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ORIGINAL RESEARCH

Comparative Analysis of Surgical Outcomes Between Robotic-Assisted Pyelolithotomy and Mini-Percutaneous Nephrolithotomy for Renal Stones Larger Than 2 cm in Older Adults: A One-Year Follow-Up Study

Hong-An Tu[1,*], Shu-Chuan Weng[2,*], Yu-Hsiang Lin[1,3], Chien-Lun Chen[1,3], Yu-Ting Chen[1], Horng-Heng Juang[3], Chen-Pang Hou[1–3]

[1]Department of Urology, Chang Gung Memorial Hospital at Linkou, Taoyuan, Taiwan; [2]Department of Healthcare Management, Yuanpei University of Medical Technology, Hsinchu, Taiwan; [3]School of Medicine, Chang Gung University, Taoyuan, 333, Taiwan

*These authors contributed equally to this work

Correspondence: Chen-Pang Hou, Department of Urology, Chang gung Memory hospital at Linko, 5 Fu-shing Street, Kwei-Shan, Taoyuan, 333, Taiwan, Tel +886 3 328 1200 ext 2137, Fax +886 3 211 8112, Email glucose1979@gmail.com

Purpose: This study aimed to compare the surgical outcomes of robotic-assisted pyelolithotomy (RAPL) and mini-percutaneous nephrolithotomy (mini-PCNL) specifically in older adults with renal stones more than 2cm. We hypothesized that robotic-assisted pyelolithotomy (RAPL) is a safe and effective approach for managing large renal stones (>2 cm) in older adults.

Patients and Methods: We retrospectively analyzed 605 patients aged 50–80 years who underwent either RAPL (n=31) or mini-PCNL (n=574) for renal stones >2 cm at Chang Gung Memorial Hospital, Taiwan, between December 2016 and November 2023. Patients were selected based on predefined inclusion and exclusion criteria. Key outcomes measured included stone-free rate, complication rate, hospital stay duration, and re-intervention rates. All patients were followed for at least one year postoperatively.

Results: RAPL patients exhibited a longer total operative time (165.2 vs 127.4 minutes, $p = 0.016$) but experienced significantly shorter hospital stays (1.8 vs 4.0 days, $p < 0.001$), lower complication rates (6.5% vs 27.7%, $p < 0.05$), and higher SFRs (90.3% vs 60.8%, $p < 0.001$). Blood transfusion, postoperative discomfort, and re-intervention rates were also markedly lower in the RAPL group.

Conclusion: For older patients with large renal stones, RAPL is a promising alternative to mini-PCNL, offering better stone clearance, fewer complications, and quicker recovery. Its minimally invasive, tissue-sparing approach benefits those at higher postoperative risk.

Keywords: urolithiasis, aged, nephrolithiasis, robotic surgical procedures, minimally invasive surgical procedures

Introduction

Urolithiasis has become an increasing global health concern, with a rising incidence that imposes both socioeconomic and clinical burdens on affected populations.[1] The prevalence of kidney stones in the US rose significantly from 8.7% to 10.1% between 2007 and 2016.[2] In Taiwan, the prevalence is estimated at 9.6%, with a higher rate in men (14.5%) than in women (4.3%).[3] Clinically, urolithiasis may present with renal colic or colic-like symptoms—including flank pain, abdominal discomfort, and dysuria—as well as urinary tract infections and hydronephrosis.[4] Treatment strategies for urolithiasis depend on patient age, stone location, and stone size. Options range from conservative management to surgical interventions such as extracorporeal shock wave lithotripsy (ESWL), ureteroscopy (URS), and percutaneous

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nephrolithotomy (PCNL).[5] Ureteral stones are generally treated with URS or medical expulsion therapy, while renal stones >2 cm typically require surgical removal.[5] In older adults, less invasive techniques are preferred due to increased surgical risks and comorbidities, making appropriate procedure selection essential.[5]

Although PCNL is the standard procedure for renal stones larger than 2 cm, it carries notable risks such as bleeding, sepsis, and renal parenchymal injury.[5] These risks are of particular concern in older adults, who are more prone to postoperative complications like acute kidney injury (AKI), chronic kidney disease (CKD), and sepsis.[6–8] Minimally invasive techniques like mini-PCNL and robot-assisted laparoscopic pyelolithotomy (RAPL) have been developed to reduce trauma to the kidney parenchyma, aiming to lower complication rates.[9–11] Mini-PCNL is less traumatic to the renal parenchyma than standard PCNL, while RAPL further minimizes tissue damage as a true parenchyma-sparing technique. However, direct comparisons between the two remain limited, especially in older adults. Given their higher surgical risk, we hypothesized that RAPL may offer better outcomes. This study compares RAPL and mini-PCNL in older patients and explores scenarios where RAPL may be preferred.

