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ASSOCIATION BETWEEN METABOLIC SYNDROME AND STONE-FREE OUTCOMES FOLLOWING EXTRACORPOREAL SHOCK WAVE LITHOTRIPSY FOR UPPER URINARY TRACT STONES: A RETROSPECTIVE STUDY

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Abstract: Background: Metabolic syndrome (MetS) is associated with urinary stone disease, but its relationship with treatment outcomes following extracorporeal shock wave lithotripsy (ESWL) remains incompletely understood. This study investigated the association between MetS and stone-free outcomes in patients undergoing ESWL for upper urinary tract stones. Methods: This retrospective observational study analyzed 991 patients with upper urinary tract stones, including 256 patients with MetS and 735 without MetS. The primary outcome was stone-free status, and the secondary outcome was retreatment. Logistic regression analyses were performed to examine associations between MetS and treatment outcomes. Three sequential models were constructed: an unadjusted model, a model adjusted for age and gender, and a fully adjusted model additionally incorporating stone size, stone location, and hydronephrosis. Results: The overall stone-free rate was 65.2% (646/991). Patients with MetS had a lower stone-free rate than those without MetS (60.2% vs. 66.9%; continuity-corrected chi-square P = 0.059). In the unadjusted logistic regression model, the odds ratio (OR) for stone-free status was 0.746 (95% confidence interval [CI]: 0.556–1.000; P = 0.0502). After adjustment for age, gender, stone size, stone location, and hydronephrosis, MetS was associated with lower odds of stone-free status (adjusted OR = 0.671, 95% CI: 0.484–0.930; P = 0.0166). Larger stone size was associated with lower odds of stone-free status (OR per mm = 0.816, 95% CI: 0.784–0.849; P < 0.001). Moderate hydronephrosis was also associated with lower odds of stone-free status (OR = 0.565, 95% CI: 0.381–0.837; P = 0.0045). MetS was not significantly associated with retreatment (adjusted OR = 1.108, 95% CI: 0.787–1.562; P = 0.557). Conclusions: MetS was associated with lower odds of stone-free status following ESWL after adjustment for demographic and stone-related factors, whereas no statistically significant association with retreatment was observed. These findings suggest that metabolic status may provide additional information when evaluating ESWL outcomes. Further studies incorporating stone density, skin-to-stone distance, and detailed metabolic characteristics are warranted.
Keywords: Metabolic syndrome; Extracorporeal shock wave lithotripsy; Urolithiasis; Stone-free rate; Retreatment; Retrospective study

1 INTRODUCTION

Urolithiasis is a common urological condition associated with considerable clinical and healthcare burdens worldwide. The prevalence of urinary stone disease varies across geographic regions and has increased alongside changes in environmental, dietary, and metabolic risk factors [1, 2]. Effective management requires consideration of stone characteristics, patient-related factors, and the relative benefits of available treatment approaches.

Extracorporeal shock wave lithotripsy (ESWL) remains an established minimally invasive treatment option for appropriately selected renal and ureteral stones. Nevertheless, treatment outcomes vary considerably, and residual fragments or additional interventions may occur. Contemporary European Association of Urology (EAU) guidelines and American Urological Association (AUA) recommendations emphasize individualized treatment selection based on stone size, anatomical location, patient characteristics, and other factors influencing procedural success [3-5].

Metabolic syndrome (MetS) is characterized by a clustering of metabolic abnormalities, including obesity, impaired glucose regulation, hypertension, and dyslipidemia. A systematic review and meta-analysis demonstrated an association between MetS and kidney stone disease [6]. Population-based research has also reported increasing kidney stone prevalence with the accumulation of metabolic abnormalities [7].

Several mechanisms may contribute to the association between MetS and urinary stone formation. Insulin resistance and impaired renal ammonium excretion may reduce urinary pH, favoring uric acid crystallization and stone formation [8-10]. However, the mechanisms underlying stone formation do not necessarily correspond to those determining successful treatment.

