourier Transform Infrared Spectroscopy: A Single-Center Retrospective Study in Northern Anhui, China

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Abstract

Background

Urinary stone composition varies substantially across geographic regions, yet data from smaller cities and rural areas in China remain scarce. This study characterized the stone composition profile and its demographic associations in a single-center cohort from northern Anhui, an underrepresented agricultural region.

Methods

This retrospective cross-sectional study included all consecutive urinary stones analyzed by Fourier transform infrared spectroscopy (FTIR) at the Second People's Hospital of Fuyang, Anhui, China, from January 2022 to May 2026 (*N* = 853). Compositions were classified into six categories. Associations with sex, age, and stone location were assessed using chi-square tests, Kruskal-Wallis tests, and logistic regression. Temporal trends were evaluated using the Cochran-Armitage test.

Results

Among 853 patients (male-to-female ratio 2.23:1; mean age 50.3 +/- 13.6 years), pure calcium oxalate (42.1%) and mixed-calcium stones (46.9%) together accounted for 89.0% of cases. By structural complexity, multi-component (mixed) stones—those containing two or more components, a superset that includes most mixed-calcium stones—comprised 49.0% of specimens, with the calcium oxalate-carbapatite combination predominating (70.6% of mixed stones). Composition was significantly associated with sex ($P < 0.001$) and age ($P < 0.001$); pure uric acid stone formers were the oldest (median 62 years). Ureteral location showed a non-significant trend toward lower odds of mixed stones (OR = 0.77; 95% CI 0.57–1.02; $P = 0.072$). No significant temporal trend was observed ($P = 0.304$).

Conclusions

Calcium-containing stones strongly predominate in northern Anhui, with a high mixed-stone proportion and a low pure uric acid stone rate (2.3%) compared with other Chinese regions. These findings highlight regional heterogeneity and the value of FTIR-based component analysis for individualized prevention.

Introduction

Urinary stone disease (urolithiasis) is a highly prevalent condition worldwide, affecting approximately 1 in 8 to 11 individuals over a lifetime, with an estimated 106 million incident cases globally in 2021 [1, 2]. In China, a nationwide cross-sectional survey reported a kidney stone prevalence of 6.4%, with higher rates among males, rural residents, and individuals with metabolic comorbidities [3]. The disease

imposes a substantial burden on healthcare systems and patient quality of life, and its prevalence continues to rise in association with dietary westernization and increasing rates of metabolic syndrome [1, 4].

Knowledge of stone composition is fundamental to understanding the pathogenesis of urolithiasis and guiding targeted prevention. Different stone types arise from distinct metabolic pathways: calcium oxalate stones are linked to hypercalciuria and hyperoxaluria, infection stones (struvite) to urease-producing bacterial infections, and uric acid stones to low urinary pH and insulin resistance [5, 6]. Fourier transform infrared spectroscopy (FTIR) has become the reference standard for stone analysis, as endorsed by the European Association of Urology guidelines, owing to its ability to identify all crystalline and amorphous components with high accuracy [7, 8]. FTIR has largely replaced wet chemical analysis in modern clinical laboratories because of its superior sensitivity for mixed-component detection [9].

Importantly, stone composition varies substantially across geographic regions, even within a single country. Multi-center studies from China have demonstrated significant regional differences in calcium oxalate, uric acid, and infection stone proportions [10, 11]. For example, uric acid stones account for 30.0% of cases in Shandong (eastern China) but only 5.3% in Henan (central China) [12, 13]. These regional variations likely reflect differences in dietary habits, climate, water quality, and genetic background. Despite extensive data from major Chinese metropolitan centers such as Beijing, Guangzhou, and Tianjin [14–16], stone composition data from smaller cities and rural areas remain limited. Northern Anhui (Wanbei), a predominantly agricultural region in eastern China, represents a geographic and socioeconomic context distinct from previously studied areas; to our knowledge, no FTIR-based stone composition data from this region have been published.

The present study aimed to (1) describe the composition profile of urinary stones in a single-center cohort from northern Anhui using FTIR analysis, (2) evaluate the associations between stone composition and demographic factors (sex, age) and stone location, and (3) assess temporal trends in stone composition over a 4-year period.

We believe that this single-center description is of regional and international relevance for two reasons. First, no peer-reviewed FTIR-based stone composition data have, to our knowledge, been published for northern Anhui (Wanbei), an agricultural prefecture of approximately 10 million residents whose dietary, climatic, and metabolic risk profile differs from previously characterized Chinese metropolitan and coastal populations. Second, the comparison of our compositional pattern—including a low pure uric acid stone rate (2.3%) and a high mixed-stone proportion (49.0%)—with published series from other Chinese regions generates testable hypotheses about regional dietary and metabolic drivers that may guide future multi-center metabolic studies.

Methods

Study design and setting

This was a retrospective, cross-sectional study conducted at the clinical laboratory of the Second People's Hospital of Fuyang, Anhui Province, China. Fuyang is a prefecture-level city located in the northwestern part of Anhui Province (northern Anhui or Wanbei region), serving a predominantly rural population of approximately 10 million. The study period spanned from January 2022 to May 2026. This study was reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines, with the completed STROBE checklist provided as an Additional file. Although the data derived from routinely generated clinical laboratory reports, the RECORD extension—developed specifically for studies using routinely collected administrative or claims databases—was judged only partially applicable; the relevant RECORD items concerning data source, extraction, and cleaning are nonetheless addressed in this section.

