

Establishing Stone Composition From Pure Dust: Feasibility and Diagnostic Yield of FTIR Spectroscopy During Suction-Assisted Flexible Ureteroscopy

Sarwar Mahmood

College of Medicine, University of Sulaymaniyah

Ahmed Noori

ahmednoorichalabi@gmail.com

College of Medicine, University of Sulaymaniyah

Arya Noori

College of Medicine, University of Sulaymaniyah

Hanisk Othman

Research Institute, Mercy Medical City, Sulaymaniyah, Iraq

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Abstract

The shift toward dust-only flexible ureteroscopy (FURS) prevents routine metabolic stone analysis due to a lack of retrievable fragments. We evaluated the technical success, diagnostic yield, and composition profile of Fourier-transform infrared (FTIR) spectroscopy performed on stone dust collected via flexible navigable suction access sheaths (FANS). This retrospective single-center study included 109 patients undergoing FURS with FANS for upper tract stone disease. The surgeon aspirated the stone dust slurry into a container. Then, the fluid samples collected were sent to the lab to be centrifuged, washed with distilled water to remove any blood/protein artifacts, air-dried, and analyzed using FTIR spectroscopy. Dust aspiration reached a 100% diagnostic yield (109/109 cases), with all samples giving an accurate FTIR reading. Calcium-based stones were the most common (64.2%, n = 70), consisting of Calcium Oxalate Monohydrate (51.4%, n = 56) and Calcium Oxalate Dihydrate (12.8%, n = 14). Uric Acid was identified in 26 cases (23.9%), followed by Carbonate-Apatite (6.4%, n = 7), Cystine (3.7%, n = 4), and Struvite (1.8%, n = 2). There was a strong relation between pre-operative CT density and the primary dust component ($p < 0.001$), with Uric Acid stones displaying significantly lower density (611.8 ± 263.2 HU) than Calcium Oxalate Monohydrate (1146.7 ± 335.7 HU). Aspirating stone dust during FURS provides an excellent sample for FTIR spectroscopy, challenging the assumption that dust-only lithotripsy is inadequate for stone analysis and allowing universal stone analysis without the need for a physical fragment.

Introduction

Urolithiasis remains one of the most common issues affecting the upper urinary tract globally, presenting a major healthcare burden due to high recurrence rates and surgical intervention costs (1). Over recent years, flexible ureteroscopy (FURS)—also known as retrograde intrarenal surgery (RIRS)—has shown to be an excellent surgical option for kidney stone management, offering high efficacy with a notable safety profile compared to more invasive percutaneous approaches (2). To improve operative efficiency, more endourologists are starting to favor stone dusting techniques, which use high-frequency lasers to pulverize stones into micro-particles intended for spontaneous passage or active clearance, thereby reducing the need for repetitive basket extraction (3). In addition, the adoption of flexible navigable suction ureteral access sheaths (FANS) has improved FURS by enabling real-time intraoperative aspiration of fine stone dust slurry under controlled intrarenal pressures (4).

Knowing the exact biochemical composition of urinary stones is universally recommended in clinical guidelines, as identifying the predominant stone type is valuable for directing targeted metabolic evaluation and preventing stone recurrence (5). However, the widespread shift toward dust-only procedures creates a significant diagnostic challenge. Since solid stone fragments are rarely retrieved during dusting, clinicians are often left without physical stone fragments to send for standard laboratory analysis (6). Nowadays, FTIR spectroscopy is the standard lab tool for stone analysis, but we still need to evaluate whether analyzing only the stone dust collected with suction sheaths is possible, practical, and reliable in everyday clinical practice (3, 6).

Therefore, the objective of this study was to evaluate the technical success, sample yield, and composition profile of FTIR spectroscopy performed directly on urinary stone dust collected via FANS during FURS in a single-center cohort.

