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The impact of chronic kidney disease stages and CROES AND GSS scores on stone free rate in kidney stones

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Abstract

Introduction This study evaluates the impact of chronic kidney disease (CKD) stages on stone-free rates (SFR) and renal function outcomes after percutaneous nephrolithotomy (PCNL). Additionally, it examines the predictive role of the CROES and Guy's Stone Score (GSS) systems.

Methods Data from 2994 patients who underwent PCNL between 2007 and 2024 were retrospectively analyzed. Patients were classified into four CKD groups based on preoperative estimated glomerular filtration rate (eGFR). SFR, complication rates, and postoperative renal function changes were assessed.

Results SFR was significantly lower in advanced CKD stages ($p < 0.001$), with the lowest in Group A (GFR < 30, 64.1%) and highest in Group D (GFR > 90, 79.1%). Postoperative eGFR increased in CKD stage 4–5 but declined in normal kidney function groups. Complication rates were higher in advanced CKD stages ($p = 0.031$). CROES and GSS scores correlated with stone complexity and surgical outcomes ($p < 0.001$).

Conclusion Advanced CKD is associated with lower SFR, greater surgical complexity, and higher complication rates. PCNL remains an effective treatment, particularly in CKD patients, with potential postoperative renal function improvement. Utilizing predictive scoring systems can optimize patient selection and surgical planning. Further prospective studies are needed to validate these findings.

Keywords Percutaneous nephrolithotomy (PCNL), Chronic kidney disease (CKD), Stone-free rate (SFR), CROES, Guy's Stone Score (GSS)

Introduction

Kidney stones are a urological disease that constitutes a significant health concern worldwide and severely affects the quality of life [1, 2]. One of the most critical criteria determining the success of kidney stone treatment is the stone-free rate. This rate plays a key role in reducing the risk of disease recurrence and preserving renal function [3]. SFR is defined as the complete absence of stone fragments in postoperative imaging. However, residual stone fragments smaller than 2 mm are considered clinically insignificant residual fragments (CIRF) and are not thought to have a significant impact on clinical outcomes [4].

Chronic kidney disease (CKD) is a condition characterized by the gradual loss of renal function and can be a determining factor in the formation and treatment of kidney stones. In advanced-stage CKD patients, the

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composition, size, and response rates of stones may vary, significantly impacting surgical outcomes [3, 5].

The presence of kidney stones can further deteriorate renal function and lead to severe outcomes such as end-stage renal disease (ESRD). However, the outcomes of stone treatment in patients with CKD and the impact of CKD stages on the stone-free rate remain incompletely understood [1, 5].

Percutaneous nephrolithotomy (PCNL), a minimally invasive surgical technique, is widely used for the treatment of kidney stones in patients with CKD [3, 6]. PCNL stands out particularly for its high stone-free rates and potential to improve renal function in the management of large and complex stones [1, 6]. However, the stone-free rates and the impact of treatment modalities on renal function may vary depending on the stages of CKD. In patients with advanced-stage CKD, the risks and complications associated with surgical interventions may be higher. Therefore, treatment strategies should be carefully planned and tailored according to CKD stages and the individual characteristics of patients [7]. Previous studies have reported that PCNL is an effective treatment modality for patients with CKD and can improve renal function in selected cases [8].

Prognostic models and scoring systems play a crucial role in evaluating PCNL outcomes. The Clinical Research Office of the Endourological Society (CROES) scoring system has been identified as an effective tool for predicting stone-free rates and complications. The CROES score assesses parameters such as the presence of staghorn stones, annual case volume, stone burden, and surgical history, making it a reliable method for predicting PCNL outcomes [5]. Similarly, the Guy's Stone Score (GSS) is used to determine the level of surgical complexity by analyzing factors such as pelvicalyceal anatomy, the number of stones, and their location [9].

The aim of this study is to evaluate the impact of chronic kidney disease (CKD) stages on stone-free rates and renal function following PCNL, analyze the effectiveness of treatment strategies across different CKD stages, and investigate the role of scoring systems such as the CROES and Guy's Stone Score (GSS) in predicting clinical outcomes.

Materials and methods

The data of 3,800 patients who underwent percutaneous nephrolithotomy (PCNL) at Çukurova University Urology Clinic between January 2007 and September 2024 were retrospectively analyzed. Patients under the age of 17, those with incomplete data, and those with renal anomalies (e.g., duplicated collecting system, horseshoe kidney, rotational anomaly, ectopic kidney, hypoplastic kidney, solitary kidney, polycystic kidney disease) were excluded from the study. Because these conditions can significantly affect the technical feasibility, surgical outcomes, and stone-free rate of PCNL.

