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Stone Disease

Comparison of Prone and Supine Positions for Suction Mini Percutaneous Nephrolithotomy (PCNL) for Kidney Stone Disease. Results from a Prospective Multicenter Series from the Endourology Section of the European Association of Urology and the Suction Mini-PCNL Collaborative Study Group

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Abstract

Background and objective: The optimal patient position for percutaneous nephrolithotomy (PCNL) remains a matter of debate. Our aim was to evaluate the association between prone versus supine positioning and perioperative and postoperative outcomes of suction mini-PCNL.

Methods: In this prospective multicenter observational study, we analyzed data for 1534 patients treated in 30 centers between March and November 2024. Outcomes included the stone-free rate (SFR) assessed via 30-d computed tomography, and complication rates. Multivariable analysis was used to assess the effect of prone positioning on stone-free status (zero fragments) and overall complications, with adjustment for other covariates.

Key findings and limitations: There were 653 patients (43%) in the prone group and 881 (57%) in the supine group. Patient demographics were similar between the groups, except for body mass index. In terms of Guy's stone score, the prone group had a higher proportion of score 1 stones (60% vs 47%) and the supine group a higher proportion of score 4 stones (6.9% vs 3.2%). Median stone volume did not differ significantly, at 1636 mm³ in the supine group and 1725 mm³ in the prone group ($p = 0.7$). The prone group had more frequent use of spinal anesthesia (68% vs 29%; $p < 0.001$), fluoroscopy-only guidance (86% vs 61%; $p < 0.001$), and supracostal access (36% vs 22%; $p < 0.001$). Surgical time, pain scores, hospital length of stay, and readmission rates were similar between the groups. Zero-fragment stone-free rates were comparable (85% prone vs 81% supine; $p = 0.052$). Prone position was associated with higher rates of blood transfusion (2.8% vs 0%; $p < 0.001$), renal pelvic perforation (2.8% vs 0.23%; $p < 0.001$), and pneumothorax (1.5% vs 0%; $p < 0.001$). Multivariable analysis revealed that prone positioning was not significantly associated with grade A stone-free status (odds ratio 0.92, 95% confidence interval [CI] 0.66–1.29; $p = 0.6$) or the overall complication rate (odds ratio 0.87, 95% CI 0.59–1.28; $p = 0.5$). The nonrandomized study design may have introduced selection bias and limited our ability to establish causal relationships between variables.

Conclusions and clinical implications: Both prone and supine positioning for PCNL achieved excellent SFRs with acceptable safety profiles.

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ADVANCING PRACTICE

What does this study add?

Suction mini percutaneous nephrolithotomy can be safely performed in prone and supine positions with no difference in stone-free rate. The safety profile of both approaches can be attributed to the minimized renal backflow and lower intrarenal pressure with the use of suction. Surgeons should tailor their approach according to patient-specific factors, stone characteristics, and institutional expertise while using suction technology to optimize outcomes.

Clinical Relevance

It currently remains unclear, whether supine or prone positioning for PCNL is superior with respect to stone-free rate as well as complications. In the present analysis of a prospective database, the authors found no statistical difference between both positioning with respect to stone-free rate, surgical time, pain scores, hospital stay duration, and readmission rates in patients undergoing suction mini-PCNL. In contrast, prone positioning was associated with higher blood transfusion rates, renal pelvic perforation, and pneumothorax. The current data suggest that both positions can be used for suction mini-PCNL and choice of technique should be based on patient-specific factors, stone characteristics, as well as center and surgeon expertise. Associate Editor: Malte Rieken.

Patient Summary

We compared two positions (lying face-down versus face-up) during suction-assisted surgery to treat kidney stones. We found that both positions had similar results for stone clearance and complication rates, but more research is needed to determine if position differences directly cause complications or if other factors are involved.

