Italian Journal of Medicine

https://www.italjmed.org/ijm

eISSN 1877-9352

Publisher's Disclaimer. E-publishing ahead of print is increasingly important for the rapid dissemination of science. The Early Access service lets users access peer-reviewed articles well before print/regular issue publication, significantly reducing the time it takes for critical findings to reach the research community.
These articles are searchable and citable by their DOI (Digital Object Identifier).

The Italian Journal of Medicine is, therefore, E-publishing PDF files of an early version of manuscripts that have undergone a regular peer review and have been accepted for publication, but have not been through the copyediting, typesetting, pagination, and proofreading processes, which may lead to differences between this version and the final one.

The final version of the manuscript will then appear in a regular issue of the journal.

The E-publishing of this PDF file has been approved by the authors.

Please cite this article as:

Chaudhry MY, Farooqi MR, Munir A, et al. **Maximizing the success of percutaneous nephrolithotomy under spinal anesthesia by postoperative bleeding and fever prediction using demographic and intraoperative risk factors**. *Ital J Med* doi: 10.4081/itjm.2025.2035

Submitted: 30-04-2025
Accepted: 30-05-2025

Maximizing the success of percutaneous nephrolithotomy under spinal anesthesia by postoperative bleeding and fever prediction using demographic and intraoperative risk factors

Muhammad Yasin Chaudhry,[1] Muhammad Rizwan Farooqi,[1] Asad Munir,[2] Umaima Jalil,[3] Razia Parveen Chaudhry,[1] Andleeb Tariq,[1] Rabia Noor,[4] Umair Ahmed,[4] Arbaz Munir[1]

[1]Yasin Hospital Urology Centre, Lalian, Punjab; [2]Services Hospital, Lahore, Punjab; [3]Lahore General Hospital, Lahore, Punjab; [4]District Head Quarter Hospital, Jhang, Punjab, Pakistan

Correspondence: Muhammad Yasin Chaudhry, Yasin Hospital Urology Centre, Lalian, Punjab, Pakistan.
E-mail: mychaudhry1971@gmail.com

Key words: 4S PCNL, postoperative bleeding, postoperative fever, percutaneous nephrolithotomy, renal, kidney stones.

Contributions: MRF, MYC, conceptualization; MYC, AsM, methodology; AT, validation; MRF, UJ, formal analysis; MRF, investigation; UJ, resources; AsM, RPC, data curation; MYC, MRF, AsM, UJ, writing-original draft; RPC, AT, RN, UA, ArM, writing-review and editing; RN, visualization; UA, supervision; ArM, project administration.

Conflict of interest: the authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Ethics approval and consent to participate: the ethical approval was attained by the International Review Board committee of Integrated Health Solutions International Ltd. (IRB-IHSI-001-2019).

Informed consent: patients were enrolled after providing informed consent. Patients were briefed about the study procedure and follow-up details. They were enrolled after getting informed consent. They were informed about the intent to publish the study.

Patient consent for publication: not applicable.

Availability of data and materials: data will be available upon request from the stated corresponding author.

Funding: none.

Abstract
The 4S percutaneous nephrolithotomy (PCNL) procedure, involving PCNL under spinal anesthesia in a supine position and with sonographic-guided single-step puncture and dilatation for kidney stone removal, faces several complications that can hinder its success. This study, conducted over four years (2019-2023) among 653 Pakistani patients with renal stones and good renal function, aimed to identify complications based on predictors of postoperative bleeding and fever. Patients with irreversible coagulopathy or congenital kidney anomalies were excluded. Risk factors documented included gender, age, stone size, surgery time, puncture type, and calyx position. Data analysis using Jeffreys's Amazing Statistics Program 0.19.3 through binary logistic regression revealed that surgery time and puncture type significantly predicted both bleeding [odds ratio (OR)=1.1 (1.06-1.2) and OR=11.2 (2.8-43.3), respectively] and fever [OR=1.07 (1.03-1.12) and OR=4.8 (1.2-18.6), respectively]. The models for predicting bleeding and fever were ~97% accurate and ~100% specific, with area under the receiver operating characteristic curve values of 0.875 and 0.876, respectively. These findings indicate that surgery time and puncture type are key predictors of postoperative complications following 4S PCNL. This insight can guide critical intensive care unit arrangements to enhance the effectiveness of 4S PCNL and improve patient outcomes.