Methods

Study Population & Design

This single-center study included 109 patients who underwent (FURS) for renal or ureteral stone disease. To avoid selection bias, this cohort represents every consecutive patient during the study period whose stone dust we submitted for FTIR analysis, with no exclusions based on sample volume or dust quality. Patient demographics, pre-operative non-contrast computed tomography (NCCT) parameters (maximum stone diameter and Hounsfield unit density), and intraoperative details were retrieved from institutional electronic medical records.

This study was conducted in accordance with the declaration of Helsinki 2024. All steps to be conducted were thoroughly explained to the Mercy Medical City Hospital directorate, and approval was obtained by the local institute ethical committee (Sulaymaniyah Committee of Clinical Sciences) (July 13th 2026 Meeting) to access records and laboratory archives and to publish with anonymity of patient records. Verbal consent was received by all participants in this study after thorough explanation of the research to publish their results and data. This research was not funded by any organization, agency, or business.

Surgical Technique & Dust Collection

All surgical procedures were performed by a single experienced endourologist using a standardized flexible ureteroscopy technique combined with a flexible navigable suction ureteral access sheath. Once intrarenal access was established, thulium fiber laser lithotripsy was used in dusting mode to pulverize the stone. During laser application, the stone dust slurry was continuously aspirated through the designated suction port of the access sheath into a closed collector container without interrupting irrigation dynamics.

FTIR Laboratory Protocol

FTIR Laboratory Protocol

Notably, our institution represents one of the few tertiary centers in Iraq equipped with an operational FTIR spectrometer, providing a unique facility for direct stone dust analysis. Aspirated stone dust fluid samples (10–20 mL) were immediately taken to the laboratory and centrifuged at 12,000 rpm for 30 minutes to isolate nonorganic urinary sediments, after which the supernatant was discarded. To prevent blood or protein contamination, the harvested sediment was washed with distilled water and re-centrifuged. The cleaned sediment was then incubated at 37°C for 24–48 hours until thoroughly dried.

Once fully dry, the sample was finely grounded, mixed with potassium bromide (KBr), and analyzed using an FTIR spectrometer (Alpha, Bruker Optik GmbH) (Fig. 1). Measured infrared absorption spectra (400–4000 cm⁻¹) were automatically cross-referenced against a validated reference library to establish primary, secondary, and trace mineral components (1, 6).

Statistical Analysis

Data were analyzed using IBM SPSS Statistics. Continuous variables, such as age, stone diameter, and CT density in Hounsfield units, are shown as means ± standard deviation (SD). Variables that are categorical, such as sex, suction yield success rate, and identified stone composition types, are shown as frequencies and percentages (N, %).

Results

Patient Demographics & Clinical Profiles

A total of 109 consecutive patients who underwent FURS with navigable suction access sheath dust aspiration were included in the final analysis. The mean age was 47.6 ± 16.1 years (range: 3–75 years), with a male predominance (n = 70, 64.2%). Regarding clinical history and comorbidities, 22 patients (20.2%) had diabetes mellitus, 30 (27.5%) had hypertension, and 67 (61.5%) had a history of prior surgical stone intervention. The demographics and clinical characteristics of the patients are summarized in Table 1.

Table 1
Patient Demographics & Clinical Characteristics (N = 109)

Parameter	Value
Age (years), mean ± SD	47.6 ± 16.1
Sex, n (%)	
• Male	70 (64.2%)
• Female	39 (35.8%)
Comorbidities, n (%)	
• Diabetes Mellitus	22 (20.2%)
• Hypertension	30 (27.5%)
History of Prior Stone Surgery, n (%)	67 (61.5%)

Pre-Operative CT Stone Parameters

Pre-operative NCCT showed a mean maximum stone diameter of 18.9 ± 15.0 mm (median: 14.5 mm) and a mean overall stone density of 995.5 ± 372.3 Hounsfield Units (HU). Solitary stones were present in 57 cases (52.3%), while 51 cases (46.8%) had with multiple. Pre-operative CT parameters and stone characteristics are demonstrated in Table 2.

