

Transient Decline and Complete Recovery of Renal Function Within Seven Days After a Single Extracorporeal Shock Wave Lithotripsy Session

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Research Article

Keywords: ESWL, renal function, acute kidney injury, serum creatinine, eGFR, urolithiasis

Posted Date: October 14th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-11012511/v1>

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Additional Declarations: No competing interests reported.

Abstract

Background

ESWL is first-line therapy for renal stones ≤ 20 mm. Its acute effects on renal function are poorly defined within 1 week of a single session, especially in lower-risk patients.

Objective

To evaluate short-term changes in serum creatinine and eGFR at Days 1, 3, and 7 after a single ESWL session in patients with preserved baseline renal function and stones ≤ 15 mm.

Methods

Of 220 patients enrolled in this prospective single-center study, 200 (90.9%) completed all scheduled follow-up assessments. Inclusion criteria were a single renal stone ≤ 15 mm, preserved baseline renal function (eGFR ≥ 60 mL/min/1.73 m²), and no previous ESWL. Exclusion criteria were a solitary kidney and chronic kidney disease. Patients underwent a single ESWL session (mean number of shocks, 3450 ± 420). Serum creatinine and eGFR (CKD-EPI 2009) were measured at baseline, Day 1, Day 3, and Day 7. Analysis was performed using a repeated-measures ANOVA with the Bonferroni correction.

Results

Mean creatinine increased by 14.8% on Day 1 (0.890 mg/dL to 1.022 mg/dL, $p < 0.001$), remained elevated by 6.2% on Day 3 ($p < 0.001$), and returned to near baseline by Day 7 (+0.4%, $p = 0.999$). Similarly, eGFR decreased by 13.9% on Day 1 (91.8 to 79.0 mL/min/1.73 m², $p < 0.001$), remained lower by 5.8% on Day 3 ($p < 0.001$), and recovered by Day 7 (-0.7%, $p = 0.998$). No cases of acute kidney injury, as defined by KDIGO, were detected.

Conclusion

A single ESWL session for stones ≤ 15 mm results in a mild, transient decline in renal function, with both serum creatinine and eGFR returning to baseline within 7 days. The return to baseline by Day 7 suggests that the observed decline was transient in this cohort, though further studies are needed.

Introduction

Urolithiasis affects about 10–15% of the world population over a lifetime. It leads to long-lasting sequelae and high morbidity [1]. Urinary stone disease is a major urological condition in the Kurdistan

Region, Iraq. Environmental, nutritional, and genetic factors predispose the population to calcium oxalate and uric acid stones [2]. ESWL has revolutionized the treatment of kidney and ureteral calculi in West Germany since the 1980s [3]. ESWL is a treatment option for renal stones and may be considered first-line in selected patients depending on stone size, location, density, anatomy, and patient factors. The European Association of Urology (EAU) highlights its non-invasive nature, safety, and technical success [4]. In ESWL, targeted shock waves pass through the body to the stone, breaking it into particles by mechanical forces such as cavitation, spalling, and shear stress [5]. However, ESWL can cause renal parenchymal injury. Shock waves travel through renal cells to the stone, and reports suggest injuries such as vascular damage, edema, hematoma, and transient perfusion loss [6,7]. Serum creatinine is a well-established marker of renal function; however, it has important limitations. Due to the nonlinear relationship between glomerular filtration rate (GFR) and serum creatinine, up to 50% of nephron function may be lost before a significant rise in serum creatinine occurs [18]. Therefore, the absence of AKI according to the KDIGO criteria does not exclude subclinical renal injury.

Clinical reports show variable renal function outcomes after ESWL, depending on patient and stone features, lithotripter type, and follow-up duration [8,9]. Most studies have focused on long-term renal function over months to years or have included patients with varying stone burdens and renal function [10,11]. Data on very short-term changes (within 1 week) after one ESWL session are limited for patients with preserved baseline renal function and stones ≤ 15 mm, the most common clinical group. This study aimed to evaluate serum creatinine and eGFR at baseline and on Days 1, 3, and 7 in 200 patients after their first single-session ESWL at a single tertiary urology center. The goal was to identify the short-term effect on renal function, the extent of recovery, and the duration of decline before renal function returns to normal.

