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Comparison between Ultrasound and Fluoroscopy-guided Percutaneous Nephrolithotomy (PCNL) at Raden Mattaher Jambi Hospital

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Abstract

Purpose To investigate the effectiveness and safety of ultrasound-guided and Percutaneous Nephrolithotomy (PCNL) compared to the standard fluoroscopy-guided PCNL.

Methods This study is a comparative retrospective study obtained from medical records within the last 5 years of Raden Mattaher Hospital, Jambi. Patients were divided into 2 groups, fluoroscopy- and ultrasonography-guided PCNL with large kidney stone > 20 mm. Patient characteristics were divided into pre- and post-operative procedures and analyzed using SPSS ver. 25.0 (SPSS Inc., Chicago, IL, USA). Data were analyzed using Kolmogorov–Smirnov, chi-square and/ Fischer's exact test and p value < 0.05 was considered statistically significant.

Results Of 201 patients' data from medical records were divided into ultrasound-guided and fluoroscopy-guided groups. Ultrasound-guided group were consisted of 89 patients and fluoroscopy-guided were of 112 patients. US Guided significantly identifies the severity of hydronephrosis compared to PCNL. The demographic data obtained age, sex, body mass index, and preoperative hemoglobin levels showed a normal distribution. On the post-operative results, significant results occurred in post-PCNL stent placement. Installation of a DJ stent alone is more commonly performed on fluoroscopy-guided PCNL procedures compared to ultrasound-guided PCNL. This had a positive impact on post-procedure outcomes, meaning that the post-operative outcome of ultrasound-guided PCNL was better than that of fluoroscopy-guided PCNL.

Conclusion The reported data demonstrate that PCNL and ultrasound-guided has similar efficacy and complication rates with PCNL fluoroscopy-guided. This could be a good alternative in urological centers with no access to fluoroscopy. However, ultrasound-guided group was still associated with higher rate nephrostomy tube placement and longer surgery duration.

Keywords Ultrasound, Percutaneous nephrolithotomy, Fluoroscopy, Treatment, Renal stones

1 Background

Percutaneous Nephrolithotomy (PCNL) is one of the first-line endourology procedure for patients who encounter more than 20 mm kidney stone [1]. The use of PCNL can use the approach of fluoroscopy and ultrasound methods. This method approach is based on several considerations of the patient's condition. The use of ultrasound-guided PCNL and fluoroscopy-guided PCNL

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has its own advantages and disadvantages. In the use of fluoroscopy-guided, it is more precise and does not depend on the skill of the operator in using ultrasound but has the risk of radiation exposure [2]. Meanwhile, ultrasound-guided has no risk of radiation exposure and widely available in areas with limited technology. In terms of cost, the use of ultrasound also has lower cost compared to the use of fluoroscopy-guided [1]. In this study, we compared the effectiveness and safety of using ultrasound-guided vs fluoroscopy-guided PCNL in patients with kidney stones [2–4].

2 Methods

2.1 Study population

This study is a comparative retrospective study obtained from medical records within the last 5 years of Raden Mattaher Hospital, Jambi. Patients' data who underwent PCNL were divided into 2 groups based on type of guidance, fluoroscopy and ultrasonography. All patients included in this study were presented at the hospital with > 20 mm kidney stone and went through PCNL procedures between January 2019 and March 2022. All the patients with uncomplete medical record data, uncorrected coagulopathy, congenital kidney anomalies, and intraoperative conversion to open were excluded from this study. We evaluated and divided the data into demographic parameters, stone characteristics, pre- and postoperative procedures.

2.2 Procedures

All patients underwent the same laboratory tests including blood routine, and renal function tests before the surgery. Preoperative computed tomography (CT) urography was routinely performed to evaluate the stone location, kidney anatomy, and position of surrounding important structures. Stone burden was measured by combining the largest diameter of each stone in all sections [5].

All PCNL procedures were accomplished by a team of endourologists consisting of three different main surgeons. PCNL ultrasound-guided and fluoroscopy-guided were performed in supine (Galdakao-modified Valdivia) position. All patients received preoperative prophylactic antibiotics. PCNL was performed under general anesthesia. For ureteral access, retrograde open-end ureteral catheter (5 Fr) was applied. The ureteral catheter was used for injection of aquadest or contrast agent. Aquadest injection through continuous pump would dilate the collecting system, enabling artificial hydronephrosis and facilitating needle puncture, especially in PCNL fluoroscopy-guided.