1. Introduction

Percutaneous nephrolithotripsy (PCNL) is a well-established surgical procedure for removing large or complex kidney stones [1]. Technological advances and procedural refinements have greatly improved PCNL outcomes, including the development of suction-assisted devices that enhance stone clearance while reducing complications [2]. However, debate regarding the ideal patient position (supine vs prone) is ongoing, as each approach presents unique benefits and challenges [3].

The supine position is often preferred because of its ergonomic benefits, lower anesthetic risks and facilitation of simultaneous retrograde access. Conversely, the prone position provides superior renal access and allows easier manipulation of instruments, particularly for complex stone burdens. However, renal pelvic pressure during prone PCNL is significantly higher at baseline and during irrigation with both rigid and flexible nephroscopes in comparison to supine PCNL [4]. Elevated pressure may contribute to the higher incidence of fever and infections observed after prone PCNL [4]. Nevertheless, a recent meta-analysis of randomized studies revealed comparable stone-free rates (SFRs) with both approaches [5].

While numerous studies have compared prone and supine positions in PCNL, establishing causal relationships between the patient position and clinical outcomes remains challenging because of the influence of multiple confounding variables, including surgeon expertise, stone complexity, and institutional practices. The observational nature of most comparative studies limits the ability to make definitive causal inferences about positioning effects on outcomes.

Given these limitations, our aim was to evaluate the association between prone versus supine positioning and perioperative and postoperative outcomes of suction mini-PCNL. We are interested in providing clinicians with comparative effectiveness data that take into account key confounding variables, recognizing that definitive causal conclusions would require randomized controlled trials.

2. Patients and methods

For this study, we defined suction mini-PCNL as PCNL performed with a single-use or reusable suction access nephrostomy sheath (14–22 Fr) combined with any energy device for lithotripsy. Data were anonymized and collected for the Suction Technology Utility in mini-PCNL Study (STUMPS) registry, which is managed by the Asian Institute of Nephro-Urology, following ethical board approval under protocol AINU



Fig. 1 – Centers included in the STUMPS registry.

#01/2024. Adult patients with kidney stones were prospectively enrolled between March and November 2024 across 30 centers in 21 countries (Fig. 1) [6].

The inclusion criteria were age ≥ 18 yr, kidney stone(s) only, a 14–22 Fr suction sheath, normal kidney anatomy, and 2-mm-slice unenhanced computed tomography (CT) scans within 6–8 wk before surgery and 30 d after the procedure. The exclusion criteria were an anomalous kidney, children/adolescents, a concomitant ureteral stone, no suspension of antiplatelet/anticoagulants, and patients unable to provide consent. Patients with incomplete data were also excluded.

Baseline patient characteristics, stone features, operative techniques, lithotripsy modalities, surgical time, complications, SFR data, and reoperation rates were documented. The largest stone diameter was recorded for single or multiple stones, and stone volume (for the largest stone in cases with multiple stones) was calculated using the ellipsoid formula (length \times width \times depth $\times \pi \times 0.167$). Guy's stone score was also determined [7]. Preoperative urine cultures were obtained, and infections were treated with appropriate antibiotics according to sensitivity test results. Antibiotic prophylaxis followed local practice, while anticoagulants/antiplatelets were discontinued 3–7 d before surgery and resumed on the basis of clinical judgment.

No specific instructions were provided for performing PCNL; surgeons conducted suction mini-PCNL according to their usual practice while adhering to the inclusion and exclusion criteria. Pain scores on the first postoperative day were assessed using a 10-point visual analogue scale (1 = lowest pain). Complications within 30 d after surgery were classified using the Clavien score for percutaneous nephrolithotomy [8].

Postoperative assessments included a low-dose unenhanced CT scan to uniformly evaluate residual fragments (RFs) using

the bone-window setting. Stone-free status was categorized as follows:

- Grade A: no RFs (100% stone-free);
- Grade B: single RF ≤ 4 mm (relatively stone-free); and
- Grade C: single RF >4 mm or multiple RFs of any size (non-stone-free).

