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Comparison between ultrasonography and fluoroscopy for renal access in percutaneous nephrolithotomy

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Abstract
In practice of Urology, percutaneous renal surgery, such as percutaneous nephrolithotomy (PCNL), is a common procedure. One of the most important steps in percutaneous renal access is the creation of a percutaneous tract into the renal collecting system. This step is usually accompanied by imaging. The benefits and drawbacks of each image guidance modality are debatable. This study compared the two commonly used imaging modalities - ultrasonography and fluoroscopy - for renal access in PCNL. This Quasi-experimental study was carried out in Department of Urology, Sir Salimullah Medical College Mitford Hospital, Dhaka, for 12-months period following the ethical approval. A total of 100 patients with renal stones of more than 2 cm in size undergoing percutaneous nephrolithotomy (PCNL) were included in this study after getting informed written consent. Study patients were divided into two groups: group-1 (n=50, PCNL under ultrasonographic guidance) and group-2 (n=50, PCNL under fluoroscopic guidance). Socio-demographic characteristics, stone related information, per- and post-operative data were collected in separate case record forms and analyzed by using SPSS 26.0. Mean age of the study patients was 41.83±9.18 years. Both groups were statistically similar regarding age, gender, BMI, size of stone, degree of hydronephrosis, and site of puncture ($p>0.05$). Maximum puncture was successful in first attempt in both groups (78% in group-1 and 86% in group-2, $p>0.05$). Ultrasonographic guided PCNL had significantly lower mean of time required for successful puncture (5.56±1.83 vs 7.40±1.14 minutes, $p<0.001$) and duration of radiation exposure (4.64±0.15 vs 6.93±0.43 minutes, $p<0.0001$) than fluoroscopic guidance. Ultrasonography guided puncture is superior to Fluoroscopic guided puncture for renal access in PCNL. However, further larger study is recommended.

Keywords: Percutaneous Nephrolithotomy, PCNL, Renal Stone, Urolithiasis, Ultrasonography, Fluoroscopy, Extracorporeal Shock Wave Lithotripsy, Retrograde Intra-Renal Surgery, RIRS, Puncture.

Introduction
Renal stone disease is prevalent worldwide, with an occurrence rate ranging from 5% to 15% and a recurrence probability of nearly 50% (Zhou *et al*., 2019; Xu *et al*., 2018). Percutaneous nephrolithotomy (PCNL) is a widely performed procedure by urologists and serves as a key treatment modality for managing large and complex renal calculi. Owing to its high success rate and minimal complications, PCNL is recognized as a safe and cost-effective approach. Since its initial introduction by Fernstrom and Johansson in 1976, advancements in the procedure have continually focused on improving post-operative outcomes and minimizing morbidity while maintaining a high success rate in stone removal (Xu *et al*., 2018). PCNL can be conducted in various patient positions, including prone, flank, semi-flank, supine, and modified supine positions (Abed & Alhamdani, 2019) [1]. It is generally indicated for renal stones exceeding 20 mm in size, staghorn, and partial staghorn calculi (Birowo *et al*., 2020) [3]. However, it is contraindicated in patients with bleeding disorders or uncontrolled urinary tract infections (Preminger *et al*., 2005).