The effectiveness of ESWL depends on both stone fragmentation and subsequent fragment clearance. Previous investigations have identified stone size, anatomical location, hydronephrosis, stone attenuation, and patient-related characteristics as relevant predictors of ESWL outcomes [11-15]. Skin-to-stone distance (SSD) and computed

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tomography attenuation have also been investigated, although their associations with treatment success vary across clinical settings [16-19].
Patients with MetS may have characteristics that exert competing influences on ESWL outcomes. A greater tendency toward uric acid stone formation could be associated with favorable fragmentation characteristics in selected patients. Conversely, increased body habitus and associated anatomical or technical factors may adversely affect shock wave delivery or stone targeting. Consequently, the overall association between MetS and postoperative stone clearance cannot be inferred from stone composition or obesity alone.
Although numerous studies have evaluated conventional predictors of ESWL success, the association between MetS as a composite metabolic condition and treatment outcomes warrants further investigation.
Therefore, the present study aimed to evaluate the association between MetS and stone-free status following ESWL in patients with upper urinary tract stones. A secondary objective was to investigate its association with retreatment, while accounting for demographic and established stone-related characteristics.

2 MATERIALS AND METHODS

2.1 Study Design and Population

This single-center retrospective observational study was conducted at the Second Affiliated Hospital of Guilin Medical University, Guilin, Guangxi, China. The study included 991 patients who underwent extracorporeal shock wave lithotripsy (ESWL) for upper urinary tract stones between July 2023 and October 2026. Of these, 735 patients were classified as having no metabolic syndrome (non-MetS), and 256 were classified as having metabolic syndrome (MetS).

2.2 Definition of Metabolic Syndrome

Metabolic syndrome (MetS) was classified using the Chinese Diabetes Society criteria presented in the Chinese guideline for the prevention and treatment of type 2 diabetes mellitus (2017 edition), selected because they include Chinese-specific cutoffs for abdominal obesity [20]. Patients meeting three or more of the five components were categorized as having MetS.
The five components were: (1) abdominal obesity (waist circumference ≥90 cm in men or ≥85 cm in women); (2) dysglycemia (fasting plasma glucose ≥6.1 mmol/L, 2-hour post-load glucose ≥7.8 mmol/L, or previously diagnosed diabetes under treatment); (3) elevated blood pressure (≥130/85 mmHg or established hypertension under treatment); (4) fasting triglycerides ≥1.70 mmol/L; and (5) fasting HDL cholesterol <1.04 mmol/L.

2.3 Clinical and Stone Characteristics

Demographic and clinical variables included age, gender, and body mass index (BMI).
Stone-related variables included stone size, anatomical location, and hydronephrosis grade.
Stone size was expressed in millimeters and treated as a continuous variable in the regression models.
Stone location was categorized as renal pelvis, upper calyx, middle calyx, lower calyx, or proximal ureter. Lower calyx was used as the reference category in the multivariable analyses.
Hydronephrosis was classified as none, mild, moderate, or severe. Absence of hydronephrosis was used as the reference category.
BMI was summarized descriptively but was not included in the prespecified primary adjusted model. The CDS 2017 five-component MetS definition uses waist circumference, rather than BMI, to define abdominal obesity. Additional adjustment for body habitus would require a clearly stated analytical purpose and a separately planned sensitivity analysis.

2.4 ESWL Procedure and Outcome Assessment

ESWL was performed according to the institutional treatment protocol in place at the time of each procedure. A Mindray ultrasound system was used for stone localization. The procedures are discussed in light of the Chinese Clinical Practice Guidelines for Extracorporeal Shock Wave Lithotripsy published in 2025 [21]; procedures performed before publication of those guidelines cannot be described as having followed them prospectively.
Post-treatment ultrasonography was scheduled at approximately 1 week, 2 weeks, and 1 month after the index ESWL session. The primary outcome was stone-free status on the 1-month ultrasound assessment, defined as no sonographically detectable residual calculi; patients with detected residual stones were categorized as non-stone-free.
Retreatment was defined as at least one additional ESWL session after the index treatment during 1 month. Patients were counted once for the binary retreatment endpoint, irrespective of the number of additional ESWL sessions.

2.5 Statistical Analysis

Statistical analyses were performed using R version 4.5.3.
Continuous variables are presented as mean ± standard deviation (SD), and categorical variables as number (percentage).

Between-group comparisons were conducted using statistical tests appropriate to the distributions and types of variables. For the unadjusted comparison of stone-free status and retreatment, Pearson's chi-square test with Yates' continuity correction was used.
Binary logistic regression analyses were performed to investigate associations between MetS and stone-free status.
Three models were established:
Model 1: Unadjusted model.
Model 2: Adjusted for age and gender.
Model 3: Adjusted for age, gender, stone size, stone location, and hydronephrosis grade.
A separate multivariable logistic regression model incorporating the same covariates was fitted for retreatment.
The dependent variable was coded as 1 for the occurrence of each respective outcome and 0 otherwise. Non-MetS was used as the reference group.
Results were expressed as odds ratios (ORs) and 95% confidence intervals (CIs). Two-sided P values below 0.05 were considered statistically significant.
Reporting was guided by the STROBE recommendations for observational studies [22].

