



CORRELATION OF CT-BASED STONE DENSITY AND SIZE WITH OUTCOMES OF PERCUTANEOUS NEPHROLITHOTOMY IN RENAL CALCULI PATIENTS: A RETROSPECTIVE STUDY

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Background: Percutaneous nephrolithotomy (PCNL) is the gold standard for renal stones >2 cm. Pre-operative non-contrast computed tomography (NCCT) stone attenuation in Hounsfield Units (HU) and dimensions are increasingly utilized to predict surgical outcomes, but comprehensive data from tertiary centres in North India remain limited.

Objectives: To correlate pre-operative CT-based stone density (mean HU) and largest stone diameter with PCNL outcomes—specifically stone-free rate (SFR) at 4 weeks, operative time, haemoglobin drop, hospital stay, and complications using the modified Clavien–Dindo classification—in adults at Saraswati Medical College, Unnao.

Methodology: A retrospective record review was conducted encompassing 118 consecutive adult patients who underwent standard 24–30Fr PCNL between July 2019 and February 2020. Pre-operative NCCT mean HU (using free-draw regions of interest) and maximum stone diameter were extracted by a radiologist blinded to outcomes. Descriptive and inferential statistical analyses (independent t-tests, Pearson correlation, ROC curve, and multivariable logistic regression) were performed using SPSS v23.0 following institutional ethical clearance.

Results: The cohort (mean age 41.7±12.6 years; 71.2% male) had a mean stone diameter of 22.4±7.8 mm and mean HU of 982±312. The SFR at 4-week NCCT was 79.7%. Stones >25 mm and density >1000 HU independently lowered SFR (aOR 3.21, p=0.014 and aOR 2.78, p=0.022 respectively for non-stone-free status). The high-density cohort (>1000 HU) experienced longer mean operative times (94.2 vs 71.6 min, p<0.001) and greater haemoglobin drops (1.6 vs 0.9 g/dL, p=0.002). ROC analysis identified an HU cut-off of 1043 predicting residual stones (AUC 0.78, sensitivity 71%, specificity 74%). Overall Clavien complications occurred in 18.6%, predominantly low-grade (I–II).

Conclusion: Pre-operative NCCT-derived stone density and diameter independently predict PCNL outcome in this North Indian demographic. An HU cut-off near 1040 serves as a practical threshold to triage patients toward staged PCNL, mini-PCNL, or pre-emptive transfusion planning.

Keywords: percutaneous nephrolithotomy; Hounsfield units; renal calculi; stone density; non-contrast CT; PCNL outcome; Uttar Pradesh

1. Introduction

Since its conceptual introduction by Fernström and Johansson in 1976, percutaneous nephrolithotomy

(PCNL) has evolved from a nascent technique into the definitive standard of care for large and complex renal calculi.³ Contemporary European Association of Urology (EAU) and American Urological Association (AUA) guidelines strongly endorse PCNL as the first-line intervention for renal stones exceeding 2 cm in diameter, as well as for complex lower pole and staghorn calculi.^{1,2} Despite advances in tract dilation, nephroscopic optics, and lithotripsy modalities, achieving complete stone clearance while minimizing haemorrhagic and infectious morbidity remains a distinct clinical challenge.

Pre-operative imaging, principally non-contrast computed tomography (NCCT), has fundamentally altered surgical planning by allowing precise quantification of stone burden, anatomical configuration, and composition surrogates. The Hounsfield Unit (HU), an index of radiodensity, correlates reliably with calculus hardness and fragility.¹⁰ Consequently, stone density estimations derived from NCCT have been hypothesized to predict lithotripsy fragmentation difficulty, procedural duration, risk of residual fragments, and subsequent bleeding.^{5,12}

While the relationship between HU parameters and surgical outcomes has been established in select global cohorts, robust data evaluating this dynamic in the North Indian "stone belt" remains surprisingly sparse.⁶ This region, characterised by specific agrarian dietary patterns, climatic extremes, and hard groundwater, frequently presents urologists with large-volume stone burdens, including staghorn and partial staghorn configurations that often require complex percutaneous planning.¹⁶ Saraswati Medical College, serving a predominantly rural catchment area in Unnao, Uttar Pradesh, frequently encounters these complex clinical phenotypes. This study was undertaken to bridge the regional data gap by establishing clear statistical correlations between pre-operative CT-derived stone metrics (density and size) and post-PCNL clinical outcomes.