Materials and Methods

Study Design and Setting. This was a prospective, single-center observational study conducted at the Department of Urology, Erbil Rizgari Teaching Hospital, Erbil, in the Kurdistan Region, Iraq, from January 2022 to January 2025. The study was approved by the Ethical Committee of the Kurdistan Higher Council of Medical Specialties (No. 1420 on 20/12/2021) and was conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from all subjects before enrollment.

Study Population: Adults (≥ 18 years) with a single renal stone ≤ 15 mm and preserved baseline renal function (eGFR ≥ 60 mL/min/1.73 m²) were enrolled. Exclusion: bilateral stones, solitary kidney, CKD, obstruction, infection, coagulopathy, anticoagulation, pregnancy, urinary anomalies, radiolucent stones, staghorn calculi, or weight > 100 kg. Patients were sequentially recruited from the outpatient clinic.

Enrollment and Completion

Out of 220 consenting patients, 200 completed all four follow-up assessments (Days 0, 1, 3, and 7), and 20 were excluded due to missed visits, consent withdrawal, or loss to follow-up. The final analysis used these 200 per-protocol cases. Completers and dropouts ($n = 200$ and $n = 20$, respectively) showed no

significant differences in baseline characteristics; missing data were considered random and unbiased. (all $p > 0.05$) All missing data were random and did not introduce bias.

ESWL Procedure

All ESWL procedures were conducted by an experienced urologist with fluoroscopic and/or ultrasound guidance using the Dornier Compact Delta II lithotripter (Dornier MedTech, Germany). One ESWL session was administered to each patient. The mean number of shocks applied was 3450 ± 420 (range 2500–4000) at 16.0 (range 14–18) power. For standard premedication, oral analgesics were administered 30 min prior to the procedure (diclofenac sodium 100 mg). Once enough stones had been fragmented, or the recommended maximum shock limit (4000 shocks) was reached, the process was discontinued. The ESWL is a non-invasive procedure that does not require endoscopy or laser. All treatments were performed externally using the lithotripter as described.

Outcome Measurements: Serum creatinine (mg/dL) samples were obtained at four time points: Baseline (immediately prior to ESWL), Day 1 (24 hours post-ESWL), Day 3 (72 hours post-ESWL), and Day 7 (one week after ESWL). After 8 hours of overnight fasting, blood samples were collected between 7:00 and 8:00 A.M. Venous blood (5 mL) was drawn from the antecubital vein with a needle and placed in serum separator tubes (SSTs). Serum creatinine was quantified using Jaffe kinetic colorimetry (Beckman Coulter AU480 analyzer). This was performed daily after collection of internal quality control samples, and the inter-assay coefficient of variation was $< 3\%$. The estimated glomerular filtration rate (eGFR) was calculated using the CKD-EPI 2009 equation [12], which is derived from serum creatinine, age, and sex. It is important to note that eGFR represents a mathematical transformation of serum creatinine and is therefore not an independent measure of renal function, particularly during acute changes when creatinine may not be in steady state.

Based on the KDIGO 2012 criteria [13], acute kidney injury (AKI) was defined as meeting any of the following: (1) an increase in serum creatinine of ≥ 0.3 mg/dL within 48 hours; (2) an increase in serum creatinine to ≥ 1.5 times baseline within 7 days; or (3) urine output < 0.5 mL/kg/h for 6 hours. Urine output was not systematically recorded in this study; therefore, AKI was assessed using serum creatinine criteria.

Statistical Analysis:

Sample size calculation

Pilot data indicated that 14 subjects were needed ($\alpha = 0.05$, 80% power) to detect a 0.12 mg/dL change in creatinine (SD = 0.10); allowing for dropout, 220 subjects were recruited and 200 analyzed. Data are shown as mean $\pm$ SD; normality was verified using the Shapiro–Wilk test. Normality was assessed at each time point using the Shapiro–Wilk test.

