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# Flank Versus Prone and Supine Positions in Percutaneous Nephrolithotomy: A Systematic Review of Stone Clearance and Perioperative Outcomes

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A R T I C L E I N F O

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A B S T R A C T

Percutaneous nephrolithotomy (PCNL) is traditionally performed in the prone position, though this may pose anesthetic risks for high-risk patients. The flank position has been proposed as an alternative, but evidence remains limited. This systematic review of seven studies (2008–2023) found that flank PCNL achieves stone-free rates of 85–91%, comparable to prone positioning, with similar complication profiles and indications of reduced bleeding and respiratory issues. Operative time varied across studies, while hospital stay remained consistent. Overall, the findings support flank PCNL as a safe and effective alternative, though small sample sizes and methodological heterogeneity highlight the need for larger multicenter research.

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## INTRODUCTION

Urolithiasis continues to represent a major public health burden worldwide, with its incidence and prevalence steadily rising over the past decades. In developed countries, approximately 10–12% of the population will develop urinary stones during their lifetime, and a similar trend is now observed in developing nations due to increasingly Westernized diets, sedentary lifestyles, and rising obesity rates. High recurrence rates—up to 50% within ten years—further underscore the chronic nature and healthcare burden of kidney stone disease. In the United States, for instance, Scales and colleagues reported that more than one in ten adults is affected, reflecting a significant increase over previous decades. Clinically, urolithiasis is a major cause of urological emergencies, with large stones frequently requiring definitive surgical management.

Management of renal calculi depends on stone characteristics and patient factors, with options including medical expulsive therapy, extracorporeal shock wave lithotripsy (ESWL), ureteroscopy, and percutaneous nephrolithotomy (PCNL). Among these, PCNL is widely regarded as the gold standard for stones larger than 2 cm, staghorn calculi, and stones refractory to other treatments. Its consistently high stone-free rates and ability to manage complex stone burdens in a single procedure have solidified its role in contemporary practice. Despite advancements in flexible ureteroscopy and miniaturized instruments, PCNL remains indispensable for managing large or complex stones.

Traditionally performed in the prone position, PCNL offers reliable access to the posterior calyces and a familiar orientation for surgeons. However, prone positioning poses challenges, including difficult airway access, hemodynamic instability, and increased risk in obese or cardiopulmonary-compromised patients. Repositioning from lithotomy to prone also prolongs operative times and limits combined antegrade–retrograde procedures.

These limitations have driven the exploration of alternative patient positions, particularly supine and flank, with the goal of improving perioperative safety and procedural flexibility. This systematic review aims to evaluate the efficacy and safety of flank PCNL compared with prone and supine positions, focusing on stone-free rates, perioperative complications, operative time, and hospital stay.

## LITERATURE REVIEW

The evolution of PCNL positioning reflects ongoing efforts to optimize patient safety and surgical efficiency. Supine PCNL, introduced by Valdivia in the late 1980s and later refined into the Galdakao-modified supine Valdivia position, addresses many anesthetic limitations of the prone approach. It offers better airway access, reduced cardiovascular strain, and allows simultaneous retrograde intrarenal surgery without patient repositioning. Large multicenter studies, including data from the Clinical Research Office of the Endourological Society, have validated supine PCNL as a safe and effective alternative. Nonetheless, debates persist regarding differences in stone-free rates and adverse event profiles compared with prone positioning.

More recently, attention has turned to the lateral decubitus or flank position. Flank PCNL seeks to combine the ergonomic and anatomical advantages of the prone position with the anesthetic benefits of the supine approach. Studies suggest that flank positioning may offer better ventilation, more stable hemodynamics, and improved comfort for the surgical team. It is particularly advantageous for patients who cannot tolerate prone positioning due to obesity, musculoskeletal restrictions, or cardiopulmonary comorbidities. Early clinical experiences have shown stone-free rates comparable to prone PCNL, with potentially reduced bleeding and fewer respiratory complications.

Despite promising findings, existing evidence on flank PCNL remains limited and heterogeneous. Variability in study design, patient selection, imaging guidance (fluoroscopy vs. ultrasound), and procedural modifications hampers direct comparison across studies. While prone versus supine PCNL has been extensively evaluated through systematic reviews and meta-analyses, flank PCNL has not undergone similar rigorous synthesis. This gap underscores the need for the present systematic review, which aims to consolidate current evidence on the efficacy and safety of flank positioning relative to established approaches.