Materials and Methods

Patient Selection and Study Design

This study is a retrospective analysis comparing the treatment outcomes of patients who underwent robotic-assisted pyelolithotomy (RAPL) and Mini-percutaneous nephrolithotomy (Mini-PCNL) at our institution between December 2016 and November 2023. The attending physician preoperatively evaluated and screened all patients for minimally invasive surgery suitability. This study was approved by the Institutional Review Board of Chang Gung Memorial Hospital, Taiwan (IRB number: 202300598B0). All participants were informed of the procedure's benefits, risks, and complications, and provided written informed consent prior to surgery. The study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki. Patients were eligible for inclusion if they met the following criteria: Individuals between 50 and 80 years of age. Adults with unilateral renal stones measuring ≥20 mm. Stone size was assessed based on its largest diameter using computed tomography (CT), intravenous pyelography (IVP), or kidney-ureter-bladder (KUB) radiography. The degree of hydronephrosis was evaluated using CT or ultrasound, following a standard hydronephrosis grading system.[12] Patients deemed suitable candidates for either RAPL or Mini-PCNL. Patients who had received medical treatment only for the target stones and had not undergone any prior invasive procedures, such as ureteric stenting or nephrostomy. Patients were excluded if they had any of the following conditions: Eastern Cooperative Oncology Group (ECOG).[13] Performance status >2, active urinary tract infection (UTI), multiple scattered stones or stones occupying more than two renal calyces, concurrent ureteral stones, atrophic kidney, history of urinary tract malignancy or congenital anomalies (including UPJO), and previous urinary tract reconstruction surgery. All RAPL procedures were performed by one surgeon with experience in robotic laparoscopic surgery to maintain objectivity and consistency, while Mini-PCNL procedures were carried out by the endourology stone treatment team at our institution. Each surgeon had over five years of surgical experience. Patients chose between RAPL and Mini-PCNL after detailed explanations of the procedures. All patients were followed for at least one year postoperatively.

Surgical Procedures and Techniques

Rapl

RAPL was done with the fourth generation da Vinci Xi Surgical System (Intuitive Surgical, Sunnyvale, CA, USA). The procedure began with the patient placed in a modified decubitus position, followed by port placement and colonic mobilization to provide adequate surgical exposure. Following extensive renal pelvis dissection, a pyelolithotomy was conducted to facilitate complete stone extraction. The surgical techniques adhered to Madi et al's methods.[14] to ensure consistency and optimal outcomes.

Mini-PCNL

In Mini-PCNL, the patients were positioned in lithotomy, and a 5-Fr retrograde ureteral catheter is inserted into the renal pelvis. A 16-Fr Foley catheter was then placed and secured alongside the ureteral catheter. The patient was subsequently repositioned to a supine position for the remainder of the procedure. Retrograde pyelography was performed to delineate

the collecting system, and under 0-degree fluoroscopic guidance, an 18-Gauge puncture needle was used to puncture the appropriate renal calyx. A guidewire was advanced antegradely into the bladder, and a 16-Fr dilator was inserted, followed by the placement of an 18-Fr metal sheath. Once the sheath was confirmed to be within the collecting system, the dilator was removed. Stone fragmentation was achieved using a 15.9-Fr nephroscope (Olympus, Tokyo, Japan) and a holmium:YAG laser (Lisa; Sphinx 30W, Katlenburg University, Germany) with a 272-μm laser fiber. The stones were extracted using a stone grasper and suction through the metal sheath. At the end of the procedure, a double-J stent replaced the ureteral catheter, and a nephrostomy tube was placed if needed to ensure a patent urine drainage.