Primary analysis (repeated measures ANOVA)

Repeated measurements were taken on the same subjects at four time points (Baseline, Day 1, Day 3, Day 7), and one-way repeated measures ANOVA comparison of serum creatinine and eGFR over all four time points was conducted. The assumption of sphericity was tested by Mauchly's test. The degrees of freedom were corrected for sphericity violation ($p < 0.05$) using the Greenhouse–Geisser correction, as per the experimental setup for ANOVA.

Post-hoc comparisons (Bonferroni correction)

In order to account for Type I error after several pairwise comparisons (six pairwise comparisons for each outcome, Day 1 vs Baseline, Day 3 vs Baseline, Day 7 vs Baseline, Day 3 vs Day 1, Day 7 vs Day 1, Day 7 vs Day 3), post-hoc comparisons were performed with the Bonferroni correction. $\alpha/\text{number of comparisons} = 0.05/6 = 0.0083$, adjusted significance threshold. As a result, $p < 0.0083$ was considered significant for pairwise comparisons; the maximum standard ANOVA value is $p < 0.05$.

Effect size

Partial eta-squared (η^2) was calculated as the effect size for repeated measures ANOVA tests; and the points of 0.01, 0.06 and 0.14 are considered small, medium, and large effects, respectively.

Data management: Of 220 enrolled patients, 20 (9.1%) did not complete all 4 scheduled follow-up measurements (12 visits missed, 5 who withdrew consent, and 3 who were lost to follow-up). Baseline covariates (age, sex, stone size, baseline creatinine, and eGFR) were compared between completers ($n = 200$) and dropouts ($n = 20$) with an independent t-test for continuous and chi-square for categorical variables. None of the statistical differences between the two groups were significant (all $p > 0.05$), indicating that both groups were missing at random (MCAR). No imputation methods were used in the analysis, and the per-protocol population ($n = 200$) was used as the sample. Statistical Analysis: SPSS version 26.0 (IBM Corp., Armonk, NY, USA) was used for all statistical analyses.

Results

In total, 220 patients met the eligibility criteria and gave written informed consent. Of these, 200 patients (90.9%) fulfilled all four scheduled follow-up measurements. A total of 20 patients (9.1%) were excluded from the final analysis, as 12 missed scheduled follow-up visits, 5 withdrew consent, and 3 were lost to follow-up. Their average age was 49.2 ± 9.1 years. There were 128 (64%) male and 72 (36%) female patients. Mean stone size was 9.8 ± 2.7 mm. The mean number of shocks administered was 3450 ± 420 at a mean power level of 16.0. All patients had preserved baseline renal function (mean creatinine 0.890 ± 0.118 mg/dL; mean eGFR 91.8 ± 11.2 mL/min/1.73 m²). The starting profiles of the 200 completers are provided in Table 1.

Table 1
Baseline Patient Characteristics (n = 200)

Variable	Value
Age, years (mean ± SD)	49.2 ± 9.1
Sex: Male, n (%)	128 (64%)
Sex: Female, n (%)	72 (36%)
Stone size, mm (mean ± SD)	9.8 ± 2.7
Stone side: Right, n (%)	106 (53%)
Stone side: Left, n (%)	94 (47%)
Stone location: Renal pelvis, n (%)	112 (56%)
Stone location: Calyx (upper/middle/lower), n (%)	88 (44%)
ESWL shocks per session (mean ± SD)	3450 ± 420
Power level (mean, range)	16.0 (14–18)
Baseline serum creatinine, mg/dL (mean ± SD)	0.890 ± 0.118
Baseline eGFR, mL/min/1.73 m ² (mean ± SD)	91.8 ± 11.2
Comorbidities: Diabetes mellitus, n (%)	34 (17%)
Comorbidities: Hypertension, n (%)	42 (21%)

Serum creatinine increased significantly from baseline (0.890 ± 0.118 mg/dL) to Day 1 (1.022 ± 0.132 mg/dL), with a mean difference of + 0.132 mg/dL ($p < 0.001$). On Day 3, creatinine remained significantly elevated compared with baseline (0.945 ± 0.125 mg/dL; mean difference + 0.055 mg/dL, $p < 0.001$). By Day 7, creatinine had decreased to 0.894 ± 0.120 mg/dL, and the mean difference from baseline was negligible (+ 0.004 mg/dL, $p = 0.999$) (Table 2).