After applying the exclusion criteria, a total of 2,994 patients were included. Preoperative and postoperative (48-h) estimated glomerular filtration rate (eGFR) levels were calculated using the *Chronic Kidney Disease Epidemiology Collaboration* (CKD-EPI) formula. Patients were categorized into four groups based on eGFR levels:

- CKD-EPI Stage 4–5: eGFR < 30 mL/min/1.73 m^2
- CKD-EPI Stage 3: eGFR 30–60 mL/min/1.73 m^2
- CKD-EPI Stage 2: eGFR 60–90 mL/min/1.73 m^2
- CKD-EPI Stage 1: eGFR > 90 mL/min/1.73 m^2

In this study, classification was performed based on eGFR levels, with patients in CKD Stage 1 representing individuals with normal renal function. The Guy's Stone Score (GSS) and CROES scoring systems were also assessed separately. The change in eGFR, defined as the difference between postoperative and preoperative eGFR levels, was calculated and expressed as a percentage.

Age, body mass index (BMI), stone burden, operative time, fluoroscopy time, hospitalization duration, estimated blood loss, and CROES score were analyzed in relation to stone-free rates and the development of complications. Postoperative complications were classified according to the Modified Clavien-Dindo grading system.The presence of residual stones postoperatively was evaluated using intraoperative fluoroscopy, postoperative plain abdominal radiography, or non-contrast abdominal computed tomography (CT) for non-opaque stones. Residual stone fragments measuring less than 2 mm were considered clinically insignificant residual fragments (CIRF). Although the threshold for clinically insignificant residual fragments (CIRF) is generally accepted as 4 mm in the literature, we considered a threshold of 2 mm in our study. Urological characteristics of the patients were compared across groups. History of endoscopic procedures, renal anomalies, urological anomalies, and other anatomical abnormalities were evaluated separately.

Ethical standards

Ethics committee approval for the study was obtained from the Non-Invasive Clinical Research Ethics Committee of Çukurova University (Approval Number: 6 December, 2024, with the decision number 150/59). The study was conducted in full compliance with relevant ethical guidelines and regulations. The research methods adhered to the ethical principles of the Declaration of Helsinki, ensuring the protection of participants' health, privacy, and rights.

Due to the retrospective nature of the study, the Non-Interventional Clinical Research Ethics Committee of Çukurova University waived the requirement for informed consent. Therefore, no informed consent was obtained from the patients, and there was no direct or indirect contact with them through face-to-face interactions or communication tools.

Statistical analysis

Categorical variables were summarized as frequencies and percentages, while numerical variables were presented as mean and standard deviation (or as median and minimum–maximum values when necessary). The Chi-square test was used to compare categorical variables between groups. The normality of numerical data was assessed using the *Shapiro–Wilk test.*

For comparisons of numerical variables among more than two groups, one-way analysis of variance (ANOVA) was performed when parametric assumptions were met, whereas the Kruskal–Wallis test was used when these assumptions were not satisfied. In cases where multiple-group comparisons yielded statistically significant results, pairwise comparisons were conducted using the Bonferroni test if assumptions were met, or the Bonferroni-adjusted Mann–Whitney U test otherwise. Additionally, post-hoc Tukey's test was applied for multiple group analyses. Statistical analyses were performed using IBM SPSS Statistics Version 20.0, and a p-value < 0.05 was considered statistically significant for all tests.

Results

The 2,994 patients included in the study were categorized into four groups based on their preoperative eGFR levels: Group A (eGFR < 30), Group B (eGFR 30–60), Group C (eGFR 60–90), and Group D (eGFR > 90). Various parameters, including age, sex, BMI, stone size, operative time, and the number of access tracts, were compared among the groups.

The stone-free rates (SFR) showed a statistically significant difference among the groups ($p < 0.001$). The lowest SFR was observed in Group A (64.1%), whereas the highest was recorded in Group D (79.1%). The clinically insignificant residual fragment (CIRF) rate was highest in Group B (17.4%) and lowest in Group D (9.1%). The clinically significant residual fragment (CSRF) rate was 23.4% in Group A and 11.8% in Group D. When all groups were analyzed together, the overall SFR was 76.8%, the CIRF rate was 10.5%, and the CSRF rate was 12.7% ($p < 0.001$).

The highest mean age was observed in Group B (61.0 [51.0–68.0] years), whereas the lowest was in Group D (41.0 [32.0–52.0] years) ($p < 0.001$). Regarding BMI, the highest mean value was found in Group B (27.8 [25.1–31.1]), while the lowest was in Group A (26.5 [24.0–28.7]) ($p < 0.001$).When evaluating stone size, the largest mean stone volume was recorded in Group A (400.0 [250.0–775.0] mm^3), whereas the smallest was in Group D (350.0 [200.0–500.0] mm^3) ($p = 0.010$).The longest operative time was observed in Group A (90.0 [60.0–120.0] minutes), while the shortest was in Group D (70.0 [50.0–100.0] minutes) ($p = 0.429$).In terms of number of access tracts, the highest single-tract access rate was recorded in Group D (82.4%), whereas the highest multiple-access rate was observed in Group A (40.6%) ($p < 0.001$).