2. Review of Literature

The utilization of NCCT parameters to prognosticate endourological success has prompted significant investigation globally. A foundational analysis of the Clinical Research Office of the Endourological Society (CROES) global database by Anastasiadis et al. firmly established that increased stone density significantly prolonged operative time and reduced stone-free rates (SFR) following PCNL.⁵ Subsequent studies, including work by Gallioli et al., further showed that CT-derived attenuation metrics, particularly HU density, were independently associated with residual fragments after PCNL, reinforcing the prognostic value of pre-operative CT characterization.¹²

In parallel to isolated metric evaluation, complex scoring systems such as Guy's Stone Score, S.T.O.N.E. nephrolithometry, and the CROES nomogram have integrated size, tract anatomy, and occasionally density to predict outcomes.^{19,20} Other PCNL outcome studies have likewise shown that increasing stone burden, access complexity, and baseline anatomical factors remain important determinants of procedural success and overall morbidity, particularly in staghorn disease subsets where higher complexity grades track with lower clearance and greater complication risk.^{8,14} Tailly et al. further noted that sophisticated 3D volumetric reconstructions, though radiologically elegant, do not vastly outperform standard 2D NCCT measurements of burden and density in routine clinical settings.⁷

In the Indian context, the application of standardized complication reporting using Clavien–Dindo-based reporting recommendations has improved the objective appraisal of PCNL safety.⁴ However, regional series specifically correlating HU parameters with Clavien-graded outcomes remain limited. Contemporary discussions around complex and staghorn PCNL, together with systematic evidence supporting selective tubeless PCNL strategies, underscore a transitioning paradigm toward tailored procedural planning based on pre-operative stone characteristics.^{15,16} Nonetheless, most detailed HU-outcome correlation literature originates from East Asia or the Middle East, necessitating a focused retrospective analysis validating these metrics within the North Indian demographic, where both stone size and density often present at the upper extremes of the spectrum.

3. Objectives

Primary Objective

To determine the correlation between pre-operative NCCT mean stone density (HU) and maximum

stone diameter with the stone-free rate (SFR) at 4-week follow-up among adults undergoing standard PCNL at Saraswati Medical College, Unnao.

Secondary Objectives

1. To assess the association of stone density and diameter with secondary procedural outcomes, including operative time, intra-operative haemoglobin drop, and length of hospital stay.
2. To systematically define the peri-operative complication profile utilizing the modified Clavien–Dindo classification.
3. To derive an optimal HU cut-off value for the prediction of residual stone presence using receiver operating characteristic (ROC) analysis.
4. To identify independent pre-operative predictors of non-stone-free status via multivariable logistic regression modeling.

4. Methodology

4.1 Study Design & Setting

This research was structured as a single-centre, retrospective record-based observational study. It was conducted collaboratively by the Departments of Urology and Radiodiagnosis at Saraswati Medical College, Unnao, Uttar Pradesh between July 2019 and February 2020.

4.2 Study Population & Sample Size

The source population comprised all consecutive adult patients (≥ 18 years) who underwent elective standard PCNL at the institution between July 2019 and February 2020. The required sample size was estimated using the formula $n = Z^2pq/d^2$. Based on an expected PCNL stone-free rate (p) of 0.78, consistent with large multicentre outcome data and published reviews of standard PCNL practice,^{20,24} a margin of error (d) of 0.08, and a 95% confidence level ($Z=1.96$), the minimum calculated sample size was 103. To accommodate a projected 10–15% rate of incomplete medical records, 118 eligible patient files were ultimately recruited and analyzed.

4.3 Sampling Method

A consecutive non-probability sampling technique was employed, wherein all medical records falling within the predefined temporal window that met the inclusion criteria were selected for analysis.

