RESEARCH ARTICLE

Association Between Computed Tomography-Based Stone Burden and Stone-Free Rates Following Percutaneous Nephrolithotomy

Muhammad Asif[1], Muhammad Asif Ammar[2], Abdul Basit Niazi[3], Syed Raza Abbas[4], Javed Imran[5], Ahmed Bilal Ghani[6]

[1]*Assistant Professor. Urology Department. King Edward Medical University. Lahore. Email ID: gimsonion2000@gmail.com*
[2]*Assistant Professor. Urology Department. CMH Kharian Medical College. Kharian. Email ID: drasifammar@gmail.com*
[3]*Associate Professor. Urology Department. Niazi Medical & Dental College. Sargodha. Email ID: drabdulbasitniazi233@gmail.com*
[4]*Assistant Professor. Urology Department. Rai Foundation Medical College. Sargodha. Email ID: srajafry@yahoo.com*
[5]*Assistant Professor. Urology Department. Rashid Latif Medical College. Lahore. Email ID: Javeedimran1980@gmail.com*
[6]*Senior Registrar. Urology Department. Rashid Latif Medical College. Lahore. Email ID: ahmadghani994@gmail.com*
***Corresponding Author:** Abdul Basit Niazi. Associate Professor. Urology Department. Niazi Medical & Dental College. Sargodha. Email ID: drabdulbasitniazi233@gmail.com*

Received: 25th October 2026; **Revised:** 28th October 2026; **Accepted:** 3rd November 2026; **Available Online:** 7th November 2026

Abstract

Background: Noncontrast computed tomography (CT) is routinely used to estimate renal stone burden before percutaneous nephrolithotomy (PCNL), but how well a simple area measurement predicts complete clearance in resource-limited settings is unclear.

Objective: To assess the association between CT-based stone burden and stone-free status after PCNL.

Methods: This retrospective multicenter cohort included 240 adults who underwent standard PCNL at tertiary hospitals in Pakistan, sampled in equal numbers (n=80) from three preoperative stone-area categories. Cumulative stone area was calculated on noncontrast CT using standard viewing tools only. Stone-free status was defined as no residual fragment of any size on low-dose CT four weeks after surgery. Logistic regression adjusted for age, diabetes, staghorn configuration, calyceal involvement and centre.

Results: Overall, 176 patients were stone-free (73.3%; 95% confidence interval [CI] 67.4–78.5%), a proportion that reflects the stratified design. Stone-free rates were 90.0%, 82.5% and 47.5% for burdens of ≤400, 401–800 and >800 mm², respectively. Each additional 100 mm² increased the odds of residual stones (adjusted odds ratio 1.35; 95% CI 1.19–1.52; p<0.001). Stone area alone had an apparent area under the receiver operating characteristic curve of 0.799. Of the 64 patients with residual stones, 34 had fragments ≤4 mm and 30 had larger fragments.

Conclusion: Larger CT-based stone burden was associated with a lower chance of complete clearance. Cumulative stone area is a simple aid to preoperative counselling alongside anatomical assessment, but it needs independent validation before routine use.

Keywords: Percutaneous nephrolithotomy, kidney calculi, computed tomography.

How to cite this article: Asif M, Ammar MA, Niazi AB, Abbas SR, Imran J, Ghani AB., Association Between Computed Tomography-Based Stone Burden and Stone-Free Rates Following Percutaneous Nephrolithotomy. Int J Drug Deliv Technol. 2026;16(90s): 988-994; DOI: 10.25258/ijddt.16.90s.96

Source of support: XX
Conflict of interest: XX

Introduction

Percutaneous nephrolithotomy (PCNL) remains the standard treatment for large renal calculi, and the choice of procedure depends on stone characteristics, collecting-system anatomy and patient factors.[1] Pakistani data show that clearance varies with stone size and location, so case complexity has to be described before surgical results can be compared.[2] For patients and surgeons alike, a realistic preoperative estimate of clearance helps set expectations about the first operation, follow-up imaging and the chance of further treatment.