In the study, patients' histories of stone surgery, endoscopic interventions (URS, DJ stent placement, PCN), and nephrostomy were also evaluated. The proportion of patients with a history of endoscopic intervention was 18.7% in Group A, 9.1% in Group B, 7.0% in Group C, and 3.7% in Group D.

In our study, the management of residual stones was determined based on the patient's clinical condition and stone size. Overall, the vast majority (90.1%–95.8%) of patients with residual stones were managed with follow-up. For patients requiring additional intervention, the most commonly used method was secondary PCNL. The rate of secondary PCNL was 4.8% in Group A and 3.3% in Group D. Extracorporeal shock wave lithotripsy (ESWL) was less frequently preferred, with an application rate of 1.1% in Group B and 0.9% in Group D.

Significant differences were observed among the groups in terms of Guy's Stone Score (GSS) classification ($p < 0.001$). The highest proportion of Grade 4 cases was found in Group A (35.9%), whereas Grade 1 was the most frequently observed category in Group D (47%).

Regarding CROES scores, Group A had the lowest values (median: 172.5 [135.0–245.0]), while Group D exhibited the highest scores (median: 215.0 [160.0–245.0]) ($p = 0.008$). In the Clavien-Dindo complication classification, Grade 1 complications were the most common across all groups, with the highest incidence observed in Group C (95.1%). Severe complications (Grade 3 and above) were more frequently encountered in Group B ($p = 0.031$) (Table 1).

The most common postoperative complications included urinary tract infection (UTI), fever, pneumonia, pain, and prolonged urinary leakage. Patients who developed UTI and fever were treated with antibiotic therapy, which necessitated prolonged hospitalization. Cases of prolonged urinary leakage were managed through follow-up or postoperative DJ stent placement. Patients who developed sepsis were monitored in the intensive care unit (ICU) and required extended hospitalization. In cases where an arteriovenous fistula was detected, angiographic embolization was performed (Table 2).

The CROES score demonstrated a significant correlation with eGFR change ($r = -0.072$, $p < 0.001$), stone

Table 1 Clinical and surgical characteristics By GFR groups

	eGFR				p
	< 30 (Stage 4–5) Group A	30–60 (Stage 3) Group B	60–90 (Stage 2) Group C	> 90 (Stage 1/ Normal) Group D	
Patient Count(N)	**(n = 64)**	**(n = 265)**	**(n = 790)**	**(n = 1875)**	
Age (Years)	57.0(45.0–62.0) #	61.0(51.0–68.0) ϕ,#	54.0(45.8–62.0) #	41.0(32.0–52.0)	***< 0.001***
Gender, N(%)					
Male	40(62.5)	157(59.2)	419(53.0)	1222(65.2)	***< 0.001***
Female	24(37.5)	108(40.8)	371(47.0)	651(34.8)	
Bmi	26.5(24.0–28.7)¥, ϕ	27.8(25.1–31.1)#	27.7(25.1–31.1)#	26.7(24.0–29.7)	***< 0.001***
Creatinine (Pre-Op)	2.80 (1.50–10.00)	1.40 (0.95–2.50)	1.00 (0.60–1.60)	0.80 (0.30–1.10)	***< 0.001***
Creatinine (Post-Op)	1.3(1.1–2.5)¥, ϕ,#	1.3(1.1–1.4)ϕ,#	1.1(1.1–1.3)	1.3(1.1–1.3)	***< 0.001***
GFR(Pre-Op)(ml/dk/1.73 m^2)	23.52 (3.73–29.84)	49.34 (30.03–59.95)	78.90 (60.03–89.95)	106.74 (90.01–172.56)	***< 0.001***
GFR(Post-Op)(ml/dk/1.73 m^2)	59.3(37.6–64.4)ϕ,#	58.1(53.7–63.2)ϕ,#	62.7(59.3–67.3)#	69.2(64.0–74.8)	***< 0.001***
Gfr Change (%)	59.7(38.6–70.3)ϕ,#	14.4(−1.8–26.4)ϕ,#	−24.6(−33.3–12.1)#	−58.8(−66.7–39.8)	***< 0.001***
Stone Size (Mm^3)	400.0(250.0–775.0)#	350.0(200.0–600.0)#	350.0(200.0–550.0)	350.0(200.0–500.0)	***0.010***
Operation Time (min)	90.0(60.0–120.0)#	80.0(60.0–112.5)	80.0(60.0–115.0)#	70.0(50.0–100.0)	***< 0.001***
Fluoroscopy Time(min)	9.5(6.0–15.0)	10.0(5.0–15.0)	10.0(6.0–15.0)	10.0(5.0–14.0)	*0.429*
Discharge (Day)	3.5(3.0–5.0)	4.0(3.0–5.0)ϕ,#	3.0(3.0–4.0)	3.0(3.0–4.0)	***< 0.001***
Special Case					
Anatomical Abnormality[a]	0(%0.0)	0(%0.0)	2(%0.3)	14(%0.8)	***< 0.001***
Endoscopic Procedure [b]	12(%18.75)	24(%9.1)	55(%7)	69(%3.7)	
Urological Anomaly[c]	10(%15.62)	45(%17)	115(%14.6)	237(%12.7)	
Other[d]	2(%3.12)	11(%4.2)	59(%7.5)	129(%6.9)	
None	40(%62.5)	185(%69.7)	559(%70.6)	1426(%75.9)	
Number Of Accesses, N(%)					
Single	38(59.4)	215(81.1)	632(80.0)	1545(82.4)	***< 0.001***
Multiple	26(40.6)	50(18.9)	158(20.0)	330(17.6)	
Renax Size (Fr)	24.0(24.0–26.0)	24.0(24.0–26.0)	24.0(24.0–26.0)	24.0(24.0–26.0)	*0.236*
Residue, N(%)					
CSRF	15(23.4)	41(15.5)	104(13.2)	221(11.8)	***< 0.001***
CIRF	8(12.5)	46(17.4)	89(11.3)	171(9.1)	
SF	41(64.1)	178(67.2)	597(75.6)	1483(79.1)	
Recommendation					
Follow-Up	59(%95,2)	247(%90,1)	673(%93,6)	1858(%95,8)	***0,002***
Eswl	0(%0)	3(%1,1)	5(%0,7)	17(%0,9)	
Secondary Pnl	3(%4,8)	24(%8,8)	41(%5,7)	64(%3,3)	
Gss, N(%)					
Grade 1	20(31.2)	110(41.5)	319(40.4)	882(47.0)	***< 0.001***
Grade 2	6(9.4)	53(20.0)	185(23.4)	424(22.6)	
Grade 3	15(23.4)	47(17.7)	130(16.5)	256(13.7)	
Grade 4	23(35.9)	55(20.8)	156(28.5)	313(16.7)	
Croes	172.5(135.0–245.0)#	195.0(155.0–240.0)#	200.0(160.0–245.0)	215.0(160.0–245.0)	***0.008***
Clavien-Dindo, N(%)					
Grade 1	60(93.8)	235(88.7)	751(95.1)	1775(94.7)	***0.031***
Grade 2	2(3.1)	11(4.2)	19(2.4)	36(1.9)	
≥ Grade 3	2(3.1)	19(7.2)	20(2.5)	64(3.4)	