Table 2
Serum Creatinine at Each Time Point (n = 200)

Time Point	Mean ± SD (mg/dL)	Change from Baseline (%)	95% CI for Difference	p-value vs. Baseline (Bonferroni)
Day 0 (Baseline)	0.890 ± 0.118	—	—	—
Day 1	1.022 ± 0.132	+ 14.8%	(0.115, 0.149)	< 0.001
Day 3	0.945 ± 0.125	+ 6.2%	(0.042, 0.068)	< 0.001
Day 7	0.894 ± 0.120	+ 0.4%	(-0.008, 0.016)	0.999

Repeated Measures ANOVA: $F(1.8, 358.2) = 186.4$, $p < 0.001$, partial $\eta^2 = 0.48$.

Bonferroni-adjusted significance threshold: $p < 0.0083$. $p < 0.001$ vs. baseline (Bonferroni-

Similarly, eGFR showed a significant period effect over time, $F(1, 378.1) = 201.5$, $p < 0.001$, partial $\eta^2 = 0.50$. The Bonferroni post hoc test showed a significant drop in eGFR from baseline (91.8 ± 11.2 mL/min/1.73 m²) to Day 1 (79.0 ± 10.9 mL/min/1.73 m²) (mean difference: -12.8 mL/min/1.73 m², $p < 0.001$). eGFR still significantly decreased on Day 3 (86.5 ± 11.8 mL/min/1.73 m², mean difference -5.3 mL/min/1.73 m², $p < 0.001$). The eGFR recovered completely by Day 7 (91.2 ± 11.5 mL/min/1.73 m², $p = 0.998$; mean difference -0.6 mL/min/1.73 m²). At no time point did any patient's eGFR fall below 60 mL/min/1.73 m². Table 3, Fig. 1B.

Regarding acute kidney injury, none of the 200 completers met the KDIGO 2012 serum creatinine criteria for AKI at any follow-up time point. The largest person-level increase in creatinine was 0.29 mg/dL (below the 0.3 mg/dL threshold), and no participant had a serum creatinine increase of ≥ 1.5 times baseline at any interval. Post-ESWL obstruction did not require urological intervention in any patient. Serious adverse events were not noted.

Table 3
eGFR at Each Time Point (n = 200)

Time Point	Mean $\pm$ SD (mL/min/1.73 m ²)	Change from Baseline (%)	95% CI for Difference	p-value vs. Baseline (Bonferroni)
Day 0 (Baseline)	91.8 $\pm$ 11.2	—	—	—
Day 1	79.0 $\pm$ 10.9	-13.9%	(-14.2, -11.4)	< 0.001
Day 3	86.5 $\pm$ 11.8	-5.8%	(-6.8, -3.8)	< 0.001
Day 7	91.2 $\pm$ 11.5	-0.7%	(-1.6, 0.4)	0.998

Repeated Measures ANOVA: $F(1.9, 378.1) = 201.5$, $p < 0.001$, partial $\eta^2 = 0.50$.

Bonferroni-adjusted significance threshold: $p < 0.0083$.

$p < 0.001$ vs. baseline (Bonferroni-corrected post-hoc test)

Table 4 summarizes the repeated measures ANOVA results for both serum creatinine and eGFR, demonstrating significant overall changes over the 7-day study period with large effect sizes.

Table 4
Summary of Repeated Measures ANOVA Results (n = 200)

Parameter	Mauchly's Test (p)	Greenhouse-Geisser ϵ	F-value (df)	p-value (Overall)	Partial η^2	Significant Pairwise (Bonferroni)
Serum Creatinine	< 0.001	0.60	F (1.8, 358.2) = 186.4	< 0.001	0.48	Baseline vs. Day 1; Baseline vs. Day 3
eGFR	< 0.001	0.63	F(1.9, 378.1) = 201.5	< 0.001	0.50	Baseline vs. Day 1; Baseline vs. Day 3

Mauchly's test of sphericity was significant for both outcomes ($p < 0.001$); therefore, the Greenhouse-Geisser correction was applied. Post-hoc pairwise comparisons used Bonferroni correction (significance threshold $p < 0.0083$).