Postoperative Care and Follow-Up

The selection of antibiotics was based on preoperative urine culture results. In cases where urine culture data were unavailable, a standardized prophylactic antibiotic regimen was followed. All patients received a single intravenous dose of cefazolin prior to surgery. Postoperatively, oral cefadroxil 500 mg was administered twice daily for seven consecutive days to prevent urinary tract infections. Acetaminophen was prescribed for seven days postoperatively to alleviate discomfort and enhance recovery. Postoperative imaging was systematically scheduled to assess residual stone burden and detect any complications. Kidney-ureter-bladder (KUB) radiography or renal ultrasonography was performed on postoperative day one, one week postoperatively, and again at one month to evaluate treatment efficacy. The recognition of AKI was based on the KDIGO (Kidney Disease Improving Global Outcomes) 2012 definition.[15] The criteria for stone clearance were defined as the absence of residual calculi or the presence of residual fragments measuring ≤3 mm on imaging at one month postoperatively. Patients were followed for at least one year to evaluate the surgical outcomes. Clinical outcomes were assessed based on various parameters, including the incidence of urinary tract infections, postoperative analgesic requirements, unplanned hospital returns, stone-free rates, surgical complications, and the necessity for additional interventions. Stone re-intervention was defined as any additional intervention performed within one year of the index surgery to manage the residual stones.

Statistical Analysis

The associations between categorical variables were assessed using the Fisher's exact test, while differences in mean values between the groups were analyzed with an independent-samples *t*-test. The distribution of continuous variables was assessed using the Shapiro–Wilk test to determine normality. The probability of an event occurring in one group compared to the other was determined by calculating relative risk values. A *p*-value of less than 0.05 was considered indicative of statistical significance across all analyses. Data processing and statistical evaluations were conducted using SPSS software (version 25; IBM, Armonk, NY, USA).

Results

A total of 832 patients with renal calculi who underwent either RAPL or mini-PCNL were retrospectively reviewed. After excluding cases with bilateral procedures, stone size <2 cm, incomplete records, or follow-up <1 year, 605 patients were included (mini-PCNL: 574; RAPL: 31). The mean follow-up duration was 44.1 months. The patient selection process is shown in Figure 1.

Our data shows that the two groups were comparable in age (55.9 ± 12.09 vs 56.6 ± 12.02 years, p = 0.759), gender distribution (p = 0.081), stone size (40.8 ± 16.8 vs 35.1 ± 15.2 mm, p = 0.163), and the prevalence of comorbidities including diabetes, hypertension, coronary artery disease, stroke, and renal function, as shown in Table 1. However, the degree of hydronephrosis differed significantly (p < 0.001): 64.4% of mini-PCNL patients had no hydronephrosis, compared to only 22.6% in the RAPL group, while moderate-to-severe hydronephrosis was more common in RAPL patients (61.3% vs 8.2%).Total operative time was significantly longer in the RAPL group, with a mean duration of 165.2 ± 73.7 minutes, compared to 127.4 ± 64.3 minutes in the Mini-PCNL group ($p = 0.016$). Additionally, the postoperative hospital stay was significantly shorter in RAPL patients (1.8 ± 0.5 days) compared to Mini-PCNL patients (4.0 ± 1.9 days, $p < 0.001$). Most patients had no history of stone-related interventions, though this was less common in the RAPL group. Prior ESWL was more frequent in RAPL patients, whereas previous PCNL and RIRS were rare in both groups. None of these differences were statistically significant, as shown in Table 2.