Introduction

Percutaneous nephrolithotomy (PCNL) is a minimally invasive surgical procedure characterized by a small skin incision, widely utilized for the removal of large or complex kidney stones that are unsuitable for conventional management. Kidney stone disease imposes a substantial global health burden, affecting approximately 15% of the population.[1,2] PCNL offers significant benefits, including high stone clearance rates, reduced pain, shorter hospital stays, and faster recovery.[3] However, its modified version, 4S PCNL, has been developed to address certain limitations of the conventional technique.

4S PCNL, which stands for PCNL under spinal anesthesia, in a supine position, and with sonographically guided single-step puncture and dilatation, overcomes several drawbacks of conventional PCNL.[4] Unlike conventional PCNL, which relies on fluoroscopy and exposes patients and staff to radiation, 4S PCNL employs real-time ultrasound for safer, radiation-free imaging.[5] Additionally, the supine position used in 4S PCNL optimizes access and control over the patient, addressing the ergonomic challenges and respiratory complications associated with the prone positioning in conventional PCNL.[6,7] Furthermore, 4S PCNL reduces procedural risks by utilizing a single-step dilation, as opposed to the multiple-dilation steps in conventional PCNL. The use of spinal anesthesia in 4S PCNL, rather than general anesthesia, also contributes to quicker recovery and better patient tolerance.[8,9]

Despite these advancements, postoperative complications remain a concern in 4S PCNL. Traditional assessment tools, such as Guy's Stone Score and the Clavien Grading System, have limitations when applied to modern 4S PCNL surgeries. Guy's Stone Score, while useful for classifying stone burden, does not fully account for anatomical variations or surgical challenges encountered during 4S PCNL, potentially leading to inaccurate predictions of stone-free rates and complications. Similarly, the Clavien Grading System, while valuable for classifying postoperative complications, lacks specificity in predicting the severity and type of complications unique to PCNL procedures.[10] These tools often fail to capture the complexity of minimally invasive procedures and the diverse patient populations undergoing treatment.

Machine learning models represent a significant advancement in analyzing complex datasets to identify patterns and risk factors that traditional statistical methods may overlook. However, these models face challenges related to explainable artificial intelligence in medical sciences. Converting model predictions into actionable clinical decisions can be difficult, and validation in real-world settings is essential to ensure meaningful insights.[11] Identifying the most relevant features for predicting surgical outcomes can also be challenging, as features significant in one dataset may not be significant in another, leading to inconsistent model performance.[12] Therefore, there is a need for simple, accurate, and interpretable models to predict surgical success and complications.

This study aims to assess the complication status of 4S PCNL among the Pakistani population, focusing on predictors of postoperative bleeding (POB) and fever. Integrating machine learning into clinical decision support systems could facilitate pre-operative stratification of patients based on various factors that determine the success of 4S PCNL. This approach would guide pre-operative patient care to maximize treatment effectiveness.

Materials and Methods

Participants data

This was a single-center study conducted over a 4-year period, from September 2019 to October 2023. The inclusion criteria consisted of patients with pre-diagnosed renal stones and good renal function. The exclusion criteria were patients with irreversible coagulopathy and congenital kidney anomalies. The study included a sample size of 653 patients, comprising both male and female participants. Patient history and intraoperative factors were documented, including gender, age, stone size (ranging from 13 mm to 68 mm), surgery time, puncture type (single or double), calyx position (lower, middle, or upper), POB (none or present), and fever (absent or present).

Percutaneous nephrolithotomy under spinal anesthesia procedure

All patients underwent PCNL in the simple supine position, under spinal block anesthesia, and with ultrasound-guided puncture. After placing a retrograde ureteric catheter (with both ends open) over a guide wire, artificial hydronephrosis was created using 0.9% normal saline to enhance visualization of the pelvicalyceal system on ultrasound. The PASS (papillary access, straight, shortest) criteria were adopted to ensure an optimal tract during PCNL. Under real-time ultrasound grayscale imaging, a kidney puncture was made after distending the pelvicalyceal system with saline from the ureteric catheter. The puncture site and path were selected in the mid-axillary line. An 18-gauge puncture needle was advanced into the appropriate calyx at a 30-degree angle, with the convex ultrasound probe set at 3 to 5 Hz, while keeping the needle aligned within the ultrasound image field. After confirming free flow, the initial papillary puncture was performed, a guide wire was advanced, and dilatation was carried out under ultrasound guidance. An olive-tipped metallic dilator was advanced over the guide wire, and 0.9% normal saline infusion was connected to the retrograde catheter for continuous infusion from below to facilitate optimal dilatation of the pelvicalyceal system.