Table 2
Pre-Operative Non-Contrast CT Stone Parameters (N = 109)

Parameter	Value
Max Stone Diameter (mm), mean $\pm$ SD	18.9 ± 15.0
Median Stone Diameter (mm)	14.5
Mean CT Density (HU), mean $\pm$ SD	995.5 ± 372.3
Stone Multiplicity, n (%)	
• Solitary Stone	57 (52.3%)
• Multiple Stones	51 (46.8%)

FTIR Dust Yield & Compositions

Intraoperative dust collection using the flexible navigable suction access sheath achieved a 100% diagnostic yield (109/109 cases), with all aspirated samples giving an interpretable FTIR composition result. Calcium-based stones made up 64.2% (n = 70) of all primary stone compositions, predominantly consisting of Calcium Oxalate Monohydrate (COM; n = 56, 51.4%) and Calcium Oxalate Dihydrate (COD; n = 14, 12.8%). Uric acid was the second most frequent primary stone type, identified in 26 cases (23.9%). Less common primary compositions included Carbonate-Apatite (n = 7, 6.4%), Cystine (n = 4, 3.7%), and Struvite (n = 2, 1.8%). Secondary mineral compositions were identified in 50 cases (45.9%).

Notably, a statistically significant correlation was seen between pre-operative NCCT density and the primary stone component identified on dust FTIR ($p < 0.001$). Stones classified as Uric Acid demonstrated significantly lower attenuation values (611.8 ± 263.2 HU) compared to Calcium Oxalate Monohydrate stones (1146.7 ± 335.7 HU; $t = 6.92$, $p < 0.001$). The diagnostic yield, FTIR primary stone composition, and corresponding CT attenuation values for each stone type are shown in Table 3.

Table 3
FTIR Stone Dust Composition & Pre-Operative CT Density Correlation (N = 109)

Primary Stone Component	N(%)	Mean CT Density (HU ± SD)
Calcium Oxalate Monohydrate (COM)	56 (51.4%)	1146.7 ± 335.7
Uric Acid	26 (23.9%)	611.8 ± 263.2
Calcium Oxalate Dihydrate (COD)	14 (12.8%)	1079.7 ± 284.0
Carbonate-Apatite	7 (6.4%)	1091.4 ± 222.7
Cystine	4 (3.7%)	733.3 ± 152.8
Struvite (MAPH)	2 (1.8%)	912.0 ± 407.3
Total Diagnostic Yield	109 (100%)	—

(MAPH = Magnesium Ammonium Phosphate Hexahydrate)

Discussion

In modern endourology, laser dusting during FURS has gained a lot of popularity due to significantly shorter operative times, lower equipment costs, and reduced chance of physical trauma compared to active basket extraction (7). However, as shown in comparative surgical trials, pure dusting creates a major clinical dilemma. Since physical stone fragments are not extracted, clinicians are frequently unable to submit the stone for metabolic analysis (8). Our study has showed that intraoperative aspiration of stone dust slurry using a FANS achieves a 100% diagnostic yield (109/109 cases) for FTIR spectroscopy (4, 6). This approach allows urologists to perform dust-only procedures without losing the chance for post-operative metabolic evaluation of the stone (9).

Achieving a 100% diagnostic yield in our 109-patient cohort represents a notable technical advancement over earlier stone dust literature (10). In the matched-pair study by Ray et al., stone dust aspirated via a 20 mL syringe yielded sufficient material for FTIR in only 68% of cases, with an overall biochemical match rate of 74% (10). Similarly, Snicorius et al. reported a 90.7% sample sufficiency rate and an 82.4% full agreement rate between dust and retrieved fragments (6). The perfect yield in our study can be attributed to the hydrodynamic advantages of modern navigable suction sheaths, which maintain low intrarenal pressures while providing continuous vacuum aspiration during laser lithotripsy (11). Aspirating sediment directly where the laser works prevents stone dust from dispersing into irrigation fluid or adhering to the renal tissue (9, 11). Furthermore, our laboratory protocol of centrifuging at 12,000 rpm and washing sediments with distilled water helped remove any blood and protein artifacts, which previously compromised stone interpretation (6, 10).