3 RESULTS

3.1 Baseline Characteristics

The study included 991 patients with upper urinary tract stones, including 735 (74.2%) without MetS and 256 (25.8%) with MetS.
The MetS group had a higher mean age than the non-MetS group (54.8 ± 12.2 vs. 49.8 ± 11.7 years). Mean BMI was also higher in the MetS group (27.3 ± 2.6 vs. 24.4 ± 2.6 kg/m²).
The proportion of male patients was similar between the groups, with 149 (58.2%) in the MetS group and 438 (59.6%) in the non-MetS group.
Mean stone size was 11.7 ± 3.9 mm in both groups. Lower calyx stones accounted for 19.1% of the MetS group and 21.8% of the non-MetS group.
Moderate or severe hydronephrosis was present in 49 (19.1%) patients with MetS and 185 (25.2%) patients without MetS.
The baseline characteristics are presented in Table 1.

Table 1 Selected Baseline Characteristics According to Metabolic Syndrome Status

Characteristic	Non-MetS (n = 735)	MetS (n = 256)
Age, years	49.8 ± 11.7	54.8 ± 12.2
Male gender, n (%)	438 (59.6)	149 (58.2)
BMI, kg/m²	24.4 ± 2.6	27.3 ± 2.6
Stone size, mm	11.7 ± 3.9	11.7 ± 3.9
Lower calyx stones, n (%)	160 (21.8)	49 (19.1)
Moderate/severe hydronephrosis, n (%)	185 (25.2)	49 (19.1)

Note: Data are presented as mean ± SD or n (%). MetS, metabolic syndrome; SD, standard deviation.

3.2 Stone-Free and Retreatment Outcomes

Among the 991 patients, 646 (65.2%) achieved stone-free status, whereas 345 (34.8%) had residual stones.
The stone-free rate was 66.9% (492/735) in the non-MetS group and 60.2% (154/256) in the MetS group, an absolute difference of approximately 6.8 percentage points (MetS minus non-MetS: −6.8 percentage points).
The difference did not reach the conventional statistical significance threshold using the continuity-corrected chi-square test (P = 0.0593).
A total of 251 patients (25.3%) underwent retreatment. Retreatment occurred in 183 (24.9%) patients without MetS and 68 (26.6%) patients with MetS, with no significant between-group difference (P = 0.6571), see Table 2.

Table 2 Stone-Free and Retreatment Outcomes According to Metabolic Syndrome Status

Outcome	Non-MetS (n = 735)	MetS (n = 256)	P value
Stone-free, n (%)	492 (66.9)	154 (60.2)	0.0593
Residual stones, n (%)	243 (33.1)	102 (39.8)	—
Retreatment, n (%)	183 (24.9)	68 (26.6)	0.6571

Note: P values were calculated using Pearson's chi-square test with Yates' continuity correction. The residual-stone category is complementary to the stone-free category and was not independently tested.

3.3 Association Between MetS and Stone-Free Status

In the unadjusted logistic regression model, the OR for stone-free status in patients with MetS compared with those without MetS was 0.746 (95% CI: 0.556–1.000; P = 0.0502).
After adjusting for age and gender, the estimated association remained similar (OR = 0.743, 95% CI: 0.551–1.002; P = 0.0516).

In the fully adjusted model, which additionally incorporated stone size, stone location, and hydronephrosis, MetS was associated with lower odds of stone-free status (OR = 0.671, 95% CI: 0.484–0.930; P = 0.0166).
The magnitude of the association increased modestly after adjustment for stone-related characteristics, suggesting that differences in measured covariates influenced the estimated association.
The sequential regression results are presented in Table 3.

Table 3 Association Between Metabolic Syndrome and Stone-Free Status Across Sequentially Adjusted Logistic Regression Models

Model	OR for MetS	95% CI	P value
Model 1: Unadjusted	0.746	0.556–1.000	0.0502
Model 2: Adjusted for age and gender	0.743	0.551–1.002	0.0516
Model 3: Fully adjusted	0.671	0.484–0.930	0.0166

Model 3 was adjusted for age, gender, stone size, stone location, and hydronephrosis. For Model 1, the rounded upper 95% CI limit of 1.000 lies marginally above unity before rounding; P = 0.0502.