Unless Otherwise Specified Data Was Expressed As Mean ± Standard Deviation Or Median(Iqr)

¥ $P < 0.05$ Comparison Between Gfr 30–60

ϕ $P < 0.05$ Comparison Between Gfr 60–90

# $P < 0.05$ Comparison Between Gfr > 90

[a] Anatomical Abnormality: Skoliosis, Bone Deformity, Spinal Cord Injury, Etc

[b] Endoscopic Procedure: Urs, Dj, Pcn, Ureteral Catheterization, Etc

[c] Urological Anomaly: Congenital Ureteropelvic Junction Obstruction, Renal Anomaly With Dextrocardia, Vesicoureteral Reflux, Etc

[d] Other: History Of Prostate Cancer, Bladder Cancer, Renal Mass, And Other Urological Malignancies, Etc

Table 2 Postoperative complications table

Complication	GFR				Intervention Performed
	Stage 4–5	Stage 3	Stage 2	Stage 1	
Urinary Tract Infection	9	2	7	2	Antibiotic Therapy—Prolonged Hospitalization[a]
Fever	5	1	3	10	Antibiotic Therapy—Prolonged Hospitalization[a]
Pneumonia	3	0	0	1	Antibiotic Therapy—Prolonged Hospitalization[a]
Pain	8	8	0	2	Analgesia—Prolonged Hospitalization[a]
Oliguria	0	1	2	5	Consultation—Follow-up
Prolonged urinary leakage	2	5	9	31	DJ Stent in the Postoperative Period
Pyuria	5	3	2	4	Percutaneous Nephrostomy
Sepsis	7	4	0	2	Intensive Care Admission—Prolonged Hospitalization
Arteriovenous Fistula	2	2	0	6	Angioembolization
İleus	4	0	0	1	Consultation—Follow-up
Bleeding	0	0	0	4	[b]
Ureteropelvic Junction Perforation	0	1	0	1	DJ Stent
Colon Perforation	0	0	1	0	Surgery
Urinoma	6	0	1	0	Drain
Ureterovesical Stricture	0	1	0	0	Surgery

[a] Patients with a hospital stay of at least 5–7 days

[b] One patient received an erythrocyte suspension, one patient underwent nephrectomy of the affected kidney one month later, one patient's stone surgery was canceled, and one patient experienced prolonged hospitalization

size ($r=0.071$, $p<0.001$), operative time ($r=0.108$, $p<0.001$), and length of hospital stay ($r=0.189$, $p<0.001$). Additionally, a significant difference was observed between the Clavien-Dindo complication classification and the CROES score; however, a weak negative correlation was noted ($r=-0.125$, $p<0.05$) (Table 3).