4.4 Ethical Clearance

The study protocol received formal approval from the Institutional Ethics Committee of Saraswati Medical College. Given the retrospective nature of the analysis, a waiver of informed consent was granted. All patient data were rigorously de-identified to ensure strict compliance with the ethical tenets of the Declaration of Helsinki.

4.5 Data Collection Tool

Data abstraction was performed utilizing a standardized, field-ready proforma. Collected parameters included demographic data, clinical presentation (BMI, hydronephrosis grade, history of prior ipsilateral intervention), and pre-operative NCCT findings. A single experienced radiologist, blinded to the surgical outcomes, reviewed the initial NCCT scans. The maximum stone diameter was recorded in millimeters. Stone density was calculated as the mean HU, measured via a free-draw region of interest (ROI) across three representative axial slices, explicitly avoiding the stone periphery to prevent partial volume averaging artifacts.¹³ Inter-rater reliability for HU measurement was validated prior to full data extraction, demonstrating a high degree of concordance (Cohen's $\kappa = 0.86$) between two independent radiologists on a 20-record subset. Operative parameters (anaesthesia type, tract size, operative duration, estimated blood loss, transfusion requirements) and outcomes (SFR, hospital stay, modified Clavien–Dindo grade) were abstracted from surgical and ward notes. SFR was strictly defined as the complete absence of residual fragments >4 mm on a protocol-mandated 4-week post-operative NCCT.

4.6 Statistical Analysis

Quantitative analyses were executed utilizing IBM SPSS Statistics version 23.0. Descriptive statistics summarized continuous variables as means with standard deviations, and categorical variables as frequencies and percentages. Inferential evaluations employed the independent t-test for continuous data and Pearson's Chi-square or Fisher's exact test for categorical data. Pearson's correlation coefficients evaluated linear relationships between HU, operative time, and haemoglobin drop. ROC curves were constructed to determine the sensitivity and specificity of specific HU cut-offs. A multivariable binary logistic regression model (forward conditional method) was utilized to identify independent predictors of residual stones. A p-value of <0.05 was considered statistically significant.

5. Inclusion and Exclusion Criteria

Inclusion Criteria

- Adult patients aged 18 years or older.
- Confirmed diagnosis of renal calculi on pre-operative NCCT with documented mean HU and dimensions.
- Underwent elective standard PCNL (utilizing 24–30 Fr access tracts).
- Availability of complete post-operative follow-up records, including a 4-week NCCT evaluating stone-free status.

Exclusion Criteria

- Patients with a solitary functioning kidney or congenital renal anomalies (e.g., horseshoe kidney).
- Presence of uncorrected bleeding diatheses or ongoing anticoagulant therapy.
- Pregnancy at the time of presentation.
- Purely ureteric or bladder calculi without a significant renal component.
- History of ipsilateral PCNL or open nephrolithotomy within the preceding 6 months.
- Patients scheduled for staged bilateral PCNL during the index hospital admission.
- Incomplete clinical, operative, or radiological documentation.

6. Results and Analysis

A total of 118 patient records met all inclusion parameters and were evaluated. The demographic and baseline clinical features of the cohort are detailed in Table 1. The mean age was 41.7±12.6 years (range 19–72 years), with a male predominance (71.2%). The study population was largely drawn from rural areas (66.9%), reflecting the specific agrarian catchment of the tertiary centre. The mean BMI was 24.8±3.6 kg/m².

Parameter	Category / Sub-group	Frequency (n)	Percentage (%) / Mean±SD
Age (years)	Mean ± SD	-	41.7 ± 12.6
	Male Female	84	71.2%
Gender		34	28.8%
	Rural Urban	79	66.9%
Residence		39	33.1%
BMI (kg/m ²)	Mean ± SD	-	24.8 ± 3.6
	Yes (ESWL, URSL)	18	15.3%
Prior Ipsilateral Intervention	No	100	84.7%
	None / Mild Moderate	28	23.7%
Hydronephrosis Grade	Severe	62	52.5%
	lithotripsy; URSL	=28	23.7%
Ureters			
ESWL = Extracorporeal shock wave			
copic lithotripsy.			