Discussion

This prospective single-center investigation of 200 patients aims to systematically examine the trajectory of renal function in the first 7 days following a single ESWL session, as assessed by serum creatinine and eGFR, in patients with kidney stones ≤ 15 mm and preserved baseline renal function. Our main clinical observation is that ESWL is associated with significant but transient and reversible reductions in renal function at the group level that peak on Day 1 and resolve completely by Day 7, without AKI by KDIGO criteria.

The mean 14.8% increase in creatinine on Day 1 (Fig. 1A, $p < 0.001$) and the corresponding 13.9% decrease in eGFR (Fig. 1B, $p < 0.001$) are similar to the transient renal parenchymal damage described in the ESWL literature. The shock waves generate cavitation bubbles that violently collapse inside renal tissue, causing localized mechanical trauma, vascular disruption, interstitial hemorrhage, and edema [6, 7]. Such events briefly impair glomerular filtration by reducing effective renal plasma flow (ERPF) and increasing renal vascular resistance [8]. The observed increase in serum creatinine on Day 1, despite the presence of a normal contralateral kidney, may be explained by additional mechanisms. The sympathetic renal-renal reflex is a well-described phenomenon in which unilateral renal injury or stimulation leads to a reflex increase in ipsilateral and contralateral renal sympathetic nerve activity [20]. This reflex can cause vasoconstriction, reduced renal blood flow, and transiently impaired glomerular filtration in both kidneys, even when only one kidney is directly affected by shock waves. Additionally, systemic factors such as pain, stress, and NSAID administration (diclofenac was given to all patients) may have contributed to transient renal vasoconstriction and reduced global GFR. Fankhauser et al. [9] conducted a systematic review and supported the notion that acute renal injury is prevalent after ESWL; however, serum creatinine changes at the group level in low-risk cohorts are often modest, findings in agreement with our findings.

It should be noted that eGFR was derived from serum creatinine using the CKD-EPI equation and is therefore not an independent measure. During acute changes, creatinine may not be in steady state, and eGFR may not accurately reflect true GFR. Thus, serum creatinine and eGFR should be interpreted as complementary rather than independent endpoints.

It is acknowledged that the presence of two functioning kidneys may have mitigated the overall functional impact, as the contralateral kidney could partially compensate for transient impairment in the treated kidney. The unshocked kidney may initiate compensatory hemodynamic hyperfiltration, increasing single-nephron GFR and transcapillary hydraulic pressure to buffer the transient functional loss of the treated side [19]. This compensatory mechanism could mask unilateral injury when assessing global serum creatinine and eGFR. However, the significant 13.9% decline in global eGFR at Day 1 ($p < 0.001$) indicates that contralateral compensation was incomplete during the acute phase. Consequently, the observed return to baseline by Day 7 reflects global function and does not exclude the possibility of ongoing, but compensated, injury in the treated kidney. This study specifically excluded patients with solitary kidneys to avoid confounding by the absence of compensatory reserve; however, the contralateral kidney's compensatory capacity in patients with two functioning kidneys remains an important confounder.

On Day 3, creatinine remained 6.2% higher than baseline, and eGFR remained 5.8% lower than baseline (both $p < 0.001$ after Bonferroni correction), suggesting that renal tissue repair was ongoing at this time point. On Day 7, creatinine and eGFR were statistically indistinguishable from baseline ($p = 0.999$ and $p = 0.998$, respectively), suggesting that renal function had returned to baseline by Day 7. This time course suggests that a 7-day interval may be reasonable; however, individualized assessment and further studies are warranted. Although the interval between ESWL sessions for renal stones has not been widely agreed upon in the EAU guidelines [4], a 7-day wait for functional recovery was considered adequate at this time.

Importantly, during our cohort, no patient met KDIGO 2012 criteria for AKI at any time. This observation reaffirms the favorable short-term renal functional trajectory associated with single-session ESWL in this select subset of patients who are showing renal function and stone reduction in the range of ≤ 15 mm, and is supported by the favorable safety assessment evidence reported in systematic reviews [9] and studies of the kidney with healthy kidney function [10]. The lack of AKI probably represents a protective factor: all patients reported normal pre-treatment eGFR, stones were ≤ 15 mm, and the mean shock count was within the recommended safe range. Connors et al. [8] demonstrated that higher shock-wave energy and increased shock numbers were associated with a greater risk of renal parenchymal injury, underscoring the importance of strict adherence to protocol.