2.1. Statistical analysis

Results are reported as the median and interquartile range (IQR) for continuous variables, and as the absolute frequency and percentage for categorical variables. To compare patient demographics, perioperative parameters, and 30-d outcomes between the prone and supine PCNL groups, a χ^2 test was used for categorical variables and the Mann-Whitney U test for continuous variables. Multivariable analysis was used to assess the effect of prone positioning on stone-free status (zero fragments) and overall complications. The model was adjusted for covariates identified in previous studies with potential to impact SFR (stone volume, mechanical lithotripsy, and sheath size) [9–11] and complications (stone volume, puncture modality, tract dilation method, mechanical lithotripsy, and sheath size) [9–14]. Results are reported as the odds ratio (OR), 95% confidence interval (CI), and *p* value. All statistical analyses were performed using R v4.3.0 (R Foundation for Statistical Computing, Vienna, Austria), with *p* < 0.05 indicating statistical significance.

3. Results

A total of 1534 patients were included in the analysis, of whom 653 (43%) underwent surgery in the prone position

Table 1 – Patient characteristics at baseline

Parameter	Prone position (<i>n</i> = 653)	Supine position (<i>n</i> = 881)	<i>p</i> value
Median age, yr (IQR)	49 (39–59)	50 (39–62)	0.14
Male, <i>n</i> (%)	256 (39)	375 (43)	0.19
American Society of Anesthesiologists score, <i>n</i> (%)			0.002
1	364 (56)	424 (48)	
2	224 (34)	372 (42)	
3	65 (10)	79 (9.0)	
4	0	6 (0.68)	
Median body mass index, kg/m ² (IQR)	25.0 (22.3–28.0)	27.2 (24.2–30.6)	<0.001
Diabetes mellitus, <i>n</i> (%)	140 (21)	162 (18)	0.14
Anticoagulant/antiplatelet use, <i>n</i> (%)	75 (11)	113 (13)	0.4
Presentation, <i>n</i> (%)			<0.001
Hematuria	23 (3.5)	88 (10)	
Pain	514 (79)	611 (69)	
Fever	35 (5.4)	40 (4.5)	
Incidental	81 (12)	142 (16)	
First-time stone-former, <i>n</i> (%)	495 (76)	644 (73)	0.2
Preoperative positive urine culture, <i>n</i> (%)	102 (16)	168 (19)	0.079
Laterality, <i>n</i> (%)			0.002
Left	338 (52)	406 (46)	
Right	295 (45)	417 (47)	
Bilateral	20 (3.1)	58 (6.6)	
Guy's stone score, <i>n</i> (%)			<0.001
1	391 (60)	418 (47)	
2	161 (25)	288 (33)	
3	80 (12)	114 (13)	
4	21 (3.2)	61 (6.9)	
Median stone density, Hounsfield units (IQR)	1159 (898–1300)	1200 (950–1400)	<0.001
Median largest stone diameter, cm (IQR)	1.8 (1.5–2.4)	2.1 (1.6–2.8)	<0.001
Median stone volume, mm ³ (IQR)	1725 (920–3200)	1636 (904–3390)	0.7
Stone location, <i>n</i> (%)			0.079
Upper pole	95 (15)	112 (13)	
Middle pole	272 (42)	300 (34)	
Lower pole	210 (32)	304 (35)	
Multiple locations	76 (12)	165 (19)	
Previous percutaneous nephrolithotomy, <i>n</i> (%)	11 (1.7)	38 (4.3)	0.004

IQR = interquartile range.