Regardless of positioning, achieving a precise puncture through the renal calyx papilla is crucial for effective percutaneous access, allowing stone fragmentation and extraction. Therefore, imaging guidance plays a vital role in preventing damage to critical surrounding structures (Falahatkar *et al*., 2016) [5]. The choice between fluoroscopic and ultrasound-guided puncture depends on calyceal anatomy and the surgeon's expertise (Mishra, Sabnis & Desai, 2012) [8]. Fluoroscopy remains the most commonly utilized technique for percutaneous renal access due to the superior image quality of modern C-arm devices and widespread familiarity among urologists. The ability to clearly visualize the needle and guidewire enhances procedural accuracy, making fluoroscopic guidance a preferred choice. It is especially useful throughout renal access, guidewire manipulation, tract dilation, and residual stone assessment during PCNL or endopyelotomy (Lojanapiwat, 2013) [7]. However, the major drawback of fluoroscopic guidance is exposure to ionizing radiation, which poses risks to both the surgical team and the patient. Despite protective measures such as lead aprons, thyroid shields, and specialized eyewear, prolonged radiation exposure increases the risk of long-term health complications (Corrales *et al*., 2021) [4]. Ultrasound-guided PCNL has emerged as an alternative technique to mitigate radiation risks while maintaining real-time procedural control (Yang *et al*., 2019). Due to the widespread availability of ultrasound machines in peripheral healthcare facilities, adopting ultrasound-guided PCNL could enhance the accessibility of the procedure, particularly in remote regions. Additionally, studies indicate that the overall cost of ultrasound-guided PCNL is approximately 30% lower than that of fluoroscopic-guided PCNL (Hudnall *et al*., 2017) [6]. Ultrasound guidance offers multiple advantages over fluoroscopy, including reduced radiation exposure, applicability in patients with pelvic kidneys, lower incidence of visceral injuries (colon, liver, spleen), real-time imaging of the collecting system and renal parenchyma, enhanced visualization of adjacent organs, and improved differentiation between anterior and posterior calyces (Agarwal *et al*., 2011; Lojanapiwat, 2013) [2, 7]. Thus, ultrasound-guided PCNL is a viable alternative that minimizes radiation risks for both patients and surgical teams, particularly in facilities where fluoroscopic equipment is unavailable (Falahatkar *et al*., 2016; Birowo *et al*., 2020) [5, 3]. PCNL is regarded as the first-line treatment for high-volume renal calculi and relies on the successful creation of a percutaneous renal tract. Fluoroscopic guidance is conventionally used for accessing the pelvicalyceal system. However, excessive fluoroscopy use results in prolonged radiation exposure to all individuals in the operating room, which is directly proportional to cumulative radiation exposure time. High doses of radiation are known risk factors for malignancy and can lead to sterility in men and ovarian failure in women. Therefore, minimizing radiation exposure is crucial, particularly in high-volume surgical centers, by adhering to the 'ALARA' principle (As Low As Reasonably Achievable).

Ultrasound-guided PCNL is gaining popularity as it significantly reduces or eliminates radiation exposure. It also facilitates imaging of intervening structures between the skin and kidney, enables three-dimensional evaluation of the pelvicalyceal system, and assists in precise stone localization. Furthermore, ultrasound is a cost-effective and readily available imaging modality, making it a favorable choice in many clinical settings. Cost-effectiveness is an essential consideration in healthcare, necessitating a thorough evaluation of the benefits, risks, and costs of all available techniques. Despite the growing adoption of ultrasound-guided PCNL globally, there is still insufficient evidence from a Bangladeshi perspective to substantiate its superiority over fluoroscopic guidance in PCNL. Hence, this study aims to compare the efficacy and safety of ultrasonography versus fluoroscopy for renal access in PCNL, contributing to the existing body of knowledge and guiding clinical decision-making in urological practice.

Materials and Methods

This quasi-experimental study was conducted in the Department of Urology, Sir Salimullah Medical College Mitford Hospital (SSMCMH) over 12 months (September 2022–August 2023) to compare ultrasonographic and fluoroscopic guidance in percutaneous nephrolithotomy (PCNL). A total of 100 patients aged 18–60 years with renal stones >2 cm, normal renal function, and anticipated single-tract PCNL were selected using purposive sampling and divided into two groups: PCNL under ultrasonographic guidance (n=50) and PCNL under fluoroscopic guidance (n=50). Patients with active urinary tract infections, uncorrected coagulopathies, congenital anomalies, complicated renal stones (except hydronephrosis), pregnancy, malignancy, or radiolucent stones were excluded. Ethical approval was obtained from the Ethical Review Committee of SSMCMH, and informed consent was secured. All procedures were performed by a single surgeon under general anesthesia, with surgical techniques varying based on imaging guidance for renal access. Data collected included demographic characteristics, intraoperative parameters (time to successful puncture, number of attempts, radiation exposure), post-operative outcomes (stone-free rate [SFR], blood loss, complications), and hospital stay. Statistical analysis was conducted using SPSS version 26.0, with the unpaired t-test for continuous variables and the chi-square test for categorical variables, considering $p<0.05$ as statistically significant. Descriptive statistics including means, standard deviations, and percentages were used to summarize the data, with SFR and other parameters compared between the two groups. The study provides a comparative analysis of ultrasonographic and fluoroscopic guidance in PCNL, contributing to optimizing imaging techniques for improved patient outcomes in urological surgery.