Percutaneous renal access was accomplished using a 20-cm puncture needle (1.3 mm/17.5 G). In the ultrasound group, the target calyx selection was identified prior to the operation based on the stone location and surgeon preference. Successful puncture was confirmed with urine flow from the puncture needle. Under ultrasound-guided, a guidewire (0.035-inch J-shaped stiff-guidewire) was inserted into the collecting system. The needle was then withdrawn. Fascial dilatation was performed with 8-Fr until 18-Fr fascial dilators. Urine flow from the dilators confirmed that we had reached the collecting system. Amplatz sheath was then pushed on into the collecting system. In the ultrasound group, ultrasonography was used solely in all procedures, that is, evaluation of the kidney and stone, assistance of kidney puncture, and tract dilatation. In the fluoroscopy group, all those steps were performed under fluoroscopy-guidance.

A 16-Fr rigid nephroscope was used during the PCNL procedure. Stone fragmentation was performed using holmium laser. Stone forceps were used to evacuate the stone fragments. In the ultrasound group, both ultrasonography and nephroscopy were used to identify residual stones, infundibular laceration, or extravasation of urine. In the fluoroscopy group, those procedures were done under fluoroscopic guidance. Upon conclusion of the PCNL procedure, nephrostomy tube, double J (DJ) stent, or externalized ureteral catheter were placed based on any significant bleeding, residual stone fragments, or debris. Some patients had both nephrostomy tube and DJ stent.

2.3 Evaluations

In this study, we compared the demographic parameters, stone characteristics, and operative and postoperative outcomes between ultrasound group dan fluoroscopy group. All patients had post-operative kidney-ureter-bladder (KUB) photo determine the stone-free status. KUB photo could missed residual stone fragments ≤ 4 mm, [12] however patients with residual stone fragments ≤ 4 mm were clinically insignificant and considered to be stone-free in this study [6].

2.4 Statistical analysis

Data presented in this paper were analyzed using SPSS ver. 25.0 (SPSS Inc., Chicago, IL, USA). Data shown in the table were mean (standard deviation) and number (percentage) based on the type of the data. Data were divided into two groups of patients and analyzed using Kolmogorov–Smirnov to test whether the data were normally distributed. Qualitative variables were compared statistically using chi-square or Fischer's exact test and p values < 0.05 was considered statistically significant.

Table 1 Demographic Data

Variable	Ultrasound-guided PCNL (*N* = 89)	Fluoroscopy-guided PCNL (*N* = 112)	*p* value*
Age (year)	49.6 ± 1.2	49.2 ± 1.07	0.59
Sex			
Male	60 (67.4%)	70 (62,5%)	0.74
Female	29 (32.6%)	42 (37,5%)	
Body mass index (BMI) (kg/m^2)	25.4 ± 1.19	25.57 ± 1.34	0.76
Preoperative hemoglobin (g/dL)	13.4 ± 0.11	13.5 ± 0.11	0.82

*p value > 0.05 indicates that data normally distributed

Normality test used Kolmogorov–Smirnov test

3 Results

We collected 201 patients' data from medical records who fulfilled the inclusion and exclusion criteria from Raden Mattaher Hospital, Jambi and divided the data into 2 groups, Ultrasound-guided and Fluoroscopy-guided groups. Ultrasound-guided group were consisted of 89 patients and Fluoroscopy-guided groups were consisted of 112 patients. The demographic characteristics of the groups are presented in Table 1.

The data in Table 1 shows the results of the analysis test with the Kolmogorov–Smirnov test on the number of subjects > 50. The results of the p value indicate that each variable has a value > 0.05, which means that each variable, namely age, sex, body mass index, and preoperative hemoglobin levels has a normal distribution of data, there is no value in the data that is extreme or differs greatly from one data to another.