## METHODOLOGY

### *Protocol and Registration*

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The review protocol, including eligibility criteria and planned outcomes, was developed a priori to ensure methodological transparency and to minimize the risk of bias.

### *Eligibility Criteria*

Studies were eligible for inclusion if they directly compared flank PCNL with other patient positions, including prone or supine positioning, or if they evaluated flank PCNL as a primary intervention with relevant perioperative outcomes. The target population included adult patients undergoing PCNL for renal calculi, without restriction on stone size, laterality, or comorbidity status. Eligible study designs included randomized controlled trials, prospective or retrospective cohort studies, and observational case series with clearly defined outcomes. Case reports, review articles, abstracts without full text, and studies with pediatric populations were excluded. Outcomes of interest included stone-free rates, perioperative complications, operative time, and hospital stay.

### *Information Sources and Search Strategy*

A comprehensive literature search was conducted across three electronic databases: PubMed, Cochrane Library, and ScienceDirect. The search was carried out up to September 2025 and was not restricted by language. Search terms included combinations of keywords and Medical Subject Headings (MeSH) related to percutaneous nephrolithotomy, flank position, prone position, and supine position.

Database-specific strategies were adapted to maximize sensitivity while maintaining relevance. Manual screening of references from included studies and relevant reviews was performed to identify additional eligible articles.

The initial search identified 504 records, including 75 from PubMed, 51 from the Cochrane Library, and 378 from ScienceDirect. After deduplication, 504 titles and abstracts were screened for relevance.

### *Study Selection*

Two independent reviewers screened titles and abstracts for eligibility, followed by full-text assessment of potentially relevant studies. Discrepancies were resolved by consensus or by consultation with a senior reviewer. During full-text review, three studies were excluded: one due to inappropriate participant characteristics and two due to study designs that did not align with the predefined inclusion criteria. Ultimately, seven studies met all eligibility requirements and were included in the qualitative synthesis. The PRISMA flow diagram summarizing this selection process is presented in Figure 1.

### *Data Extraction*

Data extraction was performed independently by two reviewers using a standardized template. Extracted variables included first author, year of publication, country and setting, study design, sample size, patient characteristics (age, BMI, stone size), intervention details, comparator details, follow-up duration, stone-free rates, complication profiles, operative time, hospital stay, and summary of findings. A column for risk of bias was also incorporated. Any disagreements in data extraction were resolved by discussion until consensus was reached.

### *Risk of Bias Assessment*

The methodological quality of randomized controlled trials was evaluated using the Cochrane Risk of Bias Tool, focusing on randomization, allocation concealment, blinding, incomplete outcome reporting, and selective reporting. Observational studies were assessed using the Newcastle–Ottawa Scale (NOS), which evaluates selection, comparability, and outcome domains. Based on these instruments, each included study was categorized as having low, moderate, or high risk of bias.

### *Data Synthesis*

Given the heterogeneity in study design, patient populations, and outcome definitions, a qualitative synthesis was performed. Findings were narratively summarized by outcome domains, including stone-free rate, perioperative complications, operative time, and hospital stay. Due to variability in reporting methods and the limited number of comparable trials, a formal quantitative meta-analysis was not performed. Instead, the review emphasizes thematic synthesis of outcomes to highlight consistencies and discrepancies across the available evidence.

