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ORIGINAL PAPER

Transition learning curve of a single surgeon performing ultrasound-guided modified lateral position percutaneous nephrolithotomy

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Summary

Background: *Ultrasound-guided percutaneous nephrolithotomy (PCNL) performed in the modified lateral position offers advantages in ergonomics, airway control, and radiation reduction. However, evidence describing the transition learning curve of surgeons previously trained in fluoroscopy-guided prone PCNL remains limited. This study evaluates learning progression, surgical efficiency, and safety outcomes as an experienced fluoroscopic surgeon adopts an ultrasound-guided modified lateral PCNL technique.*

Materials and methods: *This retrospective study included 70 consecutive patients who underwent ultrasound-guided modified lateral PCNL with extended legs, performed by a single surgeon experienced in fluoroscopy-guided prone PCNL. Patients were divided chronologically into three groups (cases 1-25, 26-50, and 51-70). Operative parameters, puncture characteristics, fluoroscopy time, stone-free rate (SFR), and complications were analyzed. Learning progression was assessed using cumulative summation (CUSUM) analysis based on operative time.*

Results: *Progressive improvements in performance were observed across the series. The proportion of single-attempt punctures increased from 40% to 75% (p = 0.023), while upper calyceal access increased from 8% to 70% (p < 0.001). Median operative, puncture, and fluoroscopy times all decreased significantly across the series. The overall SFR was 95.7%, increasing to 100% in the final group, with predominantly minor complications and no transfusion events. CUSUM analysis demonstrated a proficiency plateau at approximately 40 cases.*

Conclusions: *Surgeons experienced in fluoroscopy-guided prone PCNL can achieve proficiency in ultrasound-guided modified lateral PCNL after approximately 40 cases, with improved efficiency, enhanced puncture precision, and reduced radiation exposure, without compromising safety or stone-free outcomes.*

KEY WORDS: *Percutaneous nephrolithotomy; Learning curve; Modified lateral position; Ultrasound-guided access; Radiation reduction.*

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INTRODUCTION

Urolithiasis remains a global health burden, with prevalence ranging from 5% to 15%. *Percutaneous nephrolithotomy* (PCNL) has long been established as the gold standard, offering high *stone-free rates* (SFR) and minimally invasive access for renal stones > 20 mm (1, 2). Traditionally, PCNL has been performed in the prone position, which provides a direct posterior calyceal access and a broad working space (3). Over the past decades, numerous refinements in PCNL have aimed to improve safety, reduce morbidity, and optimize surgical ergonomics. These include innovations in patient positioning, lithotripsy devices, imaging guidance, and miniaturization of instruments as well as the tubeless approach (4-6). However, the prone position poses anesthetic and cardiopulmonary challenges and limits simultaneous retrograde ureteroscopic access. In contrast, supine and modified lateral positions have gained popularity for facilitating airway management, improving ventilation, and enabling *endoscopic combined intrarenal surgery* (ECIRS). Meanwhile, advances in imaging have transformed puncture guidance from fluoroscopy-based techniques to real-time ultrasound guidance, minimizing radiation exposure while allowing direct visualization of adjacent organs and vascular structures (7, 8).

Despite these advancements, achieving proficiency in PCNL still requires a substantial number of cases to overcome the learning curve and develop procedural consistency (9, 10). Mastery of ultrasound-guided access, in particular, demands not only spatial reorientation but also the ability to integrate real-time imaging into precise calyceal targeting and tract planning (11). Previous studies have reported varying learning thresholds, depending on surgeon experience, imaging modality, and stone complexity. However, data focusing on experienced surgeons adapting to new ergonomic and imaging environments remain scarce (7, 8, 11, 12).

To date, the learning dynamics for surgeons transitioning from fluoroscopy-guided prone PCNL to ultrasound-guided modified lateral PCNL remain underexplored. The present study aims to evaluate the learning curve of a single experienced endourologist performing ultrasound-guided modified lateral PCNL with extended legs. We aimed to identify the proficiency threshold, assess improvements in operative parameters, and determine the safety and effectiveness of this radiation-minimized approach during the transition phase.

