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PCNL in Special Renal Stone Cases with Anatomical and Clinical Complexity: Are These Patients Truly Challenging? A Matched Single-Center Study

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Abstract

Percutaneous nephrolithotomy (PCNL) is the standard treatment for renal stones larger than 2 cm; however, its application in patients with special anatomical or clinically relevant conditions remains controversial. This study aimed to evaluate the safety and efficacy of PCNL in patients with special anatomical and clinically relevant conditions compared with matched controls.

A retrospective single-center study was conducted including patients who underwent PCNL between September 2009 and June 2025. Among 3674 procedures, 341 patients with special anatomical and clinically relevant conditions, including solitary kidney, horseshoe kidney, duplex collecting system, ectopic kidney, skeletal deformity or previous ipsilateral open renal stone surgery, were identified as Group 1. Using 1:1 exact and caliper-based matching based on age, sex and stone surface area (SSA, mm^2), 341 patients without these conditions were selected as Group 2. Demographic, perioperative, and postoperative outcomes were compared between groups. Stone-free status, clinically insignificant residual fragments (CIRF, ≤ 2 mm) and clinically significant residual fragments (CSRF) were reported separately.

The mean age of the cohort was 44.0 ± 17.1 years, and 28.2% of patients were female. Stone-free rates were similar between Group 1 (patients with special anatomical and clinically relevant conditions) and Group 2 (control group) (78.3% vs 80.6%, respectively). CIRF and CSRF were reported as secondary, imaging-limited estimates; CIRF rates were 10.6% in Group 1 and 10.0% in Group 2, while CSRF rates were 11.1% and 9.4%, respectively. When SF and CIRF were considered together as a descriptive secondary measure, the corresponding rates were 88.9% in Group 1 and 90.6% in Group 2. Perioperative and postoperative transfusion rates, complication rates, nephrostomy tube removal time, and hospital stay were similar between groups (all $p > 0.05$). Subgroup analyses demonstrated higher creatinine levels in solitary kidney patients and prolonged nephrostomy-related recovery parameters in patients with skeletal deformities. Previous open surgery was associated with larger access sheath size but did not adversely affect stone-free status or complication rates.

PCNL may be performed with acceptable perioperative safety and efficacy in patients with special anatomical and clinically relevant conditions when careful preoperative planning and standardized perioperative management are applied in experienced centers. These conditions alone do not appear to significantly compromise stone-free status or increase complication rates. However, stone-free outcomes and the CIRF/CSRF distinction should be interpreted with caution because postoperative imaging was not uniformly CT-based, and small residual fragments may not be clinically insignificant in all patients.

Introduction

Urinary stone disease is a growing health problem with a reported lifetime prevalence that varies across geographical regions and patient populations [1, 2]. Although various treatment modalities are available, international guidelines still recommend percutaneous nephrolithotomy (PCNL) as the first-line treatment for renal stones larger than 2 cm [3]. First described by Fernström and Johansson in 1976, PCNL has become the standard minimally invasive treatment for large and complex renal stones [4]. Compared with open surgery, PCNL offers lower morbidity and shorter recovery times and has largely replaced open procedures for the treatment of large renal stones in many centers due to its high stone-free rates [5].

Nevertheless, certain anatomical variations and clinically relevant conditions continue to present unique challenges during the planning and performance of PCNL. Although these conditions do not necessarily alter the technical steps of the procedure itself, they may influence surgical planning, access strategy, preservation of renal function, and perioperative risk assessment. Consequently, these patients are frequently regarded as representing special clinical

scenarios requiring individualized surgical planning. Such conditions include previous ipsilateral open renal stone surgery, solitary kidney, congenital renal anomalies, including horseshoe kidney, duplex collecting system and ectopic kidney, and skeletal deformities. In particular, solitary kidney represents not only a functional high-risk condition but also a setting in which compensatory renal hypertrophy, adaptive hyperfiltration and preservation of the only functioning renal unit may influence perioperative risk assessment [6]. In such patients, PCNL remains one of the main minimally invasive treatment options alongside shock wave lithotripsy (SWL) and retrograde intrarenal surgery (RIRS) [7–9]. Previous studies have reported variable outcomes in these patient populations, particularly in those with a history of open renal surgery or anomalous kidneys [10, 11]. Additionally, anomalies such as horseshoe kidney have been associated with an increased risk of adjacent organ injury during PCNL [12].

However, there is still no clear consensus in the literature regarding PCNL outcomes in these special anatomical and clinically relevant patient populations. Some studies have suggested that such clinical and anatomical characteristics do not significantly adversely affect stone-free or complication rates following PCNL [13–15]. Nevertheless, in daily clinical practice, these patients may still be perceived by urologists as high-risk and may require more cautious preoperative assessment and individualized surgical planning. In addition, the definition of stone-free status and the clinical relevance of small residual fragments remain important methodological issues when evaluating outcomes after endourological stone surgery. In the present study, we aimed to evaluate the safety and efficacy of PCNL in patients with special anatomical and clinically relevant conditions that are commonly perceived as challenging during routine urological practice. By comparing PCNL outcomes between patients with and without these characteristics using 1:1 exact and caliper-based matching, we sought to determine whether such conditions adversely affect clinical outcomes or complication rates when PCNL is performed in experienced centers.

Methods

This retrospective single-center study was conducted at the Department of Urology, Çukurova University Faculty of Medicine. The records of all patients who underwent percutaneous nephrolithotomy (PCNL) at our institution between September 2009 and June 2025 were reviewed retrospectively. During this period, a total of 3674 PCNL procedures were performed. Among these, 362 procedures were identified in patients with special anatomical or clinically relevant conditions. Twenty-one patients were excluded because of incomplete medical records, missing critical data, or insufficient follow-up information. The remaining 341 patients were classified as Group 1. Medical records, operative histories and imaging reports were rechecked to identify possible overlap among the predefined qualifying conditions. No patient had more than one qualifying condition; therefore, no patient was counted twice and no hierarchical subgroup assignment was required. If overlapping conditions had been present, patients would have been retained only once in the overall Group 1 analysis and assigned to a single subgroup according to the condition with the greatest anticipated impact on PCNL planning and perioperative risk, prioritizing solitary kidney, followed by skeletal deformity, congenital renal anomaly, and previous ipsilateral open renal stone surgery. These patients had at least one of the following conditions: duplex collecting system, solitary kidney, horseshoe kidney, history of ipsilateral open renal stone surgery, significant skeletal deformities affecting renal anatomy or patient positioning, or ectopic kidney. The patient-selection flow diagram is shown in Fig. 1.

For comparison, patients without these special anatomical or clinically relevant conditions were selected from the remaining PCNL cohort. Among 3312 procedures without special anatomical or clinically relevant conditions, 184 were excluded because of incomplete medical records, missing critical data, or insufficient follow-up information. The remaining 3128 procedures constituted the eligible control pool. From this pool, 341 patients were selected as matched controls and assigned to Group 2. The final matched cohort therefore included 682 patients.

A 1:1 exact and caliper-based matching procedure was performed using age, sex, and stone surface area (SSA, mm^2) as matching variables. Age and sex were matched exactly, and an a priori caliper of ± 50 mm^2 was applied for SSA.

