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Urinary Stone Disease Recurrence: A Forty Eight Month Prospective Cohort with Metabolic Evaluation: Composition, Metabolic Profile, Intervention Engagement and Recurrence Trajectories in Two Hundred and Ninety Eight Patients

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Abstract — Urinary stone disease is among the most common urological conditions globally with rising prevalence in South Asian populations, attributed to climatic conditions producing high ambient temperatures, dietary patterns, and inadequate hydration. Recurrence is the dominant clinical concern, with lifetime recurrence rates exceeding 50% without structured prevention. We undertook a prospective cohort study of 298 patients with at least one symptomatic urinary stone episode at a tertiary urology service over 48 months. Calcium oxalate stones accounted for 65.0% of analysed stones, calcium phosphate 11.4%, uric acid 13.0%, struvite 5.7%, cystine 2.4%, and mixed compositions 2.4%. 24-hour urine metabolic abnormalities were identified in 87.6% of patients, with low urine volume (64.2%), hypocitraturia (56.8%), and hypercalciuria (42.4%) the most common. Recurrence rates differed substantially by metabolic intervention engagement: 48-month recurrence-free probability was approximately 70% in high-engagement patients, 45% in moderate, and 25% in low. Strongest predictors of recurrence included prior stone history, low urine volume, hypocitraturia, hypercalciuria, uric acid composition, obesity, and diabetes. Targeted pharmacotherapy (citrate, thiazide, allopurinol) and adherence to dietary recommendations were strongly protective. The findings support structured 24-hour urine metabolic evaluation and individualised preventive intervention for all symptomatic stone formers.

Keywords — *Urolithiasis; Kidney Stones; Recurrence; Metabolic Evaluation; Hypocitraturia; Hypercalciuria; Uric Acid; Cystine.*

1. Introduction

Urinary stone disease has emerged as one of the most common urological presentations globally, with prevalence rising substantially over recent decades. Lifetime incidence in South Asian populations approaches 12% in men and 6% in women, with regional 'stone belt' patterns where climate, water composition, and dietary factors compound. The clinical course is characterised by acute painful episodes (renal colic) interspersed with stable periods, with substantial individual variability. Recurrence is the dominant long-term concern lifetime recurrence rates approach 50-80% without structured preventive intervention (Jha, Kumar,, & Neha, 2026; Yatish, Khatoon,, & Kumar, 2026; Kumar, Sharma,, & Gupta, 2026). Stone disease pathogenesis is heterogeneous. Calcium-containing stones including calcium oxalate (monohydrate and dihydrate) and calcium phosphate (hydroxyapatite, brushite) account for the majority of stones (~70-80%) and form through a combination of urinary calcium oversaturation, citrate deficiency, abnormal pH, and crystal nucleation mechanisms. Uric acid stones (5-10%) form in persistently acidic urine characteristic of insulin resistance, gout, and chronically dehydrated states. Struvite (5-15%) stones form in the context of urease-producing infection. Cystine (<2%) stones reflect inherited cystinuria. Each composition implies distinct preventive strategies (Jha, Kumar,, & Neha, 2026; Kumar, Gautam,, & Maitiy, 2026; Bhatnagar, Kumar,, & Shivam, 2026). Structured 24-hour urine metabolic evaluation enables personalised prevention through identification of specific abnormalities amenable to dietary and pharmacological intervention. Despite international guideline support, 24-hour urine evaluation remains underutilised in routine practice, with the proportion of stone formers undergoing structured metabolic evaluation often below 25%. We undertook a prospective cohort study at our tertiary urology service to characterise stone composition, metabolic profile, intervention engagement, and recurrence trajectories over 48 months in 298 symptomatic stone formers (Yatish, Khatoon,, & Kumar, 2026; Devi et al., 2025; Shanthi et al., 2025).