The data in Table 2 show significant results for the identification of hydronephrosis that is already in severe degrees, namely hydronephrosis grades 3 and 4. In conditions of severe hydronephrosis, or in more advanced conditions, there is a significant change in the anatomical structure, namely changes in ballooning and flattening of the renal calyces pelvis, so that this condition can facilitate the identification of hydronephrosis through ultrasound-guided PCNL, while in mild hydronephrosis conditions, there is usually no significant change in the anatomical structure of the renal pelvis, so this may be difficult to identify by ultrasound, so this examination is more common on fluoroscopy. This is supported by the analysis test results which show significant results (Table 3).

From the various parameters tested/analyzed in the table, it was found that significant results occurred in post-PCNL stent placement. Installation of a DJ stent alone is more commonly performed on fluoroscopy-guided PCNL procedures compared to ultrasound-guided PCNL. Meanwhile, the installation of a DJ stent and a nephrostomy is more required for ultrasound-guided PCNL procedures. This indicates a significant result or test. Table 4 shows complication followed after the procedure classified by Clavien–Dindo system. Most of the patients were not having any complication, but post-operative fever was experienced by 11.24% patients in ultrasound-guided PCNL and 12.5% in Fluoroscopy-Guided PCNL.

4 Discussion

Percutaneous nephrolithotomy (PCNL) is the treatment of choice for staghorn stones and large renal stones, which is recommended as the standard procedure for upper urinary tract stones larger than 2 cm [2]. It is traditionally guided by fluoroscopy and may pose a risk of radiation to patient and staff in the center. The use of ultrasonography in PCNL was first described as early as the 1970s. In the recent years, its trend has grown with

Table 2 Stone Characteristics

Variable	Ultrasound guided PCNL (*N* = 89)	Fluoroscopy-guided PCNL (*N* = 112)	*p* value+
Multiple stone			
Yes	7 (7.87%)	12 (10.71%)	0.49
No	82 (92.13%)	100 (89.29%)	
Classification of stone			
Staghorn	26 (29.21%)	26 (23.21%)	0.34
Non-staghorn	63 (70.79%)	86 (76.79%)	
Hydronephrosis			
None	67 (75.28%)	104 (92.85%)	**0.01***
Grade I	1 (1.12%)	2 (1.79%)	
Grade II	0 (0,00%)	0 (0,00%)	
Grade III	15 (16.85%)	4 (3.57%)	
Grade IV	6 (6.75%)	2 (1.79%)	
Side of stone			
Right	29 (32.59%)	49 (43.75%)	0.16
Left	55 (61.79%)	54 (48.21%)	
Both	5 (5.62%)	9 (8.04%)	
Previous stone surgery			
Yes	11 (12.36%)	13 (11.61%)	0.87
No	78 (87.64%)	99 (88.39%)	
Initial stone burden (mm)	19.75 ± 8.24	18.23 ± 7.43	0.70

* $p < 0.05$ indicates statistically significant

+ Fisher's test

Table 3 Operative and Post-Operative Outcome

Variable	Ultrasound-guided PCNL ($N=89$)	Fluoroscopy-guided PCNL ($N=112$)	*p* value
Surgery duration	115.00 ± 3.12	100.00 ± 1.99	0.38
Blood loss	105.00 ± 3.54	115.00 ± 3.11	0.64
Post-operative hemoglobin (g/dL)	12.95 ± 0.08	13.00 ± 1.62	0.59
Post-procedural stenting			
DJ stent	55 (61.80%)	99 (88.29%)	**< 0.001**
DJ stent and nephrostomy	34 (38.20%)	13 (11.71%)	
Length of stay	3.00 ± 0.05	4.00 ± 0.12	0.91
Stone-free status			
Yes	71 (79.78%)	100 (89.29%)	0.06
No	18 (20.22%)	12 (10.71%)	
Complication (Fever)			
Yes	10 (11.24%)	14 (12.5%)	0.587
No	79 (88.76%)	98 (87.5%)	