A single-step dilatation was performed using the olive-tipped metallic dilator, which was already advanced over the guide wire and kept in place to ensure saline flow while an assistant infused saline from below through the ureteric catheter. The tract was dilated with a graduated fascial dilator (size 22) in a one-step procedure. A 20 Fr, 12-degree rigid nephoscope was used for visualization and lithoclastic stone retrieval. Pneumatic lithoclasty was employed in all patients to fragment and subsequently remove the stones. Antegrade double J stenting was performed to ensure proper kidney drainage after the procedure. No nephrostomy tubes were used in any cases. Patients were catheterized to keep the bladder empty for 24 hours postoperatively.

Statistical analysis

For data analysis, Jeffreys's Amazing Statistics Program (JASP) version 0.19.3 was utilized. Categorical variables were presented as frequencies and percentages, while continuous variables were reported as means and standard deviations. Descriptive statistics were performed. Binary logistic regression (LR) was applied using the stepwise method separately for both predictor models: POB and fever. The models were compared using metrics such as accuracy, precision, sensitivity, specificity, F1 score, and Brier scores. Receiver operating characteristic (ROC) curves were also plotted for model comparison.

Results

A total of 653 kidney stone cases, mean size of 32.8±13.7 mm, were operated on. The mean age was 40.5±12.6 years. The average procedure time of 653 surgeries was 39.2±13.1 mins. Table 1 catalogues the proportions of categorical predictors, POB, and fever. The majority of punctures were single (95.3%), while a high proportion of stones were found in the lower calyx.

Stepwise method of binary LR resulted in surgery time and puncture type ($p<0.001$) as significant predictors of POB. In addition to the two, age and calyx position were the most useful predictors of postoperative fever. The variance inflation factor of all the predictors was 1 or above, confirming multicollinearity. Nagelkerke R^2 scores showed that overall, both models were not good fits, but the prediction model POB (0.32) was a better fit than the fever model (Table 2).

The odds of occurrence of bleeding were 11 times higher in patients who received dual punctures during 4S PCNL than in those who received single; a 3.5-time increase in bleeding estimates was found with an increase in puncture sites. Moreover, a unit increase in time increased bleeding 4.4 times. Patients in whom stones were removed from lower calyx positions were 7.8 times more likely to develop fever post-PCNL than those in whom they were in upper calyx. The chances of fever increased 1.7 times with decreasing age of patients, *i.e.*, young people are more susceptible to fever than adults. Prolonged procedure time led to 1 time more vulnerability to fever; for every unit increase in surgery time, the risk of fever was 3.6 times (Table 2).

Both models were 97% accurate. Both models were successful in identifying true negatives among all negatives, *i.e.*, specificity of ~100%. Brier scores indicated that the predicted probabilities of the models were well calibrated. Fever prediction was 100% precise, whereas bleeding prediction was only 50%. Sensitivity was 12.5% for POB and only 5% for fever. This may be due to the skewness of data towards no bleedings and no fevers. The area under the ROC curve (AUROC) was 0.876 for the fever prediction model and 0.875 for the POB prediction model (Table 3 and Figure 1).

Discussion

The study developed a regression analysis using the stepwise method for determining the success of 4S PCNL surgery based on simple and practical prediction of postoperative bleeding and fever. The following predictors were taken into model generation: gender, age, puncture type, calyx position, surgery time, and stone size. Surgery time and dual punctures were statistically significant for both, whereas calyx position and age were concluded as important features for fever prediction. To the best of our knowledge, many similar studies have been done, but none or a few focus on 4S specifically.