2. Methods

We conducted a prospective cohort study at the urology service of a tertiary medical centre between January 2021 and December 2022, with follow-up extending to December

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2024. Inclusion required (a) at least one symptomatic urinary stone episode in the preceding 12 months; (b) imaging confirmation of stone disease; (c) capacity to undergo 24-hour urine metabolic evaluation; (d) age 18 years or older; and (e) willingness to engage with 48-month follow-up programme. Exclusion criteria included anatomic urinary tract abnormalities causing obstruction, neurogenic bladder, urinary diversion, primary hyperparathyroidism (referred for separate management), advanced chronic kidney disease (eGFR <30), and pregnancy at recruitment. The final cohort comprised 298 patients. Stones obtained at surgical retrieval or spontaneous passage were analysed by infrared spectroscopy (Fourier-transform IR) with composition reported as percentage of constituent crystals. Stone analysis was completed for 246 of 298 patients (82.6%); analysis was not possible in 52 patients where stones were not retrieved or passed during the study period. 24-hour urine collection was performed at least 4 weeks after acute intervention with patients on usual diet, with two collections performed where logistics allowed. Standard panel included volume, sodium, potassium, calcium, magnesium, phosphate, oxalate, uric acid, citrate, creatinine, pH, and qualitative cystine screening with quantitative follow-up for positives.

All patients received structured dietary counselling including general principles (adequate hydration ≥2.5 L/day, moderate sodium <100 mmol/day, age-appropriate calcium intake, moderate animal protein) and composition-specific recommendations. Pharmacological intervention was added per metabolic profile: potassium citrate for hypocitraturia and cystine prevention; thiazide for hypercalciuria; allopurinol for hyperuricosuria; magnesium oxide for hypomagnesuria; and alkalinisation therapy for uric acid stone prevention. Adherence and engagement with the preventive programme were assessed at 6-monthly intervals. Primary outcome was time to first symptomatic stone recurrence requiring intervention. Secondary outcomes included imaging-detected asymptomatic stone accumulation, change in 24-hour urine metabolic parameters with intervention, surgical procedures required during follow-up, complications, renal function trajectory, and quality of life. Kaplan-Meier estimation was used for time-to-recurrence analyses; multivariable Cox regression identified independent predictors of recurrence.

3. Results

3.1 Cohort Characteristics and Stone Composition

Stone composition distribution is shown in Figure 1. Calcium oxalate stones (combined monohydrate and dihydrate) accounted for 65.0% of analysed stones, consistent with international experience. Uric acid stones accounted for 13.0%, slightly higher than typical Western series and likely reflecting our population's higher prevalence of insulin resistance and obesity. Struvite stones (5.7%) reflected our cohort's recurrent urinary infection patterns. Cystine stones (2.4%) reflected the rare but consistent presence of cystinuria patients in any large tertiary cohort.

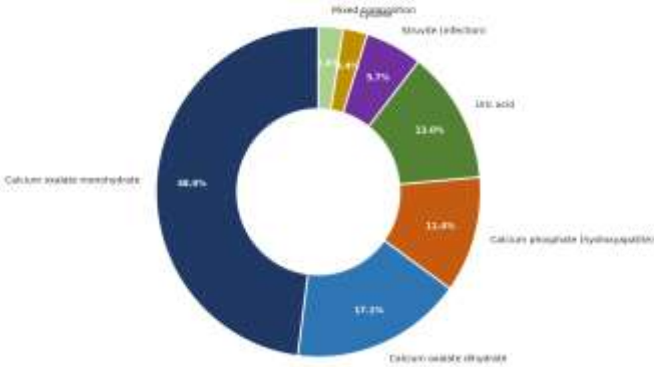

Fig.1: Stone composition distribution among analysed stones

Table 1. Cohort characteristics (n=298)