Figure 1 illustrates the distribution of CROES scores and postoperative eGFR changes across the eGFR groups. CROES scores were similar across all groups, with the highest value recorded in Group D (202). Conversely, eGFR change showed a positive trend in Group A (+45%), whereas a notable negative decline was observed in Group C (−19%) and Group D (−54%). These findings indicate that eGFR changes significantly differ according to baseline eGFR levels (Fig. 1).

When postoperative eGFR changes were evaluated according to GSS groups, the changes in Group A and Group B remained limited, whereas significant declines were observed in GSS 3 and GSS 4 levels of Group C and Group D. The highest eGFR loss was recorded in Group D among patients with GSS 3 (Fig. 2).

Table 3 Correlation between CROES score and operative data

	CROES	*p*
GFR change (%)	−0.072	***<0.001***
Stone size (mm^3)	0.071	***<0.001***
Operation duration (min)	0.108	***<0.001***
Discharge (day)	0.189	***<0.001***
Residue		
CSRF	180.0(148.0–227.5)	***<0.001****
CIRF	160.0(135.0–200.0)	
SF	220.0(170.0–245.0)	
Clavien-Dindo		***<0.001*****
Grade 1	200.0(160.0–245.0)	
Grade 2	160.0(140.0–200.0)	
≥ Grade 3	175.0(135.0–215.0)	

Data was expressed as correlation coefficient(r) or median(IQR)

[*] $p<0.05$ in all pairwise comparisons

[**] $p>0.05$ was observed solely in the comparison between grades 2 and 3

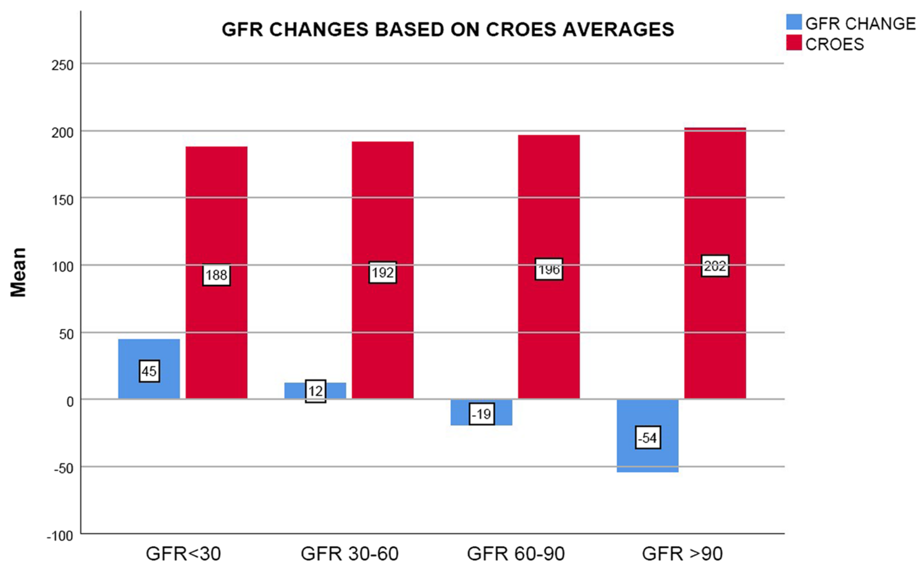

Fig. 1 Distribution of postoperative GFR changes based on CROES averages. The comparison of CROES scores and mean GFR changes within each GFR group is shown