Radiological stone characteristics obtained from pre-operative NCCTs demonstrated a mean maximum diameter of 22.4 ± 7.8 mm. Anatomically, isolated renal pelvic stones were the most frequent (34.7%), followed by partial staghorn (22.9%) and complete staghorn configurations (15.3%). The mean stone density for the entire cohort was 982 ± 312 HU (range 380–1620 HU). A substantial proportion of patients (44.9%) presented with calculi exhibiting densities greater than 1000 HU.

Table 2: Stone characteristics on pre-operative NCCT		
Radiological Parameter	Values / Frequencies	Percentage (%)
Mean Largest Diameter (mm)	22.4 ± 7.8 (Range: 12 - 48)	-
Stone Location/Configuration	Pelvic	34.7% (n=41)
	Lower Calyceal	18.6% (n=22)
	Multiple-calyceal	8.5% (n=10)
	Partial Staghorn	22.9% (n=27)
Mean Stone Density (HU)	Staghorn	15.3% (n=18)
	982 ± 312 (Range: 380 - 1620)	-
	≤ 1000 HU	55.1% (n=65)
HU Categorization	> 1000 HU	44.9% (n=53)

NCCT = Non-contrast computed tomography; HU = Hounsfield Units.

Primary operative outcomes revealed an overall SFR at the 4-week evaluation of 79.7% (94 patients). The mean operative duration was 82.4 ± 26.1 minutes. Significant bleeding necessitating blood transfusion occurred in 7 patients (5.9%), correlating with a mean haemoglobin drop of 1.2 ± 0.7 g/dL across the cohort. Complications, categorized via the modified Clavien–Dindo system, were documented in 22 patients (18.6%). These were predominantly minor (Grade I and II), with only four patients requiring auxiliary intervention (Grade IIIa/b), and zero occurrences of life-threatening Grade IV or V morbidity.

Table 3: Operative and post-operative outcomes (n=118)		
Outcome Variable	Mean $\pm$ SD / Frequency	Percentage (%)
Stone-Free Rate (SFR) at 4 weeks	94 / 118	79.7%
Operative Time (minutes)	82.4 ± 26.1	-
Haemoglobin Drop (g/dL)	1.2 ± 0.7	-
Blood Transfusion Required	7	5.9%
Hospital Stay (days)	4.6 ± 1.8	-
Modified Clavien-Dindo Complications	Total Affected	18.6% (n=22)
	Grade I (e.g., transient fever)	9.3% (n=11)
	Grade II (e.g., transfusion, antibiotics)	5.9% (n=7)
	Grade IIIa (e.g., local anesthesia intervention)	2.5% (n=3)
	Grade IIIb (e.g., general anesthesia intervention)	0.8% (n=1)
	Grade IV - V	0.0% (n=0)
	>4 mm on 4-week protocol NCCT.	

SFR definition: absence of residual fragments

Bivariate comparative analysis (Table 4) elucidated that patients harboring calculi >25 mm achieved a substantially lower SFR compared to those with smaller stones (62.5% vs. 86.0%, $p=0.004$). Similarly, stone density exceeding 1000 HU significantly depressed clearance success (66.0% vs. 90.8%, $p=0.001$). Correlation testing revealed that operative time increased linearly with both stone density ($r=0.42$, $p<0.001$) and diameter ($r=0.51$, $p<0.001$). The intra-operative haemoglobin drop also correlated significantly with increasing stone density ($r=0.31$, $p=0.001$). Patients in the >1000 HU subgroup exhibited prolonged operative times (94.2 vs. 71.6 minutes, $p<0.001$) and higher haemoglobin losses (1.6 vs. 0.9 g/dL, $p=0.002$).