3.4 Clinical Factors Associated With Stone-Free Status

In the fully adjusted analysis, larger stone size was strongly associated with lower odds of stone-free status (OR per 1-mm increase = 0.816, 95% CI: 0.784–0.849; P < 0.001).
Using lower calyx stones as the reference category, stone-free odds were higher for middle calyx stones (OR = 1.921, 95% CI: 1.248–2.957; P = 0.0030), proximal ureteral stones (OR = 2.324, 95% CI: 1.354–3.988; P = 0.0022), renal pelvic stones (OR = 2.163, 95% CI: 1.464–3.195; P < 0.001), and upper calyx stones (OR = 2.147, 95% CI: 1.347–3.424; P = 0.0013).
Compared with patients without hydronephrosis, those with moderate hydronephrosis had lower odds of stone-free status (OR = 0.565, 95% CI: 0.381–0.837; P = 0.0045).
Mild and severe hydronephrosis were not statistically significantly associated with stone-free status after multivariable adjustment.
Age and gender were also not statistically significantly associated with the primary outcome.
The complete multivariable estimates are presented in Table 4 and illustrated in Figure 1.

3.5 Factors Associated With Retreatment

In the secondary-outcome model, MetS was not statistically significantly associated with retreatment (adjusted OR = 1.108, 95% CI: 0.787–1.562; P = 0.557).
Larger stone size was associated with increased odds of retreatment (OR per mm = 1.143, 95% CI: 1.101–1.187; P < 0.001).
Compared with patients without hydronephrosis, those with severe hydronephrosis had higher odds of retreatment (OR = 1.955, 95% CI: 1.033–3.701; P = 0.0394). Moderate hydronephrosis showed an elevated point estimate, although the confidence interval included unity (OR = 1.459, 95% CI: 0.972–2.189; P = 0.0682).
No statistically significant associations were identified for age, gender, or anatomical stone location in the fully adjusted retreatment model.

Table 4 Multivariable Logistic Regression Analyses of Stone-Free Status and Retreatment

Variable	Stone-free OR (95% CI)	P value	Retreatment OR (95% CI)	P value
MetS vs. non-MetS	0.671 (0.484–0.930)	0.0166	1.108 (0.787–1.562)	0.557
Age, per year	0.998 (0.986–1.010)	0.749	1.003 (0.990–1.016)	0.646
Male vs. female	0.935 (0.698–1.253)	0.655	0.954 (0.704–1.293)	0.763
Stone size, per mm	0.816 (0.784–0.849)	<0.001	1.143 (1.101–1.187)	<0.001
Stone location				
Lower calyx	Reference	—	Reference	—
Middle calyx	1.921 (1.248–2.957)	0.0030	0.900 (0.567–1.428)	0.655
Proximal ureter	2.324 (1.354–3.988)	0.0022	0.834 (0.473–1.472)	0.532
Renal pelvis	2.163 (1.464–3.195)	<0.001	0.898 (0.595–1.357)	0.611
Upper calyx	2.147 (1.347–3.424)	0.0013	1.169 (0.726–1.882)	0.520
Hydronephrosis				
None	Reference	—	Reference	—
Mild	1.205 (0.865–1.679)	0.269	0.917 (0.647–1.299)	0.624
Moderate	0.565 (0.381–0.837)	0.0045	1.459 (0.972–2.189)	0.0682
Severe	0.687 (0.357–1.322)	0.261	1.955 (1.033–3.701)	0.0394

Note: Both models were adjusted for MetS, age, gender, stone size, stone location, and hydronephrosis. Odds ratios refer to the odds of the outcome named in each column. CI, confidence interval.

3.6 Model Convergence and Outstanding Diagnostics

The fully adjusted stone-free logistic regression model converged successfully after four Fisher scoring iterations.
The model had a null deviance of 1280.9 and a residual deviance of 1118.8, with an Akaike information criterion of 1142.8. The analysis dataset used for modelling contained no missing values.