Matching was performed without replacement, and the same control patient was not used more than once. All 341 eligible patients in Group 1 were successfully matched with 341 control patients. This approach was applied to ensure baseline comparability between the groups and to minimize selection bias. All patients who underwent PCNL for renal stones within the specified study period were included. Patients with incomplete medical records, missing critical data or insufficient follow-up information were excluded from the study. Preoperative urine cultures were obtained from all patients, and urinary tract infections were treated with culture-directed antibiotics before surgery. Antibiotic prophylaxis was administered according to institutional protocol. Anticoagulant and antiplatelet medications were discontinued 3–7 days before surgery and resumed postoperatively according to individual clinical assessment.

Patient positioning, tract size and surgical approach were individualized according to patient characteristics, renal anatomy, stone burden, stone location and surgeon preference. Both standard PCNL and mini-PCNL were performed in selected cases according to clinical judgment. Prone positioning was used whenever appropriate, whereas supine positioning was selectively preferred based on patient and stone related factors. Percutaneous access was obtained by the operating endourologist under fluoroscopic and/or ultrasonographic guidance according to renal anatomy, stone location, and surgeon preference. Tract dilation and access sheath size were selected individually according to the planned standard or mini-PCNL approach. Single-tract PCNL was preferred whenever feasible, whereas additional tracts were created when required to achieve adequate access to the stone burden. The choice of lithotripsy modality, including pneumatic lithotripsy or laser lithotripsy, was determined according to stone characteristics and intraoperative findings. Postoperative drainage, including nephrostomy tube placement or ureteral stenting, was determined according to intraoperative findings, bleeding, residual stone suspicion, collecting system integrity, and surgeon judgment. All procedures were performed by four senior endourologists, each of whom had performed more than 200 PCNL procedures before the study period, or under their direct supervision.

Ethical approval for the study was obtained from the Çukurova University Non-Interventional Clinical Research Ethics Committee (approval date: 14/11/2025; decision no: 160). The study was conducted in full compliance with relevant ethical guidelines and regulations and was designed in accordance with the principles of the Declaration of Helsinki to protect the health, privacy, and rights of the participants. Due to the retrospective nature of the study, the requirement for informed consent was waived by the ethics committee. Accordingly, informed consent was not obtained, and no direct or indirect contact was established with the patients through face-to-face interaction or any communication method.

Comprehensive preoperative, perioperative and postoperative data were collected for each patient from the electronic database and medical records by research assistants. Although the data had been recorded prospectively, they were analyzed retrospectively. Demographic variables included age, sex and body mass index (BMI). Stone-related variables included stone surface area (SSA, mm^2) and laterality (right/left). SSA was calculated on preoperative non-contrast computed tomography images using the longest stone diameter and the maximum perpendicular diameter on the axial or reconstructed plane providing the largest stone dimensions according to the following formula: SSA (mm^2) = length (mm) × width (mm) × π × 0.25. In patients with multiple renal calculi, total SSA was calculated as the sum of the surface areas of all stones. Calculated values were rounded to the nearest whole number for presentation. Stone density in Hounsfield units and stone composition were not available in a complete and standardized manner for the entire cohort because of the retrospective design and long study period; therefore, these variables were not included in the matching model.

Preoperative laboratory parameters included white blood cell count (WBC), hematocrit (Hct), platelet count (PLT), blood urea nitrogen (BUN), creatinine (Cr), sodium (Na), and potassium (K) levels. Operative variables included patient position (prone/supine), operative time (minutes), fluoroscopy time (minutes), requirement for second or third access, perioperative blood transfusion and perioperative complications. Postoperative outcomes included postoperative blood transfusion, fever, postoperative complications, stone-free status, nephrostomy tube removal time (days), duration of urine leakage after nephrostomy tube removal (days) and length of hospital stay (days). The presence of postoperative

residual stones was evaluated by intraoperative fluoroscopy, postoperative plain abdominal radiography (KUB), or non-contrast abdominal computed tomography (CT) according to routine clinical practice. Postoperative residual stone assessment was performed before discharge and/or at the first postoperative follow-up visit within 4–6 weeks. Residual fragments measuring ≤ 2 mm were classified as clinically insignificant residual fragments (CIRF), while larger residual stones were classified as clinically significant residual fragments (CSRF). Stone-free status versus any residual fragment was considered the primary residual-disease descriptor, whereas the CIRF/CSRF distinction was reported as a secondary, imaging-limited estimate. Because KUB radiography and fluoroscopy cannot reliably operationalize a ≤ 2 mm threshold, the CIRF-versus-CSRF boundary carries the same imaging-related uncertainty as the stone-free assessment. Because postoperative CT was not routinely performed in all patients during the entire study period, the imaging modality distribution could not be reliably reconstructed for all cases, and a CT-only sensitivity analysis could not be performed.

Statistical Analysis

To reduce potential confounding, patients with and without special anatomical or clinically relevant conditions were matched on age, sex, and stone surface area (SSA, mm^2). A 1:1 exact and caliper-based matching procedure was used. Age and sex were matched exactly, and an a priori caliper of ± 50 mm^2 was applied for SSA. Matching was performed without replacement. Age and sex were matched exactly, and an a priori caliper of ± 50 mm^2 was applied for SSA. Post-matching balance was assessed using standardized mean differences (SMDs), with an absolute SMD < 0.10 considered indicative of adequate balance between groups. Baseline characteristics used for matching are presented descriptively, and no statistical comparisons were performed for these variables.

Treatment period was categorized into three eras: 2009–2014, 2015–2019, and 2020–2025. The distribution of procedures across treatment eras was compared between the two groups using the chi-square test to evaluate potential temporal imbalance.

Categorical variables are presented as frequencies and percentages, while continuous variables are reported as mean±standard deviation or median and interquartile range (IQR). Group comparisons for categorical variables were performed using the chi-square test. The distribution of continuous variables was assessed for normality using the Kolmogorov–Smirnov test. As normality assumptions were not met, non-parametric analyses were conducted. Comparisons of continuous variables between two independent groups (patients with/without a specific clinical condition) were performed using the Mann–Whitney U test. When comparisons involved more than two groups, differences among groups were assessed using the Kruskal–Wallis test. Subgroup analyses were exploratory and were not based on subgroup-specific matching. Patients with duplex collecting system and ectopic kidney were included in the overall Group 1 analysis but were not evaluated as separate subgroups because of their small sample sizes. Comparisons were performed between patients without special anatomical or clinically relevant conditions and the larger clinical subgroups, including previous open surgery, horseshoe kidney, skeletal deformity, and solitary kidney.

Following a significant result, post-hoc comparisons were performed using Dunn's test. Given the a priori clinical interest in comparisons with the control group, only comparisons between patients without special anatomical or clinically relevant conditions and each subgroup were evaluated. Bonferroni adjustment was therefore applied based on four planned comparisons, rather than all possible pairwise contrasts. Statistical analyses were conducted using IBM SPSS Statistics version 20.0 (IBM Corp., Armonk, NY, USA). A two-sided p value < 0.05 was considered statistically significant.