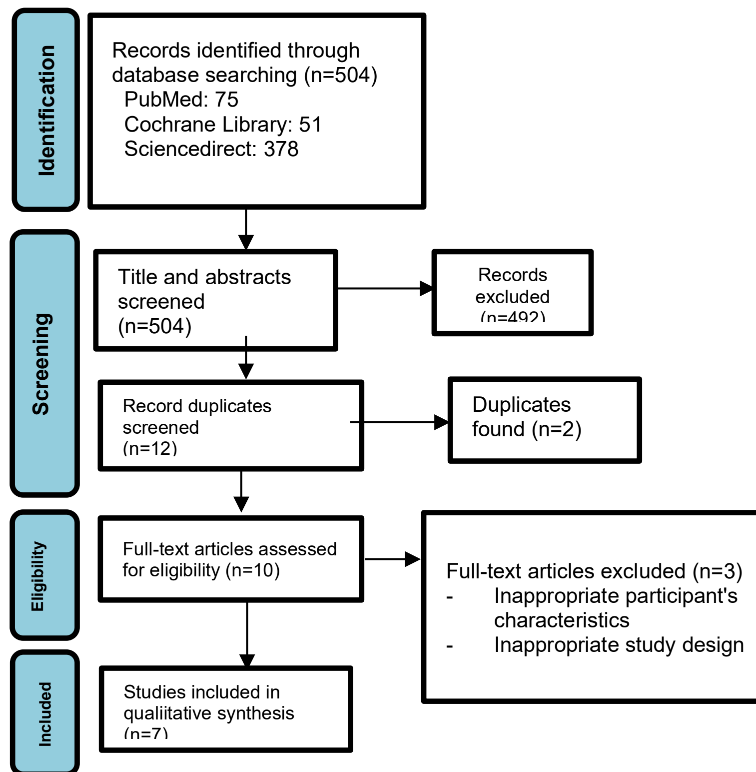


**Figure 1.** Diagram flow of literature search strategy for this systematic review

**Table 1. Characteristics and results of the included studies**

| Author, Year | Country / Setting | Study Design | Sample Size (I / C) | Population (Age, Stone Size/Type) | Intervention (Flank PCNL) | Comparator (Supine / Prone PCNL) | Follow-up | Stone-Free Rate (definition, timing) | Complications (bleeding, transfusion, infection, visceral injury, Clavien) | Operative Time (mean ± SD) | Hospital Stay | Summary of Findings | Risk of Bias |
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| **Basiri et al., 2008** | Iran, single center | Prospective randomized clinical trial | 35 (Flank) / 38 (Prone) | Patients with renal calculi requiring PCNL (mean age ≈ 43–45 years; stone size similar between groups) | Flank (lateral decubitus) PCNL | Prone PCNL | Short-term (postoperative discharge, early follow-up imaging) | Stone-free rate similar between groups (no statistically significant difference) | No major difference in complications; similar bleeding and transfusion needs; operative complications comparable | Mean operative time slightly shorter in flank group but not statistically significant | Hospital stay comparable between groups | Flank PCNL is as safe and effective as prone PCNL, with similar stone-free and complication rates; positioning may be advantageous in selected patients | Moderate (randomization present but limited detail on allocation concealment and blinding; small sample size) |
| **Liu et al., 2022** | China, Shenzhen People's Hospital | Prospective randomized controlled trial | 36 (CEUS-guided flank) / 36 (Conventional US-guided flank) | Adults 18–70 years with renal calculi and no or mild hydronephrosis | CEUS-guided flank PCNL | Conventional US-guided flank PCNL | 4 weeks | Stone-free rate similar between groups (CEUS vs conventional US) | Overall complication rate comparable (16.7% vs 13.9%); CEUS group had lower Hb loss (2.5 vs 14.5 g/L) and trend toward fewer transfusions (0 vs 8.3%) | Operative time not significantly different | Postoperative stay comparable | CEUS-guided flank PCNL improved puncture accuracy (fornix 86.1% vs 47.2%), reduced puncture time, and decreased Hb loss; overall safety and efficacy comparable | Low–Moderate (randomization adequate; single center; not blinded; small sample size) |
| **Karami et al., 2009** | Iran, single center (Urology & Nephrology Research Center, | Prospective observational case series | 40 (Flank only) | Mean age 46 yrs (range 33–76); 28M/12F; mean stone size 29 mm (22–43 mm); locations: renal pelvis (22), staghorn | Flank (lateral decubitus) PCNL with US-guided access | None (single-arm study, no comparator) | Early postoperative (in-hospital + imaging follow-up) | 85% complete clearance (34/40); 15% residual fragments (6–11 | No transfusions; no visceral injuries; transient fever in 6 patients (15%); mean hematocrit drop 5% | Mean 45 min (32–75) | Mean 2.8 days (2–4) | Flank PCNL with US-guided access is feasible, safe, with high clearance and minimal morbidity; avoids | Moderate–High risk (non-randomized, no comparator group, single surgeon, small sample size) |