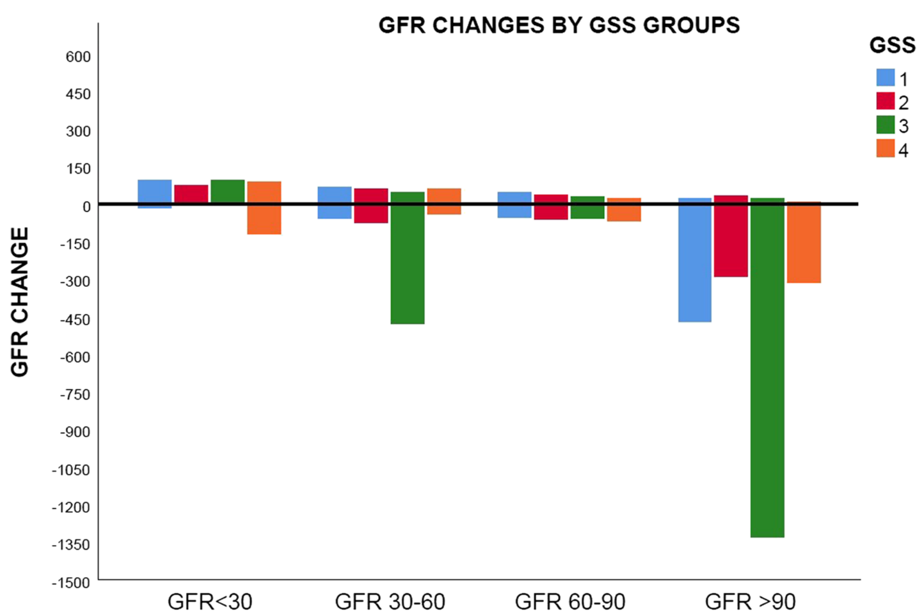

Fig. 2 Distribution of postoerative GFR changes based on GSS groups. The comparison of GFR changes across different GSS levels within each GFR group is shown

Discussion

In our study, a detailed analysis was conducted on stone-free rates, postoperative complications, and changes in renal function following PCNL in patients with chronic kidney disease (CKD). The findings contribute to a better understanding of prognostic factors influencing surgical outcomes in this specific patient population.

In the study conducted by Bilen et al., it was reported that PCNL led to a significant improvement in patients with eGFR < 30, with a stone-free rate (SFR) of 83.7% [10]. In another study conducted by Yaycıoğlu et al., the stone-free rate (SFR) was reported as 76.3% [2]. In our study, the overall stone-free rate, including both SF and CIRF cases, was determined to be 87.2%. The lower SFR and higher residual fragment rates in Group A, along with the highest SFR observed in Group D, suggest that reduced eGFR may negatively impact postoperative outcomes. The lower stone-free rates observed in Group A may be attributed to multiple factors. One possible explanation is the higher stone burden in patients with advanced CKD, which has been previously associated with lower SFR in the literature. Additionally, the technical complexity of PCNL in this patient group, due to anatomical abnormalities and impaired renal function, may contribute to the lower success rates. Another potential factor is the higher mean age in Group A, which may contribute to GFR decline due to nephron loss over time, further complicating postoperative renal function recovery. Additionally, the impact of surgical experience over time should be considered. As this study includes cases spanning from 2007 to 2024, it is possible that early cases in the dataset were performed during a period of limited surgical expertise with PCNL, which may have influenced initial outcomes. These findings emphasize the importance of carefully planning and managing PCNL in patients with low eGFR to optimize surgical success and minimize complications.

The literature also reports that stone-free rates may be lower in patients with advanced CKD, which has been attributed to anatomical alterations and difficulties in the clearance of residual stone fragments [9]. In our study, the SFR was 60% in Group A and 80% in Group D. The decrease in stone-free rates among patients with lower eGFR levels is thought to be associated with higher stone burden, anatomical abnormalities, and increased complexity of surgical techniques required for these patients.

On the other hand, the surgeon's experience and the annual PCNL case volume of the center are critical factors directly influencing stone-free rates. In the CROES nomogram, the annual PCNL case volume has been identified as one of the key parameters determining stone-free rates and surgical success [11]. Studies conducted in high-volume centers have demonstrated that increased surgical experience is associated with a significant improvement in stone-free rates (SFR) [5]. Considering that the surgeries in our study were performed by experienced surgeons, it is suggested that the most critical determinants of SFR are the CKD stage and stone complexity rather than surgical expertise alone.

A study in the literature examining the effects of PCNL on renal function in patients with CKD reported that 25% of patients with a preoperative eGFR < 60 mL/min experienced an increase in eGFR to above 60 mL/min by the third postoperative month. However, it was also noted that unexpected declines in eGFR occurred in some early-stage CKD patients [10]. In our study, post-PCNL eGFR decreased by 58% in Group D, while it increased by 60% in Group A.In patients with eGFR < 30, this increase can be attributed to the relief of obstruction through stone burden reduction, the recovery of renal function loss due to hydronephrosis, and the activation of the hyperfiltration mechanism. Our findings suggest that PCNL should not be evaluated solely based on stone-free rates but also in terms of dynamic adaptations in eGFR levels. Moreover, the postoperative renal function changes in patients with low eGFR should be carefully analyzed, emphasizing the importance of individualized perioperative management in this population.

A study in the literature reported that in patients undergoing PCNL, the mean preoperative eGFR was 96.03 mL/min, which decreased to 86.68 mL/min postoperatively, and this decline was considered statistically significant [12]. In our study, the marked decline in eGFR observed in Group D suggests that higher baseline eGFR levels may be more susceptible to postoperative variability due to renal autoregulation and hemodynamic adaptation mechanisms following surgery.

In the study conducted by İzol et al., it was demonstrated that eGFR decreases with age, and the effects of PCNL on this decline were comprehensively analyzed [13]. Similarly, in the study by Kamphuis et al., it was reported that lower eGFR levels were observed with advancing age, which could negatively impact PCNL success [5]. Consistently, our study also demonstrated a significant decline in eGFR levels with increasing age, aligning with the findings reported in the literature.