Results

Among the patients included in the analysis, the mean age was 44.0 ± 17.1 years, and 192 patients (28.2%) were female. Based on predefined clinical criteria, patients were categorized into two groups: those with special anatomical and clinically relevant conditions and those without. Among patients with special anatomical and clinically relevant

conditions, previous open renal stone surgery was present in 115 patients (33.7%), horseshoe kidney in 53 (15.5%), duplex collecting system in 11 (3.2%), ectopic kidney in 3 (0.9%), skeletal deformity in 23 (6.7%), and solitary kidney in 136 patients (39.9%). Patients with duplex collecting system and ectopic kidney were included in the overall Group 1 analysis but were not evaluated as separate subgroups in Table 3 because of their small sample sizes. No patient had more than one qualifying condition.

After matching, the two groups were well balanced with respect to the matching variables. The absolute standardized mean differences were 0.000 for age, 0.000 for sex, and 0.008 for stone surface area, indicating adequate post-matching balance (Table 1).

Table 1
Post-matching balance diagnostics for matching variables

Variable	Group 1	Group 2	Absolute SMD
Age, mean ± SD	44.04 ± 17.12	44.04 ± 17.12	0.000
Female sex, n (%)	96 (28.2)	96 (28.2)	0.000
Stone surface area, mean ± SD	364.47 ± 273.60	366.51 ± 261.06	0.008

SMD: standardized mean difference; SSA: stone surface area. An absolute SMD < 0.10 was considered indicative of adequate balance between groups.

The distribution of procedures across treatment eras was evaluated to assess potential temporal imbalance between the groups. In Group 1, 128 patients (37.5%) underwent PCNL between 2009 and 2014, 129 patients (37.8%) between 2015 and 2019, and 84 patients (24.6%) between 2020 and 2025. In Group 2, the corresponding numbers were 114 (33.4%), 117 (34.3%), and 110 (32.3%), respectively. There was no statistically significant difference between the groups regarding treatment-era distribution ($p = 0.087$).

The comparative results of demographic, laboratory, operative, and postoperative characteristics between the two groups are presented in Table 2. Preoperative laboratory characteristics were similar between the two groups, with no statistically significant differences observed (all $p > 0.05$) except for CRE, which was significantly higher in Group 1 ($p = 0.007$). Although the median operative time was higher in Group 1 than in Group 2, the difference between the two groups was not statistically significant ($p = 0.338$). Perioperative and postoperative characteristics showed similar distributions between the two groups (all $p > 0.05$).

Stone-free status versus any residual fragment was considered the primary residual-disease descriptor, while CIRF and CSRF were reported as secondary, imaging-limited estimates. The stone-free rate was 78.3% in Group 1 and 80.6% in Group 2, corresponding to a risk difference of − 2.3 percentage points (95% CI: −8.4 to 3.7) and a risk ratio of 0.97 (95% CI: 0.90 to 1.05). Postoperative complication rates were 10.3% and 8.2%, respectively, corresponding to a risk difference of 2.1 percentage points (95% CI: −2.3 to 6.4) and a risk ratio of 1.25 (95% CI: 0.78 to 2.01). These estimates were provided as effect-size measures and should not be interpreted as evidence of formal equivalence, as no prespecified non-inferiority or equivalence margin was defined.

Table 2
Baseline demographic, laboratory, perioperative, and postoperative characteristics of Group 1 and Group 2

Age(year)	**Group 1: Patients with special anatomical and clinically relevant conditions**	**Group 2: Patients without special anatomical and clinically relevant conditions**	**p**
	(n = 341)	**(n = 341)**	
	47.0(32.0–57.0)	**47.0(32.0–57.0)**	**-**
Gender(female), n(%)	96(28.2)	96(28.2)	-
BMI	26.4(23.3–29.4)	26.5(23.4–29.4)	0.855
Stone surface area (SSA, mm²)	300.0(180.0-500.0)	300.0(200.0-500.0)	-
Side(Right), n(%)	169(49.6)	158(46.3)	0.399
Position(Prone), n(%)	329(96.5)	332(97.4)	0.658
Preoperative laboratory characteristics			
WBC	8000.0(6800.0-9450.0)	8000.0(6850.0-9600.0)	0.555
HTC	42.0(38.4–45.0)	42.0(38.1–45.0)	0.986
PLT	250.0(210.0-300.0)	267.0(220.0-320.0)	0.052
BUN	14.0(12.0–18.0)	14.0(11.9–18.0)	0.595
CRE	0.9(0.7–1.1)	0.8(0.7-1.0)	0.007
NA	140.0(138.0-141.0)	139.0(138.0-141.0)	0.742
K	4.4(4.1–4.6)	4.3(4.1–4.7)	0.600
Operation characteristics			
Operative time(min)	70.0(50.0-100.0)	65.0(50.0-100.0)	0.338
Fluoroscopy time(min)	9.0(5.0–14.0)	9.0(5.0–14.0)	0.905
Access sheath size (Fr)	24.0(24.0–26.0)	24.0(24.0–26.0)	0.118
2nd procedure, n (%)	67(19.6)	67(19.6)	> 0.999
Access sheath size (Fr)	24.0(24.0–26.0)	24.0(24.0–26.0)	0.310
3rd procedure, n (%)	4(6.0)	8(11.9)	0.364
Access sheath size (Fr)	28.0(24.5–30.0)	25.0(24.0–26.0)	0.214
Perioperative blood transfusion, n(%)	14(4.1)	15(4.4)	> 0.999
Perioperative complication, n(%)	7(2.1)	15(4.4)	0.129
Postoperative blood transfusion, n(%)	15(4.4)	10(2.9)	0.415
Postoperative complication, n(%)	35(10.3)	28(8.2)	0.355
Postoperative fever, n(%)	26(7.6)	16(4.7)	0.154

Age(year)	Group 1: Patients with special anatomical and clinically relevant conditions (n = 341)	Group 2: Patients without special anatomical and clinically relevant conditions (n = 341)	p
	47.0(32.0–57.0)	**47.0(32.0–57.0)**	-
Residual stone, n(%)	267(78.3)	275(80.6)	0.708
SF	36(10.6)	34(10.0)	
CIRF	38(11.1)	32(9.4)	
CSRF			
Time to nephrostomy tube removal (days)	2.0(1.0–2.0)	2.0(1.0–2.0)	0.341
Duration of urine leakage after nephrostomy tube removal (days)	3.0(2.0–4.0)	3.0(2.0–4.0)	0.616
Time to complete continence after nephrostomy tube removal (days)	1.0(1.0–1.0)	1.0(1.0–1.0)	0.721
Length of hospital stay (days)	3.0(2.0–4.0)	3.0(2.0–4.0)	0.716

Unless otherwise specified, data are expressed as median (IQR) or n (%).

No p-values are shown for matched variables.

SSA: stone surface area; SF: stone-free; CIRF: clinically insignificant residual fragments; CSRF: clinically significant residual fragments.

The CIRF/CSRF distinction was reported as a secondary, imaging-limited estimate because postoperative imaging was not uniformly CT-based.