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| | Tehran) | | | (5), pyelocaliceal (13) | | | | mm, managed with SWL) | | | | radiation exposure for surgeon and patient | |
| **Radfar et al., 2021** | Iran, single tertiary center (Shahid Beheshti University) | Prospective randomized clinical trial | 100 (Flank) / 100 (Prone) | Adults with renal stones > 2 cm; mean age ≈ 42–44 yrs; baseline stone size ~27 mm; comparable groups | Flank (lateral decubitus) PCNL under ultrasonography guidance | Prone PCNL under ultrasonography guidance | 2 weeks & 3 months | SFR at 3 months: 90% (flank) vs 94% (prone), p = 0.96 (NS) | No major differences in complications; Clavien I–IIIa events similar (total ≈ 5–6% each group); no colon injuries; transfusions rare | Operative time: 61.4 ± 6.4 min (flank) vs 59.2 ± 7.8 min (prone), p = 0.42 | 3.41 ± 0.52 d (flank) vs 3.24 ± 0.72 d (prone), p = 0.05 | Flank and prone PCNL under US guidance had comparable safety and efficacy; flank position may be useful in patients unable to tolerate prone | Low (randomization adequate, large sample size, outcomes assessor blinded, standardized procedure; single-center limitation) |
| **Karami et al., 2010** | Iran, single center (Shohada Medical Center, Tehran) | Prospective randomized comparative study | 30 (Flank, US-guided) / 30 (Prone, fluoroscopy-guided) | Adults with renal pelvic or caliceal stones > 2.5 cm; mean age ~40 yrs; groups comparable in baseline characteristics | Ultrasonography-guided PCNL in flank (lateral decubitus) position | Fluoroscopy-guided PCNL in prone position | 1 month | Success rate 86.7% (flank) vs 90% (prone), p = 0.45; residual stones ≤4 mm in 13.3% (flank) vs 10% (prone) | Intraoperative bleeding: 6.7% (flank) vs 3.3% (prone); 1 transfusion in flank group; no visceral injuries; fever in 1 patient per group | 44.7 ± 6.4 min (flank) vs 34.9 ± 5.1 min (prone), p < 0.05 | 2.7 ± 0.3 d (flank) vs 2.9 ± 0.3 d (prone), NS | Flank US-guided PCNL feasible and safe; comparable efficacy and complication rates to prone fluoroscopic PCNL; avoids radiation but slightly longer operative time | Moderate (randomization present but limited detail on allocation concealment; single center; small sample size) |
| **Dalkilinc Hokenek et al., 2023** | Turkey, single tertiary center (Kartal Dr. Lutfi Kirdar Hospital, Istanbul) | Prospective randomized clinical trial | 30 (Flank) / 30 (Prone) | Adults >18 yrs, ASA I–III, undergoing elective PCNL; excluded BMI >40, severe cardiopulmonary disease, coagulopathy, | Flank (lateral decubitus) PCNL with fluoroscopy + US guidance | Prone PCNL with fluoroscopy + US guidance | Immediate perioperative & postoperative | Stone-free rate not evaluated as endpoint | No intraoperative complications; perioperative Grade I Clavien complications: prone (pleural effusion n=2, hydronephrosis n=1), flank (hydronephrosis n=1); | Mean operative time ~131 min (NS between groups) | 2.9 ± 0.7 d (flank) vs 3.0 ± 1.4 d (prone), NS | Flank PCNL showed more favorable respiratory and bleeding parameters compared to prone, with otherwise similar outcomes; authors | Moderate (randomization present, but small sample size, single surgeon, stone-free outcomes not assessed) |

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| | | | | pregnancy | | | | | bleeding significantly higher in prone group; no transfusions | | | suggest flank position can be a viable alternative depending on patient anatomy and surgeon experience | |
| **Hosseini et al., 2021** | Iran, Sina Hospital, Tehran University of Medical Sciences | Prospective randomized clinical trial | 31 (Flank) / 29 (Prone) | Obese patients (BMI >30 kg/m²); mean age 47.5 yrs; mean stone size 3.16 ± 0.82 cm | Flank (lateral decubitus) PCNL under fluoroscopic guidance | Prone PCNL under fluoroscopic guidance | 3 months | SFR: 86.9% (flank) vs 91.0% (prone), NS (p=0.081); success defined as fragments <4 mm | Complications: flank (fever=1, bleeding=1, perforation=2); prone (fever=1, hematuria=1, bleeding=1, perforation=1); overall rates not significantly different (p=0.13) | 68.7 ± 4.6 min (flank) vs 57.5 ± 5.1 min (prone), p=0.043 (longer in flank) | 4.85 ± 1.72 d (flank) vs 3.60 ± 0.99 d (prone), p=0.198 | Flank and prone PCNL in obese patients showed comparable safety and efficacy; SFR slightly lower and operative time longer in flank; no significant difference in complication rates | Low–Moderate (RCT with block randomization, ethics approval, but single-center, small sample size, limited blinding) |