Pakdel *et al*. researched to find a cutoff value of PCNL operation time to attenuate complications. Fever and bleeding were regarded as grade 1 complications during follow up which were significantly predicted by operation time, as indicated in our study, body mass index, and age (LR).[13] Another study, which aimed to identify predictive factors of post-PCNL complications, concluded that operation time and upper pole punctures were related to complications.[14] Adding on, research on predicting post-PCNL bleeding concluded the number of tracts (puncture types) as a responsible variable among others using the LASSO model. But the AUROC was 0.779, lower than that reported in this study. A study was conducted to predict systemic inflammatory response syndrome post-PCNL using machine learning models. One of the selected features was operation time, also included in this research, but the majority of features require sampling and quantification chaos; hence, this research provides a simpler method to predict post-PCNL complications. The AUROC of this research (0.856 and 0.857) lies within the range of the AUROC of all six models demonstrated in the study, heralding equivalent diagnostic performance of our predictions.[12] This study demonstrated that young people are more prone to fever than elders, and this may in part be due to the body's quick response to high levels of stress. A study compared the complications and success rates of PCNL according to age and stated no remarkable differences between them.[15] However, another study that measured the frailty index of patients exhibited that severely frail patients were more prone to fevers and required proficient intensive care unit (ICU) management.[16] In our study, the highest proportion of patients had stones in lower calyx positions and were 7.8 times more prone to postoperative fever. This is advocated by similar research that compared PCNL complications according to stone locations. It also revealed that PCNL success was strongly related to shorter operation time and hospital stay, and the most frequent complication was hemorrhage.[17]

Meng *et al.* predicted bleeding complications, but in the lateral decubitus percutaneous. The selected variables were easy to sample and interpret, incorporating all variables used in this study. Random forest worked out to be their best model in comparison to XGBoost and LR. LR was only 73.2% accurate, while the accuracy achieved constituting our predictors was ~97% for both POB and fever. Moreover, the AUCROC of our models was greater than that of LR (0.6) applied in the discussed study.[18] Sample sizes of studies by Zhang *et al*. and Meng *et al*. were substantially less than that employed in this study.[11,18]

This study is limited due to disapplication of complication grading scales, such as Clavien one, because its goal was to predict complications through the simplest means possible without any prior stratification burden and mistakes. It was a single-center study, which increases the chances of bias. Our proposed predictive models need external validation for generalizability and comparison with other predictive tools.

Conclusions

Postoperative bleeding and fever are both reliable for determining complications post-4S PCNL. They are significantly predicted by surgery time and puncture types. Physicians should shorten operation time and reduce the number of incisions in 4S PCNL. In other situations, critical arrangements for ICU care for postoperative bleeding and fever should be made according to the time spent on surgery and the number of punctures for successful PCNL outcomes.

References

1. Wang L, Yu Y, Jiang Z, et al. Inverse association between prognostic nutritional index and kidney stone prevalence: a population-based study. PloS One 2025;20:e0318254.
2. Hosseini MM, Hassanpour A, Farzan R, et al. Ultrasonography-guided percutaneous nephrolithotomy. J Endourol 2009;23:603-7.
3. Boggs ZD, Regalado LE, Makary MS. Procedural fundamentals for medical students: institutional outcomes of a novel multimodal course. Acad Radiol 2022;29:1095-107.
4. Mak DK, Smith Y, Buchholz N, El-Husseiny T. What is better in percutaneous nephrolithotomy–prone or supine? A systematic review. Arab J Urol 2016;14:101-7.
5. Usawachintachit M, Tzou DT, Hu W, et al. X-ray–free ultrasound-guided percutaneous nephrolithotomy: how to select the right patient? Urology 2017;100:38-44.
6. Zhao Z, Fan J, Liu Y, et al. Percutaneous nephrolithotomy: position, position, position! Urolithiasis 2018;46:79-86.
7. Falahatkar S, Farzan A, Allahkhah A. Is complete supine percutaneous nephrolithotripsy feasible in all patients? Urol Res 2011;39:99-104.
8. Meena M, Mantan K, Saxena M, et al. General versus spinal anesthesia in percutaneous nephrolithotomy: a comparative study. IAIM 2017;4:59-66.
9. Jamil MN, Haq F, Islam E, et al. Comparison between supine position versus prone position in percutaneous nephrolithotomy: a single centered analysis of 623 cases. J Ayub Med Coll Abbottabad 2022;34:1003-7.
10. Bux KI, Ahmed RR, Farooq F, et al. Clinical utility of STONE, Guy's Scoring System, and Renal Stone Complexity Scoring in predicting outcome of single-Tract percutaneous nephrolithotomy. Cureus 2023;15:e50983.
11. Li P, Tang Y, Zeng Q, et al. Diagnostic performance of machine learning in systemic infection following percutaneous nephrolithotomy and identification of associated risk factors. Heliyon 2024;10:e30956.
12. Zhang T, Zhu L, Wang X, et al. Machine learning models to predict systemic inflammatory response syndrome after percutaneous nephrolithotomy. BMC Urol 2024;24:140.
13. Pakdel A, Mohammadi A, Shamshirgaran A, et al. Operation time as a prognostic indicator on postoperative complications following percutaneous nephrolithotomy. SAGE Open Med 2025;13:20503121251318902.
14. Said DF, Ferreira DB, Hayek KK, et al. Factors associated with complications after percutaneous nephrolithotomy: an analysis of 1,066 cases. Rev Assoc Med Bras 2023;69:e20221089.
15. Iqbal N, Hasan A, Malik HA, et al. A comparison of complications and success rates after PCNL in younger and elderly patients. J Coll Physicians Surg Pak 2020;30:1316-20.
16. Bhatia VP, Aro T, Smith SM, et al. Frailty as predictor of complications in patients undergoing percutaneous nephrolithotomy (PCNL). World J Urol 2021:3971-3977.
17. Taşkıran M, Dogan K. Comparison of success and complication rates of percutaneous nephrolithotomy operations according to kidney stone localization. Endoüroloji Bülteni 2023;15:115-24.
18. Meng R, Wang W, Zhai Z, Zuo C. Machine learning algorithm to predict postoperative bleeding complications after lateral decubitus percutaneous nephrolithotomy. Medicine 2024;103:e37050.