and 881 (57%) in the supine position. The baseline characteristics of the two groups are summarized in Table 1. Median age was similar between the groups ($p = 0.14$), at 49 yr (IQR 39–59) in the prone group and 50 yr (IQR 39–62) in the supine group. The proportion of male patients was comparable (39% in prone group vs 43% in supine group; $p = 0.19$). Median body mass index was significantly higher in the supine group (27.2 kg/m², IQR 24.2–30.6) than in the prone group (25.0 kg/m², IQR 22.3–28.0; $p < 0.001$). The prevalence of diabetes mellitus was similar between the groups (21% vs 18%; $p = 0.14$). Regarding clinical presentation, pain was the most common presentation in both groups, affecting 79% of prone and 69% of supine patients. Preoperative positive urine-culture rates were comparable (16% prone vs 19% supine; $p = 0.079$). The distribution of Guy's stone scores significantly differed between the groups ($p < 0.001$): the prone group had a higher proportion of score 1 stones (60% vs 47%) and the supine group had a higher proportion of score 4 stones (6.9% vs 3.2%). The supine group had stones with higher median density (1200 Hounsfield units, IQR 950–1400) than the prone group (1159 Hounsfield units, IQR 898–1300; $p < 0.001$). Median stone volume did not differ significantly (1636 mm³, IQR 904–3390 vs 1725 mm³, IQR 920–3200; $p = 0.7$).

Table 2 shows procedural characteristics. Use of spinal anesthesia was more frequent in the prone group (68% vs 29%; $p < 0.001$). Puncture modality significantly differed between the groups ($p < 0.001$): fluoroscopy-only guidance was preferred for prone procedures (86% vs 61%), and combined fluoroscopy and ultrasound guidance for supine cases (33% vs 12%).

Supracostal access was more frequent in the prone group (36% vs 22%; $p < 0.001$). Tract dilation methods differed significantly between the groups ($p < 0.001$): serial metal dilators were more common in the prone group (50% vs 16%) and single-step dilation was preferred in the supine group (73% vs 32%). The sheath size distribution varied significantly between the groups ($p < 0.001$): 16-Fr sheaths were more common in the supine group (52%), while 18-Fr sheaths were the most frequent size in the prone group (29%). Mechanical lithotripsy was more frequent in the prone group (42% vs 23%; $p < 0.001$).

Despite these technical differences, there were no statistically significant differences between the groups in median lithotripsy time (prone: 18 min, IQR 9.0–30; supine: 18 min, IQR 10–29; $p = 0.9$) or median operation time (prone: 47 min, IQR 30–70; supine: 44 min, IQR 30–80; $p = 0.6$).

The intraoperative SFR, assessed via surgeon visualization or fluoroscopy, was significantly higher in the prone group (85% vs 79%; $p = 0.002$). Exit strategies differed significantly ($p < 0.001$): nephrostomy tubes were more common in the supine group (20% vs 11%) and double-J ureteral stents were used more frequently in the prone group (52% vs 47%).

Table 3 shows intraoperative and postoperative outcomes. The blood transfusion rate (Clavien grade 2) was significantly higher in the prone group (2.8% vs 0%; $p < 0.001$).