Subgroup analyses were exploratory and were not based on subgroup-specific matching; therefore, these findings should be interpreted with caution because subgroup-level differences in age, BMI, and stone surface area may have influenced the observed results. Creatinine levels were significantly higher in the solitary kidney group compared with the control group (1.0 [0.9–1.4] vs 0.8 [0.7–1.0], $p < 0.001$), whereas they were significantly lower in the skeletal deformity group (0.5 [0.3–0.7] vs 0.8 [0.7–1.0], $p < 0.001$). The lower creatinine level observed in the skeletal deformity group should be interpreted cautiously, as this subgroup was younger and had a lower BMI, suggesting that age and muscle mass may have contributed to this difference rather than reflecting superior renal function. Access sheath size was significantly larger in patients with a history of open surgery compared with the control group (26.0 [24.0–30.0] vs 24.0 [24.0–26.0], $p < 0.001$), while no significant differences were observed among the other groups. Time to nephrostomy tube removal was longer in the skeletal deformity group compared with the control group (2.0 [2.0–3.0] vs 2.0 [1.0–2.0], $p < 0.001$), and a significant difference was also observed in patients with a history of open surgery (1.0 [1.0–2.0] vs 2.0 [1.0–2.0], $p < 0.001$). Similarly, the duration of urine leakage after nephrostomy tube removal was longer in the skeletal deformity group (4.0 [3.0–4.0] vs 3.0 [2.0–4.0], $p = 0.006$). Length of hospital stay was also significantly longer in the skeletal deformity group compared with the control group (5.0 [3.0–6.0] vs 3.0 [2.0–4.0], $p < 0.001$). Because these subgroup comparisons were exploratory and unmatched, differences in nephrostomy-related recovery parameters and length of hospital stay should be interpreted as hypothesis-generating rather than definitive subgroup effects. No significant differences were observed among the groups with respect to other perioperative and postoperative parameters (Table 3).

Table 3. Demographic, laboratory, perioperative, and postoperative outcomes according to specific clinical subgroups

	Patients without special anatomical and clinically relevant conditions (n = 341)	Open surgery (n = 115)	Horseshoe kidney (n = 53)	Skeletal deformity (n = 23)	Solitary kidney (n = 136)	p
Age(year)	47.0(32.0–57.0)[c]	49.0(33.0–57.0)	46.0(29.5–58.0)	21.0(8.0–47.0)	48.0(35.0–59.0)	< 0.001
Gender(female), n(%)	96(28.2)	42(36.5)	8(15.1)	6(26.1)	35(25.7)	0.063
BMI	26.5(23.4–29.4)[c]	27.3(24.9–31.1)	25.4(22.9–28.3)	20.8(16.5–27.5)	26.3(23.4–29.4)	< 0.001
Stone surface area (SSA, mm^2)	300.0(200.0-500.0)[a]	400.0(200.0-600.0)	280.0(175.0-400.0)	200.0(180.0-500.0)	250.0(150.0-400.0)	< 0.001
Side(Right), n(%)	158(46.3)	51(44.3)	29(54.7)	13(56.5)	68(50.0)	0.588
Position(Prone), n(%)	332(97.4)	114(99.1)	53(100.0)	23(100.0)	126(92.6)	0.010
Preoperative laboratory characteristics						
WBC	8000.0(6850.0-9600.0)	7900(6800.0-9100.0)	8000.0(6000.0-9800.0)	8800.0(6600.0-9600.0)	8500.0(7000.0-10000.0)	0.169
HTC	42.0(38.1–45.0)	42.0(39.0–45.0)	42.4(39.0–45.0)	40.0(36.0-42.6)	41.1(38.0–44.0)	0.108
PLT	267.0(220.0-320.0)	248.0(208.0-295.0)	250.0(204.5-317.5)	278.0(245.0-389.0)	258.5(210.0-300.0)	0.065
BUN	14.0(11.9–18.0) [c,d]	13.0(11.0–17.0)	13.0(10.9–16.8)	11.0(8.0-14.6)	16.0(13.7–20.7)	< 0.001
CRE	0.8(0.7-1.0) [c,d]	0.8(0.7-1.0)	0.8(0.7-1.0)	0.5(0.3–0.7)	1.0(0.9–1.4)	< 0.001
NA	139.0(138.0-141.0) [a]	140.0(138.0-142.0)	139.0(137.0-141.0)	139.0(138.0-140.0)	139.0(137.0-141.0)	0.009
K	4.3(4.1–4.7)	4.4(4.1–4.6)	4.3(4.0-4.6)	4.3(4.1–4.5)	4.4(4.1–4.6)	0.586
Operation characteristics						
Operative time(min)	65.0(50.0-100.0)	60.0(45.0–90.0)	80.0(60.0-115.0)	90.0(60.0-105.0)	80.0(60.0-113.8)	0.003‡
Fluoroscopy time(min)	9.0(5.0–14.0)	9.0(5.0–12.0)	10.0(7.0–15.0)	8.0(5.0–14.0)	8.0(5.0–15.0)	0.744
Access sheath size (Fr)	24.0(24.0–26.0) [a,c]	26.0(24.0–30.0)	24.0(24.0–26.0)	24.0(20.0–24.0)	24.0(24.0–26.0)	< 0.001
2nd procedure, n (%)	67(19.6)	30(26.1)	7(13.2)	3(13.0)	25(18.4)	0.271

Table 3. Demographic, laboratory, perioperative, and postoperative outcomes according to specific clinical subgroups

	Patients without special anatomical and clinically relevant conditions (n = 341)	Open surgery (n = 115)	Horseshoe kidney (n = 53)	Skeletal deformity (n = 23)	Solitary kidney (n = 136)	p
3rd procedure, n (%)	8(11.9)	4(13.3)	0(0.0)	0(0.0)	0(0.0)	0.338
Perioperative blood transfusion, n(%)	15(4.4)	9(7.8)	0(0.0)	1(4.3)	4(2.9)	0.170
Perioperative complication, n(%)	15(4.4)	2(1.7)	0(0.0)	1(4.3)	3(2.2)	0.330
Postoperative blood transfusion, n(%)	10(2.9)	5(4.3)	0(0.0)	1(4.3)	9(6.6)	0.173
Postoperative complication, n(%)	28(8.2)	20(8.7)	2(3.8)	3(13.0)	19(14.0)	0.165
Postoperative fever, n(%)	16(4.7)	17(14.8)	1(1.9)	1(4.3)	7(5.1)	0.006
Residual stone, n(%) SF CIRF CSRF	275(80.6) 34(10.0) 32(9.4)	97(84.3) 10(8.7) 8(7.0)	37(69.8) 8(15.1) 8(15.1)	20(87.0) 1(4.3) 2(8.7)	100(73.5) 17(12.5) 19(14.0)	0.325
Time to nephrostomy tube removal (days)	2.0(1.0–2.0) [a,c]	1.0(1.0–2.0)	2.0(2.0-2.8)	2.0(2.0–3.0)	2.0(1.0–3.0)	< 0.001
Duration of urine leakage after nephrostomy tube removal (days)	3.0(2.0–4.0) [c]	3.0(2.0–3.0)	3.0(3.0–4.0)	4.0(3.0–4.0)	3.0(2.0–4.0)	0.006
Time to complete continence after nephrostomy tube removal (days)	1.0(1.0–1.0)	1.0(1.0–1.0)	1.0(1.0–1.0)	1.0(1.0–1.0)	1.0(1.0–1.0)	0.324
Length of hospital stay (days)	3.0(2.0–4.0)[c]	3.0(2.0–4.0)	3.0(3.0–4.0)	5.0(3.0–6.0)	3.0(3.0–5.0)	< 0.001

Table 3. Demographic, laboratory, perioperative, and postoperative outcomes according to specific clinical subgroups

	Patients without special anatomical and clinically relevant conditions (n = 341)	Open surgery (n = 115)	Horseshoe kidney (n = 53)	Skeletal deformity (n = 23)	Solitary kidney (n = 136)	p

Unless otherwise specified, data was expressed as median (IQR). [a]p < 0.05 compared with open surgery, [b]p < 0.05 compared with horseshoe kidney, [c]p < 0.05 compared with skeletal deformity, [d]p < 0.05 compared with solitary kidney.