Noncontrast computed tomography (NCCT) allows stone diameter, area and volume to be measured, yet more elaborate measurements do not necessarily predict outcome better.[3] Stone density adds information, but its relationship with PCNL clearance differs from that of size; in one series, density-to-area ratios and stone location were more informative than Hounsfield units alone.[4] A practical description of burden therefore needs to separate the amount of stone from its density and distribution.

Nephrolithometry systems combine these features into structured estimates of procedural complexity, and validation studies have linked higher S.T.O.N.E. scores with lower clearance.[5] In Pakistan, both S.T.O.N.E. nephrolithometry and Guy's stone score have been associated with postoperative stone-free status,[6] and regional work has highlighted the number of involved calyces as a determinant of clearance.[7] Prospective data also relate nephrolithometry scores to operative time and other markers of procedural difficulty.[8]

These scores do not transfer equally well between settings. A multicentre study of miniaturized PCNL found lower discrimination than is usually reported for standard techniques.[9] An international consensus documented wide variation in tract definitions, postoperative imaging and acceptable residual-fragment thresholds, all of which complicate comparison of published success rates.[10] A recent comparison found that established nomograms took different amounts of time to calculate but discriminated clearance similarly.[11] Measurements that can be reproduced without commercial software are therefore worth examining.

How success is defined matters just as much. A systematic review found little agreement on residual-fragment thresholds or imaging schedules, which limits comparison across studies.[12] Guideline overviews stress that postoperative imaging should be interpreted in light of the treatment performed and the sensitivity of the imaging method, which may detect very small fragments.[13] Randomized comparisons of standard and smaller-tract PCNL have also shown that technique changes perioperative outcomes even when clearance looks similar.[14]

In Pakistani tertiary hospitals, a stone-area estimate taken from an existing NCCT examination is a practical candidate for such a measure, provided it is measured consistently, judged against a clearly specified endpoint and adjusted for anatomical differences. Routine CT viewing is widely available in these hospitals, whereas volumetric segmentation software often is not. The present study therefore examined cumulative CT stone area in relation to complete clearance after standard PCNL, assessing burden categories, adjusted associations and residual-fragment outcomes, and keeping complete clearance distinct from small residual fragments.

Materials and Methods

This retrospective multicentre cohort study included adults who underwent standard PCNL at tertiary hospitals in Pakistan between July 2025 and June 2026, with outcomes reviewed until September 2026. The study was approved by the institutional review boards of the participating hospitals, and individual consent was waived because data were collected retrospectively. Patients were sampled by stratum: 80 were selected from each of three preoperative stone-area categories, giving 240 in total. Equal allocation allowed comparison across burden levels, but it means the overall stone-free proportion describes this selected cohort rather than an unselected hospital population.

Patients aged 18 years or older who underwent unilateral PCNL with preoperative NCCT and documented postoperative CT were eligible. Each patient contributed one renal unit and one index procedure. Exclusion criteria were pregnancy, untreated urinary infection, uncorrected coagulopathy, major congenital collecting-system anomalies and simultaneous bilateral surgery. Records lacking the primary imaging endpoint or essential regression variables were excluded before selection, so the analysed cohort had complete data for all reported variables.

NCCT performed within four weeks before surgery was reviewed on axial images and coronal reconstructions. Cumulative stone area was calculated as the sum of the elliptical areas of separate stones (area = $\pi \times$ maximum length $\times$ perpendicular width / 4), with each stone measured in millimetres in the plane showing its largest cross-section. A continuous branching calculus was counted as one stone so that branches were not counted twice. The result is an area approximation, not a segmented surface area or a three-dimensional volume.

Maximum stone diameter, mean attenuation (Hounsfield units), staghorn configuration, calyceal involvement and hydronephrosis were also recorded. Calyceal involvement was dichotomized at three or more calyces, and moderate or severe hydronephrosis was distinguished from absent or mild dilatation using the reported imaging interpretation. Operational definitions are given in Table 1. Measurements were not repeated by an independent reader, and blinding to outcome was not recorded, so interobserver agreement could not be estimated.