Table 4: Bivariate analysis of stone size and density against SFR and complications						
Variable	Subgroup	Total (n)	Stone-Free Rate n (%)	p-value (SFR)	Complications n (%)	p-value n(Comp)
Stone Diameter	≤ 25 mm	86	74 (86.0%)	0.004*	11 (12.8%)	0.012*
	> 25 mm	32	20 (62.5%)		11 (34.4%)	
Stone Density (HU)	≤ 1000 HU	65	59 (90.8%)	0.001*	7 (10.8%)	0.021*
	> 1000 HU	53	35 (66.0%)		15 (28.3%)	
	*Statistically significant at p < 0.05 using Pearson Chi-square test					

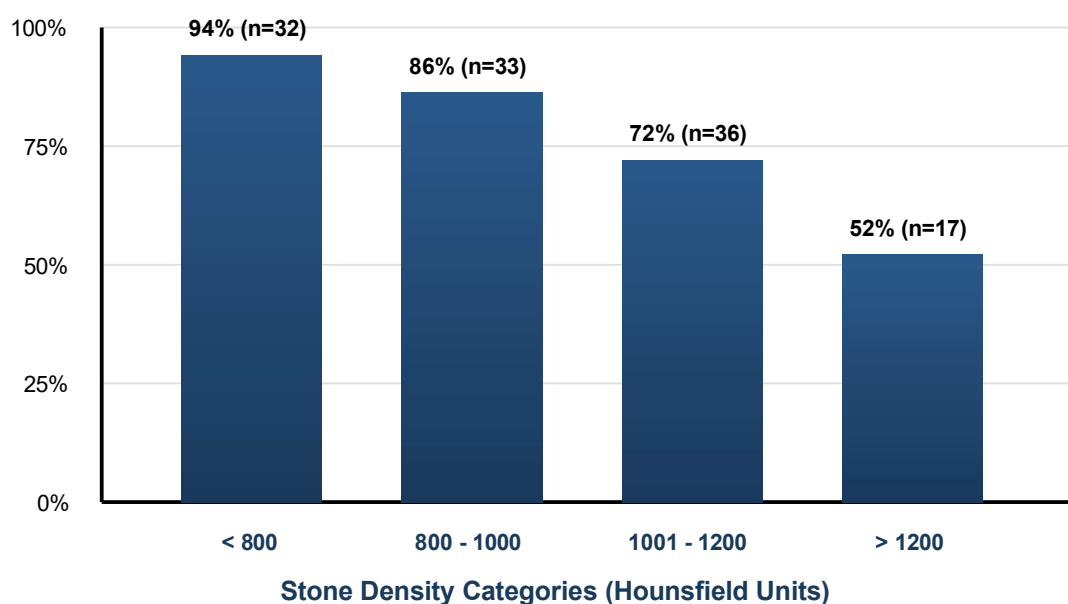


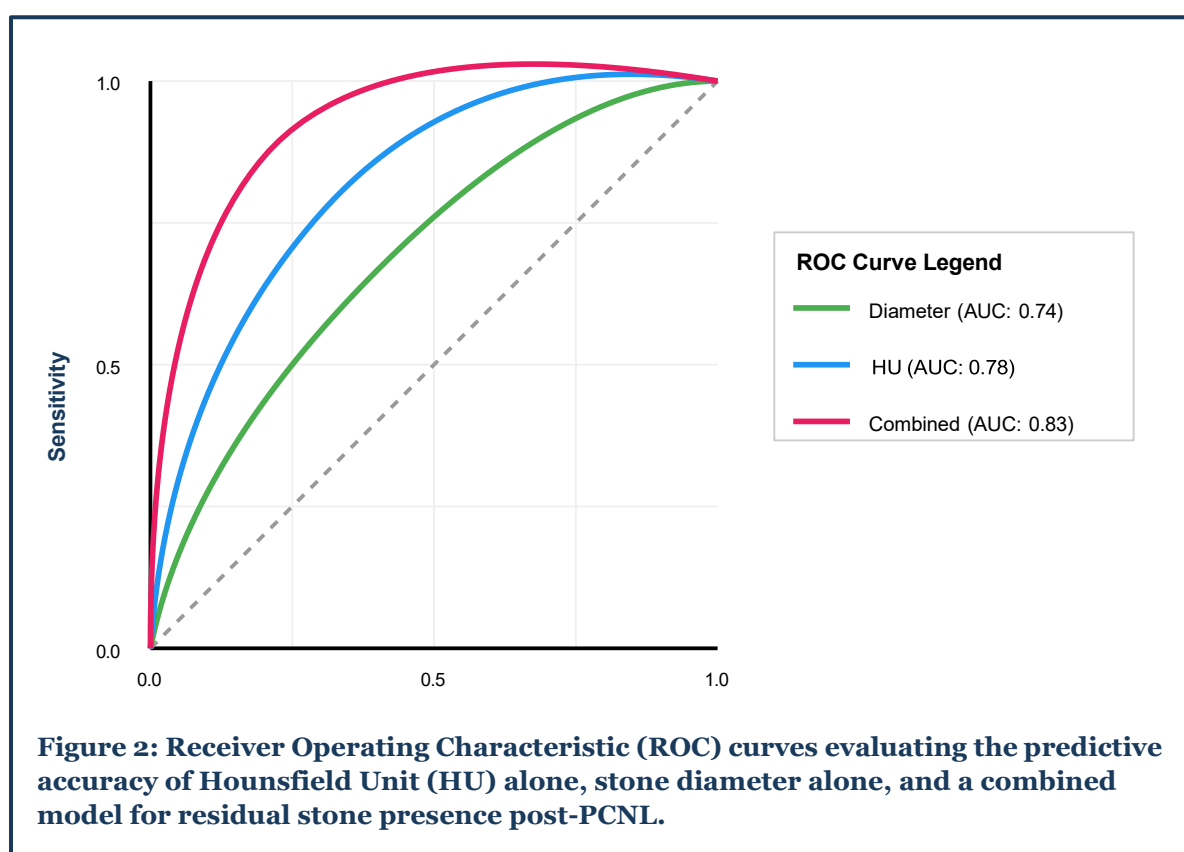
Figure 1: Bar chart displaying the inverse relationship between increasing Hounsfield Unit categories and PCNL stone-free rates at 4 weeks.