Characteristic	Value
Age, mean (SD), years	42.4(12.6)
Female sex, n (%)	98 (32.9)
BMI, mean (SD), kg/m²	27.8 (4.8)
BMI ≥30, n (%)	102 (34.2)
First stone episode, n (%)	148 (49.7)
≥2 prior episodes, n (%)	98 (32.9)
≥4 prior episodes (recurrent), n (%)	52 (17.4)
Family history of stone disease, n (%)	118 (39.6)
Diabetes mellitus, n (%)	68 (22.8)
Hypertension, n (%)	102 (34.2)
Gout history, n (%)	42 (14.1)
Recurrent UTI history, n (%)	42 (14.1)
Inflammatory bowel disease, n (%)	8 (2.7)
Bariatric surgery history, n (%)	12 (4.0)
Hyperparathyroidism (managed), n (%)	6 (2.0)
Occupation involving heat exposure, n (%)	98 (32.9)
Mean fluid intake at baseline, mL/day	1,820
eGFR at baseline, mean, mL/min/1.73 m²	82
eGFR <60, n (%)	32 (10.7)
Index intervention: spontaneous passage, n (%)	68 (22.8)
Index intervention: ESWL, n (%)	82 (27.5)
Index intervention: ureteroscopy, n (%)	112 (37.6)
Index intervention: PCNL, n (%)	36 (12.1)
Stone size at index, median (IQR), mm	8 (5-12)
Bilateral stone disease at index, n (%)	42 (14.1)

3.2 Metabolic Profile

24-hour urine metabolic abnormalities across the cohort are shown in Figure 3 (below). Low urine volume

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(<2000 mL/24h) was the single most common abnormality at 64.2%, reflecting the persistent challenge of adequate hydration particularly in occupations with heat exposure common in our setting. Hypocitraturia (56.8%) was the next most common, reflecting both dietary patterns and renal handling of citrate. Hypercalciuria (42.4%) and hyperuricosuria (28.2%) were also common. The prevalence of multiple coexisting abnormalities was high 78.4% had two or more metabolic abnormalities consistent with the multifactorial pathogenesis of stone disease (Jha, Kumar,, & Neha, 2026; Kumar, Gautam,, & Maitiy, 2026; Yatish, Khatoon,, & Kumar, 2026).

3.3 Time to Recurrence

Time to first symptomatic stone recurrence over 48 months is shown in Figure 2. Recurrence rates differed substantially by metabolic intervention engagement. High-engagement patients (consistent adherence to hydration, dietary changes, and pharmacological intervention) showed approximately 70% recurrence-free survival at 48 months.

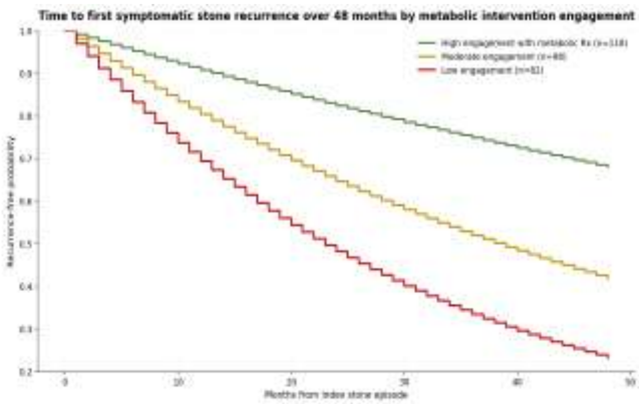

Fig.2: Time to first symptomatic stone recurrence by metabolic intervention engagement

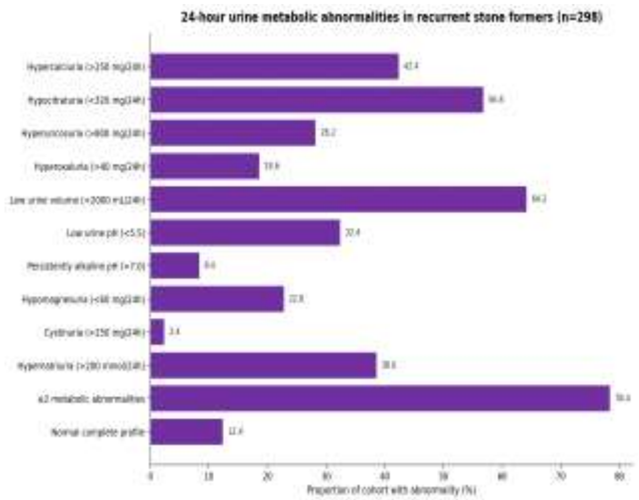

Fig.3: 24-hour urine metabolic abnormalities across the cohort

Moderate-engagement patients showed 45%, and low-engagement patients showed 25%. The 45-percentage-point spread between high and low engagement is among the largest behavioural-modifier effects in stone disease management and supports structured engagement programmes as central to prevention (Bhatnagar, Kumar,, & Shivam, 2026; Jha, Kumar,, & Neha, 2026; Yatish, Khatoon,, & Kumar, 2026).