‡No significant differences were found between the patients without a specific clinical condition group and the other groups in pairwise comparisons. Percentages for second procedures were calculated using the total number of patients in each group or subgroup as the denominator. Percentages for third procedures were calculated among patients who underwent a second procedure. Access sheath size for additional procedures was reported only for patients who underwent the corresponding procedure.

SSA: stone surface area; SF: stone-free; CIRF: clinically insignificant residual fragments; CSRF: clinically significant residual fragments.

Discussion

In the present study, we demonstrated that the presence of special anatomical and clinically relevant conditions alone was not associated with significantly worse perioperative outcomes of PCNL in two cohorts matched for age, sex, and stone surface area. Stone-free rates were 78.3% in patients with special anatomical and clinically relevant conditions and 80.6% in the control group, with similar distributions of residual stone status (CIRF/CSRF) between the groups. Likewise, no significant differences were observed in perioperative and postoperative transfusion rates, perioperative and postoperative complication rates, time to nephrostomy tube removal, or length of hospital stay. Because the clinical significance of small residual fragments remains debated, stone-free status was considered the main descriptive efficacy outcome, while CIRF and CSRF were reported separately. Although SF plus CIRF has historically been used as a composite estimate of treatment success in some endourological studies, this combined measure should be interpreted cautiously and was not regarded as equivalent to a strictly fragment-free outcome [5, 16, 17]. When SF and CIRF were evaluated together as a descriptive secondary measure, the rates were 90.6% in the control group and 88.9% in patients with special anatomical and clinically relevant conditions.

The concept of clinically insignificant residual fragments has been increasingly questioned in contemporary endourological literature. Although small residual fragments have traditionally been considered acceptable in some studies, recent evidence suggests that fragments in the 1–4 mm range may be associated with stone-related events, regrowth, complications, and need for secondary intervention [18, 19]. Therefore, the term “clinically insignificant” should be interpreted as a historical convention rather than definitive evidence of biological or clinical harmlessness [20]. In the present study, long-term follow-up data regarding stone-related events, fragment growth, renal colic, emergency visits, or secondary procedures were not available in a standardized manner. Consequently, we could not directly determine whether CIRF cases remained clinically silent over time. For this reason, SF, CIRF, and CSRF were presented separately, and the composite SF plus CIRF rate should be interpreted only as a descriptive outcome rather than a definitive measure of clinical success. In addition, because postoperative imaging was not uniformly CT-based, the distinction between CIRF and CSRF should also be interpreted as a secondary, imaging-limited estimate rather than a definitive classification of residual fragment burden.

Although guidelines recommend PCNL as the first-line treatment for renal stones larger than 2 cm, this procedure may still raise concerns among urologists when performed in patients with special anatomical or clinically relevant conditions[21]. However, multicenter prospective data have demonstrated that PCNL outcomes are influenced by institutional case volume and surgical experience, with more experienced centers achieving higher stone-free rates and lower complication rates [22]. In this context, our findings suggest that when stone burden and patient characteristics are balanced, patients with anatomical anomalies or additional clinical conditions can achieve comparable clinical outcomes in experienced centers.

In the subgroup analysis of renal malformations from the CROES database, stone-free rates in patients with congenital renal anomalies who underwent PCNL were found to be comparable to those without anomalies, and complication rates were not significantly increased. However, longer operative times and higher rates of failed access were reported in patients with anomalous kidneys [23]. Similarly, although not every duplex collecting system necessarily increases the technical complexity of PCNL, variations in collecting system anatomy may influence access planning, calyceal orientation and surgical strategy depending on the type of duplication and stone location. Therefore, these patients may require individualized preoperative assessment rather than being considered uniformly technically difficult. In contrast to the literature, the absence of a statistically significant difference in operative time in our study may be explained in part by balancing stone burden through matching for stone surface area and by the standardization of access sheath selection in a high-volume center. However, subgroup-level comparisons were exploratory and were not based on subgroup-specific matching; therefore, these findings should not be interpreted as definitive evidence that each anatomical subgroup carries the same operative risk.

PCNL is also considered technically challenging in patients with skeletal deformities because of marked anatomical variations, impaired respiratory function, and limited availability of an appropriate percutaneous access tract [24, 25]. In this patient group, relatively lower stone-free rates after a single session have been reported; however, final stone-free rates may reach 88–100% following auxiliary procedures [25, 26]. Furthermore, displacement of anatomical landmarks in patients with scoliosis may complicate percutaneous access, and it has been emphasized that detailed preoperative imaging, appropriate patient positioning, and ultrasound-guided access may help reduce the risk of complications [27]. Although severe scoliosis has been described as a relative contraindication in some guidelines, PCNL has been shown to be a safe and effective treatment option in experienced centers [24, 28]. In our study, the absence of significant differences in operative time, complication rates, and postoperative outcomes suggests that PCNL may be feasible in this patient group with appropriate patient selection and careful preoperative planning. However, the skeletal deformity subgroup was younger and had a lower BMI than the control group, and the lower creatinine level observed in this subgroup may reflect age and muscle mass rather than a true difference in renal function. Therefore, subgroup findings, including nephrostomy-related recovery parameters and length of hospital stay, should be interpreted as exploratory and hypothesis-generating. Nevertheless, as reported in the literature, individualized surgical planning and preparedness for auxiliary procedures remain important because of the anatomical challenges encountered in these patients.

PCNL in patients with a history of previous ipsilateral open surgery has remained a controversial issue in the literature. A meta-analysis including 17 studies reported that prior open surgery may be associated with greater hemoglobin decrease, increased need for embolization, longer operative times, and lower stone-free rates [29]. In contrast, prospective cohort data have shown that, particularly with modern equipment and surgical experience, final success and morbidity rates are comparable to those reported in the literature, although fluoroscopy and operative times may be prolonged [30]. Similarly, in our study, no significant differences were observed in operative or fluoroscopy times in the subgroup of patients with a history of open surgery. In addition, consistent with the literature, no significant differences were found in stone-free or complication rates. However, the significantly larger renal access sheath size observed in this subgroup may be explained by altered intrarenal pressure dynamics related to perinephric fibrosis. Nevertheless, the

limited differences compared with the control group and the absence of prolonged operative time suggest that this finding should be interpreted more as a cautionary signal rather than a clinically substantial disadvantage.