A multivariable binary logistic regression model adjusted for clinically pertinent covariates (age, BMI, hydronephrosis severity, and history of prior intervention). The model confirmed that both a maximal stone diameter >25 mm (adjusted Odds Ratio [aOR] 3.21, 95% CI 1.26–8.18, $p=0.014$) and a mean density >1000 HU (aOR 2.78, 95% CI 1.16–6.65, $p=0.022$) independently predicted failure to achieve complete stone clearance.

Table 5: Multivariable logistic regression predictors of NON-stone-free status (presence of residual stones)

Predictor Variable	Adjusted Odds Ratio (aOR)	95% Confidence Interval	p-value
Age (> 50 years)	1.45	0.58 - 3.65	0.428
BMI (> 25 kg/m ²)	1.62	0.71 - 3.70	0.254
Hydronephrosis (Moderate/Severe)	1.88	0.82 - 4.31	0.136
Prior Ipsilateral Intervention	2.10	0.91 - 4.88	0.082
Stone Diameter (> 25 mm)	3.21	1.26 - 8.18	0.014*
Mean Density (> 1000 HU)	2.78	1.16 - 6.65	0.022*

Forward conditional regression model. * $p < 0.05$ indicates statistical significance.



To establish optimal clinical thresholds, Receiver Operating Characteristic (ROC) curves were constructed. The ROC analysis identified a specific HU cut-off of 1043 as highly predictive for residual stone presence, yielding an Area Under the Curve (AUC) of 0.78 (95% CI 0.69–0.87), accompanied by a sensitivity of 71% and specificity of 74%. For stone diameter, a cut-off of 24 mm generated an AUC of 0.74 (sensitivity 67%, specificity 76%). A combined predictive model utilizing both HU and diameter optimized the prognostic accuracy to an AUC of 0.83.

7. Discussion and Interpretation

The results of this retrospective investigation corroborate the hypothesis that pre-operative stone metrics—specifically density as quantified by mean Hounsfield Units, alongside maximal stone diameter—act as robust, independent predictors of PCNL efficacy and morbidity. By utilizing regression analysis to control for morphological confounders such as hydronephrosis and prior interventions, we established that calculi exceeding 1000 HU or 25 mm in diameter more than double the odds of residual fragments. This central finding aligns cleanly with large-scale international validations. Anastasiadis et al., analyzing the vast CROES database, identically demonstrated that increasing stone radiodensity inversely tracked with SFR and directly correlated with operative duration.⁵ Our multivariable observations also reflect broader PCNL prediction literature, where conventional burden-related variables retain strong clinical value even without elaborate reconstruction-based modeling.^{7,19}