Materials and methods

This retrospective study included 70 consecutive patients who underwent *percutaneous nephrolithotomy* (PCNL) in a modified lateral position with extended legs between February 2020 and September 2022 at *Binh Dan Hospital (Ho Chi Minh City, Vietnam)*. All operations were performed by a single board-certified urologist with 15 years of clinical experience, who had completed formal urology residency training and practiced independently. Prior to this study, the surgeon had performed more than 200 conventional fluoroscopy-guided prone PCNL procedures and was newly transitioning to the ultrasound-guided modified lateral approach. The study was approved by the Institutional Ethics Committee (Approval No. 98/HĐĐĐ, approval date 18 February 2020), and all participants provided informed consent. This study was conducted in accordance with the principles of the Declaration of Helsinki. Patients were divided into three chronological cohorts (Cases 1-25, 26-50, and 51-70) to evaluate temporal changes in surgical performance and outcomes.

Preoperative evaluation included routine blood tests, urine culture, and non-contrast *computed tomography* (CT) for assessment of stone characteristics. Body mass index (BMI) was classified according to the Asian criteria, with overweight defined as BMI > 23 kg/m² and obesity as BMI > 25 kg/m² (13). The stone burden was calculated as stone volume (mm³) using the ellipsoid formula: length × width × depth × π × 1/6 (14). Patients with renal calculi ≥ 20 mm or lower calyceal stones ≥ 15 mm were included, while those with uncontrolled urinary tract infection, complete staghorn stones, or bleeding diathesis were excluded. All surgeries were performed under general anesthesia.

The operative technique followed a uniform protocol. After retrograde ureteral catheterization, patients were positioned in a modified lateral decubitus orientation with the operative side up and the ipsilateral leg extended (Figure 1). Renal puncture was performed under real-time ultrasound guidance using a Philips Affiniti 30 ultrasound system (*Philips Healthcare, Amsterdam, Netherlands*) with a convex 2-6 MHz probe using a 16-gauge needle; a 0.038-inch J-tipped guidewire was then advanced into the collecting system. The tract was serially dilated up to 18 Fr using fascial dilators (*Karl Storz, Tuttlingen, Germany*) and an Amplatz sheath inserted. Fragmentation was achieved with a holmium:YAG laser (*Raykeen, Wuhan, China; 40 W, 20 Hz*) via a 12 Fr mini-nephroscope, under continuous low-pressure irrigation. Ultrasound served as the primary imaging modality throughout the procedure; fluoroscopy (*Shimadzu Corporation, Kyoto, Japan*) was used selectively to confirm accurate needle entry and guidewire placement, and check antegrade double-J stent or nephrostomy placement. Stone clearance was verified intraoperatively with ultrasound and limited fluoroscopic confirmation before completing drainage.

Recorded variables included operative time, puncture time, number of punctures, fluoroscopy time, calyceal access site, SFR, and postoperative complications, classified according to the Clavien-Dindo system. Puncture time was defined as the interval from needle contact with the skin to successful guidewire placement within the collecting system (7, 11). Stone-free status was defined as the absence of residual fragments ≥ 4 mm according to non-contrast CT one month after surgery (15).

Continuous variables were tested for normality and expressed as mean ± SD or median (*Interquartile range* - IQR), while categorical variables were presented as frequencies and percentages. Group comparisons were performed using the Kruskal-Wallis test for continuous data and Chi-square or Fisher's exact tests for categorical variables. CUSUM analysis was plotted using the cumulative differences between each case's operative time and the series mean, following the methodology described by Usawachintachit et al and *Lu et al* (8, 11). All statistical analyses were conducted using STATA version 17.0 (*StataCorp, College Station, TX, USA*), and a p-value < 0.05 was considered statistically significant.

Results

A total of seventy patients underwent modified lateral position PCNL with extended legs, all performed by a single surgeon. Baseline demographic variables, including age, sex distribution, and body mass index, were comparable among the three chronological groups (Table 1). Most stones were unilateral and evenly distributed between kidneys. Stone complexity according to Guy's stone score was comparable across chronological groups. The overall median stone burden was 2,282 mm³, with no significant intergroup difference. Despite comparable stone complexity, progressive improvements in technical parameters were observed across the series, indicating a clear learning effect.