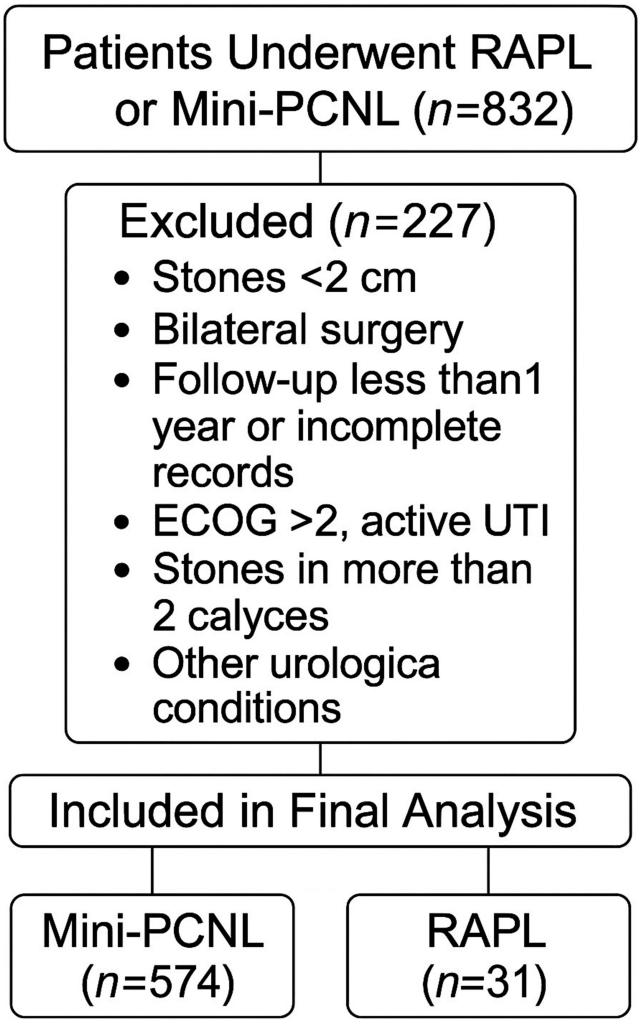

Figure 1 The patient selection flowchart. Patient selection flowchart. A total of 832 patients who underwent RAPL or mini-PCNL were initially reviewed. After excluding 227 patients due to factors such as stone size < 2 cm, bilateral surgery, follow-up less than 1 year or incomplete records, ECOG > 2, active urinary tract infection, stones involving more than two calyces, or other urological conditions, 605 patients were included in the final analysis. Among them, 574 underwent mini-PCNL and 31 underwent RAPL.

Postoperative Outcomes

As shown in Table 3, pain levels assessed by the Numeric Rating Scale (NRS) were comparable between groups. On postoperative day 1, 35.3% of mini-PCNL and 16.1% of RAPL patients reported NRS <1 (RR: 2.190, 95% CI:

Table 1 Pre- and Peri-Operative Data of the Patients

	Mini-PCNL (n=574)	**RAPL (n=31)**	***p* value**
Age (years, SD)	55.9 (12.09)	56.6(12.02)	0.759
Male/Female	335/239	23/8	0.081
Stone diameter (mm, SD)	40.8(16.8)	35.1(15.2)	0.163
Comorbidity factors (n, %)	DM: 131(22.8%) HTN: 271(47.3%) CAD: 21(3.7%) Stroke: 7(1.2%) Cr > 1.3 ng/dL:84(14.8%)	DM 7(22.6%) HTN: 12(38.7%) CAD:0(0%) Stroke:1(3.2%) Cr > 1.3 ng/dL:8(25.8)	0.975 0.351 0.618 0.416 0.120

(*Continued*)

Table 1 (Continued).

	Mini-PCNL (n=574)	**RAPL (n=31)**	***p* value**
Hydronephrosis (n, %)	No: 371(64.4%)	No: 7(22.6%)	<0.001
	Mild: 156(27.2%)	Mild: 5(16.1%)	
	Moderate: 39(6.8%)	Moderate: 10(32.3%)	
	Severe: 8(1.4%)	Severe: 9 (29.0%)	
OP time (minute, SD)	127.4 (64.3)	165.2 (73.7)	0.016
Postop hospital stays (days, SD)	4.0 (1.9)	1.8 (0.5)	<0.001

Notes:. *p*-values are derived using independent-samples *t*-test for continuous variables and Fisher's exact test for categorical variables.
Abbreviations: Mini-PCNL, Mini Percutaneous Nephrolithotomy; RAPL, Robotic-Assisted Pyelolithotomy; DM, Diabetes Mellitus; HTN, Hypertension; CAD, Coronary Artery Disease; Cr, Serum creatinine; SD, Standard Deviation; OP time, Operative time; AKI, Acute Kidney Injury.

Table 2 Previous Stone Management History and Present Treatment Choice

(n, %)	**Mini-PCNL (n=574)**	**RAPL (n=31)**	***p* value**
Intervention naive	446(77.7)	18(58.1)	0.451
ESWL	85(16.9)	8(25.8)	
URS+SM	30(6.0)	3(6.7)	
PCNL	9(1.8)	1(3.2)	
RIRS	4(0.8)	1(3.2)	

Notes: *p*-values are derived using Fisher's exact test for categorical variables.
Abbreviations: PCNL, Percutaneous Nephrolithotomy; RAPL, Robotic-Assisted Pyelolithotomy; ESWL, extracorporeal shockwave lithotripsy; URS, Ureterorenal scope; RIRS, Retrograde intrarenal surgery; SM, Stone management.