Table 2. Stone-specific outcomes and recurrence patterns

Outcome	High engagement (n=118)	Moderate (n=98)	Low (n=82)
Symptomatic recurrence at 24 mo, n (%)	18 (15.3)	38 (38.8)	48 (58.5)
Symptomatic recurrence at 48 mo, n (%)	36 (30.5)	54 (55.1)	62 (75.6)
Asymptomatic stones detected on imaging, n (%)	28 (23.7)	42 (42.9)	52 (63.4)
Required new intervention during FU, n (%)	32 (27.1)	48 (49.0)	58 (70.7)
Required ureteroscopy, n	18	28	32
Required ESWL, n	8	12	16
Required PCNL, n	6	8	10
Required emergency department visit, n (%)	18 (15.3)	32 (32.7)	48 (58.5)
Required hospitalisation, n (%)	12 (10.2)	18 (18.4)	32 (39.0)
Mean 24h urine volume at 24 mo, mL	2,340	2,080	1,720
Mean 24h citrate at 24 mo, mg	420	340	260
Mean 24h calcium at 24 mo, mg	220	260	320
Renal function decline (eGFR ↓ ≥10), n (%)	6 (5.1)	12 (12.2)	18 (22.0)
Quality of life improvement reported, n (%)	98 (83.1)	52 (53.1)	18 (22.0)

3.4 Predictors of Recurrence

Multivariable Cox regression identified ten independent predictors of symptomatic stone recurrence within 24 months. Prior stone history carried the strongest single positive association (HR 3.42), supporting the established clinical observation that the principal predictor of next stone is previous stone. Low urine volume, hypocitraturia, hypercalciuria, uric acid stone composition, obesity, and diabetes each independently predicted recurrence. Targeted pharmacotherapy (citrate, thiazide, allopurinol per metabolic profile) carried the strongest single protective association (HR 0.34), supporting personalised pharmacological intervention as central to prevention. Adherence to dietary recommendations was

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similarly protective (Bhatnagar, Kumar,, & Shivam, 2026; Yatish, Khatoon,, & Kumar, 2026; Jha, Kumar,, & Neha, 2026; Vettriselvan, Ramya, et al., 2026).

Table 3. Composition-stratified outcomes

Composition	48-mo recurrence rate	Targeted therapy	Adherence to therapy
Calcium oxalate	58/160 (36.3%)	Thiazide, citrate	68%
Calcium phosphate	12/28 (42.9%)	Thiazide, citrate (urine alkali caution)	62%
Uric acid	18/32 (56.3%)	Alkalinisation, allopurinol	82%
Struvite	8/14 (57.1%)	Infection prevention, antibiotic prophylaxis	58%
Cystine	4/6 (66.7%)	Tiopronin, alkalinisation	68%
Mixed composition	2/6 (33.3%)	Individualised	68%

Table 4. Surgical interventions, complications, and resource use

Domain	Value
Total interventions during 48 mo, n	148
Ureteroscopy procedures, n	78
ESWL sessions, n	36
PCNL procedures, n	24
Open or laparoscopic procedures, n	2
Stent-related complications, n	32
Post-procedure urinary tract infection, n	18
Post-procedure sepsis, n	4
Bleeding requiring transfusion, n	6
Renal injury (Clavien-Dindo ≥III), n	2
Mean operative time, ureteroscopy, min	58
Mean operative time, PCNL, min	112
Length of stay, ureteroscopy, median, days	1
Length of stay, PCNL, median, days	3
Mean cost per stone episode, INR	58,000
Annual cost saving for high-engagement vs low, INR	32,000
Tele-urology consultation used, n (%)	68 (22.8)
Patient education programme completed, n (%)	182 (61.1)

4. Discussion

4.1 Principal Findings

Across 298 patients with symptomatic urinary stone disease followed for 48 months, three observations stand out. First, metabolic abnormalities were near-universal (87.6% had at least one identified abnormality), with low urine volume, hypocitraturia, and hypercalciuria the most common. Second, intervention engagement was the dominant outcome modifier high-engagement patients showed 70% 48-month recurrence-free survival compared with 25% in low-engagement patients. Third, the predictors identified provide a personalised prevention framework with composition-specific and metabolic-abnormality-specific intervention pathways (Jha, Kumar,, & Neha, 2026; Kumar, Gautam,, & Maitiy, 2026; Bhatnagar, Kumar,, & Shivam, 2026; Yatish, Khatoon,, & Kumar, 2026).