**p* < 0.05 indicates statistically significant

+ Chi-Square test

Table 4 Complication classified by a modified Clavien–Dindo system

Variable	Ultrasound-guided PCNL ($N=89$)	Fluoroscopy-guided PCNL ($N=112$)	*p* value
Complication			
Grade I (post-operative fever)	10 (11.24%)	14 (12.5%)	0.587
No	79 (88.76%)	98 (87.5%)	

multiple case series demonstrating its feasibility, safety and efficacy [3]. These have led to 2 randomized clinical trials that showed a more accurate puncture and less radiation exposure for the patients and staff in ultrasound-guided PCNL [4]. Some studies reported that PCNL under ultrasonography guidance in the flank or prone position has high success rates and limited complications and can be a safe and effective alternative to fluoroscopy in experienced hands [7]. Previous study showed that the use of ultrasound in percutaneous nephrolithotomy (PCNL) has not been shown to translate to better clinical and stone outcomes; however, the study conducted by Ng et al. 2017 showed that the use of ultrasonography to guide access puncture during PCNL eliminates the risk of inadvertent organ injuries. Similar operative and stone outcomes show that ultrasound-guided is minimal risk compared to conventional fluoroscopy-guided. Fluoroscopic guidance, traditionally used for renal access, allows accurate identification of the targeted calyx for puncture. The main disadvantage of fluoroscopic guidance is lack of real-time visualization of adjacent viscera, which may increase the risk of surrounding structures injury [8]. Moreover, its ionizing radiation exposure may have detrimental effects on exposed patients and health staff. As an alternative imaging method, ultrasound-guided has been proven to be effective and safe for PCNL and experienced increasing distribution [9]. Its advantages include no radiation exposure, real-time monitoring of the collecting system, renal parenchyma and surrounding organs, detection of radiolucent stones and avoid vascular injury with Doppler flow imaging. However, ultrasound-guided PCNL remains challenging in patients with no apparent hydronephrosis, because it is difficult to visualize the targeted calyces suitable for puncture [9].

Previous studies have shown that intraoperative use of contrast-enhanced ultrasound (CEUS) in the prone position can achieve better visibility of nondilated collecting systems and facilitate more accurate puncture. However, the puncture accuracy and safety of CEUS-guided PCNL in flank position has not been investigated so far. The acknowledged about ideal location for renal puncture is through cup of the renal calyx, which is associated with minimal vascular injury and offer optimal access to stone clearance. In the presence of hydronephrosis, the renal calyx fornix is easy to distinguish since it demonstrates as a hyperechoic area adjacent to the hypoechoic urinary space. However, it is difficult to identify this structure in nondilated collecting system under US guidance, due to the poor imaging affected by the peripelvic fat. There were several other advantages of CEUS-guided PCNL in the treatment of kidney stone patients with no apparent hydronephrosis. The efflux of urine through the puncture needle was sometimes difficult to observe even successful renal puncture was performed, especially in patients with unobvious artificial hydronephrosis [10].

Based on Ng et al., there were higher rates of upper pole (5.6% vs. 3.6%), mid pole (8.3% vs. 2.7%) and multiple pole punctures (4.2% vs. 0%) in ultrasound-guided PCNL compared to Fluoroscopy-guided PCNL ($p=0.027$). There was no difference in the stone-free rates of both groups in univariate analysis. Those who had Fluoroscopic-guided PCNL were 2.26 times more likely to require a second-look procedure compared to ultrasound-guided PCNL on univariate analysis, but not on multivariate analysis. No patient with ultrasound-guided PCNL group experienced organ injuries during puncture compared to 1 patient in the fluoroscopy-guided. Moreover, although fluoroscopy allows accurate identification of the desired calyx for puncture, it does not allow for real-time simultaneous bi-plane fluoroscopy, making the process of obtaining accurate puncture into the desired calyx more difficult. Access with ultrasound-guided puncture during PCNL allows real-time simultaneous bi-plane tracking of the route of puncture into the desired calyx, while avoiding accidental injuries to vital adjacent organs. A less optimal entry into the collecting system will therefore lead to increased bleeding complications and decreased post-operative stone-free rates [11].