Participants

All consecutive urinary stone specimens submitted for composition analysis by FTIR during the study period were eligible. Original records comprised 861 standardized FTIR reports. The following records were removed: exact duplicate reports (n = 3), specimens with missing composition data (n = 4), and one specimen with an implausible recorded age (> 110 years; n = 1). After exclusions, 853 specimens from 853 patients were included in the final analysis. Patient demographic information (sex, age, stone location, episode status, and region of residence) was extracted from accompanying clinical reports. All data were anonymized prior to analysis.

Variables and definitions

Stone composition classification. Each stone specimen was classified into one of six major clinical categories based on its FTIR-determined composition: (1) pure calcium oxalate stone (calcium oxalate monohydrate [COM], calcium oxalate dihydrate [COD], or unspecified calcium oxalate); (2) mixed-calcium stone (calcium oxalate combined with carbapatite [a carbonated calcium phosphate] or other calcium phosphate components); (3) infection stone (struvite [magnesium ammonium phosphate hexahydrate], with or without carbapatite); (4) pure phosphate stone (pure carbapatite, brushite, or hydroxyapatite, without calcium oxalate); (5) pure uric acid stone (uric acid or urate without calcium oxalate); and (6) metabolic mixed stone (uric acid combined with calcium oxalate). Stones containing two or more distinct chemical components were classified as mixed stones (multi-component); those containing a single component were classified as pure stones. Throughout, "mixed-calcium" denotes a composition category, whereas "multi-component (mixed)" denotes any stone with two or more components—a structural superset that includes all mixed-calcium and metabolic mixed stones. Classification was based on the presence of chemical components rather than their relative predominance, following standard infrared stone-analysis practice; the FTIR reports did not provide quantitative component proportions.

Demographic and clinical variables. Age was recorded as a continuous variable and further categorized into four groups: <30, 30–44, 45–59, and > = 60 years. Stone location was categorized as kidney, ureter, or lower urinary tract (bladder and urethra combined; *n* = 23). Episode status was classified as first-episode or recurrent. Region of residence was grouped as urban districts (Yingzhou, Yingquan, and Yingdong districts of Fuyang city) versus counties (Linquan, Funan, Yingshang, and others). Sampling year was derived from the date of stone analysis.

Stone composition analysis

Stone specimens were collected during surgical procedures (percutaneous nephrolithotomy, ureteroscopy, or open surgery) or after spontaneous passage. All specimens were washed with distilled water, air-dried, and ground into fine powder using an agate mortar. Approximately 1–2 mg of powder was mixed with potassium bromide (KBr) and pressed into pellets for analysis. Specimens were analyzed using a Fourier transform infrared spectrometer (SUN-3G; Jinan Dingshun Medical Equipment Co., Ltd., Jinan, China) in the clinical laboratory of the Second People's Hospital of Fuyang. Spectra were recorded in the range of 4000 − 400 cm^-1 at a resolution of 4 cm^-1. Each spectrum was compared against a standard mineral reference library to identify the crystalline and amorphous components present. Component identification was performed by an experienced laboratory technician and independently verified by a second experienced reader, with any discrepancies resolved by consensus, in accordance with standard infrared stone-analysis practice. A stone was classified as mixed when two or more chemically distinct components were identified by FTIR; no minimum proportion threshold was applied for minor components. The composition and relative proportions of each component were recorded in a standardized report format.

Statistical analysis

Continuous variables were expressed as mean +/- standard deviation (SD) and median with interquartile range (IQR) after assessment for normality. Categorical variables were presented as frequencies and percentages, with 95% Wilson confidence intervals (CIs) calculated for stone composition proportions. Between-group comparisons of categorical variables were performed using Pearson's chi-square test or Fisher's exact test when expected cell counts were fewer than 5. Continuous variables were compared across groups using the Kruskal-Wallis test (for more than two groups) or the Mann-Whitney U test (for two groups), as data were non-normally distributed. Effect sizes were reported as Cramer's V for chi-square tests and epsilon-squared for the Kruskal-Wallis test.

Binary logistic regression was performed to evaluate the associations of sex, age group, and stone location with mixed stone status (mixed vs. pure). Results were expressed as odds ratios (ORs) with 95% Wald CIs, and overall model fit was summarized by the Nagelkerke pseudo-R-squared. The Cochran-Armitage test for trend was used to evaluate temporal changes in the proportion of mixed stones across the five sampling years (primary analysis); a sensitivity analysis restricted to the three complete calendar years (2023–2025) and excluding the partial years 2022 and 2026 was performed to confirm

robustness. Given multiple comparisons in the univariate association analysis, a Bonferroni-corrected significance threshold of $P < 0.006$ (0.05/8, corresponding to the eight univariate association tests assessed) was applied; for all other analyses, statistical significance was set at $P < 0.05$ (two-tailed). No a priori sample-size calculation was performed; all consecutive eligible specimens during the study period were analyzed (a convenience sample). All analyses were performed in Python 3 with SciPy 1.17, statsmodels 0.14, NumPy 2.4, and pandas 2.3.

Use of large language models

Large language models (LLMs, including OpenAI ChatGPT and Anthropic Claude) were used as writing aids to assist with English-language editing, structure suggestions, and reference formatting. No LLM was used to generate, interpret, or modify scientific data, statistical results, or substantive scientific conclusions. All output produced with LLM assistance was reviewed, verified, and finalized by the authors, who take full responsibility for the content of this manuscript. LLMs are not listed as authors.