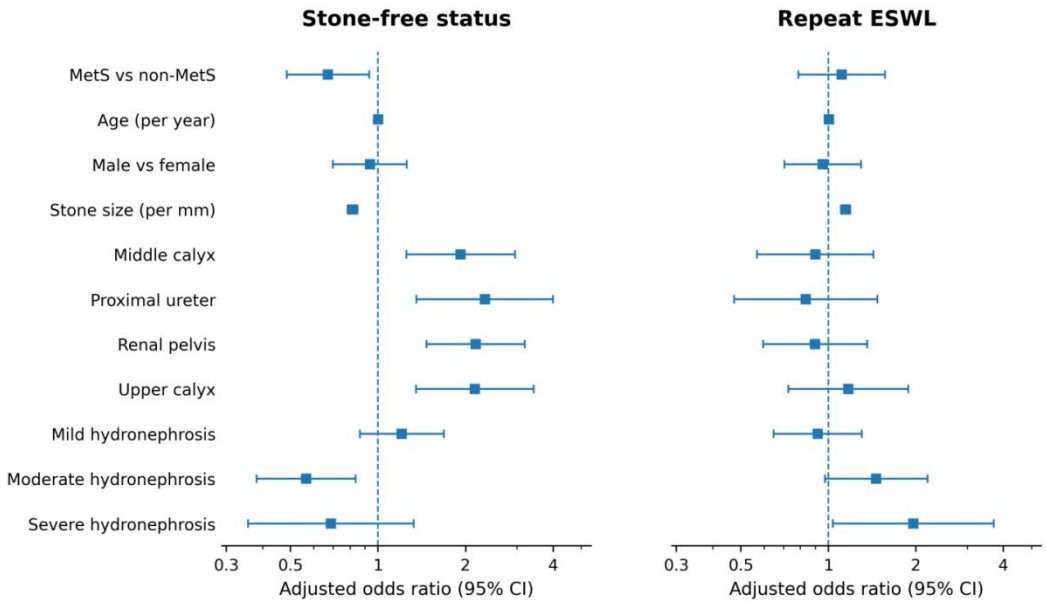


Figure 1 Multivariable Associations of Clinical Characteristics With Stone-Free Status and Retreatment
Note: Points represent adjusted odds ratios; horizontal lines represent 95% confidence intervals. The dashed vertical line corresponds to an odds ratio of 1. Both models include MetS status, age, gender, stone size, stone location, and hydronephrosis. Lower calyx and no hydronephrosis are the reference categories for stone location and hydronephrosis. Exact values appear in Table 4.

4 DISCUSSION

4.1 Principal Findings

In this retrospective study of 991 patients undergoing ESWL for upper urinary tract stones, MetS was associated with lower odds of achieving stone-free status after adjustment for demographic characteristics and established stone-related variables.
Although the unadjusted difference in stone-free rates between patients with and without MetS did not reach the conventional significance threshold using a continuity-corrected chi-square test, multivariable regression demonstrated a statistically significant association.
The fully adjusted model estimated approximately 33% lower odds of stone-free status among patients with MetS compared with those without MetS. This finding should be interpreted as a difference in odds rather than a corresponding reduction in absolute probability.
Larger stone size and moderate hydronephrosis were also associated with lower odds of successful clearance. By contrast, MetS was not significantly associated with retreatment, whereas stone size and severe hydronephrosis were associated with increased odds of additional treatment.
These findings suggest that metabolic status and conventional stone-related characteristics may provide complementary information when evaluating ESWL outcomes.

4.2 Metabolic Syndrome and ESWL Outcomes

Previous research has demonstrated an association between MetS and kidney stone disease. A systematic review and meta-analysis reported an increased prevalence of kidney stone disease among individuals with MetS [6]. Population-based investigations also support an association between metabolic abnormalities and nephrolithiasis [7].
Insulin resistance, obesity, and altered urinary acidification may contribute to the formation of uric acid stones. Maalouf and colleagues demonstrated an association between increasing metabolic abnormalities and decreasing urinary pH [8]. Other investigations have emphasized the importance of defective urinary ammonium buffering and acidic urine in uric acid stone formation [9, 10].
However, the biological factors promoting stone formation may not predict treatment success in a straightforward manner. Some uric acid stones have relatively favorable fragmentation characteristics. Nevertheless, successful ESWL treatment depends not only on stone fragmentation but also on accurate targeting, energy transmission, fragment passage, and the anatomy of the collecting system.
Consequently, metabolic abnormalities may be associated with stone formation and treatment response through distinct mechanisms.

The present findings support further investigation of MetS in the context of ESWL outcomes, while avoiding the assumption that stone composition alone explains the observed association.