Table 2 – Procedural characteristics

Parameter	Prone position (n = 653)	Supine position (n = 881)	p value
Spinal anesthesia, n (%)	446 (68)	252 (29)	<0.001
Puncture modality, n (%)			<0.001
Fluoroscopy only	559 (86)	539 (61)	
Ultrasound only	9 (1.4)	34 (3.9)	
Fluoroscopy + ultrasound	78 (12)	290 (33)	
Endoscopy-guided	7 (1.1)	18 (2.0)	
Number of tracts, n (%)			0.4
1	608 (93)	822 (93)	
2	43 (6.6)	54 (6.1)	
3	1 (0.15)	5 (0.57)	
4	1 (0.15)	0	
Supracostal access (above 11th rib), n (%)	236 (36)	197 (22)	<0.001
Tract dilation method, n (%)			<0.001
Serial with metal dilators	325 (50)	137 (16)	
Serial with nonmetal dilators	79 (12)	96 (11)	
Balloon	39 (6.0)	1 (0.11)	
Single-step dilatation	210 (32)	647 (73)	
Safety wire inserted during surgery, n (%)	156 (24)	460 (52)	<0.001
Sheath brand, n (%)			0.001
Clearpetra	149 (23)	277 (31)	
Shah	232 (36)	276 (31)	
Other	272 (42)	328 (37)	
Sheath size, n (%)			<0.001
12 Fr	1 (0.15)	0	
14 Fr	36 (5.5)	89 (10)	
15 Fr	140 (21)	18 (2.0)	
16 Fr	42 (6.4)	454 (52)	
17.5 Fr	4 (0.61)	0	
18 Fr	190 (29)	194 (22)	
20 Fr	122 (19)	91 (10)	
22 Fr	118 (18)	35 (4.0)	
Mechanical lithotripsy, n (%)	271 (42)	200 (23)	<0.001
Stone fragmentation modality, n (%)			<0.001
Fragmentation only	358 (55)	495 (56)	
Dusting only	50 (7.7)	14 (1.6)	
Popcorning only	0	1 (0.11)	
Combination of the above	184 (28)	314 (36)	
Data missing	61 (9.3)	57 (6.5)	
Basket required for stone extraction, n (%)	171 (26)	158 (18)	<0.001
Median lithotripsy time, min (IQR)	18 (9.0–30)	18 (10–29)	0.9
Median total operation time, min (IQR)	47 (30–70)	44 (30–80)	0.6
Sheath change required, n (%)	0	0	0.7
Sheath able to access all of the kidney, n (%)			0.7
Yes	538 (83)	641 (84)	
No	107 (17)	121 (16)	
Intraoperative SFS assessment via F/VI, n (%)			0.002
100% clear	555 (85)	692 (79)	
Only dust remains	69 (11)	150 (17)	
Fragments remain	29 (4.4)	39 (4.4)	
Exit strategy, n (%)			<0.001
Nephrostomy tube only	70 (11)	177 (20)	
Double-J ureteral stent only	337 (52)	418 (47)	
Overnight ureteric catheter only	60 (9.2)	67 (7.6)	
Nephrostomy tube and ureteral stent	173 (26)	213 (24)	
Totally tubeless	13 (2.0)	6 (0.68)	
Tract closure modality, n (%)			<0.001
No stitch	327 (50)	361 (41)	
Stitch placed	324 (50)	502 (57)	
Hemostatic agent	2 (0.31)	18 (2.0)	

F/VI = fluoroscopy or visual inspection; IQR = interquartile range; SFS = stone-free status.

Table 3 – Intraoperative and postoperative outcomes

Parameter	Prone position (n = 653)	Supine position (n = 881)	p value
Intraoperative bleeding after dilatation, n (%)			0.020
No bleeding	554 (85)	750 (85)	
Oozing partly obscured vision despite suction but surgery could continue	18 (2.7)	46 (5.2)	
Suction helped keep vision clear	80 (12)	81 (9.2)	
Case abandoned	1 (0.15)	4 (0.45)	
Bleeding managed with IVF without blood transfusion (Clavien 1), n (%)	5 (0.77)	4 (0.45)	0.7
Blood transfusion (Clavien 2), n (%)	18 (2.8)	0	<0.001
Infectious complications, n (%)	67 (10)	104 (12)	0.3
POF managed with observation without antibiotics (Clavien 1)	41 (6.3)	30 (3.4)	
POF managed with antibiotics in the ward (Clavien 2), n (%)	25 (3.8)	72 (8.2)	
Sepsis needing ICU admission (Clavien 4)	1 (0.15)	2 (0.23)	
Colon perforation managed conservatively with IVF/A (Clavien 2), n (%)	0	2 (0.23)	0.2
Bleeding managed with angioembolization (Clavien 3b), n (%)	0	1 (0.11)	0.4
RPP managed with prolonged or postoperative NPT (Clavien 3a), n (%)	18 (2.8)	2 (0.23)	<0.001
Pneumothorax managed with ICD-LA (Clavien 3a), n (%)	10 (1.5)	0	<0.001
Median postoperative pain score (IQR)	2.0 (1.0, 3.0)	2.0 (1.0, 4.0)	0.02
Median hospital stay, d (IQR)	2.0 (2.0, 4.0)	3.0 (2.0, 3.0)	0.16
Readmission for any reason within 72 h, n (%)	10 (1.5)	16 (1.8)	0.7
Postoperative RF grade on 30-d computed tomography, n (%)			0.052
Grade A: zero RF	555 (85)	717 (81)	
Grade B: single RF ≤4 mm	76 (12)	112 (13)	
Grade C: single RF >4 mm/multiple of any size	22 (3.4)	52 (5.9)	
RF reintervention after 30 d, n (%)	10 (1.5)	27 (3.1)	0.053
Median time to reintervention, d (IQR)	5.5 (3.0–6.0)	4.0 (1.0–5.2)	0.2
Reintervention modality, n/N (%)			0.037
Shockwave lithotripsy	2/10 (20)	0/27	
Retrograde intrarenal surgery	7/10 (70)	16/27 (59)	
Percutaneous nephrolithotripsy	1/10 (10)	3/27 (11)	
Endoscopic combined intrarenal surgery	0/10	8/27 (30)	