Results

Patient demographics

A total of 853 patients were included in the analysis. The demographic and clinical characteristics are summarized in Table 1. The mean age was 50.3 +/- 13.6 years (median 51; IQR 40–59), and the male-to-female ratio was 2.23:1 (589 males [69.1%] vs. 264 females [30.9%]). The largest age group was 45–59 years (*n* = 358; 42.0%), followed by 30–44 years (*n* = 230; 27.0%) and > = 60 years (*n* = 211; 24.7%). Ureteral stones were the most common location (*n* = 538; 63.1%), followed by kidney stones (*n* = 292; 34.2%) and lower urinary tract stones (*n* = 23; 2.7%). The majority of patients were first-episode stone formers (*n* = 823; 96.5%), with only 30 patients (3.5%) reporting recurrent episodes. Geographically, 41.4% of patients resided in Yingzhou District (the main urban area), with the remainder distributed across surrounding counties and districts.

Stone composition distribution

The distribution of stone compositions is presented in Table 2 and Fig. 1. Calcium-containing stones were strongly predominant, with pure calcium oxalate stones accounting for 42.1% (*n* = 359; 95% CI 38.8–45.4%) and mixed-calcium stones for 46.9% (*n* = 400; 95% CI 43.6–50.2%) of all cases. Together, these two categories represented 89.0% of the study population. Infection stones (struvite-based) comprised 5.2% (*n* = 44; 95% CI 3.9–6.9%), pure uric acid stones 2.3% (*n* = 20; 95% CI 1.5–3.6%), metabolic mixed stones (uric acid plus calcium oxalate) 2.1% (*n* = 18; 95% CI 1.3–3.3%), and pure phosphate stones 1.4% (*n* = 12; 95% CI 0.8–2.4%). Among detailed compositions, the most frequent individual types were COM (36.1%) and the calcium oxalate-carbapatite combination (31.5%).

Mixed stone patterns

Multi-component (mixed) stones accounted for 49.0% (418/853; 95% CI 45.7–52.4%) of all specimens, while pure (single-component) stones comprised 51.0% (435/853). Among the 418 mixed stones (Table 3; Fig. 4), the calcium oxalate-carbapatite combination was by far the most common pattern (*n* = 295; 70.6% of mixed stones), followed by carbapatite plus COD (*n* = 61; 14.6%), carbapatite plus COM (*n* = 44; 10.5%), and uric acid plus calcium oxalate (*n* = 18; 4.3%).

Associations between stone composition and demographic factors

The results of univariate association tests are summarized in Table 4 and Fig. 2.

Sex and stone type. A significant association was found between sex and major stone type (chi-square = 25.78, df = 5, $P < 0.001$; Cramer's V = 0.17). Infection stones showed a marked female predominance, with 24 of 44 (54.5%) infection stone formers being female, compared with 30.9% female representation in the overall cohort. All 18 metabolic mixed stones (uric acid plus calcium oxalate) occurred in males. Pure uric acid stones showed a strong male predominance (16 of 20; 80.0%), with 4 female cases. Among pure calcium oxalate stone formers the male proportion was 72.7% (261/359), and among mixed-calcium stone formers it was 66.0% (264/400).

Age and stone type. The Kruskal-Wallis test confirmed significant age differences across stone types ($H = 29.62$, df = 5, $P < 0.001$; epsilon-squared = 0.03). Pure uric acid stone formers were the oldest group (median 62 years; IQR 54–70), followed by metabolic mixed stones (median 58 years), pure calcium oxalate (median 52 years; IQR 42–60), mixed-calcium (median 49 years; IQR 39–58), infection stones (median 49 years), and pure phosphate stones, which occurred in the youngest patients (median 42 years).

Stone location and stone type. A significant association was found between stone location and major stone type (chi-square = 36.11, df = 10, $P < 0.001$; Cramer's V = 0.15).

Logistic regression analysis

The results of the binary logistic regression for mixed stone status are presented in Table 5. In the multivariable model including sex, age group, and stone location, no variable reached statistical significance. Ureteral location showed a non-significant trend toward lower odds of mixed stones compared with kidney stones (OR = 0.77; 95% CI 0.57–1.02; $P = 0.072$). Male sex (OR = 0.82; 95% CI 0.61–1.10; $P = 0.175$) and age group were not independently associated with mixed stone status. The estimate for lower urinary tract stones was imprecise owing to the small subgroup (*n* = 23; OR = 1.09; 95% CI 0.46–2.58) and should not be interpreted. The model explained little of the variance in stone complexity (Nagelkerke pseudo-R-squared = 0.02), indicating that demographic and anatomical variables alone are insufficient predictors; the low explained variance precludes firm conclusions about the relative contribution of unmeasured (including metabolic) factors.

Temporal trends

The distribution of major stone types across sampling years (2022–2026) showed no significant temporal trend (Fig. 3). The number of analyzed specimens per year was 64 (2022, partial), 266 (2023), 231 (2024), 239 (2025), and 53 (2026, partial). The proportion of mixed stones ranged from 42.1% (2023) to 51.9% (2024), but the Cochran-Armitage test across all five years indicated no statistically significant linear trend (z = 1.03, $P = 0.304$). A sensitivity analysis restricted to the three complete calendar years (2023–2025) yielded a similar null result. The proportions of individual stone types remained relatively stable across years, with pure calcium oxalate stones ranging from 39.0% to 44.4% and pure uric acid stones from 2.1% to 3.8%.

Subgroup and exploratory analyses

Infection stones. Among 44 infection stone formers, the female proportion (54.5%) was substantially higher than in the overall cohort (30.9%). The median age was 49 years. Most were located in the ureter (50.0%) or kidney (43.2%), and most were first-episode cases (93.2%).