The stone compositions in our cohort, predominantly Calcium Oxalate Monohydrate (51.4%) followed by Uric Acid (23.9%), helps support clinical and metabolic characteristics of our population (12). The high prevalence of Uric Acid stones (23.9%) correlates with the metabolic burden of our cohort, in which

20.2% of patients presented with Diabetes Mellitus and 27.5% with Hypertension (12, 13). Type 2 diabetes and metabolic syndrome induce renal insulin resistance, which impairs tubular ammoniogenesis and leads to acidic urinary pH—the main driver of uric acid stone crystallization (12). Furthermore, 61.5% of our patients had a history of prior stone intervention, noting that our cohort consisted of high-risk, recurrent stone formers (5). Because non-calcium oxalate stone formers face a much higher 5-year surgical recurrence rates and progressive renal impairment, knowing an accurate composition from lasered dust is vital to initiating chemoprevention and protecting long-term renal function (14).

A key finding of our study is the significant correlation seen between pre-operative CT density (Hounsfield Units) and the primary stone component identified on dust FTIR ($p < 0.001$). Uric Acid stones demonstrated a mean attenuation of 611.8 ± 263.2 HU, which was markedly lower than Calcium Oxalate Monohydrate stones (1146.7 ± 335.7 HU) (15). Non-contrast CT Hounsfield unit density has been established as a reliable predictor of calcium versus non-calcium stone subtypes in vivo (15, 16). While our study lacked paired solid stone fragment controls, a reflection of real-world dust-only surgical practice, this relation provides strong internal validation, confirming that lasered dust accurately reflects the real composition of the stone (6, 15).

This study has many strengths, including a well-characterized cohort of 109 consecutive patients, a standardized single-surgeon surgical technique utilizing navigable suction access sheaths, and a 100% analytical yield (4, 6). Nevertheless, certain limitations should be acknowledged. First, the retrospective, single-center design is prone to inherent selection bias (6). Second, while our findings demonstrate technical feasibility and internal consistency with CT attenuation, long-term clinical follow-up is necessary to evaluate whether dust-guided metabolic therapy alters recurrence rates (5, 13). Overall, our results indicate that intraoperative aspiration of stone dust via flexible navigable suction access sheaths is a highly feasible, reliable, and practical technique, enabling universal stone composition analysis in the modern era of dust-only endourology (6, 9).

Conclusion

Suction-assisted stone dust aspiration during flexible ureteroscopy provides a practical, high-yield method for FTIR spectroscopy without requiring physical fragment retrieval. This technique leads to a more efficient surgical procedure while still ensuring precise stone composition analysis for long-term secondary prevention.

Declarations

Affiliation

This research was not supported or affiliated with any agencies.

Conflicting Interests

The authors stated that they had no interests posing a conflict or bias.

Ethical Approval

Ethical approval was granted by the local institute ethical committee. Consent was provided verbally by all cohorts involved.

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Author Contribution

First Author: Sarwar Noori Mahmood Contribution: Surgeon for every procedure, Conceptualization, Supervision. Second Author: (Corresponding Author) Ahmed Sarwar Noori Contribution: Data Collection, Complete Manuscript Draft Writing and Editing, Data Analysis Manuscript Review, Table Creator. Third Author: Arya Sarwar Noori Contribution: Data Collection, Plagiarism Check, AI Check, Grammar Check, Data Analysis, Reference Check. Fourth Author: Hanisk Mohammed Othman Contribution: Data Collection

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Availability of Data and Materials

The datasets analyzed during the current study are not publicly available due to patient privacy and institutional confidentiality but are available from the corresponding author on reasonable request.

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Figures



A

B

C

Figure 1

Workflow of FTIR stone dust processing, showing the intraoperative dust aspirate (**A**), the washed and dried sediment (**B**), and the final sample disc prepared for FTIR spectroscopic analysis (**C**).