Figure 1.
Patient positioned in the modified lateral orientation with the ipsilateral leg extended and secured.

The operative metrics demonstrated a consistent trend toward increased efficiency as case numbers advanced (Table 2). Median operative time declined from 65 minutes in the first 25 cases to 55 minutes in the last 20 cases, and puncture time was significantly shortened after the early phase ($p < 0.001$). The proportion of single-attempt punctures improved markedly, increasing from 40% in the first phase to 75% in the late phase ($p = 0.023$).

Correspondingly, the median fluoroscopy time decreased significantly from 15 seconds (IQR: 11-25) in the first cohort to 12 seconds (IQR: 10-13) in the final group ($p = 0.049$). Regarding access site selection, the utilization of the upper calyx increased markedly from 8% (2/25 cases) in the initial phase to 70% (14/20 cases) in the final phase ($p < 0.001$). Postoperative outcomes corroborated the progressive refinement of technique (Table 3).

Table 1.
Comparison of demographic and stone-related characteristics across chronological case groups.

	All Patients	Cases 1-25	Cases 26-50	Cases 51-70	p-value
Age (years)	52.23 ± 11.32	54.04 ± 12.23	52.04 ± 10.69	50.20 ± 11.11	0.532**
Gender					0.952*
· Male	42 (60%)	14 (56%)	16 (64%)	12 (60%)	
· Female	28 (40%)	11 (44%)	9 (36%)	8 (40%)	
BMI (kg/m²)	23.89 ± 3.13	24.01 ± 2.41	23.06 ± 3.37	24.77 ± 3.51	0.189**
BMI categories					0.667*
· Underweight	2 (2.9%)	0 (0%)	2 (8%)	0 (0%)	
· Normal	42 (60%)	16 (64%)	14 (56%)	12 (60%)	
· Overweight#	26 (37.1%)	9 (36%)	9 (36%)	8 (40%)	
Intervention side					0.830*
· Left	35 (50%)	11 (44%)	13 (52%)	11 (55%)	
· Right	35 (50%)	14 (56%)	12 (48%)	9 (45%)	
Stone Burden (mm³)	2282 (1416; 3553)	2788 (1574; 4029)	2824 (1511; 3393)	2058 (1317; 2703)	0.297**
Guy's stone score					0.323*
· 1	31 (44.3%)	12 (48.0%)	8 (32.0%)	11 (55.0%)	
· 2	31 (44.3%)	12 (48.0%)	13 (52.0%)	6 (30.0%)	
· 3	8 (11.4%)	1 (4.0%)	4 (16.0%)	3 (15.0%)	

*# No patients had BMI ≥ 25 kg/m². * Chi square/Fisher test. ** Kruskal Wallis test.*

Table 2.
Comparison of surgical characteristics among chronological case groups.

	All Patients	Cases 1-25	Cases 26-50	Cases 51-70	p-value
Calyx access site					< 0.001*
· Upper calyx	20 (28.6%)	2 (8%)	4 (16%)	14 (70%)	
· Middle calyx	28 (40%)	16 (64%)	10 (40%)	2 (10%)	
· Lower calyx	22 (31.4%)	7 (28%)	11 (44%)	4 (20%)	
Number of punctures					0.023*
· 1	43 (61.4%)	10 (40%)	18 (72%)	15 (75%)	
· 2	19 (27.1%)	10 (40%)	4 (16%)	5 (25%)	
· 3	3 (4.3%)	1 (4%)	2 (8%)	0 (0%)	
· 4	4 (5.7%)	4 (16%)	0 (0%)	0 (0%)	
· Over 4	1 (1.4%)	0 (0%)	1 (4%)	0 (0%)	
Puncture time (minutes)	1.5 (1; 3)	3 (2; 7)	1.5 (0.8; 2)	1 (0.8; 1.1)	< 0.001**
Fluoroscopy time (seconds)	13 (11; 15.8)	15 (11; 25)	12 (12; 15)	12 (10; 13)	0.049**
Operative time (minutes)	57.5 (50; 73.8)	65 (55; 80)	55 (45; 75)	55 (50; 61.2)	0.049**

** Chi square/Fisher test. ** Kruskal Wallis test.*

Table 3.
Treatment outcomes of ultrasound-guided modified lateral PCNL across chronological case groups.