Results

Table 1: Socio-demographic characteristics of the study patients (n=100)

Variables	Group-1 (n=50) N (%)	Group-2 (n=50) N (%)	All (n=100) N (%)	p-value
Age group (in years)				
18-29	6 (12)	6 (12)	12 (12)	1.0 $^{\alpha}$
30-39	11 (22)	10 (20)	21 (21)	0.81 $^{\alpha}$
40-49	25 (50)	25 (50)	50 (50)	1.0 $^{\alpha}$
50-60	8 (16)	9 (18)	17 (17)	0.79 $^{\alpha}$
Mean ± SD	41.38±8.88	42.28±9.53	41.83±9.18	0.63 β
Gender				0.79 α
Male	40 (/80)	41 (82)	81 (81)	
Female	10 (20)	9 (18)	19 (18)	
BMI (in kg/m2)				
Mean ± SD	23.22±2.57	23.31±2.52	23.26±2.53	0.86 β

Group-1: PCNL under ultrasonographic guidance
Group-2: PCNL under fluoroscopic guidance
SD=Standard deviation

Values are expressed as Mean ± SD and within parenthesis percentage (%) over column in total. p-values were obtained by $^{\alpha}$ Pearson Chi-square test and $^{\beta}$ Independent Sample T test

Table 2: Stone size of the study participants (n=100)

Variables	Group-1 (n=50) N (%)	Group-2 (n=50) N (%)	All (n=100) N (%)	p-value
Stone size (in cm)				0.84 **α**
2.01-3.0	25 (50)	26 (52)	51 (51)	
3.01-4.0	25 (50)	24 (48)	49 (49)	
Mean ± SD	3.12±0.48	3.05±0.56	3.08±0.52	0.50 β

Group-1: PCNL under ultrasonographic guidance
Group-2: PCNL under fluoroscopic guidance
SD=Standard deviation

Values are expressed as Mean±SD and within parenthesis percentage (%) over column in total.
p-values were obtained by $^{\alpha}$ Pearson Chi-square test and $^{\beta}$ Independent Sample T test

Table 3: Site of puncture in study patients (n=100)

Variables	Group-1 (n=50) N (%)	Group-2 (n=50) N (%)	All (n=100) N (%)	p-value
Site of puncture				
Upper pole	1 (2)	3 (6)	4 (4)	0.31 α
Mid pole	2 (4)	3 (6)	5 (5)	0.65 α
Lower pole	46 (92)	43 (86)	89 (89)	0.34 α
Multiple	1 (2)	1 (2)	2 (2)	1.0 α

Group-1: PCNL under ultrasonographic guidance
Group-2: PCNL under fluoroscopic guidance
SD=Standard deviation

Values are expressed as Mean ± SD and within parenthesis percentage (%) over column in total. p-values were obtained by $^{\alpha}$ Pearson Chi-square test

Table 4: Time required for successful puncture in study patients (n=100)

Variables	Group-1 (n=50) N (%)	Group-2 (n=50) N (%)	All (n=100) N (%)	p-value
Time required (in minutes)				0.017 α
1-5 min	29 (58)	40 (80)	69 (69)	
>5 min	21 (42)	10 (20)	31 (31)	
Mean ± SD	5.56±1.83	7.40±1.14	6.48±1.78	<0.001 β

Group-1: PCNL under ultrasonographic guidance
Group-2: PCNL under fluoroscopic guidance
SD=Standard deviation

Values are expressed as Mean ± SD and within parenthesis percentage (%) over column in total. p-values were obtained by $^{\alpha}$ Pearson Chi-square test and $^{\beta}$ Independent Sample T test

Table 5: Number attempts for successful puncture in study patients (n=100)

Variables	Group-1 (n=50) N (%)	Group-2 (n=50) N (%)	All (n=100) N (%)	p-value
Number of attempts				0.353 $^{\alpha}$
Once	39 (78)	43 (86)	82 (82)	
Twice	8 (16)	7 (14)	15 (15)	
Three times	2 (4)	0 (0)	2 (2)	
Four times	1 (2)	0 (0)	1 (1)	

Group-1: PCNL under ultrasonographic guidance
Group-2: PCNL under fluoroscopic guidance
SD=Standard deviation
Values are expressed as Mean ± SD and within parenthesis percentage (%) over column in total. p-values were obtained by $^{\alpha}$ Pearson Chi-square test