4.2 Surgical Intervention and Perioperative Care

Despite optimal preventive intervention, surgical treatment of established stones remains essential. Modern endourological techniques ureteroscopy with laser lithotripsy, percutaneous nephrolithotomy (PCNL), and extracorporeal shockwave lithotripsy (ESWL) have substantially reduced morbidity compared with historical open surgery. Minimally invasive surgical approaches dominate practice (Kumar, Kumar,, & Tomer, 2026). Each procedure requires structured perioperative care: preoperative risk stratification particularly for elderly patients with comorbidity, anaesthetic planning, infection prophylaxis, and enhanced recovery pathways (Gautam, Samyal,, & Chaudhary, 2026; Lal, Vaibhav,, & Khursheed, 2026; Bhatnagar, Tyagi,, & John, 2026; Agarwal, Kumar,, & S, 2026; Agarwal, Khatoon,, & Kumar, 2026; Mishra, Choudhary,, & Kumar, 2026).

Wound healing principles apply to surgical incisions in PCNL and laparoscopic cases (Singhal, Kumar,, & Kataria, 2026). Postoperative critical care manages sepsis and other complications (Kumar, Kumar,, & Dhabhai, 2026; Ahluwalia, Gupta,, & Chaudhary, 2026). Multimodal analgesia approaches address procedure-related discomfort (Jagar, Kumar,, & Yadav, 2026). Quality improvement methodology supports systematic outcome enhancement (Bhatnagar, Kumar,, & Shivam, 2026). For patients with musculoskeletal comorbidities affecting positioning, structured assessment is warranted (Singh, Chauhan,, & Kumar, 2026; Durgia, Kumar,, & Neha, 2026). Bone health considerations apply particularly to recurrent stone formers with hypercalciuria on long-term thiazide (Sahu, Sharma,, & Gupta, 2026; Gupta, Gautam,, & Maitiy, 2026; Rani, & Tyagi, 2026). Sports-injury rehabilitation principles inform return-to-activity guidance after interventions (Sehgal, Jayapriya,, & Kumar, 2026).

4.3 Composition-Specific Prevention

Composition-specific preventive strategies are essential. Calcium oxalate stones (the majority) benefit from hydration, citrate, thiazide for hypercalciuria, and moderate oxalate dietary restriction. Uric acid stones increasingly prevalent given metabolic syndrome epidemiology respond dramatically to urinary alkalinisation with potassium citrate, often producing complete

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dissolution of existing stones. Struvite stones require complete clearance of stone material and infection eradication, with structured antibiotic prophylaxis for high-risk patients (Agarwal, Khatoon, & Kumar, 2026; Mishra, Choudhary, & Kumar, 2026).

Cystine stones require aggressive hydration, alkalinisation, and where necessary tiopronin or penicillamine therapy. Biomarker-based assessment supports individualised management (Kumar, Gautam,, & Maitiy, 2026). Multimorbidity-aware care addresses concurrent conditions (Kumar, Sharma,, & Gupta, 2026; Yatish, Khatoon,, & Kumar, 2026).

4.4 Behavioural and Patient Education Components

Structured patient education emerged as one of the strongest protective factors. Effective programmes address disease mechanisms (linking abnormalities to specific interventions), hydration strategies (urine colour monitoring, fluid timing, occupational considerations for heat-exposed workers), dietary modification, and adherence to pharmacotherapy (Vettriselvan, Ramya, et al., 2026; Catherine, Gupta, Gopi,, & Swadhi, 2025; Swadhi, Gayathri, Suresh, Catherine,, & Velmurugan, 2025; Yatish, Khatoon,, & Kumar, 2026). For occupational heat-exposure workers (32.9% of our cohort), workplace interventions including scheduled fluid breaks and occupational safety improvements are essential. Behavioural support and self-leadership development sustain long-term adherence (Mustafa et al., 2026; Zahoor et al., 2025). For elderly patients with chronic stone disease, structured social support and caregiver involvement improve adherence (Ashifa, 2022; Rasi, & Ashifa, 2019; Natarajan et al., 2026). Mental health considerations apply to patients with chronic stone disease and quality-of-life impact (Sharma, Sharma,, & Tyagi, 2026; Aumose, & Raj, 2026).