Initial versus recurrent episodes. The recurrent group ($n = 30$) showed a higher proportion of mixed stones (63.3%) than the first-episode group (48.5%), but inferential comparison was not performed owing to the small recurrent sample size.

Regional differences. No significant difference in stone composition was found between urban districts and surrounding counties (chi-square = 9.52, df = 5, $P = 0.09$; Cramer's V = 0.11), a result non-significant at both the nominal ($P < 0.05$) and Bonferroni-corrected ($P < 0.006$) thresholds, nor in the mixed stone proportion (urban 50.3% vs. county 46.6%).

Discussion

To our knowledge, this is the first systematic FTIR-based characterization of urinary stone composition from a single center in northern Anhui (Wanbei region), China, based on analysis of 853 consecutive specimens. Our principal findings are that calcium-containing stones account for 89.0% of all cases, multi-component (mixed) stones represent a substantial proportion (49.0%), and stone composition is significantly associated with sex and age. These results fill a geographic gap in the Chinese stone composition literature and provide regionally specific data for clinical practice and preventive counseling.

Comparison with other Chinese regions

The dominance of calcium-containing stones in our cohort is consistent with national data [10] and other regional studies from China [12–16]. Our combined calcium-containing rate of 89.0% (pure calcium oxalate 42.1% plus mixed-calcium 46.9%) is at the higher end of Chinese series such as Henan (77.5%) [13], Guangdong (76.6%) [17], and Tianjin (74.6%) [16]. This may partly reflect classification methodology —our scheme counted any calcium oxalate-carbapatite combination as a calcium-containing (mixed-calcium) stone—but may also indicate a genuinely higher regional calcium oxalate burden related to

dietary oxalate intake from locally consumed vegetables and tea. Our pure uric acid stone rate (2.3%) was notably low compared with other Chinese regions, particularly Shandong (30.0%) [12], Beijing (10.6%) [15], and Tianjin (10.6%) [16]. Even when metabolic mixed stones (uric acid plus calcium oxalate; 2.1%) are added, the combined uric-acid-containing rate (4.4%) remains markedly lower than these coastal and metropolitan series. Our infection stone rate (5.2%) was moderate, falling between the low rate of the nationwide multicenter study (2.7% struvite) [10] and the higher rates from Guangdong (13.2%) [17] and Tianjin (11.8%) [16].

Gender differences in stone composition

The significant association between sex and stone type ($P < 0.001$) is well established in the literature [27]. The female predominance among infection stone formers (54.5% female vs. 30.9% in the overall cohort) is consistent with the higher susceptibility of women to urinary tract infections involving urease-producing organisms, which favor struvite crystallization in alkaline urine [18, 5]. Uric-acid-containing stones in our series showed a strong male predominance: all 18 metabolic mixed stones occurred in males, and pure uric acid stones were 80.0% male (16/20). This is consistent with the well-documented male preponderance of uric acid stone formation—commonly reported at a male-to-female ratio of roughly 3:1—attributed to lower urinary pH, higher serum uric acid, and greater dietary purine intake in men [6, 28]. Importantly, uric acid stones were not confined to men: the 4 female cases were predominantly postmenopausal (ages 49–74; three aged > = 60), in keeping with the recognized rise in uric acid stone risk after menopause, when the loss of estrogen-mediated effects on urate handling and urinary pH increases susceptibility [29]. Our overall male-to-female ratio of 2.23:1 is consistent with the global range of 2:1 to 3:1 for urolithiasis [2, 19, 20].

Age and uric acid stone formation

Pure uric acid stone formers in our cohort were significantly older than formers of other stone types (median 62 years), with metabolic mixed stone formers also relatively old (median 58 years). This age-dependent pattern is consistent with established physiology, although our dataset contained no metabolic measurements (serum urate, urinary pH) to test these mechanisms directly. Aging is associated with decreased renal ammonium excretion and lower urinary pH, both of which favor uric acid crystallization [6, 21, 28]. Additionally, the prevalence of insulin resistance and metabolic syndrome increases with age; these conditions lower urinary pH and are established drivers of uric acid nephrolithiasis [28, 30]. Type 2 diabetes in particular markedly increases uric acid stone risk [30], and age-associated increases in uric acid stone risk have likewise been reported in other Asian cohorts [22]. Pure phosphate stones, by contrast, occurred in the youngest patients (median 42 years), which may reflect a higher relative contribution of infection-related and developmental factors in younger populations, although the small subgroup size ($n = 12$) limits interpretation.

Regional dietary hypothesis for the low uric acid stone rate

The low pure uric acid stone rate in our cohort (2.3%) is among the lowest reported in Chinese series, in striking contrast to the 30.0% observed in coastal Shandong [12] and 10.6% in both Beijing [15] and

Tianjin [16]. Although this study did not collect dietary or metabolic data, northern Anhui is a predominantly agricultural region where the traditional diet is wheat- and vegetable-based with relatively low consumption of animal protein and seafood, in contrast to the protein- and purine-rich dietary patterns of coastal eastern China. It is plausible—though unproven by our data—that a lower regional prevalence of metabolic syndrome and type 2 diabetes, both established risk factors for uric acid nephrolithiasis through their effects on urinary pH [28, 30], contributes to the low uric acid stone rate. This remains a hypothesis requiring formal testing. If confirmed, it would have practical implications: clinicians in northern Anhui may prioritize calcium oxalate-directed prevention rather than the uric acid-focused approaches more appropriate for coastal regions. Future studies incorporating dietary surveys, serum uric acid measurements, and urinary pH profiling are needed to test this hypothesis.