ICD-LA = intercostal drain under local anesthesia; ICU = intensive care unit; IQR = interquartile range; IVF/A = intravenous fluid and antibiotics; NPT = nephrostomy tube; POF = postoperative fever (>38.0 °C); RF = residual fragment; RPP = renal pelvic perforation.

There was no significant difference in overall infectious complications ($p = 0.3$). The majority of patients in both groups did not experience any infection (prone 90% vs supine 88%). Rates of postoperative fever requiring antibiotics (Clavien grade 2; prone 3.8% vs supine 8.2%) and sepsis (Clavien grade 4; prone 0.15% vs prone 0.23%) were low and similar between the groups.

Renal pelvic perforation (Clavien grade 3b) was more frequent in the prone group (2.8% vs 0.23%; $p < 0.001$). Pneumothorax requiring drainage (Clavien grade 3a) was exclusively observed in the prone group (1.5% vs 0%; $p < 0.001$). Conversely, colon perforation managed conservatively (Clavien grade 2) was only observed in the supine group (0.23% vs 0%; $p = 0.2$).

There was no significant difference in median hospital stay (prone: 2.0 d, IQR 2.0–4.0; supine: 3.0 d, IQR 2.0–3.0; $p = 0.16$). Readmission rates within 72 h were low (prone 1.5% vs supine 1.8%; $p = 0.7$).

At 30-d follow-up CT imaging, the SFR did not differ significantly ($p = 0.052$), and grade A stone-free status was achieved in 85% of prone cases and 81% of supine cases. RF reintervention rates were low (prone 1.5% vs supine 3.1%; $p = 0.053$).

Multivariable analysis (Table 4) revealed that prone positioning was not significantly associated with grade A stone-free status (OR 0.92, 95% CI 0.66–1.29; $p = 0.6$) or the overall complication rate (OR 0.87, 95% CI 0.59–1.28; $p = 0.5$).

4. Discussion

The prone position has been the most widely used approach for PCNL since its introduction in the mid-1970s [15]. Since the 1990s, patient positioning for PCNL has changed from prone to semi-lateral to supine to allow easier simultaneous antegrade and retrograde access, as in endoscopic combined intrarenal surgery [16], and even to allow simultaneous bilateral endoscopic surgery [17] and surgery in patients who cannot tolerate the prone position [18]. The supine position was first described by Valdivia Uría in 1987 [19] as an office-based treatment under local anesthesia, and the debate on the best position has been ongoing for two decades, with many factors favoring either the prone [20] or the supine [21] position.

Alongside changes in patient position, mini-PCNL and suction or vacuum assistance have been increasingly adopted over standard PCNL [22]. The introduction of suction for mini-PCNL has reformed the way in which this surgical intervention is performed, and has shortened surgical times and hospital length of stay, and reduced the rates of complications and auxiliary procedures [23]. The disposable and reusable instruments available are versatile and can suit both positions, and both options were equally used in our study.

