How practical is the application of percutaneous nephrolithotomy scoring systems? Prospective study comparing Guy’s Stone Score, S.T.O.N.E. score and the Clinical Research Office of the Endourological Society (CROES) nomogram

Anurag Singla a, Nikhil Khattar a,*, Rishi Nayyar a, Shibani Mehra b, Hemant Goel a, Rajeev Sood a

a Department of Urology, Postgraduate Institute of Medical Education and Research (PGIMER) and Dr. Ram Manohar Lohia Hospital, Baba Karhak Singh Marg, New Delhi, Delhi, India
b Department of Radio-diagnosis, Postgraduate Institute of Medical Education and Research (PGIMER) and Dr. Ram Manohar Lohia Hospital, Baba Karhak Singh Marg, New Delhi, Delhi, India

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Abstract Objective: To prospectively compare the Guy’s Stone Score (GSS), S.T.O.N.E. [stone size (S), tract length (T), obstruction (O), number of involved calices (N), and essence or stone density (E)] score and the Clinical Research Office of the Endourological Society (CROES) nephrolithometric nomogram to predict percutaneous nephrolithotomy (PCNL) success rate and assess the correlation with perioperative complications.

Patients and methods: We prospectively evaluated all consecutive PCNL patients at our institute between 1 November 2013 and 31 May 2015. The above scoring systems were applied to preoperative non-contrast computed tomography and the practical difficulties in such applications were noted. Perioperative complications and the stone-free rate (SFR) were also recorded. Receiver operating characteristic curves were drawn and the areas under curves were compared and appropriate statistical analysis done.

KEYWORDS
Clinical Research Office of the Endourological Society (CROES); Percutaneous nephrolithotomy (PCNL); Renal stone; Guy’s Stone Score; S.T.O.N.E. score
Introduction

Urinary stone disease is a prevalent problem throughout the world, with an incidence of 5–10% in the general population [1] and of which 15–20% of patients with renal stones require invasive intervention [2]. The goal of any such intervention is to achieve maximum stone clearance with minimum morbidity. Among the several treatment options, percutaneous nephrolithotomy (PCNL) has the highest stone clearance rates [3]. It is now the treatment of choice for large and complex renal stones, including staghorn stones [3]. But as with any

Results: In all, 48 renal units were included in the study. The overall SFR was 62.2%. The presence of staghorn stones (β = 27.285, 95% confidence interval 1.19–625.35; P = 0.039) was the only significant variable associated with the residual stones on multivariate analysis. Stone-free patients had significantly lower median GSS (2 vs 4) and S.T.O.N.E. scores (6 vs 10) and higher median CROES scores (83% vs 63%) (all P < 0.001) compared to residual-stone patients. All scoring systems were significantly associated with SFR (all P < 0.001). There was no significant difference in the areas under curves of the scoring systems (0.858, 0.923, and 0.931, respectively). Furthermore, all scoring systems had weak correlations with Clavien–Dindo classified complications (r = 0.29, P = 0.045; r = 0.40, P = 0.005 and r = −0.295, P = 0.04, respectively). We found no standardisation for the measurement of stone dimensions, tract length, Hounsfield units, and staghorn definition.

Conclusions: All scoring systems equally predicted SFR and had a weak correlation with Clavien–Dindo complications. Standardisation is needed for the variables in which they have been found deficient.

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surgery, PCNL too is not 100% successful and complication free despite its minimally invasive nature. The success of PCNL is defined by a stone-free rate (SFR), which has been reported to vary from 56% to 98% [4–8].

Attempts have been made by various authors to predict SFRs preoperatively by using various clinicoradiological parameters and designed various scores and tools but as such, currently, no single model has been standardised as the ‘gold standard’. Further, to date, there has been no prospective study to directly compare these tools in the same patient cohort and to assess practical application of these scoring systems in various clinical scenarios. Thus, we prospectively applied three of such models: Guy’s Stone Score (GSS) [9], S.T.O.N.E. [stone size (S), tract length (T), obstruction (O), number of involved calices (N), and essence or stone density (E)] nephrolithometry score [10], and the Clinical Research Office of the Endourological Society (CROES) nephrolithometric nomogram [11], on preoperative non-contrast CT (NCCT) and compared them in the same cohort to determine which was most predictive of the SFR and was easiest to use clinically. We also assessed if they could predict perioperative complications too during PCNL. We present the various difficulties and discrepancies encountered in the calculation and the application of these scoring systems.