Mixed-component stones and clinical implications

The proportion of mixed stones in our cohort (49.0%) is noteworthy. Reported mixed stone rates vary widely across studies, ranging from approximately 42% in an ethnic minority region of Hubei [23] to over 70% in a large German series [25, 26], largely reflecting differences in classification methodology: some laboratories classify any detectable trace component as constituting a mixed stone, while others require a component to exceed a defined proportion threshold. Standardization of mixed-stone classification criteria would enhance cross-study comparability.

The predominance of the calcium oxalate-carbapatite combination among mixed stones (70.6%) is consistent with the physicochemical relationship between these crystal phases: carbapatite (calcium phosphate) nuclei can serve as heterogeneous nucleation sites for calcium oxalate crystallization (epitaxial growth) [7, 25]. The clinical significance lies in prevention: patients with mixed calcium oxalate-carbapatite stones may benefit from strategies targeting both oxalate reduction and urinary acidification, rather than single-pathway interventions. This distinction can only be made through component-level analysis such as FTIR; treating all calcium-containing stones with a uniform protocol risks under-addressing the phosphate component in nearly half of our patients. Routine FTIR-based composition analysis, rather than presumptive treatment based on stone appearance alone, is therefore essential to guide individualized prevention in this population.

Binary logistic regression did not identify any independent demographic or anatomical predictor of mixed stone status; ureteral location showed only a non-significant trend toward lower odds of mixed stones (OR = 0.77; $P = 0.072$). The low explained variance indicates that demographic and anatomical variables alone are insufficient to predict stone complexity; it does not, however, establish which unmeasured factors are responsible, and a larger metabolic contribution remains a hypothesis for future study.

Absence of temporal trends

We found no significant temporal trend in the proportion of mixed stones over the study period ($P = 0.304$), a finding confirmed by sensitivity analysis excluding incomplete years. This contrasts with some

longer-duration studies that have documented increasing trends in uric acid or calcium phosphate stones over longer periods [15, 16, 24]. Our relatively short observation period (4.3 years) may be insufficient to detect gradual compositional shifts, and the stable socioeconomic and dietary conditions in the Fuyang region during this period may also have contributed to the observed compositional stability.

Limitations

This study has several limitations. First, as a single-center retrospective study, the findings may not be generalizable to the broader northern Anhui population or to other regions of China and may be subject to referral bias. Second, no metabolic data (serum calcium, uric acid, urinary oxalate, urinary pH) were available, precluding assessment of the metabolic underpinnings of different stone types. Third, the study period of 4.3 years is relatively short for detecting temporal trends, and the incomplete data for 2022 and 2026 reduce power for annual comparisons. Fourth, the recurrent stone group was small (n = 30), preventing inferential comparison with first-episode formers. Fifth, information on stone size, number, and surgical method was unavailable. Sixth, several subgroups (pure uric acid, metabolic mixed, pure phosphate) had small sample sizes, limiting the precision of estimates. Seventh, composition was determined on a clinical infrared spectrometer using the standard KBr-pellet method with an automated stone-component spectral library; as is usual in routine clinical practice, per-run calibration logs were not separately archived for this retrospective dataset. Finally, because the laboratory reports did not quantify component proportions, any detectable second component defined a stone as mixed, so the mixed-component rate (49.0%) should be regarded as an upper bound relative to series applying a minimum-proportion threshold.

Conclusions

To our knowledge, this single-center study provides the first FTIR-based stone composition data from northern Anhui, China. Calcium-containing stones strongly predominate (89.0%), with a substantial multi-component (mixed) proportion (49.0%) dominated by the calcium oxalate-carbapatite combination. Stone composition is significantly associated with sex (infection stones female-predominant; uric-acid-containing stones strongly male-predominant, with metabolic mixed stones occurring only in males in this cohort) and age (uric acid stones strongly age-dependent). The low pure uric acid stone rate (2.3%) and moderate infection stone rate (5.2%) differ markedly from other Chinese centers, highlighting important regional heterogeneity. These findings support the routine use of FTIR analysis for individualized stone prevention and underscore the need for multi-center studies with metabolic data to further elucidate regional differences in stone composition across China.

Abbreviations

CI, confidence interval; COD, calcium oxalate dihydrate; COM, calcium oxalate monohydrate; EAU, European Association of Urology; FTIR, Fourier transform infrared spectroscopy; IQR, interquartile range; IRB, Institutional Review Board; LLM, large language model; OR, odds ratio; RECORD, REporting of studies

Conducted using Observational Routinely-collected health Data; SD, standard deviation; STROBE, Strengthening the Reporting of Observational Studies in Epidemiology.

Declarations

Ethics approval and consent to participate

This study was approved by the Institutional Review Board of the Second People's Hospital of Fuyang (approval number: 20260519161; approval date: 19 May 2026). Because the study was a retrospective analysis of previously generated, de-identified clinical laboratory records spanning January 2022 to May 2026, the institutional review board granted retrospective (chart-review) approval for the research use of these existing records covering the entire study period; no prospective patient recruitment or intervention was involved, and the approval date reflects the timing of the research-ethics application rather than the data-collection window. The study was conducted in accordance with the Declaration of Helsinki. The requirement for individual informed consent was waived by the Institutional Review Board because the analysis used de-identified data extracted retrospectively from existing laboratory records, and no patient identifying information was accessed by the study team.

Consent for publication

Not applicable. The manuscript does not contain any individual person's identifying data (images, videos, or personal details) in any form.