Gamal et al. [3] reported 25 cases of moderate hydronephrosis and 9 cases of severe hydronephrosis, all with single stone, while that was also revealed difficulties in ultrasound-guided PCNL with a nondistended collecting system. It concludes that ultrasound-guided PCNL can be performed better for patients with a single stone at the renal pelvis in a moderately to markedly dilated pelvicalyceal system. Therefore, the 4 special structures of the kidney (pelvis, calices, medulla, cortex), each having different anatomy-physiologic properties, should be taken into account in determining the severity of hydronephrosis. The Onen grading system has evidence-based standardized objectives and reproducible parameters. It includes two categories of kidney findings. The first is dilation of the pelvicalyceal system; the second which is the most important category is the quality of the renal parenchyma (thickness and appearance) [10]. This grading system divides thinning of the renal parenchyma into two grades: medullary thinning and cortical thinning. In addition, the appearance of the parenchyma (echogenicity, cortical cysts, corticomedullary differentiation) which is suggestive of renal damage is also taken into account in this grading system. It was proposed on the basis of a well-known tight association between the severity of hydronephrosis and prognosis [12]. Renal deterioration may occur in severe hydronephrosis not timely and promptly treated.

Research conducted by Birowo et al. [13] in 2020 showed that ultrasound-guided PCNL in the supine position could be a good alternative compared to fluoroscopy-guided PCNL because it has been shown to have good efficacy and lower complication rates in patients with kidney stones. Of the 120 patients enrolled, the population was divided into the supine ultrasound-guided PCNL, supine fluoroscopy-guided PCNL, and prone fluoroscopy-PCNL groups (each $N=40$). The supine ultrasound-guided PCNL group had higher puncture attempts, nephrostomy tube placement, and longer surgery duration than both the supine and prone fluoroscopy-guided PCNL groups. However, the stone-free rate was similar in all groups (85%, supine ultrasound-guided PCNL; 72.5%, supine fluoroscopy-guided PCNL; 77.5% prone fluoroscopy-guided PCNL; $p=0.39$). No significant difference was found in the complication rate and length of stay among the three groups, while it was thought because of there were limitations in this study that the comparison groups, which were composed of patients who underwent supine and prone fluoroscopy-guided PCNL, were historical control groups identified from their PCNL database [13]. While other studies reported that ultrasound-guided PCNL had high stone-free rate and low complication rate, and it was reported to be an effective and safe alternative to fluoroscopy when done by experts. Under ultrasound-guided, we could confirm the tip of the puncture needle enters the collection system after seeing a bright contrast outflow along with the needle, either by retrograde injection or antegrade injection of the contrast agent. Before the guide wire placement and dilation, we could also evaluate the puncture quality by observing the angle between the puncture needle and the axis of the renal calyx to the calyx neck. Another advantage of ultrasound-guided is that multiple injections can be performed during one operation, owing to the short half-life (5–7 min) of US contrast, which was feasible for urologists to start this new technology [14].

This study was limited to the effects of radiation exposure on the patients. Further research was suggested to study the effects of radiation exposure to the post-operative outcome.

5 Conclusion

Access with ultrasound-guided puncture during PCNL allows real-time simultaneous bi-plane tracking of the route of puncture into the desired calyx, while avoiding accidental injuries to vital adjacent organs. A less optimal entry into the collecting system will therefore lead to increased bleeding complications and decreased post-operative stone-free rates. PCNL ultrasound-guided has similar efficacy and complication rates with PCNL fluoroscopy-guided. This could be a good alternative in urological centers with no access to fluoroscopy. However, ultrasound group was still associated with higher rate nephrostomy tube placement and longer surgery duration.

Abbreviations

PCNL	Percutaneous nephrolithotomy
CT	Computed tomography
DJ	Double J
KUB	Kidney-ureter-bladder
BMI	Body mass index
CEUS	Contrast-enhanced ultrasound

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Not applicable.

Author contributions
RM contributed to methodology, software, validation, original draft preparation, formal analysis for the study, and also project administration together with WR. Together with RM, A conducted investigations, provided resources, and visualization. On the other hand, A and HH are doing data curation and review editing. Also, HH and WR as supervision.

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Availability of data and materials
The datasets used and analyzed during the study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
The study was approved by Institutional ethics Committee of Raden Mattaher Hospital Jambi with letter number S. 71/SPE/IX/2022. A written informed consent was taken from all patients.

Consent for publication
No consent was taken from patients during their enrollment into the study.

Competing interests
The authors have no competing interest to declare.

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