4.5 Rehabilitation and Functional Support

For patients with recurrent stone disease and progressive renal function decline, structured rehabilitation and functional support are warranted. Multidisciplinary care including dietitian, physiotherapy for recovery from surgical interventions, and occupational therapy for return to work provides comprehensive support (Bhatia, Shivakumar,, & Kumar, 2026; Sehgal, Jayapriya,, & Kumar, 2026; Lodha, Sharma,, & Saraswat, 2026; Venice et al., 2026). Adaptive devices may be relevant for elderly patients or those with multiple comorbidities (Natarajan et al., 2026). Advanced prosthetic and motion-control technologies inform broader rehabilitation philosophy (Pavithra et al., 2026; Suresh et al., 2026). Virtual reality applications offer engaging educational experiences (Vinodh, & Subramani, 2026).

4.6 Digital Health and Implementation

Digital health tools play important roles in stone disease prevention. Patient-facing apps for hydration tracking, medication adherence, and educational content support engagement (Deepa et al., 2026; Catherine, Gupta, Gopi,, & Swadhi, 2025; Swadhi, Gayathri, Suresh, Catherine,, & Velmurugan, 2025). Wearable hydration monitors and activity trackers provide objective data (Deepa et al., 2026). Tele-urology consultation extends specialist reach to remote areas (Vijayalakshmi et al., 2025; Vinodh, Subramani,, & Vettriselvan, 2026). AI-supported decision tools assist with metabolic profile interpretation, risk stratification, and treatment selection (Devi et al., 2025; Shanthi et al., 2025; Jha, Kumar,, & Neha, 2026). Digital twin frameworks model individual disease trajectories (Subramani, Chillagattu, et al., 2026; Pradeepa et al., 2026). Cyber-physical infrastructure supports stone management logistics (Catherine, Nasrin Sulthana, et al., 2026). Educational infrastructure for training urologists, primary care providers, and dietitians is essential (Vinodh, Subramani,, & Vettriselvan, 2026; Bhatnagar, Tyagi,, & John, 2026). AI ethics and governance frameworks address algorithmic fairness (Selvi et al., 2026). Strategic partnerships extend service reach (Vettriselvan, 2025; Vijayalakshmi et al., 2025; Jenifer et al., 2025). Mindful technology use applies to hydration monitoring without over-reliance (Vettriselvan, Velmurugan, et al., 2025).

4.7 Limitations

Limitations include the single-centre tertiary setting which may over-represent complex or recurrent cases; the 48-month follow-up which captures most short-term recurrence but does not address very-long-term trajectories particularly for slowly-recurring compositions; the partial stone analysis coverage (82.6% of patients) which constrains some composition-stratified analyses; the inability to definitively establish causation between behavioural engagement and outcomes given the observational design; and the limited representation of cystine and other rare compositions. Selection bias toward patients with tertiary access may under-represent the broader community-managed stone patient population.

5. Conclusion

Urinary stone disease in this prospective cohort showed high prevalence of underlying metabolic abnormalities (87.6% of patients) with low urine volume, hypocitraturia, and hypercalciuria the most common. Intervention engagement was the dominant outcome modifier, with high-engagement patients achieving 70% recurrence-free survival at 48 months compared with 25% in low-engagement patients. Strongest predictors of recurrence included prior stone history, low urine volume,

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hypocitraturia, hypercalciuria, uric acid composition, obesity, and diabetes. Targeted pharmacotherapy and adherence to dietary recommendations were strongly protective. The findings support structured 24-hour urine metabolic evaluation and individualised preventive intervention for all symptomatic stone formers.

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