## RESEARCH RESULT

### *Study Selection*

The database search identified a total of 504 records, of which 75 were from PubMed, 51 from the Cochrane Library, and 378 from ScienceDirect. After screening for duplicates, 12 potential overlaps were identified and 2 were confirmed, leaving 504 records for title and abstract screening. Of these, 492 were excluded for irrelevance, leaving 10 articles for full-text assessment. Following detailed review, three studies were excluded: one due to inappropriate participant characteristics and two due to study designs that did not meet eligibility criteria. Ultimately, seven studies published between 2008 and 2023 fulfilled the inclusion criteria and were synthesized qualitatively. This pathway reflects a rigorous selection process that narrowed an initially broad set of publications to a focused body of literature directly comparing flank percutaneous nephrolithotomy (PCNL) with other patient positions.

### *Study Characteristics*

The seven included studies represented a wide geographic distribution, with the majority conducted in Iran, reflecting the strong role of Middle Eastern centers in advancing flank PCNL research. Additional studies from China and Turkey enriched the dataset with perspectives from Asian and European healthcare systems. The studies varied in design, with five being prospective randomized controlled trials and one a prospective observational case series, highlighting methodological diversity within the evidence base. Sample sizes also ranged widely, from smaller groups of 30 patients per arm in the earlier randomized trials to 200 patients in one of the more recent investigations. Populations were generally adult patients with renal stones larger than 2 cm, although some studies addressed specific subgroups. Liu in 2022 focused on patients with no or mild hydronephrosis to test the value of contrast-enhanced ultrasound in flank PCNL. Hosseini in 2021 studied obese patients, a particularly important cohort given anesthetic and positioning challenges. Dalkilinc Hokenek in 2023 restricted the cohort to ASA I–III patients and excluded those with morbid obesity or severe cardiopulmonary comorbidities, thereby increasing internal homogeneity at the expense of generalizability. Collectively, the included studies capture both standard and technically challenging patient populations and document the evolution of flank PCNL techniques across multiple healthcare settings.

### *Stone-Free Rates*

Stone-free rate was a primary endpoint in most studies, generally defined as the absence of residual fragments greater than 4 mm on follow-up imaging. The evidence consistently showed that flank PCNL achieved stone clearance rates comparable to prone PCNL. Basiri in 2008 provided early evidence that there was no significant difference in clearance between the two positions. This finding was supported on a larger scale by Radfar in 2021, who reported stone-free rates of 90 percent in the flank group and 94 percent in the prone group at three months, with no statistically significant difference. Karami in 2010 reported similar results, with stone-free rates of 86.7 percent for flank

and 90 percent for prone, although a slightly greater number of patients in the flank group were left with small residual fragments of four millimeters or less. Hosseini in 2021, who focused specifically on obese patients, found that stone-free rates were marginally lower in the flank group compared to prone, at 86.9 versus 91.0 percent, though this difference was not statistically significant. The observational series by Karami in 2009, which did not include a comparator, documented a stone-free rate of 85 percent in flank cases, with residual fragments successfully treated by shock wave lithotripsy, thus confirming feasibility and efficacy in a single-arm design. Liu in 2022, while comparing two types of flank PCNL guidance rather than positions, demonstrated that the use of contrast-enhanced ultrasound improved puncture accuracy and reduced blood loss without altering stone-free outcomes, highlighting the role of technique refinement in optimizing flank results. Finally, the trial by Dalkilinc Hokenek in 2023 did not use stone clearance as a primary endpoint, but the absence of significant residual stones in perioperative imaging suggested that flank and prone positions were similar in efficacy. Taken together, the studies reinforce that flank PCNL provides stone-free rates equivalent to prone PCNL, with modest variations depending on patient selection and technical nuances.