*Author for Correspondence: drabdulbasitniazi233@gmail.com

Table 1 Operational definitions

Variable	Definition
CT stone burden	Sum of elliptical stone areas in mm²
Burden categories	≤400; 401–800; >800 mm²
Staghorn calculus	Branching stone occupying pelvis and calyces
Extensive calyceal involvement	At least three calyces
Primary endpoint	No fragment on CT at four weeks
Residual-fragment categories	≤4 mm or >4 mm
Ancillary treatment	Further stone procedure within 90 days

CT, computed tomography.

PCNL was performed prone through a standard 24–30 Fr tract under fluoroscopic guidance, followed by rigid nephroscopy with pneumatic or ultrasonic lithotripsy. Preoperative work-up included urine culture, renal function, blood count and coagulation tests. Positive cultures were treated before surgery, and perioperative antibiotics followed local protocols. Additional access, drainage and ureteric stenting were left to the operating surgeon, based on stone distribution, intraoperative findings and clinical condition. Operator experience and differences in equipment were not included in the adjusted analysis.

The primary endpoint was complete clearance (stone-free status) on low-dose NCCT at four weeks, with a two-week scheduling window, before any elective ancillary treatment. Any visible residual fragment counted as failure, and patients who needed earlier intervention for residual stones were classed as failures regardless of later imaging. Residual fragments ≤4 mm were recorded separately from larger fragments. Secondary outcomes were operative time, any documented postoperative complication (not graded for severity) and further stone treatment within 90 days, counting at most one ancillary procedure per patient. Final clearance after retreatment was not assessed.

No formal power calculation was performed; the sample comprised the available complete records within each stratum. Continuous variables are reported as mean ± standard deviation or median (interquartile range) and categorical variables as frequencies and percentages. Groups were compared with Welch's t-test, the Mann–Whitney U test or Fisher's exact test, and Wilson intervals were calculated for stone-free proportions. Binary logistic regression modelled residual stones using stone area (per 100 mm²), age (per decade), diabetes, staghorn configuration, involvement of three or more calyces and two centre indicators, all entered simultaneously. Area and maximum diameter were not entered together because both measure stone size, and the 64 residual-stone events limited model complexity. Discrimination was summarized by the area under the receiver operating characteristic (ROC) curve, with a 2,000-resample percentile bootstrap confidence interval for area alone. Analyses were run in Python (NumPy, SciPy and statsmodels). Two-sided $p<0.05$ was considered significant, and secondary comparisons were treated as exploratory.

Results

The 240 patients were distributed equally across the three centres and the three stone-burden strata. After the index procedure, 176 patients (73.3%; 95% CI 67.4–78.5%) were stone-free and 64 had residual stones, which provided the events for regression analysis.

Baseline characteristics by clearance status are shown in Table 2. Age, sex, body mass index, diabetes and previous ipsilateral surgery were similar in the two groups.

Table 2 Baseline characteristics by clearance status

Characteristic	Stone-free n=176	Residual stones n=64	P value
Age years	43.3 ± 11.5	43.5 ± 12.6	0.896
Male sex	119 (67.6)	41 (64.1)	0.644
Body mass index kg/m²	26.0 ± 3.6	25.5 ± 3.7	0.329
Diabetes mellitus	36 (20.5)	13 (20.3)	1.000
Previous ipsilateral surgery	28 (15.9)	10 (15.6)	1.000

Values are mean ± SD or n (%), compared with Welch's t-test or Fisher's exact test.

Imaging characteristics are compared in Table 3. Residual stones were more common with larger stone burden and more extensive anatomical involvement, whereas stone density and hydronephrosis differed little between groups. Diameter and area both describe stone size, so their unadjusted differences should not be read as two independent effects.