	All patients (n = 70)	Cases 1-25 (n = 25)	Cases 26-50 (n = 25)	Cases 51-70 (n = 20)	p-value
Stone-free rate	95.7% (67/70)	92% (23/25)	96% (24/25)	100% (20/20)	0.772*
Hemoglobin drop (g/dL)	1.26 ± 0.9589	1.716 ± 1.2645	1.088 ± 0.6591	0.905 ± 0.5708	0.008**
Clavien-Dindo grade					
· Grade 0	87.1% (61/70)	72% (18/25)	96% (24/25)	95% (19/20)	
· Grade 1	4.3% (3/70)	12% (3/25)	0% (0/25)	0% (0/20)	
· Grade 2	7.1% (5/70)	12% (3/25)	4% (1/25)	5% (1/20)	
· Grade 3	1.4% (1/70)	4% (1/25)	0% (0/25)	0% (0/20)	

** Chi square/Fisher test*
*** Kruskal Wallis test.*

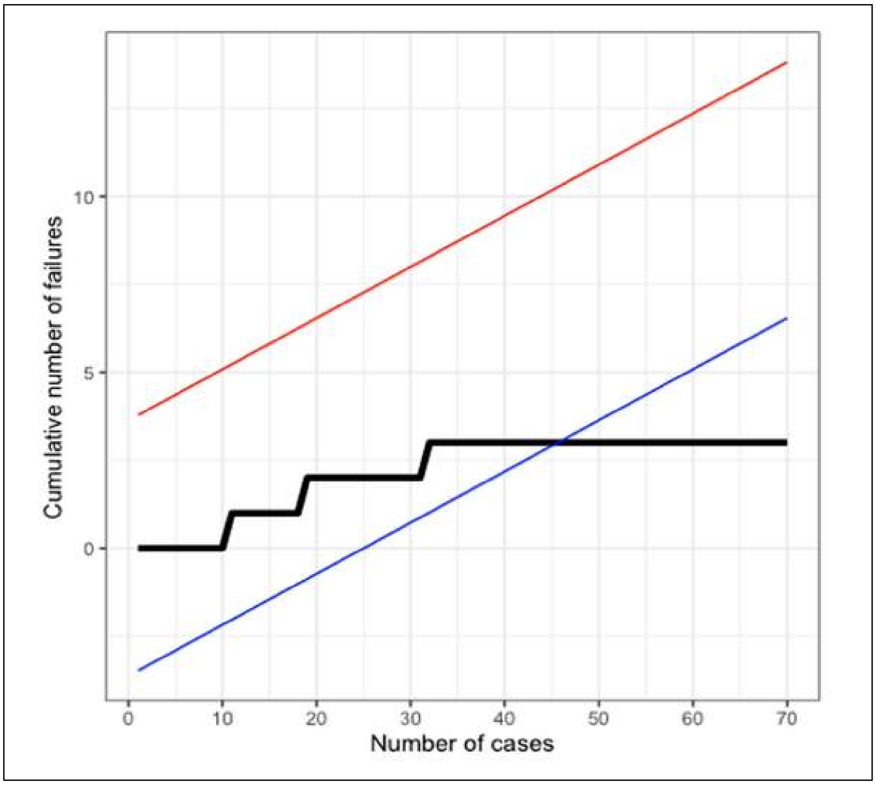


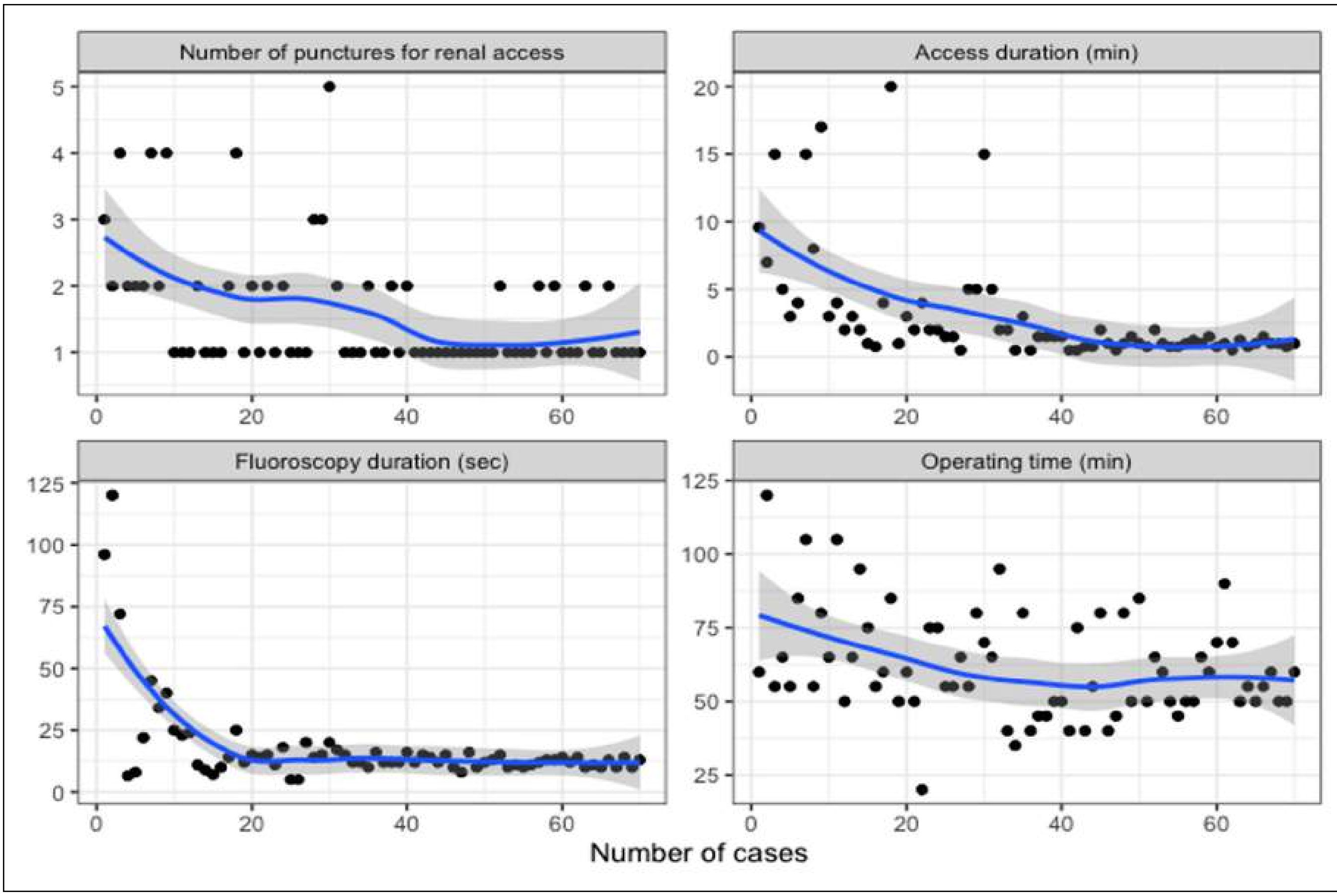
Figure 2.
Cumulative summation (CUSUM) analysis of operative time across 70 consecutive cases.

The overall SFR reached 95.7%, improving from 92% in the early phase to 100% in the final cohort, without a rise in complications. The mean hemoglobin drop decreased significantly from 1.72 g/dL to 0.91 g/dL (p = 0.008), and transfusion was not required in any patient. According to the Clavien-Dindo classification, most complications were grade I or II and limited to transient fever or mild infection, with only one Grade III complication requiring intervention under anesthesia.
CUSUM analysis based on operative time demonstrated a clear inflection point at approximately the 40th case, indicating transition from the learning phase to procedural proficiency (Figure 2). Beyond this threshold, both operative duration and puncture success stabilized, indicating consolidation of surgical skill (Figure 3). Collectively, these findings demonstrate that mastery of ultrasound-guided modified lateral PCNL can be achieved safely within forty cases by a surgeon already proficient in prone, fluoroscopy-guided techniques, achieving optimal stone clearance with minimal morbidity (Table 4).