Table 3 Postoperative Data

(n, %)	**PCNL (n=574)**	**RAPL (n=31)**	**PCNL/RAPL**
			RR (95% CI)
NRS day 1 $\leq$ 1	201(35.3%)	5(16.1%)	2.190(0.974–4.925)
NRS day 2 $\leq$ 1	257(46.1%)	11(36.7%)	1.256(0.778–2.028)
Surgical complication	159 (27.7%)	2(6.5%)	4.294(1.116–16.517)
Postop UTI	96(16.8%)	4(12.9%)	1.298(0.511–3.299)
Prolonged analgesics	100(17.25%)	4(12.9%)	1.355(0.534–3.440)
URH	65(11.4%)	1(3.2%)	3.074(0.443–21.322)
BT	139(24.2%)	1(3.2%)	1.213(1.128–1.306)
Emergent CT	60(10.5%)	1(3.2%)	2.847(0.410–19.776)

(*Continued*)

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Table 3 (Continued).

(n, %)	PCNL (n=574)	RAPL (n=31)	PCNL/RAPL
			RR (95% CI)
Emergent TAE	12(2.1%)	0(0%)	–
AKI	34 (5.9%) Stage I: 32 Stage II: 2	1(3.2%) Stage I: 1	1.028(0.965–1.089)
Emergent operation	10(1.9%)	0(0%)	–
Re-intervention	185(32.2%)	3(9.7%)	3.330 (1.129–9.826)
Stone free rates	349(60.8%)	28(90.3%)	0.939(0.909–0.971)

Notes: *p*-values for group comparisons were calculated using Fisher's exact test. Relative risks (RR) and 95% confidence intervals (CI) were calculated for each clinical outcome.
Abbreviations: PCNL, Percutaneous Nephrolithotomy; RAPL, Robotic-Assisted Pyelolithotomy; NRS, Numeric Rating Scale; UTI, Urinary Tract Infection; URH, Unexpected Return to Hospital; BT, Blood Transfusion; CT, Computed Tomography; TAE, Transarterial Embolization; AKI, Acute Kidney Injury; RR, Relative Risk; CI, Confidence Interval.

0.974–4.925). By day 2, this increased to 46.1% and 36.7%, respectively (RR: 1.256, 95% CI: 0.778–2.028), without statistical significance.

The overall complication rate was significantly higher in the mini-PCNL group (27.7%) compared to RAPL (6.5%) (RR: 4.294, 95% CI: 1.116–16.517). Most events were minor (Clavien grade I–II; Table 4), with common issues including blood transfusion (24.2% vs 3.2%), urinary tract infection (16.8% vs 12.9%), and prolonged analgesic use (17.25% vs 12.9%). The rate of unexpected return to hospital (URH) was also higher in the mini-PCNL group (11.4% vs 3.2%), though this difference did not reach statistical significance.

Emergent CT imaging was more frequently required in mini-PCNL patients (10.5%) compared to those undergoing RAPL (3.2%). Additionally, only patients in the mini-PCNL group required transarterial embolization (2.1%) or emergent surgical intervention (1.9%). Among the eight emergent surgeries performed in the mini-PCNL group were procedures for hemoperitoneum, massive hematuria, stent malposition, colon perforation, and ureteral obstruction. No RAPL patients required surgical rescue.

Acute kidney injury (AKI) occurred in 5.9% of mini-PCNL patients and 3.2% of RAPL patients, without significant difference (RR: 1.028, 95% CI: 0.965–1.089). All AKI cases were limited to KDIGO Stage I or II.

Stone-Free and Re-Intervention

The stone-free rate (SFR) was significantly higher in the RAPL group (90.3%) compared to mini-PCNL (60.8%) (RR: 0.939, 95% CI: 0.909–0.971). Re-intervention was more frequently required in the mini-PCNL group (32.2%) than in

Table 4 Clavien-Dindo Classification of Surgical Complications

	PCNL (n=159)	RAPL (n=2)
Grade I	86	1
Grade II	61	1
Grade III	12	0
Grade IV	0	0
Mortality	0	0

Table 5 Re-Intervention Procedures

(n, %)	Mini-PCNL (n=185, 32.2%)	RAPL (n=3, 9.7%)
ESWL	83	2
URS-SM	50	1
RIRS	29	0
Mini-PCNL	23	0

Abbreviations: PCNL, Percutaneous Nephrolithotomy; RAPL, Robotic-Assisted Pyelolithotomy; ESWL, Extracorporeal Shockwave Lithotripsy; URS-SM, Ureterorenoscopic Stone Management; RIRS, Retrograde Intrarenal Surgery.