Table 3 CT characteristics by clearance status

Characteristic	Stone-free n=176	Residual stones n=64	P value
Cumulative area mm²	481.3 (285.5–745.2)	944.9 (729.4–1272.3)	<0.001
Maximum diameter mm	31.0 (23.0–38.2)	43.6 (36.8–49.9)	<0.001
Stone density HU	1014.8 ± 242.7	1024.1 ± 208.3	0.772
Staghorn configuration	34 (19.3)	33 (51.6)	<0.001
At least three calyces	49 (27.8)	39 (60.9)	<0.001
Moderate or severe hydronephrosis	41 (23.3)	15 (23.4)	1.000

Values are median (IQR), mean ± SD or n (%). HU, Hounsfield units. Mann–Whitney U, Welch's or Fisher's tests.

Figure 1 shows stone-free rates and perioperative outcomes across stone-area categories. Clearance fell most sharply in the highest category, and operative time rose steadily with burden. Complication rates did not rise uniformly and were lowest in the middle stratum. These category boundaries are descriptive and are not validated treatment thresholds.

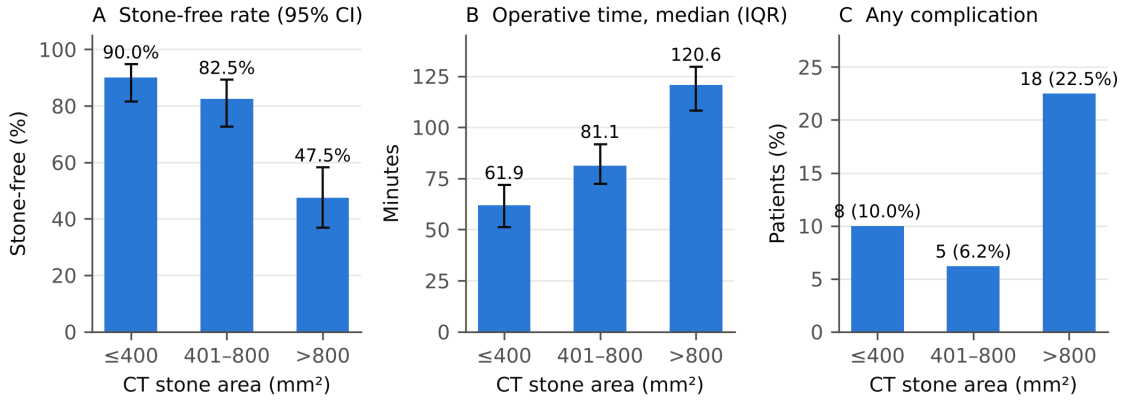

Figure 1 Stone-free rate (A), operative time (B) and complications (C) by CT stone burden

n=80 per category. Error bars show Wilson 95% confidence intervals (A) and interquartile ranges (B). Complications were exploratory.

The adjusted analysis is presented in Table 4. Stone area remained associated with residual stones after adjustment; the odds ratio describes a change in odds, not a percentage-point change in risk. Estimates for the other covariates were imprecise, with confidence intervals that included 1. Centre indicators capture systematic differences between hospitals but not between individual surgeons.

Table 4 Adjusted associations with residual stones

Predictor	Adjusted OR	95% CI	P value
Area per 100 mm²	1.35	1.19–1.52	<0.001
Age per 10 years	1.22	0.90–1.65	0.200
Diabetes	0.86	0.36–2.06	0.742
Staghorn configuration	1.55	0.72–3.37	0.264
At least three calyces	1.66	0.80–3.47	0.177
Centre B versus A	2.23	0.97–5.11	0.058
Centre C versus A	0.90	0.38–2.16	0.814

Outcome: residual stones=1. OR, odds ratio. All predictors were entered simultaneously; centre A was the reference.

Stone area alone had an apparent area under the ROC curve of 0.799 (bootstrap 95% CI 0.732–0.859), compared with 0.830 for the full model. These values describe discrimination within the study cohort and are probably optimistic, because sampling by stone-area stratum over-represents the extremes of burden. No external validation, clinical-utility analysis or cutoff selection was performed, so sensitivity and specificity are not reported.