Table 1. Frequency distribution of categorical predictors and postoperative bleeding and fever.

Categorical Predictors	Level	Counts	Proportion (%)
POB	No	637	97.5
	1 POB	16	2.5
Fever	No	630	96.5
	Yes	23	3.5
Gender	F	263	40.3
	M	390	59.7
Puncture type	Single	622	95.3
	Dual	31	4.7
Calyx position	Upper	195	29.9
	Lower	305	46.7
	Middle	153	23.4

POB, postoperative bleeding; F, female; M, male.

Table 2. Model summaries of postoperative bleeding and fever with associated coefficients of logistic regression using the stepwise method.

Models	Odds (95% CI)	Wald Test p (df)	z estimates	Nagelkerke R^2
POB				
Surgery time	1.1 (1.06-1.2)	<0.001 (1)	4.4	0.32
Puncture type (dual)	11.2 (2.8-43.3)	<0.001 (1)	3.5	
Fever				
Surgery time	1.07 (1.03-1.12)	<0.001 (1)	3.6	0.26
Puncture type (dual)	4.8 (1.2-18.6)	<0.001 (1)	2.3	
Age	1 (0.9-1)	0.09 (1)	-1.7	
Calyx position (middle)	3.1 (0.1-53.8)	0.44 (1)	0.8	
Calyx position (lower)	7.8 (0.9-61.8)	0.05 (1)	2	

CI, confidence interval; df, degree of freedom; POB, postoperative bleeding.

Table 3. Performance metrics of postoperative bleeding and fever models.

Models	Accuracy	Sensitivity	Specificity	Precision	F1 score	Brier score
POB	0.974	0.125	0.997	0.5	0.2	0.02
Fever	0.97	0.05	1	1.0	0.1	0.027

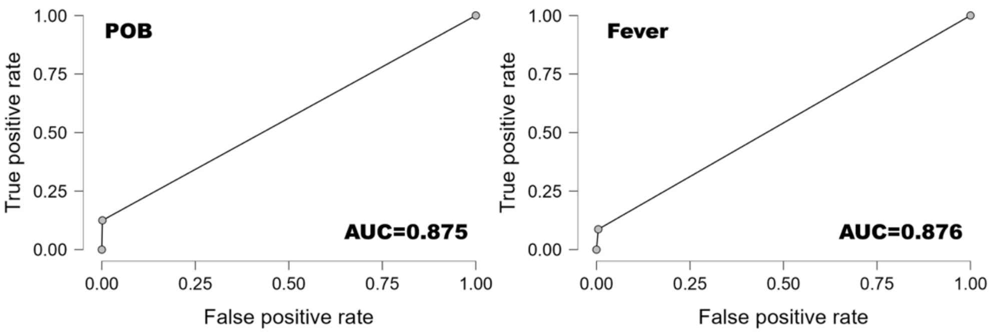

Figure 1. Receiver operating characteristic curves for postoperative bleeding (POB) and fever prediction models. POB area under the curve (AUC)=0.875; fever AUC=0.876.