In our cohort, ROC curve methodology isolated a critical HU cut-off of 1043. While predictive cut-offs inherently fluctuate due to scanner calibration and tube kilovoltage variations (our data utilized a standard Philips 16-slice protocol), this threshold appears consistent with established literature. For context, Anastasiadis proposed a threshold near 970 HU for predicting clearance difficulties, while Gok et al. reported that higher HU values on non-contrast CT were associated with longer operative and fluoroscopy durations and less favorable PCNL performance indices. Gallioli et al. likewise demonstrated that HU-derived density indices, rather than raw diameter alone, independently predicted residual fragments after PCNL.^{5,12,23} Wiesenthal et al., albeit focusing on shock wave lithotripsy, similarly observed that density exceeding 1000 HU severely curtailed lithotripsy success.¹⁰ From a clinical standpoint, a cut-off of roughly 1040 HU, especially when combined with a diameter greater than 24 mm, may justify pre-operative counseling regarding the likely necessity of staged PCNL interventions or concurrent retrograde intrarenal surgery (RIRS).

Our secondary analysis explored the physiological toll of extracting dense calculi. We documented a statistically significant linear correlation between escalating HU values, prolonged operative times, and increased peri-operative bleeding (reflected via haemoglobin drop). Dense matrices logically resist pneumatic, ultrasonic, or laser fragmentation, necessitating sustained energy delivery and persistent manipulation of nephroscopy tracts, which in turn exacerbates mucosal and parenchymal trauma. This pathway is also consistent with complication patterns described in complex and staghorn PCNL series by Sfoungaristos et al.¹⁶ In carefully selected subsets, selective tubeless PCNL strategies may help reduce postoperative morbidity and shorten hospital stay without compromising stone-free rates, and therefore merit consideration as part of individualized planning.¹⁵

Crucially, contextualizing these findings within the North Indian demographic is imperative. The UP stone belt consistently yields an outsized proportion of bulky, high-density calculi compared to temperate global registries, likely driven by pervasive agrarian dehydration, mineral-heavy groundwaters, and delayed healthcare-seeking behaviour.⁶ Our study's documentation of an 18.6% overall modified Clavien complication rate underlines that standard PCNL here carries non-trivial risks when managing massive stones. Consequently, there is a compelling regional argument for making standardized HU mapping mandatory on all NCCT urology requisition reports, fostering a proactive, rather than reactive, approach to endourological stone management.

8. Conclusion

To conclude, this study substantiates that pre-operative NCCT-derived measurements of mean stone density and maximum diameter independently and additively predict the outcomes of standard PCNL in a North Indian tertiary hospital cohort. Specifically, an HU cut-off near 1040 and a diameter threshold of 25 mm emerged as highly practical clinical benchmarks identifying patients at elevated risk for residual stones, protracted operative times, and greater peri-operative bleeding. The integration of these

quantifiable radiological indices into routine pre-operative surgical planning may optimize patient counseling, justify pre-emptive blood transfusion arrangements, and facilitate targeted triaging toward specialized modalities like mini-PCNL or planned multi-staged interventions.

9. Limitations of the Study

- The single-centre, retrospective architectural design carries an inherent risk of selection and documentation bias.
- An 8-month temporal window may fail to adequately capture seasonal variations in calculus presentation or dietary hydration patterns inherent to the region.
- Hounsfield Unit calculations are fundamentally dependent on specific CT scanner models and kilovoltage parameters (a single Philips 16-slice unit was used here), inserting a caveat for broad inter-institutional generalizability.
- Direct physiochemical stone composition analysis (e.g., via dual-energy CT or infrared spectroscopy) was unavailable; HU was utilized solely as a functional proxy for stone hardness.
- The study lacked longitudinal follow-up beyond the protocol 4-week NCCT, preventing assessments of long-term stone recurrence or delayed complications.
- Operator-dependent variables, specifically minor variations in surgical technique and fragmentation philosophy between the two primary consultant urologists, were not formally modeled or controlled for.

10. References

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