When compared with the literature on residual stone management, it has been shown that secondary PCNL is preferred for larger and more complex stones, whereas ESWL is utilized for smaller residual stone fragments [14, 15]. Additionally, the literature indicates that in cases with high residual stone rates, secondary PCNL is an effective approach for improving stone-free rates [16]. Similarly, in our study, secondary PCNL was more frequently performed in patients with a higher stone burden. In conclusion, residual stone management was evaluated on a patient-specific basis. While most patients were managed with follow-up, selected cases underwent additional interventions, such as ESWL and secondary PCNL, when deemed necessary.

A study has reported that an increase in BMI may indirectly affect renal function, thereby potentially impacting PCNL success [1]. In our study, the lowest mean BMI was observed in Group A (26.5), while higher BMI values were recorded in Group B (27.8) and Group C (27.7), compared to Group D (26.7). However, although the literature suggests that lower BMI levels are generally associated with better eGFR, our findings did not align with this expectation. This discrepancy may be attributed to the multifactorial nature of renal function changes and the complex interplay between BMI, metabolic status, and kidney health.

Studies in the literature have demonstrated that patients with lower eGFR levels tend to have larger stone volumes. It has been reported that individuals with a history of kidney stones have an increased risk of stone formation as eGFR declines, with those having eGFR 30–59 exhibiting a nearly twofold higher risk of stone formation compared to individuals with eGFR > 90 [17, 18]. Consistently, our study also observed that stone volume increased as eGFR declined, with the largest stone volume found in Group A, whereas the smallest was observed in Group D. This finding suggests that lower eGFR levels may be associated with an increased propensity for stone formation, and as renal function deteriorates, stones may become larger and more complex.

In patients with low eGFR levels, stone complexity, anatomical variations, and renal anomalies can have a direct impact on operative time and the number of access tracts. In patients with eGFR < 30 mL/min, the prolonged fluoroscopy time and increased number of access tracts may be attributed to the presence of renal anomalies or anatomical abnormalities [19]. In our study, the highest rate of multiple access tracts (40.6%) was observed in Group A, which may be directly related to the increased operative time and, consequently, the greater need for fluoroscopy. This finding underscores the technical challenges associated with PCNL in patients with advanced CKD, highlighting the need for meticulous preoperative planning and intraoperative decision-making to optimize outcomes.

The literature has reported that renal anomalies and complex stone anatomy contribute to prolonged fluoroscopy time. In a study conducted by Kurien et al., it was emphasized that fluoroscopy duration in PCNL procedures for nephrolithiasis is directly correlated with stone burden and the number of access tracts [1]. Similarly, Kamphuis et al. demonstrated that fluoroscopy time is significantly prolonged in patients with a high stone burden, and this effect becomes particularly pronounced in cases requiring multiple access tracts [5]. Shabaninia et al. reported that renal anomalies and anatomical variations increase the technical challenges of PCNL, consequently leading to a greater need for fluoroscopy during the procedure [7]. In our study, operative time was longer in patients with lower eGFR levels, whereas it decreased as eGFR increased. However, no such correlation was observed between fluoroscopy time and length of hospital stay.

The proportion of patients with a history of stone surgery, endoscopic intervention (URS, DJ stenting, PCN), or nephrostomy was 18.7% in Group A and 3.7% in Group D. This finding suggests that patients with lower eGFR levels are more likely to experience stone recurrence and undergo prior interventions. Previous procedures have been reported to increase the technical difficulty of PCNL due to fibrosis and tissue scarring, which can also lead to a higher risk of complications [20]. Particularly in the presence of obstructive uropathy, careful surgical planning is essential for these patients to optimize outcomes and minimize complications [18].

The GSS and CROES nomograms are commonly used to predict stone-free rates (SFR) after PCNL. Although the existing literature lacks specific data on the direct impact of these scoring systems on eGFR, it has been suggested that higher stone-free rates may contribute to the preservation of renal function [21, 22]. In our study, the lowest eGFR values were observed in Group A, which also had the lowest mean CROES score, whereas Group D had the highest CROES score. A positive correlation was noted between increasing eGFR, higher CROES scores, and improved stone-free rates (SFR). This finding can be explained by the greater stone burden, complex stone anatomy, anatomical abnormalities, and intricate stone structures in the low eGFR patient group. Additionally, the highest CROES scores in Group D coincided with the highest SFR, further supporting this association.

In the study conducted by Rashid et al., it was demonstrated that as GSS increases, stone-free rates decrease, while complication rates significantly rise [23]. In our study, when the distribution of patients according to GSS grades was analyzed, GSS Grade 4 was most frequently observed in Group A, while it was least common in Group B.