4.3 Stone Size and Treatment Outcomes

Stone size was one of the strongest factors associated with ESWL outcomes in the present analysis.
Each additional millimeter of stone diameter was associated with lower odds of stone-free status and higher odds of retreatment.
This finding is consistent with previous investigations showing that larger stones are more likely to require additional treatment or have residual fragments.
Park and colleagues identified stone size and stone attenuation as important predictors of renal stone fragmentation [14].
El-Nahas and colleagues similarly reported that obesity and increased stone attenuation were associated with less favorable fragmentation outcomes [15].
Bajaj and colleagues demonstrated that stone size and skin-to-stone distance were relevant factors associated with ESWL success in a contemporary clinical cohort [13].
These findings support the clinical relevance of incorporating pretreatment stone characteristics when evaluating the association between MetS and stone clearance.
The present analysis treated stone size as a continuous variable. Because the estimated OR reflects a one-millimeter increment, interpretation assumes that the effect is adequately represented on the logit scale. The possibility of a nonlinear relationship should be assessed during final model validation.

4.4 Obesity and Skin-to-Stone Distance

Obesity represents a plausible link between MetS and ESWL treatment outcomes.
Increased body habitus may affect stone targeting and shock wave transmission, potentially contributing to less favorable treatment outcomes in selected patients.
Dede and colleagues compared normal-weight and morbidly obese patients with upper ureteral stones and reported lower stone-free rates in the morbidly obese group [23].
Skin-to-stone distance has also been investigated as a potentially important factor in ESWL outcomes. Pareek and colleagues reported an association between shorter SSD and improved treatment success [16]. Wiesenthal and colleagues identified greater SSD and higher stone attenuation as independent predictors of less favorable outcomes [17].
However, published findings are not entirely consistent.
Jacobs and colleagues found no statistically significant association between SSD and stone-free status in their study population [24]. Differences in lithotripter characteristics, patient selection, stone location, SSD measurement methods, and definitions of treatment success may partly explain these inconsistent results.
Importantly, BMI and SSD are not interchangeable measurements. BMI characterizes body mass relative to height, whereas SSD more directly describes the distance between the skin and the target calculus.
Although the MetS group in the present study had a higher mean BMI than the non-MetS group, standardized SSD measurements were unavailable. The contribution of SSD to the observed association therefore remains uncertain.
These considerations also highlight the need to distinguish an observed association between MetS and ESWL outcomes from a demonstrated causal mechanism.

4.5 Stone Location and Hydronephrosis

Anatomical stone location was associated with stone-free outcomes after adjustment for other clinical variables.
Compared with lower calyx stones, stones located in the middle calyx, upper calyx, renal pelvis, and proximal ureter were associated with higher odds of stone-free status.
This pattern is consistent with the recognized challenges of clearing lower-pole renal stone fragments.
The Lower Pole I randomized trial reported less favorable stone-free outcomes following shock wave lithotripsy for selected lower-pole stones, particularly with greater stone burden [25]. A recent systematic review and meta-analysis also demonstrated differences in stone-free outcomes among treatment modalities for lower-pole renal stones [26].
Anatomical factors may affect the clearance of fragments after successful fragmentation, potentially explaining why lower calyx stones are less likely to achieve complete clearance in some settings.
Hydronephrosis was also associated with outcomes in the present study.
Moderate hydronephrosis was associated with lower odds of stone-free status, while severe hydronephrosis was associated with higher odds of retreatment.
Previous research has similarly identified hydronephrosis and stone characteristics as important factors in ESWL outcomes. Liang and colleagues reported associations between stone location, stone size, hydronephrosis, and treatment effectiveness in a large retrospective cohort [12].
Interestingly, the association between severe hydronephrosis and the primary outcome did not reach statistical significance in the present study. This should not be interpreted as evidence that severe hydronephrosis is clinically harmless. Differences in subgroup sizes, clinical characteristics, and statistical precision may contribute to such findings.

4.6 Retreatment Outcomes

MetS was not significantly associated with retreatment after multivariable adjustment.
This finding differs from the association observed for stone-free status and suggests that these endpoints should be interpreted separately.
Retreatment may depend on factors beyond the presence of residual fragments, including residual stone size, symptoms, obstruction, clinical judgment, patient preference, and available treatment alternatives.
A patient with residual fragments may not require immediate additional intervention, while a patient with symptomatic obstruction or an unfavorable residual stone burden may undergo retreatment.
In contrast to MetS, larger stone size was associated with increased odds of retreatment in the present analysis.
Severe hydronephrosis was also associated with increased odds of additional treatment, although this result requires cautious interpretation given the number of subgroup comparisons.
These findings support the importance of evaluating retreatment as a distinct clinical outcome rather than using it interchangeably with stone-free status.