Availability of data and materials

The de-identified dataset analyzed in this study is not publicly available because permissions to share patient-level laboratory records were not obtained at the time of data collection. De-identified, aggregated data underlying the figures and tables of this article are available from the corresponding author upon reasonable academic request and after approval by the Institutional Review Board of the Second People's Hospital of Fuyang.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

Conceptualization: Wenjian Liu, Erpeng Wang; Methodology: Wenjian Liu, Erpeng Wang; Software: Wenjian Liu; Validation: Wenjian Liu, Yang Zhan; Formal analysis: Wenjian Liu; Investigation: Wenjian Liu, Zhenyong Fan, Haijiang Wang, Tingshan Dai, Ligang Guo; Resources: Yang Zhan, Zhenyong Fan, Haijiang

Wang, Tingshan Dai, Ligang Guo; Data curation: Wenjian Liu, Yang Zhan; Writing—original draft: Wenjian Liu; Writing—review & editing: all authors; Visualization: Wenjian Liu; Supervision: Erpeng Wang; Project administration: Erpeng Wang. All authors read and approved the final manuscript.

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Tables

Table 1. Demographic and clinical characteristics (*N* = 853)

Variable	Value
Sex	
Male	589 (69.1%)
Female	264 (30.9%)
Age (years)	
Mean +/- SD	50.3 +/- 13.6
Median [IQR]	51 [40-59]
Age group	
<30	54 (6.3%)
30-44	230 (27.0%)
45-59	358 (42.0%)
>=60	211 (24.7%)
Stone location	
Kidney	292 (34.2%)
Ureter	538 (63.1%)
Lower urinary tract	23 (2.7%)
Episode	
First-episode	823 (96.5%)
Recurrent	30 (3.5%)
Region of residence	
Yingzhou District	353 (41.4%)
Linquan County	131 (15.4%)
Yingquan District	81 (9.5%)
Funan County	65 (7.6%)
Yingshang County	60 (7.0%)
Other areas	163 (19.1%)

Table 2. Stone composition distribution with 95% confidence intervals (*N* = 853)

Category	n	%	95% CI
Pure calcium oxalate stone	359	42.1	38.8-45.4
Mixed-calcium stone	400	46.9	43.6-50.2
Infection stone	44	5.2	3.9-6.9
Pure uric acid stone	20	2.3	1.5-3.6
Metabolic mixed stone (uric acid + calcium oxalate)	18	2.1	1.3-3.3
Pure phosphate stone	12	1.4	0.8-2.4
Calcium-containing (sum)	759	89.0	86.7-90.9
Multi-component (mixed)	418	49.0	45.7-52.4
Pure (single-component)	435	51.0	47.6-54.3

Table 3. Mixed stone combination patterns (*N* = 418)

Combination	n	% of mixed
Calcium oxalate + Carbapatite	295	70.6
Carbapatite + COD	61	14.6
Carbapatite + COM	44	10.5
Uric acid + Calcium oxalate	18	4.3

Abbreviations: COM, calcium oxalate monohydrate; COD, calcium oxalate dihydrate. "Calcium oxalate + Carbapatite" denotes specimens reported by FTIR as calcium oxalate plus carbapatite without further crystalline differentiation; the COM/COD rows denote specimens for which the monohydrate or dihydrate form was explicitly identified.

Table 4. Summary of univariate association tests

Comparison	Test	Statistic	df	P-value	Effect size
Sex x major stone type	Chi-square	25.78	5	<0.001*	Cramer's V = 0.17
Age across major types	Kruskal-Wallis	H = 29.62	5	<0.001*	epsilon-squared = 0.03
Location x major stone type	Chi-square	36.11	10	<0.001*	Cramer's V = 0.15
Region (urban vs. county) x major type	Chi-square	9.52	5	0.09	Cramer's V = 0.11
Temporal trend in mixed proportion	Cochran-Armitage	z = 1.03	--	0.304	--

*Significant after Bonferroni correction (threshold $P < 0.006$). Effect sizes: Cramer's V interpreted as small (~0.1), moderate (~0.3); epsilon-squared as proportion of variance.

Table 5. Binary logistic regression: predictors of mixed stone status

Variable	OR	95% CI	P-value
Male (ref: Female)	0.82	0.61-1.10	0.175
Age 30-44 (ref: <30)	1.31	0.72-2.38	0.371
Age 45-59 (ref: <30)	0.79	0.45-1.41	0.431
Age >=60 (ref: <30)	0.73	0.40-1.35	0.317
Ureter (ref: Kidney)	0.77	0.57-1.02	0.072
Lower urinary tract (ref: Kidney)	1.09	0.46-2.58	0.838