PCNL in patients with a solitary kidney represents a particularly relevant clinical setting in which the balance between maximal stone clearance and minimal morbidity is of critical importance because of the limited functional renal reserve. Although the surgical technique itself may be similar to that used in patients with two functioning kidneys, solitary kidneys, particularly congenital or long-standing solitary kidneys, may undergo compensatory renal hypertrophy and adaptive hyperfiltration [6]. This adaptive response may be accompanied by increased renal blood flow, parenchymal enlargement, and altered intrarenal hemodynamics. Therefore, percutaneous access and tract dilation in a solitary kidney may carry greater clinical consequences in terms of bleeding, parenchymal injury and postoperative renal functional deterioration [31], even when the technical steps of PCNL are not fundamentally different. Preservation of the only functioning renal unit is therefore of paramount importance. Therefore, surgeons frequently approach these cases with greater caution because potential complications, particularly bleeding, collecting system injury, infection, obstruction or residual fragments, may have greater clinical consequences than in patients with two functioning kidneys. A meta-analysis reported that PCNL in solitary kidneys could achieve initial stone-free rates of 72% and final stone-free rates approaching 90%; however, minor complications as well as complications such as transfusion requirement and postoperative fever were found to be significantly increased and should not be overlooked [32, 33]. In our study, the similarity of postoperative complication rates between the solitary kidney group and the control group suggests that outcomes may be stabilized through appropriate management of stone burden and surgical experience, even in highly sensitive patient populations such as those with a solitary kidney.

One of the major strengths of the present study is that patients with special anatomical and clinically relevant conditions were evaluated in a single high-volume center with extensive experience in PCNL. In addition, matching for age, sex and stone surface area enabled balancing of major confounding variables, thereby allowing more reliable comparisons between the groups. Post-matching standardized mean differences were below 0.10 for all matching variables, supporting adequate balance between the two matched groups. This methodological approach reduces an important limitation frequently emphasized in the literature, namely that comparisons based solely on anatomical complexity may be misleading because of differences in stone burden and patient characteristics. Furthermore, evaluating subgroups such as previous open surgery, horseshoe kidney, solitary kidney, and severe skeletal deformity within the same methodological framework provides a more comprehensive and clinically applicable perspective for the heterogeneous patient population undergoing PCNL. Nevertheless, these subgroup analyses were exploratory and were not based on subgroup-specific 1:1 exact and caliper-based matching.

In the present cohort, the surgical approach was individualized rather than restricted to a uniform standard PCNL technique. Accordingly, both standard PCNL and mini-PCNL were performed in selected cases depending on patient characteristics, renal anatomy, stone burden, stone location, and surgeon judgment. However, the present study was not designed to compare standard PCNL and mini-PCNL, and mini-PCNL was therefore not analyzed as a separate technical subgroup. Similarly, endoscopic combined intrarenal surgery (ECIRS) may be particularly useful in complex renal stones by facilitating calyceal orientation, assisting percutaneous puncture through simultaneous retrograde visualization, and potentially improving stone-free rates. Nevertheless, ECIRS was not applied as a standardized protocol throughout the entire study period and was not evaluated separately in the present retrospective analysis. Therefore, the present findings should be interpreted as reflecting outcomes of individualized PCNL practice in a high-volume center rather than comparative evidence regarding standard PCNL, mini-PCNL, or ECIRS. Future prospective studies using standardized surgical protocols are needed to better define the role of mini-PCNL and ECIRS in patients with special anatomical and clinically relevant conditions.

Nevertheless, several limitations of the study may restrict the generalizability of the findings. The retrospective single-center design is susceptible to temporal bias related to changes in energy sources, lithotripsy devices, imaging protocols,

access strategies, tract size, miniaturization, and surgeon experience over time. Although the distribution of procedures across treatment eras did not differ significantly between the groups, the control group included a relatively higher proportion of patients treated during the most recent era, 2020–2025, compared with Group 1. This imbalance may have biased outcomes slightly in favor of the control group because endourological technology, miniaturization, energy sources, access strategies and perioperative imaging strategies evolved substantially between 2009 and 2025. In addition, the heterogeneous nature of the special clinical condition group may mask subgroup-specific differences under a single summary effect, while the relatively small sample sizes of certain rare anomalies, such as duplex collecting systems and ectopic kidneys, limit the statistical power of subgroup analyses. These rare anomalies were included in the overall Group 1 analysis but were not evaluated as separate subgroups because of their small sample sizes. Moreover, subgroup comparisons were not based on subgroup-specific matching and may therefore be confounded by age, BMI, and stone burden.

Another limitation is that stone burden was assessed using stone surface area rather than stone volume. Although stone volume may provide a more comprehensive estimate of the true stone burden [34, 35], stone surface area has been widely used in the endourological literature and allowed standardized comparison across our study population. Nevertheless, the use of SSA rather than CT-based volumetric stone burden may leave residual confounding by stone complexity. In addition, stone density in Hounsfield units and stone composition were not available in a complete and standardized manner for the entire cohort and therefore could not be incorporated into the matching model.

The most important limitation of the present study is the lack of uniform CT-based postoperative stone-free assessment. Residual stones were assessed using intraoperative fluoroscopy, KUB radiography, or non-contrast CT according to routine clinical practice. Because CT was not routinely performed in all patients during the entire study period and imaging modality was not consistently documented in a standardized format, the proportion of patients assessed by each modality could not be reliably reconstructed, and a CT-only sensitivity analysis could not be performed. KUB radiography and fluoroscopy have limited sensitivity for small residual fragments and cannot reliably operationalize a ≤ 2 mm CIRF threshold [5, 16, 20]. Therefore, residual fragments may have been underestimated and stone-free rates may have been overestimated. This limitation is particularly relevant when interpreting the SF plus CIRF composite rate, which should not be considered equivalent to a strictly CT-confirmed fragment-free outcome.

Finally, no formal non-inferiority or equivalence margin was prespecified, and the absence of statistically significant differences should not be interpreted as proof of equivalence. In addition, no formal a priori sample-size calculation was performed because of the retrospective design. Long-term stone-related events, fragment regrowth, emergency visits, and secondary interventions were not available in a standardized manner; therefore, the clinical course of patients with CIRF could not be directly assessed. Future prospective multicenter studies incorporating standardized CT-based imaging protocols, volumetric stone burden assessment, validated nephrolithometry scoring systems [36], and long-term follow-up of residual fragments are needed. Such studies may better define optimal access strategies, infection and bleeding risks, and long-term renal functional outcomes for each special anatomical or clinically relevant condition.

Conclusion

The findings of the present study suggest that PCNL may be performed with acceptable perioperative safety and efficacy in patients with special anatomical and clinically relevant conditions when appropriate center selection, careful preoperative planning, and standardized perioperative management are applied. The achievement of similar perioperative complication rates and stone-free rates in this patient population supports PCNL as a feasible treatment option in experienced centers. However, stone-free outcomes should be interpreted with caution because postoperative imaging was not uniformly CT-based and small residual fragments may not be clinically insignificant in all patients. Nevertheless, future multicenter prospective studies incorporating stratified analyses based on nephrolithometry scoring systems, standardized CT-based postoperative imaging, long-term residual-fragment follow-up, and volumetric stone burden

assessment are needed to better define optimal access strategies, infection and bleeding risks, and long-term renal functional outcomes for each special anatomical or clinically relevant condition.

Declarations

Funding

No funding was received for conducting this study.

Competing Interests

The authors declare no competing interests.