The results of our study are consistent with Smolić and Markić [14], who reported an independent relationship between longer ESWL sessions and impaired long-term kidney function (OR 1.28/session, $p = 0.041$), and hence the need to limit cumulative exposure. Single-session treatments, such as those in our study, have a low potential to increase renal disease risk in patients with preserved baseline function.

Cass [15] also observed that bilateral ESWL alone did not have meaningful long-term functional effects on kidneys in patients with two working kidneys, while their solitary counterparts were more sensitive – an age group that was also appropriately not included in our study. Likewise, Maeda et al. [16] observed that patients who underwent multiple ESWL sessions had a higher prevalence of CKD than those treated with a single session, supporting the rationale for minimizing cumulative shockwave exposure.

Clinical interpretation

Large effect sizes (partial $\eta^2 = 0.48$ for creatinine and 0.50 for eGFR) support the clinical relevance of these ESWL-induced functional changes. The conservative Bonferroni correction indicated that Day 3 changes remained statistically significant ($p < 0.001$), whereas Day 7 changes were not significant ($p = 0.999$ for creatinine; $p = 0.998$ for eGFR), indicating complete functional recovery one week later. Recent studies have investigated the optimal interval between ESWL sessions. A randomized trial by Li et al. [22] demonstrated that patients with a 7-day interval between sessions had lower rates of persistent tubular injury and better preservation of split renal function compared with those with shorter intervals. Similarly, Chen et al. [23] found that a 7-day interval was associated with a more complete recovery of urinary biomarkers of renal injury than 3- to 5-day intervals. These findings support the clinical relevance of a 7-day interval to allow for functional recovery. In addition, baseline features did not differ significantly between completers and dropouts (all $p > 0.05$), suggesting that selective attrition is unlikely to bias the per-protocol analysis.

Limitations

This study assessed renal function using serum creatinine and eGFR, which are functional markers rather than direct biomarkers of renal injury. An important limitation is that due to the nonlinear relationship between GFR and serum creatinine, a significant reduction in nephron mass (up to 50%) can occur without a commensurate rise in serum creatinine [18]. Therefore, the absence of AKI by KDIGO criteria does not guarantee the absence of subclinical renal injury. More sensitive biomarkers, such as neutrophil gelatinase-associated lipocalin (NGAL), kidney injury molecule-1 (KIM-1), and cystatin C [21], were not measured. Cystatin C is less affected by muscle mass, age, and sex compared with serum creatinine and may more accurately reflect GFR during acute changes. Future studies incorporating these biomarkers could provide a more comprehensive assessment of ESWL-induced renal injury and recovery. While creatinine and eGFR are the clinical standards for AKI diagnosis (KDIGO), they may not detect subclinical injury that does not affect filtration [17].

Conclusion

These findings suggest a favorable short-term renal functional trajectory of single-session ESWL in patients with preserved baseline renal function and appropriately sized stones, while highlighting the importance of post-procedural monitoring at Day 1 and Day 3. The observed recovery kinetics suggest that a 7-day interval may be reasonable, though further studies are needed. Larger prospective

multicenter studies with extended follow-up and sensitive urinary biomarkers are warranted to further define the cumulative renal impact of multiple ESWL sessions.

Declarations

Ethics approval and consent to participate:

The study was approved by the Ethical Committee of the Kurdistan Higher Council of Medical Specialties (Approval No. 1420, 20 December 2021) and was conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from all participants before enrollment.

Consent for publication:

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

Clinical trial number:

Not applicable.

Data availability:

The datasets generated and/or analyzed during the current study are not publicly available due to ethical restrictions and patient confidentiality. Still, they are available from the corresponding author on reasonable request.

Competing interests:

The author declares no competing interests.

Funding:

This research has no specific grant from any government, commercial, or not-for-profit funding agency.