Residual-fragment categories and subsequent treatment are summarized in Figure 2. Most ancillary procedures were performed in patients with fragments larger than 4 mm. All took place after the primary endpoint assessment and therefore did not alter the single-procedure stone-free rate, and small fragments were still counted as residual disease.

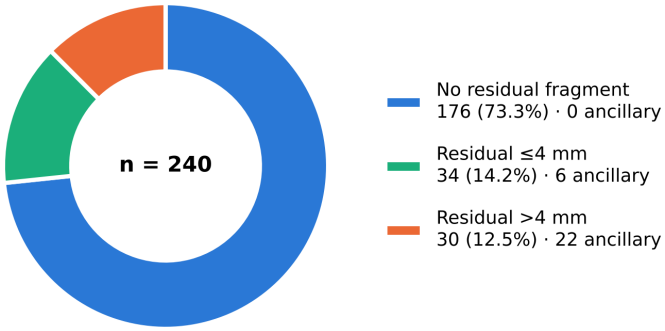

Figure 2 Residual fragments on four-week CT and subsequent ancillary procedures

Percentages use all 240 patients. Ancillary procedures followed primary endpoint assessment.

Of the 28 ancillary procedures, eight were repeat PCNL, 13 ureteroscopy and seven shockwave lithotripsy, with one procedure per treated patient. Final clearance after retreatment, cumulative stone-related morbidity, costs and patient-reported outcomes were not assessed. The primary finding therefore concerns baseline burden and initial complete clearance, and subsequent treatment is reported descriptively.

Discussion

Larger CT stone area was associated with a lower chance of complete clearance after PCNL, and the association persisted after adjustment for selected anatomical and clinical factors. This agrees with recent work comparing practical stone measurements, although one study found that software-free three-dimensional proxies discriminated clearance better than conventional area or diameter.[15] Area is therefore a feasible measure, but its value relative to more detailed volume estimates remains uncertain.

A study comparing nephrolithometry systems with stone surface area reported only moderate predictive performance, suggesting that size alone does not capture every determinant of success.[16] A revised S.T.O.N.E. model that weighted several stone characteristics likewise underlines the contribution of multiple imaging features.[17] The non-significant adjusted anatomical coefficients in the present study do not show that stone distribution is unimportant; correlation between features and limited precision are more likely explanations.

The strict endpoint shapes how these results should be read. Hartung and colleagues found frequent disagreement between endoscopic and CT assessment of clearance, showing the limits of intraoperative impressions.[18] Kingma and colleagues reported more stone-related events in patients with small residual fragments than in those who were completely stone-free, questioning the assumption that fragments ≤4 mm are insignificant.[19] Zhu and colleagues similarly linked larger residual fragments, particularly those of at least 4 mm, with unplanned stone events.[20] Reporting fragment size separately therefore preserves information that more permissive definitions of success would hide.

Intraoperative imaging studies show that detecting residual stones changes management. A prospective portable-CT study reported higher clearance and fewer planned reinterventions than a historical comparison group, although its design limits causal inference.[21] A feasibility study showed additional fragment removal after intraoperative CT, with the caveats of nonrandomized allocation and nonuniform follow-up.[22] In a randomized trial, intraoperative cone-beam CT raised the stone-free rate from 61% to 76%, but success was defined with a 4-mm fragment threshold.[23] These discrepancies show why the imaging method and fragment threshold must be stated explicitly.

Longer follow-up of that trial found fewer patients with fragments larger than 4 mm, while the difference in stone-related events remained statistically uncertain.[24] Its cost analysis relied on Dutch hospital costs and utilization assumptions, which limits direct application to Pakistani services.[25] In the Pakistani setting, an area measurement taken from an existing NCCT is a practical aid to risk assessment. Postoperative CT, however, carries radiation exposure, access requirements and costs to patients, none of which were measured.