Ethics Approval

This retrospective study was conducted in accordance with the principles of the Declaration of Helsinki. Ethical approval was obtained from the Institutional Ethics Committee of Çukurova University Faculty of Medicine (Approval No: 160; Date: 14.11.2025).

Consent to Participate

Informed consent was waived due to the retrospective nature of the study.

Consent for Publication

Not applicable.

Data Availability

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

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this manuscript, the authors used ChatGPT solely for grammar and language editing. Following the use of this tool, the authors carefully reviewed and revised the manuscript and take full responsibility for the final content of the publication.

Author's Contributions

Nebil Akdoğan: Project development, supervision, manuscript review and editing.

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Mehmet Gürkan Arıkan: Data collection, data analysis, manuscript review and editing.

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References

1. Halbritter J (2021) Genetics of kidney stone disease-Polygenic meets monogenic. Nephrol Ther 17S:S88–S94. https://doi.org/10.1016/j.nephro.2020.02.003
2. Zhe M, Hang Z (2017) Nephrolithiasis as a risk factor of chronic kidney disease: a meta-analysis of cohort studies with 4,770,691 participants. Urolithiasis 45:441–448. https://doi.org/10.1007/s00240-016-0938-x
3. Akram M, Jahrreiss V, Skolarikos A et al (2024) Urological Guidelines for Kidney Stones: Overview and Comprehensive Update. J Clin Med 13:1114. https://doi.org/10.3390/jcm13041114
4. Fernström I, Johansson B (1976) Percutaneous pyelolithotomy. A new extraction technique. Scand J Urol Nephrol 10:257–259. https://doi.org/10.1080/21681805.1976.11882084
5. European Association of Urology (2024) EAU Guidelines on Urolithiasis. EAU Guidelines Office, Arnhem
6. Tantisattamo E, Dafoe DC, Reddy UG et al (2019) Current Management of Patients With Acquired Solitary Kidney. Kidney Int Rep 4:1205–1218. https://doi.org/10.1016/j.ekir.2019.07.001
7. Lavan L, Herrmann T, Netsch C et al (2020) Outcomes of ureteroscopy for stone disease in anomalous kidneys: a systematic review. World J Urol 38:1135–1146. https://doi.org/10.1007/s00345-019-02810-x
8. Prakash G, Sinha RJ, Jhanwar A et al (2017) Outcome of percutaneous nephrolithotomy in anomalous kidney: Is it different? Urol Ann 9:23–26. https://doi.org/10.4103/0974-7796.198836
9. Sofikerim M, Demirci D, Gülmez I, Karacagil M (2007) Does previous open nephrolithotomy affect the outcome of percutaneous nephrolithotomy? J Endourol 21:401–403. https://doi.org/10.1089/end.2006.0293
10. Gulani A, Kumar U, Yadav SS et al (2021) Percutaneous nephrolithotomy in previously operated patients: A prospective study. Urol Ann 13:24–29. https://doi.org/10.4103/UA.UA_175_19
11. Salvi M, Muto G, Tuccio A et al (2020) Active treatment of renal stones in pelvic ectopic kidney: systematic review of literature. Minerva Urol Nefrol 72:691–697. https://doi.org/10.23736/S0393-2249.20.03792-3
12. Escobar Monroy R, Proietti S, De Leonardis F et al (2025) Complications in Percutaneous Nephrolithotomy. Complications 2:5. https://doi.org/10.3390/complications2010005
13. Kurtulus FO, Fazlioglu A, Tandogdu Z et al (2008) Percutaneous nephrolithotomy: primary patients versus patients with history of open renal surgery. J Endourol 22:2671–2675. https://doi.org/10.1089/end.2007.0431
14. Etemadian M, Maghsoudi R, Abdollahpour V, Amjadi M (2013) Percutaneous nephrolithotomy in horseshoe kidney: our 5-year experience. Urol J 10:856–860
15. Akman T, Binbay M, Tekinarslan E et al (2011) Outcomes of percutaneous nephrolithotomy in patients with solitary kidneys: a single-center experience. Urology 78:272–276. https://doi.org/10.1016/j.urology.2010.12.029
16. Tzelves L, Geraghty R, Lombardo R et al (2023) Duration of Follow-up and Timing of Discharge from Imaging Follow-up, in Adult Patients with Urolithiasis After Surgical or Medical Intervention: A Systematic Review and Meta-analysis from the European Association of Urology Guideline Panel on Urolithiasis. Eur Urol Focus 9:188–198. https://doi.org/10.1016/j.euf.2022.06.016
17. Kingma RA, Doppen C, Bus MTJ et al (2024) The significance of clinically insignificant residual fragments after percutaneous nephrolithotomy: an analysis into the relevance of complete stone clearance. World J Urol 42:78. https://doi.org/10.1007/s00345-024-04774-z
18. Chew BH, Brotherhood HL, Sur RL et al (2016) Natural History, Complications and Re-Intervention Rates of Asymptomatic Residual Stone Fragments after Ureteroscopy: a Report from the EDGE Research Consortium. J Urol 195:982–986. https://doi.org/10.1016/j.juro.2015.11.009
19. Werth H, Zorzi F, Bravo-Balado A et al (2025) Post ureteroscopy stone status, comparing stone free rate and zero fragment rate - does the difference matter ? World J Urol 43:670. https://doi.org/10.1007/s00345-025-05989-4
20. Çavdar OF, Aydin A, Tokas T et al (2025) Residual stone fragments: systematic review of definitions, diagnostic standards. World J Urol 43:194. https://doi.org/10.1007/s00345-025-05572-x