Table 6: Duration of radiation exposure in study patients (n=100)

Duration of radiation exposure (in minutes)	Group-1 (n=50) N (%)	Group-2 (n=50) N (%)	All (n=100) N (%)	p-value
Mean ± SD	4.64±0.15	6.93±0.43	5.79±1.19	<0.001 β

Group-1: PCNL under ultrasonographic guidance
Group-2: PCNL under fluoroscopic guidance
SD=Standard deviation
Values are expressed as Mean ± SD and within parenthesis percentage (%) over column in total. p-values were obtained by $^{\beta}$ Independent Sample T test

Discussion

Percutaneous nephrolithotomy (PCNL) is the preferred treatment for staghorn and large renal stones, recognized as the standard procedure for upper urinary tract stones exceeding 2 cm in size (Ng *et al*., 2017). Traditionally performed under fluoroscopic guidance, this approach ensures precise renal access but carries the risk of radiation exposure to both patients and medical staff. In recent years, ultrasound-guided PCNL has gained popularity, with multiple studies demonstrating its feasibility, safety, and efficacy (Fauzan *et al*., 2023). Fluoroscopy facilitates accurate identification of the target calyx but lacks real-time visualization of adjacent structures, increasing the potential risk of injury. Conversely, ultrasound guidance offers radiation-free, real-time monitoring of the collecting system, renal parenchyma, and surrounding organs while also enabling the detection of radiolucent stones. However, its effectiveness may be limited in patients without apparent hydronephrosis due to the difficulty in visualizing the targeted calyces (Falahatkar *et al*., 2016) [5]. This study compared ultrasonography- and fluoroscopy-guided calyceal puncture during PCNL in 100 patients with renal stones >2 cm, who were equally divided into an ultrasonography-guided group (n=50) and a fluoroscopy-guided group (n=50). The mean patient age was 41.83±9.18 years, with no significant difference between groups (p>0.05), aligning with findings from previous studies. Males constituted the majority of the study population (80% in the ultrasound group and 82% in the fluoroscopy group), a trend commonly observed in renal stone cases due to dietary habits favoring high protein and salt intake. The mean BMI was 23.26±2.53 kg/m², with no significant intergroup differences (p>0.05), indicating that BMI did not influence procedural outcomes. Despite the technical challenge of ultrasound-guided puncture in obese patients, this study confirms its safety and feasibility, consistent with previous findings (Fauzan *et al*., 2023; Hathaivasiwong, 2022; Mohammed *et al*., 2021). The mean stone size was 3.08±0.52 cm, with most patients having stones in the 2–3 cm range (50% in the ultrasound group and 52% in the fluoroscopy group), and no significant differences between groups (p>0.05), corroborating prior research. The mean time to successful puncture was significantly shorter in the ultrasound group (5.56±1.83 vs. 7.40±1.14 minutes, p<0.001), aligning with previous findings, though some studies reported no significant difference (Hathaivasiwong, 2022). Most patients achieved successful puncture on the first attempt (78% in the ultrasound group and 86% in the fluoroscopy group), with no significant difference (p>0.05), consistent with earlier studies and meta-analyses (Hathaivasiwong, 2022; Bahri *et al*., 2023). Radiation exposure duration was significantly lower in the ultrasound group (4.64±0.15 vs. 6.93±0.43 minutes, p<0.0001), reinforcing previous findings that fluoroscopic guidance prolongs exposure due to its necessity in multiple procedural steps. Given these results, ultrasound-guided PCNL appears to offer a safer alternative with reduced radiation exposure while maintaining comparable efficacy in renal access.

Conclusion

This study compared ultrasonography and fluoroscopy guidance for renal access in PCNL, with results indicating that ultrasound-guided PCNL required significantly less time for successful puncture and lower radiation exposure compared to fluoroscopic guidance. Given the reduced radiation exposure and quicker puncture time associated with ultrasound guidance, it can be concluded that ultrasonography is superior to fluoroscopy for renal access in PCNL. However, since the expertise of the ultrasound operator may influence the outcomes, it is recommended to implement a training program for those performing the procedure. Additionally, further large-scale studies in various surgical environments are recommended to validate these findings.

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