The study has several strengths. It drew on tertiary centers, used a clearly defined area measurement that needs only routine CT viewing tools, and applied a strict CT endpoint that kept complete clearance separate from small residual fragments. Its main limitations are the retrospective design and stratified sampling, which may have introduced selection bias and mean that the overall stone-free rate and AUC do not apply to unselected patients. Residual-stone events were modest in number, measurement reproducibility was not tested and no external validation was performed. Larger studies with longer follow-up should test simple CT measurements alongside anatomical complexity.

Conclusion

Larger CT-based stone burden was associated with lower stone-free rates after PCNL. Cumulative stone area is a practical preoperative measure when interpreted alongside stone distribution and a clearly defined postoperative imaging endpoint. It merits further evaluation for counselling and operative planning, but independent validation is needed first.

References

1. Skolarikos A, Geraghty R, Somani B, Tailly T, Jung H, Neisius A, et al. European Association of Urology Guidelines on the Diagnosis and Treatment of Urolithiasis. Eur Urol. 2025;88(1):64-75.

2. Khalil MAU, Patujo YH, Ullah F, Ibrar U, Adil R, Inam QA, et al. An Analysis of Percutaneous Nephrolithotomy (PCNL) Performed at the Institute of Kidney Disease, Pakistan: Stone Clearance and Complications. Cureus. 2024;16(12):e75430.

3. Tailly T, Nadeau BR, Violette PD, Bao Y, Amann J, Nott L, et al. Stone Burden Measurement by 3D Reconstruction on Noncontrast Computed Tomography Is Not a More Accurate Predictor of Stone-Free Rate After Percutaneous Nephrolithotomy Than 2D Stone Burden Measurements. J Endourol. 2020;34(5):550-557.

4. Moon HW, Taeyb M, Park YH, Bae WJ, Ha US, Hong SH, et al. The impact of Hounsfield unit-related variables on percutaneous nephrolithotomy outcomes. Sci Rep. 2022;12(1):18451.

5. Abdrabuh AMI, Ghanem MMA, Yahia MAA, Fawzy MN. Reliability and validity of "S.T.O.N.E" nephrolithometry scoring system to predict the stone-free rate after percutaneous nephrolithotomy. Urol Ann. 2021;13(1):14-18.

6. Khan N, Nazim SM, Farhan M, Salam B, Ather MH. Validation of S.T.O.N.E nephrolithometry and Guy's stone score for predicting surgical outcome after percutaneous nephrolithotomy. Urol Ann. 2020;12(4):324-330.

7. Illahi Bux K, Rizwan Ahmed R, Farooq F, Daggula NR, Mahmood J, Wasim U, et al. Clinical Utility of S.T.O.N.E, Guy's Scoring System, and Renal Stone Complexity Scoring in Predicting Outcome of Single-Tract Percutaneous Nephrolithotomy. Cureus. 2023;15(12):e50983.

8. Danis E, Polat EC, Bozkurt M, Erkoc M, Can O, Altunrende F, et al. Application of S.T.O.N.E. Nephrolithometry Score for Prediction of Stone-Free Status and Complication Rates in Patients Who Underwent Percutaneous Nephrolitotomy for Renal Stone. J Laparoendosc Adv Surg Tech A. 2022;32(4):372-377.

9. Mazzon G, Claps F, Pavan N, Choong S, Zeng G, Wu W, et al. Reliability of nephrolithometric nomograms in patients treated with minimally invasive percutaneous nephrolithotomy: A precision study. Asian J Urol. 2023;10(1):70-80.

10. Zeng GH, Zhong W, Mazzon G, Zhu W, Lahme S, Khadgi S, et al. International Alliance of Urolithiasis (IAU) consensus on miniaturized percutaneous nephrolithotomy. Mil Med Res. 2024;11(1):70.

11. Ozsoy C, Ates E, Tuzcu G, Kol A. A Comparative Evaluation of the Predictive Accuracy, Clinical Utility, and Application Efficiency of Four Nephrolithometric Nomograms for Percutaneous Nephrolithotomy Outcomes. J Coll Physicians Surg Pak. 2026;36(7):938-944.