RAPL (9.7%) (χ^2 = 5.971, p = 0.015; RR: 3.33, 95% CI: 1.129–9.826). As shown in Table 5, ESWL was the most common re-intervention in both groups. Among mini-PCNL patients, URS-SM, RIRS, and repeat mini-PCNL were also performed, while no RAPL patients required RIRS or repeat surgery.

Discussion

This study aimed to compare the surgical outcomes of RAPL and mini-PCNL in older adults with large renal stones, and to identify clinical scenarios where RAPL may offer distinct advantages. While PCNL is a standard treatment for renal stones >2 cm, it is associated with overall complication rates ranging from 18.5% to 27.7%, primarily involving bleeding, infection, and access-related injury.[16–18] RAPL has emerged as another alternative, with evidence from meta-analyses demonstrating its safety, lower intraoperative bleeding, and improved stone clearance compared to PCNL[1]. Our data revealed comparable baseline characteristics between RAPL and Mini-PCNL, indicating a fair basis for comparing surgical outcomes. However, the degree of hydronephrosis was significantly more severe in patients undergoing RAPL (p < 0.001), with a notably higher proportion of moderate-to-severe hydronephrosis (61.3%) compared to the Mini-PCNL group (8.2%). RAPL is well-suited for patients with a prominent or extra-renal pelvis, often seen in moderate to severe hydronephrosis. The dilated pelvis offers better exposure, allowing easier dissection and stone removal without cutting through renal tissue, thus reducing bleeding and avoiding vascular control.[14] The robotic system's enhanced dexterity, 3D visualization, and articulating instruments improve access within an expanded collecting system, facilitating removal of large or impacted stones.[14] Despite longer operative times, RAPL patients had significantly shorter hospital stays (1.8 ± 0.5 vs 4.0 ± 1.9 days, p < 0.001), indicating a potential benefit in recovery. RAPL avoids renal parenchymal injury, does not require postoperative bed rest, and omits continuous irrigation and intracorporeal lithotripsy, reducing the risk of bacterial spread from stone dust and minimizing the need for extended observation.

Reported complication rates for mini-PCNL vary. Wishahi et al observed a 20% rate in 2–4 cm stones;[19] Wang et al reported 23.7% minor and 7% major complications;[20] Schulste et al noted 18.5% overall and 7.4% major complications.[21] In our study, mini-PCNL had a significantly higher complication rate than RAPL (27.7% vs 6.5%; RR: 4.294). Most were minor, but bleeding (24.2%), UTI (16.8%), and prolonged analgesic use (17.25%) were more frequent in the mini-PCNL group. The transfusion rate was substantially lower with RAPL (3.2%), indicating reduced bleeding risk.

AKI rates following mini-PCNL range from 4–14%, depending on patient factors and AKI definitions.[22,23] In our study, AKI occurred in 5.9% of mini-PCNL and 3.2% of RAPL patients, with no significant difference, indicating a similarly low risk in both groups. Meta-analyses report stone-free rates (SFR) for mini-PCNL between 70–90%,[11] while RAPL achieves around 87%.[24] In our cohort, SFR was significantly higher in the RAPL group (90.3%) compared to mini-PCNL (60.8%), which is lower than most published data but consistent with some clinical observations. Several factors may explain the relatively low SFR in our mini-PCNL group. First, the mean stone size was 40.8 mm, larger than in many studies reporting higher SFRs, increasing technical difficulty and risk of residual fragments, especially with single-tract access. Second, most patients had no or mild hydronephrosis, limiting collecting system distensibility and

visibility. Lastly, the older age of the cohort (50–80 years) may have prompted more conservative surgical approaches to minimize bleeding and renal injury. These factors likely contributed to the lower clearance rate observed. This difference suggests that RAPL may be more effective in achieving complete stone clearance in selected patients. The higher SFR observed in the RAPL group could be attributed to the direct visualization and precise extraction techniques used in robotic surgery, which allow for thorough removal of renal calculi.