Our results show that the safety of both approaches was generally favorable, with low rates of overall complications and of infectious complications, which can be attributed to minimization of renal backflow and the lower intrarenal pressure when using suction [2]. Notably, the prone position was associated with higher incidence rates for blood transfusion, renal pelvic perforation, and pleural injury, which are significant concerns in PCNL procedures. While we do not have details on the reasons for the higher blood transfusion rate, we assume that this was multifactorial, including but not limited to larger tract dilatation, which is a known risk factor for bleeding [24]. Absence of data on real hemoglobin loss precludes further analysis and is a limitation of our study. Pleural injuries were probably related to access above the 11th rib and the lack of ultrasound use, both of which are associated with 46-fold greater risk of intrathoracic complications in comparison to subcostal access [25]. Perhaps our surgeons assumed that mini-PCNL has a lower risk of injury than standard PCNL. However, a recent meta-analysis comparing standard to

Table 4 – Multivariable regression results for association between surgical position and grade A stone-free status and overall complications

	Grade A stone-free status ^a		Overall complications ^b	
	aOR (95% CI)	p value	aOR (95% CI)	p value
Supine position (vs prone)	0.92 (0.66–1.29)	0.6	0.87 (0.59–1.28)	0.5

aOR = adjusted odds ratio; CI = confidence interval.
^a Model adjusted for stone volume, mechanical lithotripsy, and sheath size.
^b Model adjusted for stone volume, puncture modality, tract dilation method, mechanical lithotripsy, and sheath size.

mini-PCNL showed that injury can still occur with the latter, especially if the stone burden is high [22]. Importantly, there were two cases of colonic injury, both in the supine group. This complication is not typical of the supine position according to the literature. In the supine position, the colon falls anteromedially, away from the puncture paths, reducing the risk of injury [26]. It is possible that a missed retrorenal colon, renal hypermobility, and/or lack of ultrasound use in both cases might have inadvertently contributed the colonic injuries. These details are missing and are a study limitation. However, the associations between positioning and specific complications observed warrant careful interpretation. The higher rates of pleural injury and blood transfusion associated with prone positioning and of colonic injury associated with supine positioning in our series may reflect differences in surgical technique, patient selection, or other unmeasured confounders rather than direct causal effects of patient positioning alone.

Interestingly, the overall rate of infectious complications was low, with no significant difference between the groups. This can be explained by lower intrarenal pressure and faster aspiration of the irrigation fluid, which prevents pyelovenous and lymphatic backflow and inadvertent bacteremia, especially during lithotripsy of infected stones [2]. The direct effect of a suction sheath on intrarenal pressure during mini-PCNL is associated with lower backflow in comparison to standard mini-PCNL, probably because of the suction pressure generated within the sheath [27]. Miniaturization of the percutaneous tract can lead to an increase in renal pelvic pressure and greater absorption of irrigation fluid because of restricted outflow. It has been shown that during nephroscopy, non-suction mini-PCNL sheaths generate higher intrarenal pressure in comparison to both standard PCNL and suction-assisted mini-PCNL [28]. This is particularly concerning when mini-PCNL is performed for infected stones. In such cases, elevated intrarenal pressure has been linked to a higher risk of bacterial dissemination to other organs. Importantly, the use of suction during PCNL in patients with urinary tract infection has been associated with significantly lower rates of infectious complications [29]. Suction not only reduces intrarenal reflux of infected urine caused by elevated pressure, but also aids in draining the infected system, thereby minimizing the risk of infection-related issues. This probably contributed to the low rate of infectious complications observed in our study. Nevertheless, while the literature supports the effectiveness of suction mini-PCNL in maintaining low intrarenal pressures, it is important to consider other influential factors. These include the positioning of the sheath or nephroscope tip and whether or not active aspiration is used during the

procedure. Such variables can increase intrarenal pressure and should always be taken into account when performing suction mini-PCNL.