Figures

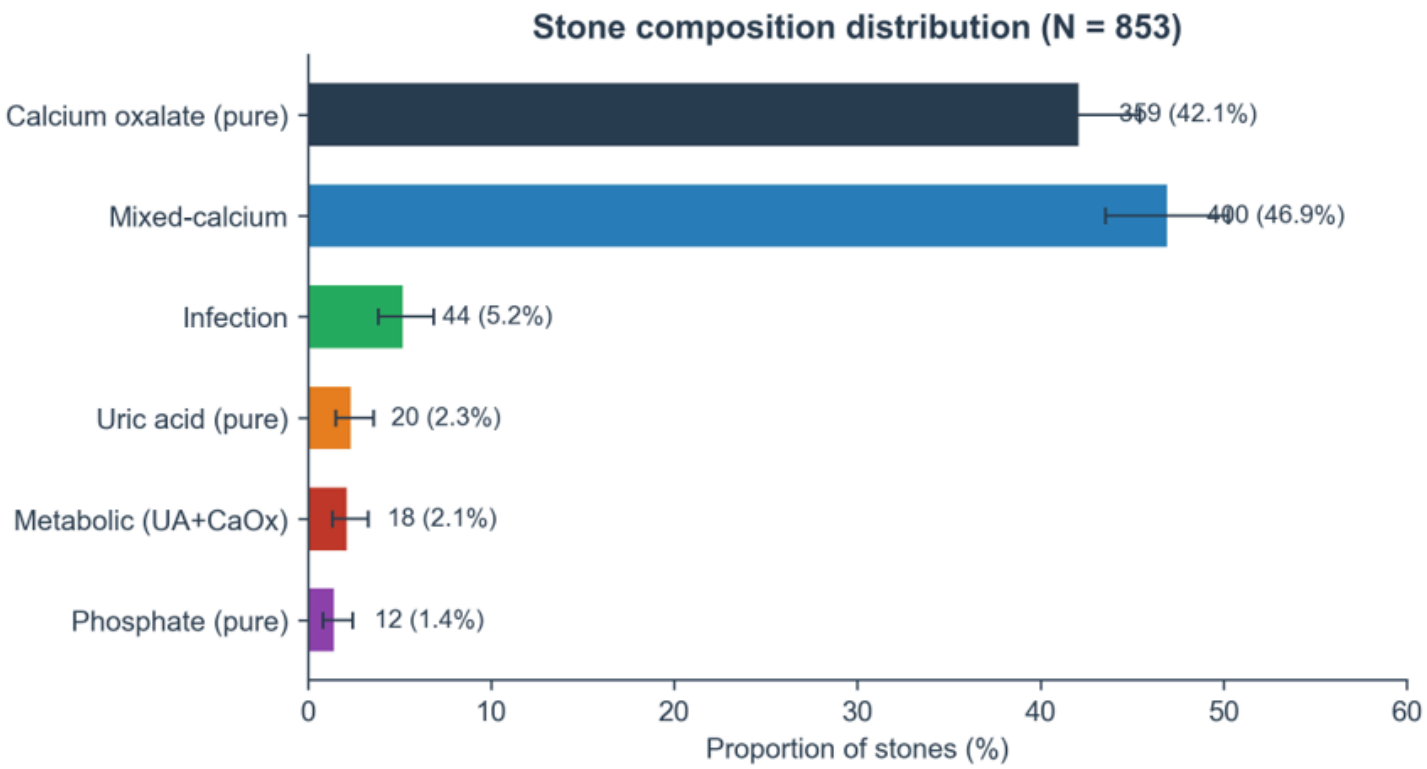


Figure 1

Distribution of urinary stone compositions by major type (N = 853).

Figure 2.

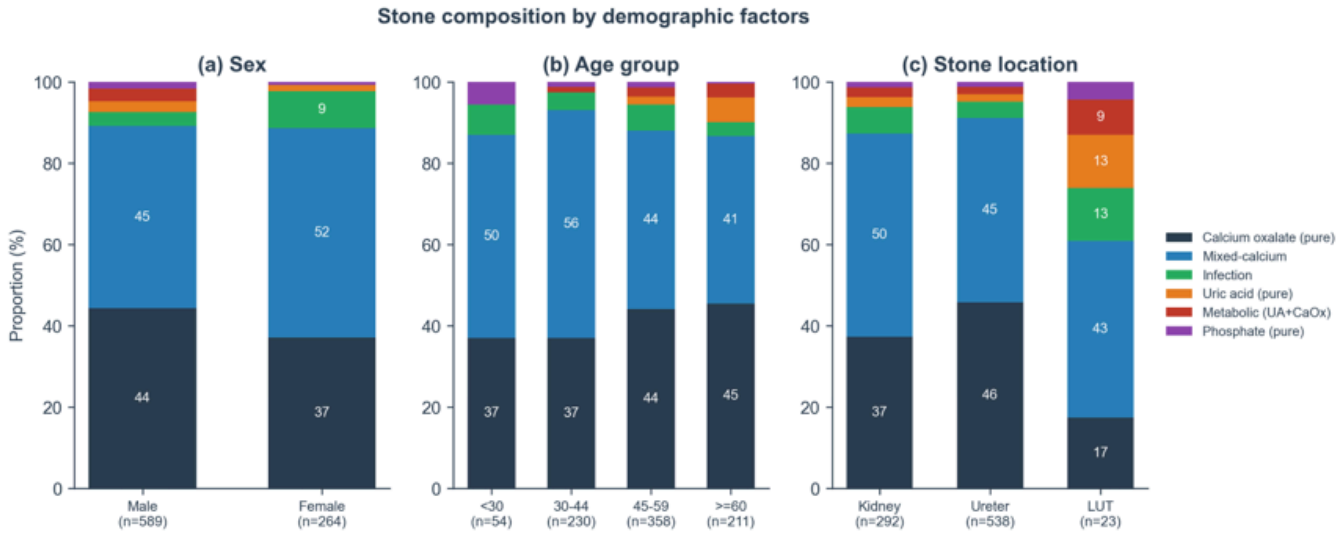


Figure 2

Stone composition stratified by sex, age group, and stone location.