12. Çavdar OF, Aydin A, Tokas T, Tozsin A, Gadzhiev N, Sönmez MG, et al. Residual stone fragments: systematic review of definitions, diagnostic standards. World J Urol. 2025;43(1):194.

13. Akram M, Jahrreiss V, Skolarikos A, Geraghty R, Tzelves L, Emilliani E, et al. Urological Guidelines for Kidney Stones: Overview and Comprehensive Update. J Clin Med. 2024;13(4):1114.

14. Guddeti RS, Hegde P, Chawla A, de la Rosette JJMCH, Laguna Pes MP, Kapadia A. Super-mini percutaneous nephrolithotomy (PCNL) vs standard PCNL for the management of renal calculi of <2 cm: a randomised controlled study. BJU Int. 2020;126(2):273-279.

15. Wei B, Ning F, Fu Y, Ji L, Gu S, Wang Y. Bridging the gap in PCNL preoperative planning: software-free stone metrics that outperform conventional measures. BMC Urol. 2026;26(1):107.

16. Fernández Baltar C, Gude Sampedro F, Pérez Fentes D. Does success in percutaneous nephrolithotomy depend only on stone size? Analysis of the predictive capacity for success and complications of the current nephrolithometry scoring systems and their relationship with the stone surface. Actas Urol Esp. 2024;48(8):603-610.

17. Wei B, Chen J, Fu Y, Ji L, Gu S, Wang Y. A data-driven revision of the S.T.O.N.E. nephrolithometry score: Improved predictive accuracy for stone-free

status after PCNL. Sci Prog. 2025;108(4):368504251396066.

18. Hartung FO, Müller KJ, Herrmann J, Grüne B, Michel MS, Rassweiler-Seyfried MC. Comparison of endoscopic versus CT assessment of stone-free status after percutaneous nephrolithotomy (PCNL). Urolithiasis. 2023;51(1):120.

19. Kingma RA, Doppen C, Bus MTJ, Altobelli E, de Jong IJ, Roemeling S. The significance of clinically insignificant residual fragments after percutaneous nephrolithotomy: an analysis into the relevance of complete stone clearance. World J Urol. 2024;42(1):78.

20. Zhu D, Mali K, Carlisi C, Cheng G, Doersch KM, Quarrier SO, et al. Impact of Residual Stone Fragments on Risk of Unplanned Stone Events Following Percutaneous Nephrolithotomy. J Endourol. 2024;38(12):1380-1386.

21. Patel PM, Kandabarow AM, Chuang E, McKenzie K, Druck A, Seffren C, et al. Using Intraoperative Portable CT Scan to Minimize Reintervention Rates in Percutaneous Nephrolithotomy: A Prospective Trial. J Endourol. 2022;36(10):1382-1387.

22. Van den Broeck T, Zhu X, Kusters A, Futterer J, Langenhuijsen J, d'Ancona F. Percutaneous Nephrolithotomy with Intraoperative Computed Tomography Scanning Improves Stone-Free Rates. J Endourol. 2021;35(3):267-273.

23. Roemeling S, Kingma RA, Suijker CA, Altobelli E, Bus MTJ, Greuter MJW, et al. Intraoperative Cone Beam Computed Tomography Increases Single Procedure Stone-Free Rates in Percutaneous Nephrolithotomy: Results of a Randomized Controlled Trial. J Endourol. 2025;39(7):671-678.

24. Suijker CA, Kingma RA, van Ee R, Steffens EN, Altobelli E, Bus MTJ, et al. Longer-term effects of intraoperative cone-beam computed tomography in percutaneous nephrolithotomy: 18-month retrospective randomised controlled trial analysis. BJU Int. 2025;136(5):848-857.

25. van Ee R, Suijker CA, van Asselt ADI, van Oort IM, Kingma RA, Roemeling S. Cost Comparison of Percutaneous Nephrolithotomy With and Without Intraoperative Cone-beam Computed Tomography: 18-month Postoperative Analysis. Eur Urol Open Sci. 2026;83:125-132.