There are some limitations in our study. The selection of surgical procedures in our study was based on the principle of shared decision-making, as this was not a randomized prospective study. The marked imbalance in sample sizes (RAPL: 31; Mini-PCNL: 574) could limit statistical power, particularly for rare events. Although the sample sizes between the two groups were unbalanced, the major baseline characteristics were well matched without significant differences. Therefore, propensity score matching was not applied. All RAPL procedures were performed by a single experienced surgeon, whereas Mini-PCNL cases were managed by a surgical team, introducing potential bias due to variability in surgical expertise. In addition, pain management data were limited to the prescription of acetaminophen and the recorded need for prolonged analgesic use. The actual consumption and use of additional analgesics (eg, NSAIDs or opioids) were not documented, which may limit the accuracy of postoperative pain assessment.

Despite its limitations, this study provides valuable real-world insights by directly comparing RAPL and mini-PCNL for large renal stones (>2 cm) in older adults. The large mini-PCNL cohort enhances the robustness of outcome analysis, while the superior SFR and lower complication rate observed with RAPL highlight its potential value, particularly in patients with complex anatomy such as moderate-to-severe hydronephrosis. These findings support individualized surgical planning based not only on stone size, but also on patient age, comorbidities, and renal anatomy. RAPL may be preferable in elderly patients requiring renal preservation, whereas mini-PCNL remains a practical option for less complex cases.

Conclusion

Our study reveals both RAPL and mini-PCNL are effective and safe options for treating large renal stones (>2 cm) in older adults. RAPL showed higher stone-free rates, fewer complications, and shorter hospital stays, suggesting it may be particularly beneficial for patients with moderate-to-severe hydronephrosis or those at higher surgical risk. While mini-PCNL remains a reliable standard approach, RAPL offers added value in selected cases due to its minimally invasive and tissue-sparing nature. These findings support more personalized surgical planning in elderly patients. Future studies should further evaluate long-term renal outcomes, cost-effectiveness, and patient satisfaction to guide optimal treatment selection.

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Disclosure

The authors report no conflicts of interest in this work.

References

1. Lang J, Narendrula A, El-Zawahry A, Sindhwani P, Ekwenna O. Global trends in incidence and burden of urolithiasis from 1990 to 2019: an analysis of global burden of disease study data. *Eur Urol Open Sci*. 2022;35:37–46. doi:10.1016/j.euros.2021.10.008
2. Xu C, Shapiro DJ, Yaskolka-Meir A, Landman J, Eisenberg ML. Trends in the prevalence of kidney stones in the United States from 2007 to 2016. *Kidney Res Clin Pract*. 2022;41(3):345–353. doi:10.23876/j.krcp.21.264
3. Lee YH, Huang WC, Tsai JY, et al. Epidemiological studies on the prevalence of upper urinary calculi in Taiwan. *Urol Int*. 2002;68(3):172–177. doi:10.1159/000048445
4. Pietrzyk Ł, Gałązka P, Róg L, et al. Prevalence, correlates, and treatment behaviors for urolithiasis and renal colic-like pain symptoms at the population level in Poland. *Sci Rep*. 2025;15(1):11252. doi:10.1038/s41598-025-95504-x
5. Akram M, Jahrreiss V, Skolarikos A, et al. Urological guidelines for kidney stones: overview and comprehensive update. *J Clin Med*. 2024;13(4):1114. doi:10.3390/jcm13041114
6. Golomb D, Shemesh A, Goldberg H, et al. Effect of age on presentation and outcome in renal colic. *Urologia*. 2023;90(1):36–41. doi:10.1177/03915603221116992
7. Chang-Panesso M. Acute kidney injury and aging. *Pediatr Nephrol*. 2021;36(10):2997–3006. doi:10.1007/s00467-020-04849-0