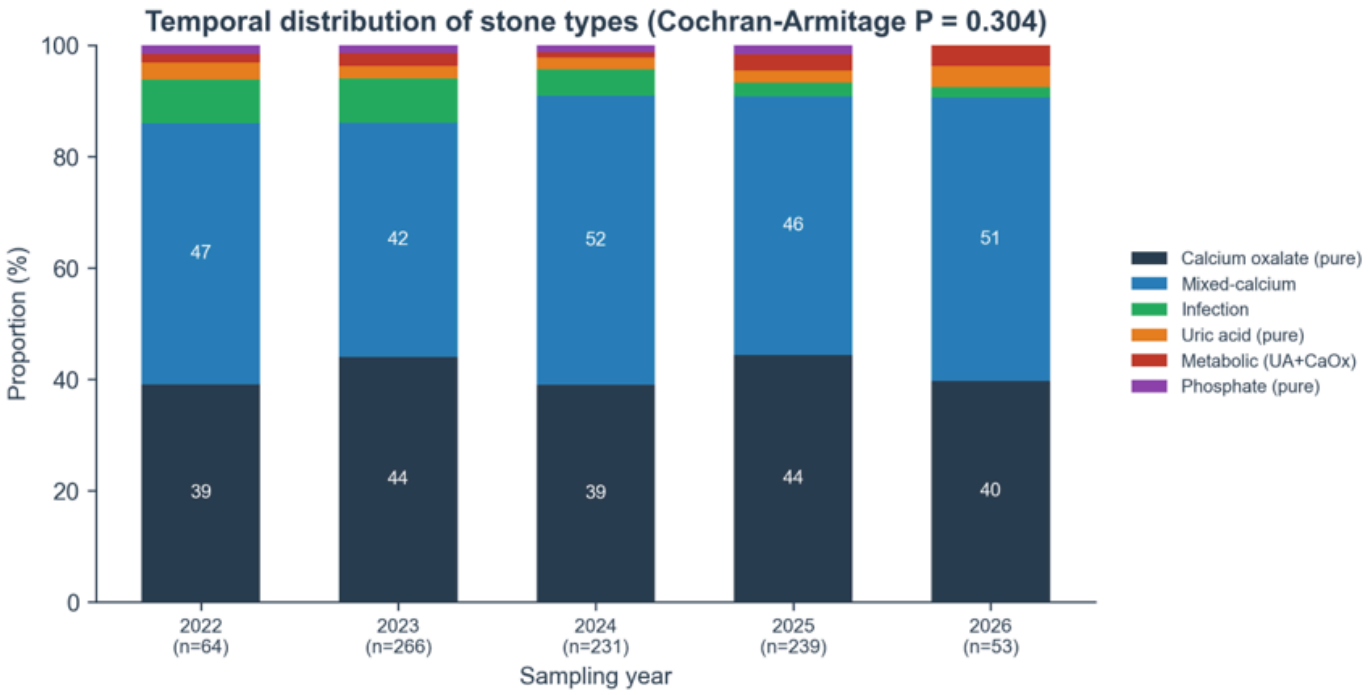


Figure 3

Temporal distribution of major stone types across sampling years (2022-2026).

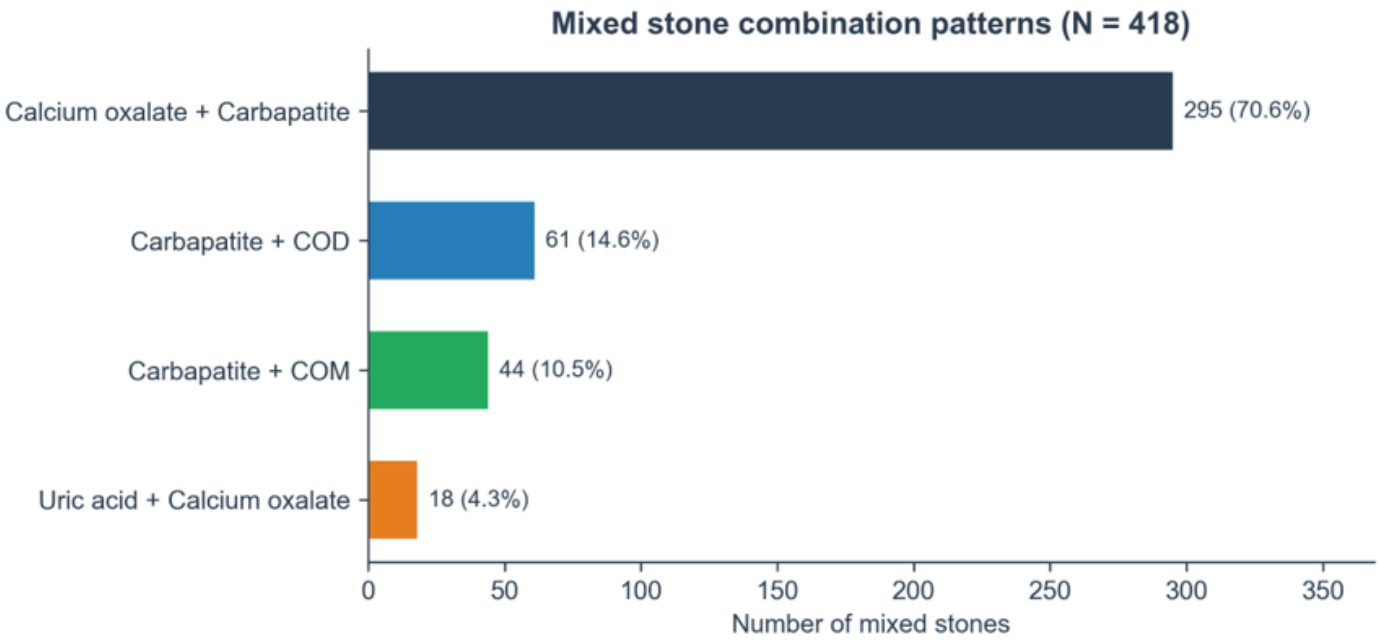


Figure 4

Mixed stone combination patterns (N = 418).

Supplementary Files

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