The safety of both positions was also reflected in the short hospital length of stay, in line with other large series [30,31], and low readmission rates within 3 d of discharge.

High single-stage SFRs and the ability to achieve imaging-confirmed zero fragments are other important findings from our study. CT is currently probably the gold-standard imaging modality for assessing RFs, especially in terms of fragment size and quantity for predicting possible future RF-related events after endourological treatment of kidney stones [32,33]. In our study, standardized reporting of stone-free status revealed that suction mini-PCNL achieved zero fragments in more than 80% of patients in both groups. In addition, the very low rate of ancillary RF procedures is a testament to the excellent outcomes of suction mini-PCNL irrespective of patient position. Achievement of zero fragments is important because post-PCNL stone-related events can occur in 58.8% of patients with RFs ≤ 4 mm and in 71.4% of those with RFs > 4 mm [34]. This means that there are no “clinically insignificant” RFs in modern endourology. Larger stones require more extensive fragmentation, which increases the procedure time and the likelihood of RFs [35]. Even with suction-assisted devices, complete clearance of larger stone volumes is technically challenging, especially in anatomically complex kidney structures. This is particularly true for stones located in calyces and stones of an irregular shape, which are harder to access and clear completely. For these challenging stones, use of a larger sheath alongside suction might help in improving stone clearance.

Our study has several limitations. First, the lack of randomization may have introduced selection bias. Second, variability across centers regarding surgeon expertise and procedural techniques could have influenced outcomes. Third, the variable use of instruments for access and lithotripsy according to surgeon preference, the lack of suction irrigation parameters, and the devices used introduced biases that preclude an understanding of the reasons for high-grade complications. Fortunately, such complications were rare, which reflects the safety of suction mini-PCNL in either position in real-world practice. Fourth, variability in suction devices may affect the generalizability of the results. Furthermore, a lack of stone analysis, hemoglobin levels, and other laboratory parameters precludes any in-depth analysis to garner more information for mitigation of overall complications. Nevertheless, our study findings provide a foundation for validation in future research. Our prospectively collected data covering a wide array of

sheath types and lithotripsy modalities, and homogeneous assessment via 30-d CT imaging demonstrate excellent SFR results for both prone and supine positions. This should encourage urologists to focus less on position and to adopt suction mini-PCNL for optimal outcomes.

5. Conclusions

Our results reveal comparable SFRs and overall low complication rates between supine and prone positioning for suction mini-PCNL. However, the observational nature of the study limits our ability to establish causal relationships between patient positioning and clinical outcomes. Multiple confounding variables, including surgeon expertise, institutional practices, and technical factors (such as access-site selection and imaging guidance), may have an influence on the associations observed. While these findings provide valuable comparative effectiveness data for clinical decision-making, definitive conclusions about the causal effects of patient positioning on specific complications would require randomized controlled trials that can better control for confounding variables. Until such evidence is available, surgeons should consider patient-specific factors, stone characteristics, institutional expertise, and their own technical preferences when selecting the position for suction mini-PCNL, recognizing that both approaches can achieve excellent SFRs with acceptable safety profiles.

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Study concept and design: All authors.

Acquisition of data: Castellani, Gauhar, Kalathia, Mehta, Gadzhiev, Malkhasyan, Kumar, Kalbit, Gorgotsky, Gokce, Laymon, Inoue, Tak, Baker, Dholaria, Chawla, Beltrán-Suárez, Mahajan, Yuen, Tan, Omar, Petkova, Taguchi, Ketsuwan, Lakmichi, Palaniappan, Tanidir, Akdogan, Cepeda, Martov, Tokhtiyev, Tzelves, Skolarikos, Acuña, Zawadzki, Kamal, Gomes Lopes, Gorelov, Agrawal, Chandra Mohan.

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