Patients and methods

After obtaining Institutional Review Board approval and patient’s informed consent, we prospectively included all consecutive patients with renal stones in our study who underwent PCNL between 1 November 2013 and 31 May 2015. Only the patients who underwent bilateral concomitant PCNL and patients with bleeding diathesis/uncorrected coagulopathy were excluded from the study.

Preoperative NCCT was performed and the GSS, S.T.O.N.E. score and CROES scores were calculated for each patient as described by Thomas et al. [9], Okhunov et al. [10], and Smith et al. [11], respectively. All difficulties in reaching a conclusive value for a scoring system were noted together with the ways to circumvent such difficulties.

Demographic, clinical, perioperative, and follow-up data were collected in a prospective fashion for all patients and included: age, sex, body mass index (BMI), surgical and medical history [Charlson Comorbidity Index (CCI)] [12], renal anomalies, operative time, number and location of punctures and dilated tracts, complications (modified Clavien-Dindo [13,14]), and other necessary details that were required for the calculation of the scores.

All our patients underwent PCNL in a prone position using a rigid 26-F nephroscope (Karl-Storz) and combined pneumatic-ultrasonic Lithoclast (Swiss-Lithoclast-Master) as per the standard protocol. A 24-F nephrostomy tube was placed at the end of the procedure in most of the cases. A plain abdominal radiograph of the kidneys, ureters and bladder (KUB) was taken for all patients on postoperative day 1 and if significant residual fragments were seen, a second-look PCNL through the same or a new tract was performed after 72 h.

The SFR (success rate) was defined as the absence of residual stone or the presence of asymptomatic clinically insignificant residual fragment of ≤4 mm on NCCT at 3 months postoperatively. Wherever the application of any variable of a scoring system was not straightforward, the solution was discussed among the authors and applied to all the cases.

The Statistical Package for the Social Sciences (SPSS®) 20 was used for statistical analysis. The test of normality was done using the Kolmogorov–Smirnov and Shapiro–Wilk tests. Continuous variables were presented as means (SDs) in cases of normal distribution and compared using the independent Student’s t-test, while as median and interquartile range (IQR) in cases of skewed distributions and compared using the Mann–Whitney U-test. Categorical variables were presented as numbers with percentages and were compared using chi-square or Fisher’s exact tests. Correlations between continuous variables were assessed using Pearson’s/Spearman rank correlation coefficients. Logistic regression analysis was performed to correct for any possible confounders and assess the size effect of different variables on stone-free status (SFS). Statistical significance was considered for two-tailed P values of <0.05. Receiver operating characteristic (ROC) curves were drawn for each scoring system and the area under curve (AUC) was calculated for each. The AUCs were compared using the online calculator of significance of difference between the area under two independent ROC curves from the following website: http://vasarstats.net/roc_comp.html, accessed on 22 August 2015. Assuming the incidence of SFR as 77% (based on literature review), and probability of type 1 error as 0.05, the power of this study with 28 patients in the stone-free group and 17 patients in the residual-stone group was calculated as 96.9%.

Results

In all, 48 patients underwent 50 PCNLs during our study period. One patient who underwent bilateral concomitant PCNL was excluded but the other patient who underwent PCNL on bilateral sides sequentially was included in the study. Thus, 48 renal units in 47 patients were treated with PCNL and were included in the present study.

Table 1 lists the descriptive details of all patients with stone characteristics and perioperative data. The mean
Patient age was 41.9 years and the mean BMI was 24 kg/m². Based on the CCI score distribution, nine patients (18.75%) had a CCI score of 1 and six (12.5%) had a CCI score of ≥2. Treatment of a prior ipsilateral renal stone was present in 18.8% patients. Renal anomalies were present in 11.4% patients (horseshoe kidney was present in one and PUJ obstruction and bifid moieties were present in two patients each). There were staghorn stones in 29.2% of the patients. The median (IQR) GSS, S.T.O.N.E. score and predicted success rate using the CROES nomogram were 2 (1–4), 7 (6–9), and 75 (65.5–89)%, respectively.