Several studies have demonstrated that as GSS grade increases, the associated rise in stone burden and anatomical challenges makes it more difficult to preserve renal function. Consequently, postoperative eGFR changes are influenced by these factors, highlighting the importance of stone complexity and anatomical considerations in surgical planning and renal function outcomes [9]. As shown in Fig. 2, in low eGFR groups, particularly among Grade 4 patients, eGFR change reached the most pronounced negative values. In Group B, the decline in eGFR among Grade 4 patients was significantly more prominent compared to other groups. These findings suggest that GSS is not only associated with stone-free rates but may also have a significant impact on postoperative renal function. Therefore, in patients with high GSS scores, careful postoperative renal function assessment and the development of protective strategies to preserve renal function are of clinical importance.

In studies evaluating complications following PCNL, urinary tract infection (UTI) and fever are reported as the most common complications. Additionally, it has been documented that in patients who develop sepsis, there is an increased need for intensive care unit (ICU) admission [1, 5]. In patients who develop arteriovenous fistula, angiographic embolization has been demonstrated to be an effective treatment method [7]. Bilen et al. reported that in patients with chronic kidney disease (CKD) and low eGFR, the risk of Clavien-Dindo complications following PCNL is higher. However, they also emphasized that renal function can be preserved with appropriate patient selection [10]. In our study, postoperative complications were analyzed using the Clavien-Dindo classification, and Grade 3 or higher complications were found to be more frequent in Group B. Notably, urinary tract infection, fever, pneumonia, prolonged urinary leakage, and pyuria were among the complications that prolonged hospital stay following surgery.

Yanaral et al. reported that in patients with chronic kidney disease (CKD), Grade 3 or higher complications were more frequently observed following PCNL. They emphasized that while PCNL is effective in preserving renal function in CKD patients, it is associated with a higher risk of complications [24]. Özden et al. evaluated post-PCNL complications in CKD patients using the Clavien-Dindo classification and emphasized that Grade 2 or lower complications were common, while Grade 3 or higher required careful management [6]. In our study, when the relationship between Clavien-Dindo complications, CROES, and GSS scores was evaluated, low-grade complications were found to be the most common. Higher GSS and lower CROES scores were associated with an increased frequency of higher-grade complications, suggesting that greater stone complexity contributes to surgical challenges and complication risk. Interestingly, despite the expectation that patients with lower eGFR levels would have a higher complication rate, our findings showed a relatively lower incidence of severe complications in this group, which appears to contrast with existing literature.

Our study has certain limitations. First, its retrospective design may introduce potential biases, including selection bias and data limitations. Second, as a single-center study, the generalizability of the findings to broader patient populations is limited. Third, the assessment of renal function is based on short-term follow-up results, and data on long-term outcomes are not available.

Conclusion

This study comprehensively assessed the impact of chronic kidney disease (CKD) stages on stone-free rate (SFR) and renal function outcomes following percutaneous nephrolithotomy (PCNL). Lower eGFR levels were associated with increased stone burden, greater surgical complexity, higher complication rates, and reduced SFR. Postoperative eGFR changes varied across CKD stages, with a potential improvement observed in advanced CKD patients, likely due to obstruction relief and renal recovery mechanisms.

Given these findings, further multicenter prospective studies with long-term follow-up are essential to better understand the long-term effects of PCNL in CKD patients and to refine treatment strategies.

Supplementary Information

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Supplementary Material 1.

Authors' contributions

• Nebil Akdoğan: Conceived and designed the study, developed the methodology, contributed to data collection, wrote the manuscript, and performed the final revisions. • Mehmet Zubaroğlu: Conducted data analysis and interpretation, contributed to the drafting of the manuscript, performed statistical analyses, and reviewed the final version of the manuscript. • Mehmet Gürkan Arıkan: Participated in data collection, conducted the literature review, contributed to the interpretation of the results, and supported the writing of the manuscript. • Ismail Onder Yılmaz: Conceptualized the study, provided methodological guidance, supervised the research process, and critically reviewed the manuscript. • Mutlu Değer: Contributed to data collection and analysis, supported the evaluation of the results, and reviewed the manuscript for scientific accuracy.

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Data availability

The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Ethics approval and consent to participate

This study was approved by the Non-Invasive Clinical Research Ethics Committee of Çukurova University (Approval Number: 6 December 2024, Decision Number: 150/59). The study was conducted in full compliance with relevant ethical guidelines and regulations. The research methods adhered to the ethical principles of the Declaration of Helsinki, ensuring the protection of participants' health, privacy, and rights. Due to the retrospective nature of the study, the Non-Interventional Clinical Research Ethics Committee of Çukurova University waived the requirement for informed consent. Therefore, no informed consent was obtained from the patients, and there was no direct or indirect contact with them through face-to-face interactions or communication tools.

Consent for publication

As the study was retrospective and no identifiable personal data were used, consent for publication was not required.

Competing interests

The authors declare no competing interests.

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