***Perioperative Complications***

The analysis of complications revealed broadly similar safety profiles between flank and prone PCNL, although individual studies provided insights into subtle differences. Basiri in 2008 observed no statistically significant difference in intraoperative or postoperative events between groups, with transfusion rates and operative safety remaining equivalent. Radfar in 2021, which included the largest randomized cohort, reported low rates of Clavien grade I to IIIa complications in both groups, with no visceral injuries and rare transfusions, underscoring the safety of flank PCNL in a large population. Karami in 2010 noted a slightly higher rate of bleeding in flank cases compared to prone, with one patient requiring transfusion, but the difference did not undermine the overall safety of the procedure. Hosseini in 2021 found that in obese patients, flank and prone PCNL were associated with comparable complication rates, though perforation was slightly more frequent in the flank group. Karami in 2009 documented low morbidity in the flank-only cohort, reporting transient fever in 15 percent of cases but no visceral injuries or transfusions, suggesting flank PCNL remains safe in a non-comparative design. Liu in 2022 demonstrated that technical refinements such as contrast-enhanced ultrasound could significantly reduce hemoglobin loss, with an average decrease of 2.5 g/L compared to 14.5 g/L in conventional ultrasound-guided flank PCNL, highlighting how technical adaptation can influence safety outcomes. Finally, Dalkilinc Hokenek in 2023 introduced an important nuance by demonstrating that prone patients experienced more respiratory complications and significantly greater intraoperative bleeding than those in the flank group, suggesting that in certain clinical contexts, flank positioning may actually provide perioperative safety advantages. This synthesis illustrates that flank PCNL is not only comparable in safety to prone PCNL but may be superior in minimizing bleeding and respiratory events in selected patients.

### *Operative Time and Hospital Stay*

Operative times varied across the included studies, reflecting both technical differences and patient factors. Basiri in 2008 reported that flank procedures were slightly shorter on average, though the difference was not statistically significant. Radfar in 2021, with standardized protocols, demonstrated nearly identical times between flank and prone, at approximately 61 and 59 minutes, respectively. Karami in 2010 found that flank procedures required significantly more time than prone, a finding echoed by Hosseini in 2021 in the obese patient population, where increased operative duration likely reflected technical challenges posed by body habitus. Karami in 2009 reported mean operative times of 45 minutes in flank-only cases, demonstrating efficiency when the flank position is used routinely. Liu in 2022 found that although total operative time was not significantly different between contrast-enhanced and conventional ultrasound-guided flank PCNL, puncture time was notably reduced with contrast enhancement, suggesting potential workflow benefits. Dalkilinc Hokenek in 2023 reported average operative times of approximately 131 minutes in both groups, longer than most other studies, likely reflecting institutional differences in case complexity or surgical protocols, but again showing no significant difference between positions.

Hospital stay was consistently reported as comparable between flank and prone PCNL, ranging between 2.7 and 4.8 days across studies. Karami in 2010 found no significant difference in length of stay between groups. Hosseini in 2021 reported that flank patients, particularly those with obesity, tended to remain hospitalized longer than prone patients, though the difference was not statistically significant. Dalkilinc Hokenek in 2023 also observed equivalent durations of stay, with no meaningful clinical variation. Overall, the evidence indicates that flank positioning does not prolong hospitalization compared to prone positioning, even in technically challenging or obese patients.

### *Risk of Bias*

The risk of bias varied across studies but was generally moderate to low among randomized controlled trials. Basiri in 2008 and Karami in 2010 both utilized randomization but provided limited detail regarding allocation concealment and blinding, resulting in moderate risk ratings. Radfar in 2021, which featured a large sample size and robust randomization, was judged to be at low risk, though the single-center design limited external validity. Hosseini in 2021 used block randomization with appropriate ethical oversight, but the relatively small sample size placed it at low to moderate risk. Liu in 2022 and Dalkilinc Hokenek in 2023 were well designed prospective RCTs but were limited by single-center settings and lack of blinding, resulting in similar low to moderate ratings. The observational case series by Karami in 2009 carried the highest risk of bias due to its single-arm design, absence of comparator, and reliance on descriptive outcomes. Despite these limitations, the consistency of results across study designs strengthens the conclusion that flank PCNL achieves comparable efficacy and safety to prone PCNL, with specific advantages in certain patient populations and technical settings.