8. Bhojani N, Miller LE, Bhattacharyya S, Cutone B, Chew BH. Risk factors for urosepsis after ureteroscopy for stone disease: a systematic review with meta-analysis. *J Endourol*. 2021;35(7):991–1000. doi:10.1089/end.2020.1133
9. Moretto S, Zazzara M, Marino F, et al. Percutaneous nephrolithotomy vs. robotic pyelolithotomy for large renal stones: an inverse probability treatment weighting analysis. *Minerva Urol Nephrol*. 2024;76(6):726–735. doi:10.23736/S2724-6051.24.06074-9
10. Thapa BB, Niranjan V. Mini PCNL over standard PCNL: what makes it better? *Surg J*. 2020;6(1):e19–e23. doi:10.1055/s-0040-1701225
11. Qin P, Zhang D, Huang T, Fang L, Cheng Y. Comparison of mini percutaneous nephrolithotomy and standard percutaneous nephrolithotomy for renal stones >2cm: a systematic review and meta-analysis. *Int Braz J Urol*. 2022;48(4):637–648. doi:10.1590/S1677-5538.IBJU.2021.0347
12. Onen A. Grading of hydronephrosis: an ongoing challenge. *Front Pediatr*. 2020;8:458. doi:10.3389/fped.2020.00458
13. Oken MM, Creech RH, Tormey DC, et al. Toxicity and response criteria of the Eastern Cooperative Oncology Group. *Am J Clin Oncol*. 1982;5 (6):649–655. doi:10.1097/00000421-198212000-00014
14. Madi R, Hemal A. Robotic pyelolithotomy, extended pyelolithotomy, nephrolithotomy, and anatrophic nephrolithotomy. *J Endourol*. 2018;32(S1): S73–S81. doi:10.1089/end.2017.0718
15. Levin A, Stevens PE, Bilous RW, et al. KDIGO 2012 clinical practice guideline for the evaluation and management of chronic kidney disease. *Kidney Int Suppl*. 2013;3(1):1–150.
16. Reis LO, Barreto W, Bertolo R, et al. Surgical complications of percutaneous nephrolithotomy: a retrospective analysis using the Clavien classification system. *Int Braz J Urol*. 2021;47(6):1222–1229. doi:10.1590/S1677-5538.IBJU.2020.0737
17. Singh P, Raj A, Priyadarshi V, et al. Complications of percutaneous nephrolithotomy: experience from a tertiary care center. *Cureus*. 2024;16(5): e56924. doi:10.7759/cureus.56924
18. Fernández Baltar C, Martínez Corral ME, Pérez Fentes D. Predicting and avoiding complications in percutaneous nephrolithotomy in the era of personalized medicine: a scoping review. *J Pers Med*. 2024;14(9):962. doi:10.3390/jpm14090962
19. Wishahi M, El Feel A, Elkhouly A, et al. Concerns about stone free rate and procedure events of percutaneous nephrolithotripsy (PCNL) for 2–4 cm kidney stones by standard-PCNL vs mini-PCNL- comparative randomised study. *BMC Urol*. 2023;23(1):96. doi:10.1186/s12894-023-01270-1
20. Wang L, Chen SY, Wu FQ, et al. Robotic pyelolithotomy for treating large renal stone disease: a systematic review and single-arm meta-analysis. *J Robot Surg*. 2024;18(1):316. doi:10.1007/s11701-024-02064-9
21. Schulster ML, Sidhom DA, Sturgeon K, Borin JF, Bjurlin MA. Outcomes and peri-operative complications of robotic pyelolithotomy. *J Robot Surg*. 2020;14(3):401–407. doi:10.1007/s11701-019-01004-2
22. Hasan AM, Riyad AM, Ahmed MA. Predictors of acute kidney injury after percutaneous nephrolithotomy in adult patients: prospective observational study. *Int Urol Nephrol*. 2024;56(6):1843–1850. doi:10.1007/s11255-024-03960-7
23. Paymannejad S, Dehghani M, Dehkordi RJ, et al. Prevalence of acute kidney injury following percutaneous nephrolithotomy. *J Res Med Sci*. 2024;29:17. doi:10.4103/jrms.jrms_317_23
24. Mahmud H, Shvero A, Kleinmann N, Dotan ZA, Zilberman DE. Robot-assisted pyelolithotomy in pelvic kidney. *J Clin Med*. 2024;13(24):7727. doi:10.3390/jcm13247727
25. Mantica G, Balzarini F, Chierigo F, et al. The fight between PCNL, laparoscopic and robotic pyelolithotomy: do we have a winner? A systematic review and meta-analysis. *Minerva Urol Nephrol*. 2022;74(2):169–177. doi:10.23736/S2724-6051.21.04587-0