21. Liatsikos E, Tsaturyan A, Kallidonis P (2021) Percutaneous Nephrolithotomy for Stone Disease: Which Position? Prone Position! Eur Urol Open Sci 35:6–8. https://doi.org/10.1016/j.euros.2021.07.009
22. Opondo D, Tefekli A, Esen T et al (2012) Impact of case volumes on the outcomes of percutaneous nephrolithotomy. Eur Urol 62:1181–1187. https://doi.org/10.1016/j.eururo.2012.03.010
23. Osther PJ, Razvi H, Liatsikos E et al (2011) Percutaneous nephrolithotomy among patients with renal anomalies: patient characteristics and outcomes; a subgroup analysis of the clinical research office of the endourological society global percutaneous nephrolithotomy study. J Endourol 25:1627–1632. https://doi.org/10.1089/end.2011.0146
24. Tan H-T, Yi W-T, Shi L et al (2021) Clinical application of percutaneous nephrolithotomy in a patient with kyphoscoliosis. J Int Med Res 49:300060520987937. https://doi.org/10.1177/0300060520987937
25. Goumas-Kartalas I, Montanari E (2010) Percutaneous nephrolithotomy in patients with spinal deformities. J Endourol 24:1081–1089. https://doi.org/10.1089/end.2010.0095
26. Kara C, Resorlu B, Ozyuvali E, Unsal A (2011) Is percutaneous nephrolithotomy suitable for patients with scoliosis: single-center experience. Urology 78:37–42. https://doi.org/10.1016/j.urology.2010.11.004
27. Li H, Zhang Z, Li H et al (2012) Ultrasonography-Guided Percutaneous Nephrolithotomy for the Treatment of Urolithiasis in Patients with Scoliosis. Int Surg 97:182–188. https://doi.org/10.9738/CC93.1
28. Alomar MA, Alghamdi OS, Alghafees MA et al (2021) Clinical Application of a Two-Step Percutaneous Nephrolithotomy in a Patient With Severe Kyphoscoliosis and a Malrotated Kidney. Cureus 13:e17340. https://doi.org/10.7759/cureus.17340
29. Hu H, Lu Y, Cui L et al (2016) Impact of previous open renal surgery on the outcomes of subsequent percutaneous nephrolithotomy: a meta-analysis. BMJ Open 6:e010627. https://doi.org/10.1136/bmjopen-2015-010627
30. Sakly A, Khaldi S, Touati A et al (2024) Outcomes and complications of percutaneous nephrolithotomy as primary versus secondary procedure for kidney stones: a prospective cohort study. Ann Med Surg (Lond) 86:5711–5715. https://doi.org/10.1097/MS9.0000000000002502
31. Bucuras V, Gopalakrishnam G, Wolf JS et al (2012) The Clinical Research Office of the Endourological Society Percutaneous Nephrolithotomy Global Study: nephrolithotomy in 189 patients with solitary kidneys. J Endourol 26:336–341. https://doi.org/10.1089/end.2011.0169
32. Peng L, Meng C, Xia Z et al (2022) Determining the safety and effectiveness of percutaneous nephrolithotomy and retrograde intrarenal surgery in treating nephrolithiasis in patients with solitary kidneys. Urolithiasis 51:2. https://doi.org/10.1007/s00240-022-01386-3
33. Sun W, Niyazi S, Gao X et al (2024) Safety and Effectiveness of Percutaneous Nephrolithotomy for Patients with Stones in a Solitary Kidney: A Meta-Analysis. Indian J Surg 86:39–56. https://doi.org/10.1007/s12262-023-03787-z
34. Vuruskan E, Dilek O, Karkin K et al (2022) Volume should be used instead of diameter for kidney stones between 10 and 20 mm to determine the type of surgery and increase success. Urolithiasis 50:215–221. https://doi.org/10.1007/s00240-022-01305-6
35. Geraghty R, Pietropaolo A, Tzelves L et al (2025) Which Measure of Stone Burden is the Best Predictor of Interventional Outcomes in Urolithiasis: A Systematic Review and Meta-analysis by the YAU Urolithiasis Working Group and EAU Urolithiasis Guidelines Panel. Eur Urol Open Sci 71:22–30. https://doi.org/10.1016/j.euros.2024.10.024
36. Farhan M, Nazim SM, Salam B, Ather MH (2015) Prospective evaluation of outcome of percutaneous nephrolithotomy using the 'STONE' nephrolithometry score: A single-centre experience. Arab J Urol 13:264–269. https://doi.org/10.1016/j.aju.2015.07.006

Figures

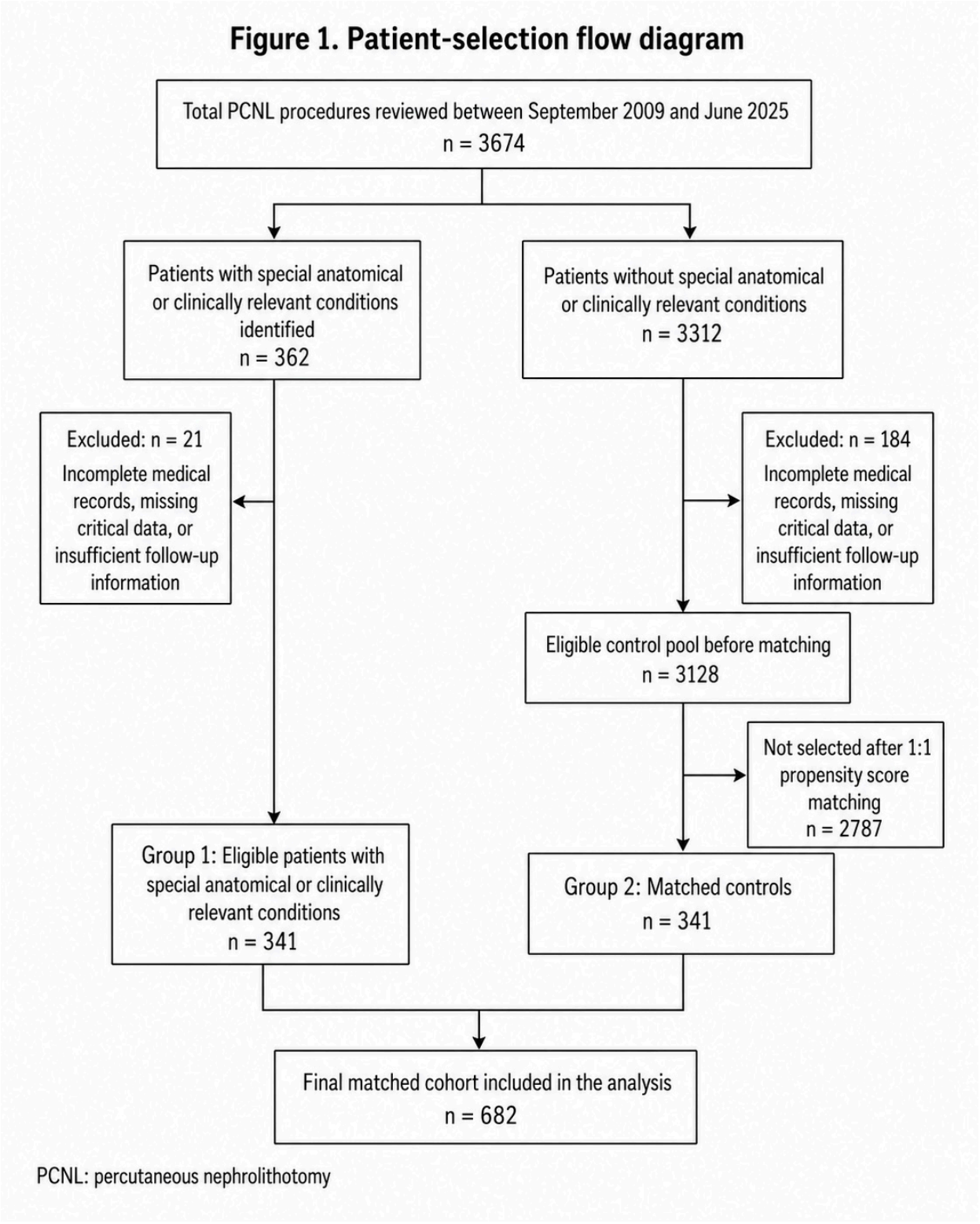


Figure 1

Patient-selection flow diagram. A total of 3674 PCNL procedures performed between September 2009 and June 2025 were reviewed. Among 362 patients identified with special anatomical or clinically relevant conditions, 21 were excluded because of incomplete medical records, missing critical data, or insufficient follow-up information, leaving 341 patients in Group 1. Among 3312 patients without these conditions, 184 were excluded for the same reasons, leaving 3128 eligible controls. After 1:1 exact and caliper-based matching based on age, sex, and stone surface area, 341 matched controls were selected as Group 2. The final matched cohort included 682 patients. PCNL: percutaneous nephrolithotomy.