Author contributions:

The sole author of this work conceived and designed the study, acquired, analyzed, and interpreted the data, performed the statistical analysis, drafted and revised the manuscript, and approved the submitted version.

Acknowledgements:

The author gratefully acknowledges the administrative and technical support provided by the Department of Urology, Erbil Rizgari Teaching Hospital, Erbil, Kurdistan Region, Iraq. The author also sincerely thanks all patients who voluntarily participated in this study.

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Figures

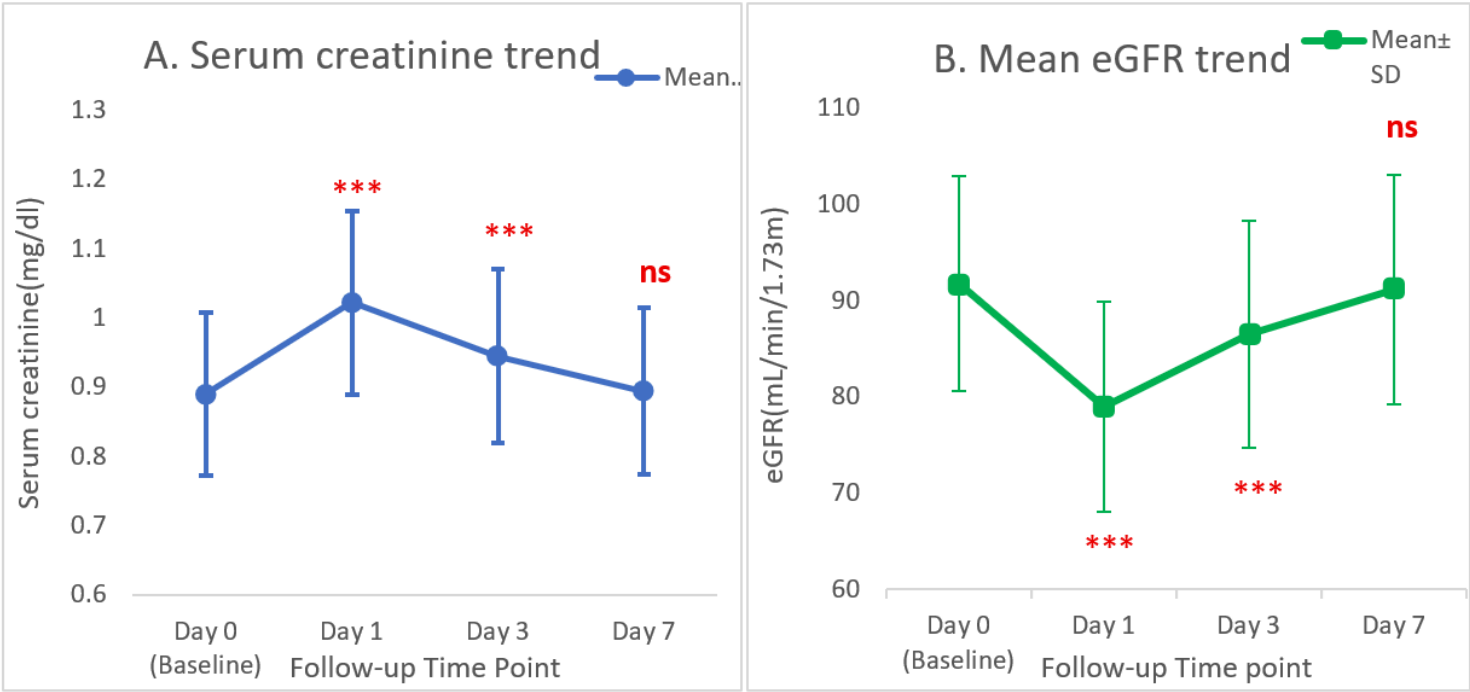


Figure 1

Short-term renal function trajectory following ESWL (n = 200). (A) Mean serum creatinine showed a transient, significant increase peaking at 24 hours. (B) Mean eGFR shows a corresponding significant

decline at Day 1 and Day 3. Denotes $p < 0.001$ compared to (Day 0) baseline using Bonferroni-corrected post-hoc tests; not significant