Table 4.
Summary of representative studies evaluating the learning curve of PCNL.

Study	N (cases)	Study design	Surgeon experience	Position	Imaging guidance	Type of stones	Plateau (cases)
Tanriverdi et al. 2007 (Eur Urol) (18)	104	Prospective	Novice	Prone	Fluoroscopy	Mixed	60
Jang et al. 2011 (Korean J Urol) (19)	53	Retrospective	Intermediate-level surgeon	Flank (modified lateral)	Combined fluoroscopy and ultrasound	Solitary renal stones	36
Song et al. 2015 (PLoS ONE) (7)	120	Retrospective	Novice	Prone	Ultrasound	Non-staghorn stones	60
Usawachintachit et al. 2016 (J Endourol) (11)	120	Prospective	Experienced, transitioning from fluoroscopy	Prone	Ultrasound (n=100) Fluoroscopy (n=20)	Mixed	20
Lu et al. 2024 (J Int Med Res) (8)	72	Retrospective	Trained PCNL surgeon by simulation	Prone	Ultrasound	Complex/ staghorn stones	36
Zoeir et al. 2024 (Minerva Urol Nephrol) (12)	150	Prospective comparative	Novice	Prone vs Supine	Fluoroscopy	Mixed	25 (supine)/ 50 (prone)
Bulut et al. 2024 (Medicina) (22)	100	Prospective	Residents (no solo experience)	Supine vs Prone	Fluoroscopy	Mixed	10 (supine)/ 40 (prone)
Present study	70	Retrospective	Experienced prone-PCNL with fluoroscopy surgeon	Modified lateral	Ultrasound	Non-staghorn stones	40

Figure 3.
Key operative metrics progressively stabilized across cases, reaching a proficiency transition at 40 cases overall.



Discussion

PCNL remains the gold standard for the management of large or complex renal calculi, with continual refinements improving safety and efficiency (1, 2, 4). This study evaluated the transition learning curve of a single surgeon shifting from fluoroscopy-guided prone PCNL to an ultrasound-guided modified lateral approach. CUSUM analysis is an established method for learning curve evaluation, as it enables objective detection of performance stabilization and proficiency thresholds over sequential cases (8, 11). The results demonstrate that procedural proficiency can be achieved after approximately 40 consecutive cases, reflected by a significant reduction in operative time, improved single-attempt puncture rates, and decreased fluoroscopy time without compromising safety or stone-free outcomes. The surge in upper calyx access from 8% to 70% signifies a critical cognitive shift unique to the transition from fluoroscopy to ultrasound. Surgeons often avoid the supracostal upper pole due to the unseen risk of pleural injury (16). However, the real-time visualization of the 'lung curtain sign' during respiration allows for the precise delineation of the pleura, enabling safe upper pole puncture (17). Ultimately, this evolution in access strategy suggests that the learning curve involves not only procedural efficiency but also adaptation to ultrasound-based cognitive frameworks (7).

Earlier studies have shown that novice surgeons performing fluoroscopic prone PCNL typically require 50-60 cases to achieve operative stability. Tanriverdi et al. reported that surgical competence was reached after 60 procedures, with both operative and fluoroscopic times plateauing thereafter (18). Similarly, *Song et al.* observed that total ultrasound-guided PCNL required around 60 cases before reaching consistent efficiency (7). In contrast, Jang et al. identified a plateau after 36 flank PCNL cases in a single-surgeon series (19), and *Usawachintachit et al.* demonstrated that experienced fluoroscopic surgeons could master ultrasound-guided access after only 20-40 cases (11). Our results fall within this range reinforcing the notion that prior expertise with fluoroscopy expedites adaptation to ultrasound-based techniques.