4.7 Clinical Implications

The findings of this study suggest that metabolic status may provide additional information when assessing ESWL outcomes.
Patients with MetS may benefit from careful pretreatment assessment of stone characteristics and structured postoperative evaluation. Nevertheless, the presence of MetS alone should not determine treatment selection.
Extracorporeal shock wave lithotripsy (ESWL) remains an established treatment option for selected patients with upper urinary tract stones, ESWL candidacy should continue to be guided by stone size, location, imaging characteristics, anatomical conditions, patient preferences, and other established clinical considerations [3-5].
The observed association between MetS and stone-free status may also encourage further investigation of metabolic health in procedural outcome studies.
However, direct clinical changes based solely on this association would be premature without confirmation in additional cohorts and a clearer understanding of potential residual confounding.

4.8 Strengths and Limitations

This study has several strengths.
First, it addresses a clinically relevant question concerning the association between a common metabolic condition and treatment outcomes.
Second, the analysis includes a cohort of 991 patients and evaluates both stone-free status and retreatment.
Third, sequential adjustment for demographic and stone-related factors allows the association between MetS and stone-free status to be examined beyond crude group differences.
Fourth, the analysis incorporates stone size, anatomical location, and hydronephrosis, which are clinically relevant determinants of ESWL outcomes.
Several limitations should also be considered.
First, the retrospective single-center design may introduce selection bias and limit generalizability.
Second, detailed measurements of stone attenuation and skin-to-stone distance were unavailable. These factors have been associated with ESWL effectiveness and may contribute to residual confounding.
Third, detailed stone composition, urine pH, and urinary alkalinization history were not incorporated into the current analysis. Thus, the potentially competing effects of stone composition and body habitus could not be evaluated directly.
Fourth, the interpretation of stone-free status depends on the imaging modality and the postoperative assessment interval. Differences in these characteristics may influence the classification of residual fragments.
Fifth, treatment-related variables such as lithotripter settings, shock wave delivery, localization technique, and operator-related factors were not included in the regression models.
Finally, this observational study cannot establish a causal relationship between MetS and ESWL outcomes.
Future multicenter prospective investigations incorporating standardized imaging, metabolic assessments, and treatment protocols are warranted.

5 CONCLUSION

In this retrospective analysis of 991 patients undergoing ESWL for upper urinary tract stones, MetS was associated with lower odds of stone-free status after adjustment for age, gender, stone size, stone location, and hydronephrosis.
Larger stone size and moderate hydronephrosis were also associated with less favorable stone-free outcomes, whereas MetS was not significantly associated with retreatment.
These findings suggest that metabolic status may provide additional information in the assessment of ESWL outcomes, although further studies incorporating detailed imaging and metabolic characteristics are required to clarify the mechanisms underlying this association.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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ETHICS APPROVAL

This retrospective observational study was reviewed and approved by the Ethics Committee of the Second Affiliated Hospital of Guilin Medical University (approval No. QWJW-2024018). All procedures were performed in accordance with the ethical standards of the institutional research committee and the 1964 Declaration of Helsinki and its later amendments.

CONSENT TO PARTICIPATE

The requirement for written informed consent was waived by the Ethics Committee of the Second Affiliated Hospital of Guilin Medical University, given the retrospective design of the study and the fully anonymized processing of all patient clinical data.

DATA AVAILABILITY

De-identified data may be made available from the corresponding author upon reasonable request, subject to institutional approvals and data-protection requirements.

AUTHORS' CONTRIBUTIONS

FangMing Xu: Methodology, data curation, formal analysis, visualization, and writing – original draft.
ZiLe Pan: Investigation, data collection, data curation, formal analysis, and writing – original draft.
Min Xiong and KaiLu Wei: Investigation, data validation, literature review, and writing – review and editing.
JiaQiang Pan: Conceptualization, supervision, project administration, funding acquisition, and writing – review and editing.
FangMing Xu and ZiLe Pan contributed equally to this work and share first authorship.
All authors reviewed and approved the final manuscript.

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