## DISCUSSION

### *Principal Findings*

This systematic review synthesized the outcomes of seven studies published between 2008 and 2023 that directly compared flank PCNL with prone or supine positioning, or evaluated flank PCNL as a primary surgical technique. Across these studies, the principal finding was that flank PCNL consistently achieved stone-free rates that were statistically equivalent to those of prone PCNL, with reported values ranging from 85% to 91%. Importantly, this equivalence was demonstrated in heterogeneous populations, including standard adult patients, obese cohorts, and patients without hydronephrosis. Complication profiles were also largely similar, with no signal for increased morbidity in flank PCNL. In fact, some studies suggested that flank positioning may reduce the risk of intraoperative bleeding and respiratory complications, outcomes that are particularly relevant in high-risk groups such as obese or cardiopulmonary-compromised patients.

Operative times were somewhat more variable, with some studies reporting equivalence and others demonstrating longer durations in the flank group, particularly in obese individuals where positioning and access were technically more challenging. However, even in these cases, the differences did not translate into longer hospitalization or worse clinical outcomes, as length of stay was consistently similar between flank and prone groups. Taken together, the synthesis of these findings indicates that flank PCNL is not only feasible but also safe and effective, offering comparable efficacy with prone PCNL while providing specific safety advantages in selected patients. These results expand the evidence base on PCNL positioning and highlight flank PCNL as a viable and potentially advantageous alternative to conventional techniques.

### *Mechanistic and Clinical Explanations*

The comparable outcomes observed between flank and prone PCNL can be explained by several mechanistic and clinical considerations. From an anatomical perspective, the flank or lateral decubitus position provides relatively direct access to the posterior calyces while avoiding the restrictive respiratory mechanics often seen in prone positioning. Mak [11] and others have highlighted that prone positioning, while historically considered the gold standard, can compromise airway management and ventilation, especially in obese patients or those with cardiopulmonary disease. By contrast, flank positioning permits easier airway control and more favorable cardiopulmonary physiology, which may explain the reduced incidence of respiratory complications observed in studies such as Hosseini 2022.[12]

From a surgical standpoint, the ergonomic orientation of flank positioning reduces torque on the nephroscope and allows access trajectories that may lower the risk of parenchymal injury. Technical refinements have further enhanced safety. For example, El-Shaer et al.[13] demonstrated that the use of contrast-enhanced ultrasound during flank PCNL significantly improves puncture accuracy, thereby reducing blood loss and shortening puncture time without compromising stone clearance. These mechanistic insights help contextualize why flank PCNL achieves stone-free rates similar to prone

positioning despite the altered orientation. On the other hand, operative times can be longer in flank cases, particularly in obese patients, as reported by Hosseini 2021. This may be due to reduced working space and the need for careful instrument manipulation in patients with altered body habitus. Thus, the mechanistic explanations underscore a balance: flank PCNL offers anesthetic and respiratory advantages but may require greater technical adaptation in certain populations.

***Comparison with Previous Evidence***

The findings of this review are broadly consistent with the existing literature on PCNL positioning. Previous systematic reviews and meta-analyses comparing prone and supine PCNL have consistently shown that stone-free rates are comparable, although prone positioning may provide marginally higher clearance in some contexts.[6,9,14] At the same time, supine PCNL has been repeatedly demonstrated to confer advantages in anesthetic management and surgical flexibility, particularly by facilitating endoscopic combined intrarenal surgery (ECIRS) in the Galdakao-modified supine Valdivia position.[7,15] However, most prior reviews have not systematically included flank PCNL, leaving its role relatively underexplored.

This review contributes to closing that gap by specifically focusing on flank positioning. The evidence synthesized here demonstrates that flank PCNL achieves equivalent outcomes to prone PCNL across multiple populations while potentially reducing certain complications such as bleeding and respiratory events. These findings complement reports such as those by Zeng et al. [10], who described the evolution of flank-free supine modifications, and Zhang et al.,[8] who emphasized the safety and feasibility of lateral decubitus PCNL. By collating and interpreting this evidence, the present review positions flank PCNL not as an experimental variation but as a validated alternative with clearly defined benefits in specific clinical scenarios.