The positioning used in this study represents a minor modification of the modified Valdivia position and was selected as the institutional default due to its compatibility with ultrasound-guided access, anesthetic considerations, and operative workflow. Compared with the prone position, the lateral orientation facilitates improved airway management and ergonomics for both surgeon and anesthesiologist, while enabling simultaneous retrograde access when needed. Even without *endoscopic combined intrarenal surgery* (ECIRS), the lateral orientation provides technical advantages, including gravity-assisted fragment evacuation, improved endoscopic visualization, and dependent fluid drainage, which may facilitate efficient stone clearance and pressure control (3, 4, 20, 21). These factors may enhance procedural confidence and reduce cognitive load during puncture acquisition – key determinants of the learning curve's slope. *Lu et al.* recently confirmed that in ultrasound-guided PCNL for complex calculi, technical proficiency is typically achieved after 36 cases, emphasizing that ergonomic optimization can reduce both operative time and complication rates (8). Likewise, *Bulut et al.* and *Zoeir et al.* independently demonstrated that supine PCNL, which offers similar ergonomic advantages, reached proficiency after 25-40 cases among novice urologists (12, 22). Taken together, these findings support the hypothesis that positions improving respiratory mechanics and visual alignment, such as the modified lateral approach, may accelerate technical maturation.

Importantly, the current study also reinforces the growing evidence base that ultrasound-guided access can be safely integrated into routine PCNL practice. Beyond eliminating ionizing radiation exposure, real-time ultrasound provides visualization of adjacent viscera and vasculature, enhancing safety during tract creation (7, 8, 23). Our data showed a steady decline in fluoroscopy time and radiation use as experience increased, echoing the findings of *Usawachintachit et al.*, who reported a fivefold reduction in radiation exposure after ultrasound adoption (11). Moreover, despite the transition phase, our series maintained high stone-free rates (> 95%) and no major complications, consistent with prior reports of radiation-free PCNL being both efficacious and safe when performed by experienced endourologists (7, 8).

From an educational perspective, these results have implications for surgical training frameworks. The systematic review by *Wirtzfeld et al.* emphasized that achieving proficiency in PCNL typically requires 40-60 cases, depending on surgeon experience, imaging modality, and stone complexity (24). Our findings contribute to this evolving literature by suggesting that structured mentorship and case-based progression can shorten the learning period when transitioning to ultrasound and modified lateral positioning. In the context of competency-based education, a minimum of 40 ultrasound-guided PCNL cases may serve as a benchmark for achieving technical independence among surgeons previously trained in fluoroscopy-guided prone PCNL.

Several limitations should be acknowledged when interpreting our findings. The retrospective single-surgeon design may introduce selection and performance bias, and results may not generalize to surgeons without prior PCNL experience. Moreover, stone complexity and anatomical variation were modest in our cohort, therefore, standalone PCNL was sufficient and incorporating ECIRS could have confounded the evaluation of the transition learning curve. Future multicenter prospective studies should incorporate simulation-based training modules and standardized CUSUM-derived benchmarks to validate these findings across varying experience levels.

Despite these limitations, our data provide meaningful insight into the transition learning curve of an experienced prone-PCNL surgeon adopting ultrasound-guided modified lateral access. Our findings suggest that ultrasound-guided modified lateral PCNL could be adopted widely in centers transitioning away from fluoroscopy, particularly where radiation exposure and ergonomic considerations are priorities. Future multicenter and prospective comparative studies are warranted to validate these findings across different surgeon experience levels and stone complexities.

Conclusions

Transitioning from fluoroscopy-guided prone PCNL to ultrasound-guided modified lateral PCNL is both feasible and efficient for surgeons already proficient in conventional techniques. In this single-surgeon series, procedural proficiency was achieved after approximately 40 cases, with significant reductions in operative and puncture times, minimal complications, and a 95.7% stone-free rate. Importantly, the adoption of ultrasound facilitated a confident shift toward upper calyceal access thereby optimizing stone clearance. These findings highlight that adopting radiation-minimized, ergonomically favorable PCNL approaches can be safely accomplished through structured experience, providing a practical pathway toward safer and more sustainable endourologic practice.

Declarations

Ethical approval and consent for participate: *This study was approved by the Institutional Ethics Committee (Approval No. 98/HĐĐĐ). Written informed consent was obtained from all participants prior to enrollment. The study was conducted in accordance with the principles of the Declaration of Helsinki.*

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Availability of data and material: *The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.*

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