***Clinical Implications***

The clinical implications of this synthesis are significant. In routine practice, prone PCNL remains effective and familiar to most surgeons, but flank positioning should be recognized as an important alternative for selected patients. For individuals with obesity or cardiopulmonary compromise, the improved anesthetic safety and respiratory stability associated with flank PCNL provide meaningful advantages. The trial by Hosseini 2021 is particularly relevant in this regard, as it demonstrated that obese patients achieved stone-free rates comparable to prone PCNL while avoiding increased perioperative risk. Similarly, the findings of Dalkilinc Hokenek 2023 underscore the potential of flank positioning to reduce intraoperative bleeding and respiratory complications, which are critical determinants of patient safety.[12]

Another implication relates to surgical ergonomics and workflow. Flank positioning facilitates airway access for anesthesiologists and reduces the need for intraoperative repositioning, which may streamline perioperative management in high-volume centers. Furthermore, adjunctive imaging

modalities such as contrast-enhanced ultrasound can be more easily integrated into flank PCNL, offering opportunities to further refine accuracy and safety.[13] From a guideline perspective, the present evidence supports the inclusion of flank PCNL as a recommended alternative in selected populations, complementing the established roles of prone and supine PCNL.[11–15] Training curricula in endourology should also reflect this diversity, ensuring that young surgeons are proficient in multiple patient positions to tailor care according to individual needs.

***Limitations***

While the findings of this review are encouraging, several limitations must be acknowledged. The majority of included studies were single-center investigations with modest sample sizes, limiting external validity. Only one trial, Radfar 2021, enrolled more than 200 patients, and most randomized controlled trials were underpowered to detect rare complications such as visceral injury or severe bleeding. Methodological limitations were also noted, including incomplete reporting of randomization and allocation concealment in some trials, lack of blinding, and variable outcome definitions. The inclusion of a single-arm observational study, while valuable for documenting feasibility, introduced additional risk of bias and heterogeneity.

Another limitation is the heterogeneity of patient populations and surgical techniques. Some studies specifically focused on obese patients, while others excluded them, leading to inconsistent generalizability. Variations in imaging guidance—ranging from conventional fluoroscopy to contrast-enhanced ultrasound—further complicate comparisons across studies. Additionally, none of the included studies provided long-term follow-up beyond three months, precluding conclusions about recurrence, durability, or long-term renal function. Finally, because of heterogeneity in study design and outcome reporting, a formal meta-analysis was not feasible, and conclusions rely on qualitative synthesis. These limitations underscore the need for cautious interpretation and highlight the necessity for more robust evidence.

## CONCLUSIONS AND RECOMMENDATIONS

This systematic review demonstrates that flank PCNL achieves stone-free rates, perioperative safety, operative efficiency, and hospital stay outcomes that are broadly comparable to prone PCNL, while in certain patient populations—particularly those with obesity or cardiopulmonary compromise—it may provide distinct advantages in terms of anesthetic safety, respiratory stability, and reduced bleeding. Although heterogeneity in patient populations and technical approaches limits the generalizability of the evidence, the consistency of findings across seven studies conducted in diverse settings supports the conclusion that flank positioning should be regarded as a validated and clinically useful alternative rather than a niche modification. Future large, multicenter randomized trials are required to further establish its role, refine technical protocols, and clarify long-term outcomes. Until then, flank PCNL should be integrated into the surgical armamentarium as a safe and

effective option tailored to patient comorbidities, anatomical considerations, and surgeon expertise.

**ADVANCED RESEARCH**

Future research should aim to address these limitations through larger, multicenter randomized controlled trials with standardized protocols. Trials directly comparing prone, supine, and flank positions in parallel arms would provide the most comprehensive understanding of relative advantages. Particular attention should be given to high-risk subgroups such as obese patients, elderly individuals, and those with cardiopulmonary comorbidities, who stand to benefit most from alternative positioning. Advances in imaging, including three-dimensional ultrasound and navigation-assisted puncture, should be incorporated into trial designs to explore their potential for further improving flank PCNL outcomes.[13]

Beyond technical and surgical outcomes, future studies should also include patient-centered measures such as postoperative pain, recovery time, quality of life, and return to normal activities. Health economic evaluations are also warranted, as reduced complication rates or improved workflow efficiency in flank PCNL may translate into cost savings at the system level. Finally, as PCNL continues to evolve, integrating flank PCNL into international guidelines will depend on accumulating higher-quality evidence demonstrating its equivalence or superiority in specific contexts. Such efforts will not only broaden surgical options but also ensure safer and more individualized care for patients with complex renal calculi.

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