SFS

Results were evaluable in 45 renal units as postoperative CT was not available for the rest (Table 1). The stone-free and residual-stone patients had a similar distribution for age, sex, BMI, and stone laterality. Overall, the SFR was 62.2%. The median stone burden in the stone-free and residual-stone patients was 283 and 730.5 mm², respectively (P < 0.001). Hydronephrosis was seen in 25% of the stone-free and 70% of the residual-stone patients (P = 0.003). Among the potential variables, tract length, stone density, and stone number were not associated with the presence of residual stones. However, increasing stone burden (P < 0.001), staghorn stones (P < 0.001), increasing number of calyces involved (P < 0.001), and stones at multiple sites (P = 0.013) were significantly associated with the presence of residual stones. In the multivariate logistic model, only the presence of staghorn stones remained significantly associated with the likelihood of residual stones. The number of renal punctures and dilated tracts, and the operative time were also significantly different between the two groups.

When compared with residual fragments, stone-free patients had significantly lower median GSS (2 vs 4) and S.T.O.N.E. scores (6 vs 10) and higher median predicted success rates on the CROES nomogram (83% vs 63%) (all P < 0.001). All the scoring systems were significantly associated with the SFS (all P < 0.001). On comparing the AUCs, all were found to have similar accuracy in predicting SFS (Fig. 1).

Perioperative complications were noted in all 48 renal units and classified as per the Clavien–Dindo system

Table 1 The patients’ characteristics, stone characteristics and perioperative data.

| Variable                          | Total (n = 48) | Stone free (n = 28) | Residual stone (n = 17) | P      |
|----------------------------------|---------------|---------------------|-------------------------|--------|
| Age, years, mean (SD; range)     | 41.9 (14.2; 15–73) | 39.3 (15.6)         | 44.4 (11.3)              | 0.246  |
| Sex, n (%)                       |               |                     |                         | 0.789  |
| Male                             | 30 (62.5)     | 17 (60.7)           | 11 (39.3)               |        |
| Female                           | 18 (37.5)     | 11 (41.4)           | 6 (26.1)                |        |
| BMI, kg/m², mean (SD; range)     | 24 (5.4; 16–44) | 24.2 (6.0)          | 23.6 (4.6)              | 0.73   |
| Stone laterality, n (%)          |               |                     |                         | 0.299  |
| Right                            | 25 (52.1)     | 16 (69.6)           | 7 (30.4)                |        |
| Left                             | 23 (47.9)     | 12 (54.5)           | 10 (45.5)               |        |
| Stone number, n (%)              |               |                     |                         | 0.13   |
| Single                           | 27 (56.3)     | 18 (72)             | 7 (28)                  |        |
| Multiple                         | 21 (43.8)     | 10 (50)             | 10 (50)                 |        |
| Stone burden, mm², median (IQR; range) | 319.1 (249.7–598.9; 78–1633) | 283 (181–348.5) | 730.5 (365–1010.7) | <0.001 |
| Tract length, mm, mean (SD; range) | 90 (15.8; 61–140) | 90 (17.9) | 90.9 (13.4) | 0.858  |
| Obstruction, n (%)               |               |                     |                         | 0.003  |
| None/mild                        | 28 (58.3)     | 21 (80.8)           | 5 (19.2)                |        |
| Moderate/severe                  | 20 (41.7)     | 7 (36.8)            | 12 (63.2)               |        |
| Number of calyces involved, n (%)|               |                     |                         | <0.001 |
| 1–2                              | 33 (68.8)     | 27 (84.4)           | 5 (15.6)                |        |
| 3                                | 15 (31.2)     | 1 (7.7)             | 12 (92.3)               |        |
| Essence, HU, mean (SD; range)    | 1023.9 (245; 420–1750) | 1023.9 (271.2) | 1015.7 (211.9) | 0.916  |
| Stone location, n (%)            |               |                     |                         | 0.005  |
| Upper/middle/lower pole          | 9 (18.7)      | 7 (78.5)            | 1 (12.5)                |        |
| Pelvis                           | 8 (16.7)      | 8 (100)             | 0                       |        |
| Multiple                         | 31 (64.6)     | 13 (44.8)           | 16 (55.2)               |        |
| Presence of staghorn stone, n (%)|               |                     |                         | <0.001 |
| Yes                              | 14 (29.2)     | 1 (8.3)             | 11 (91.7)               |        |
| No                               | 34 (70.8)     | 27 (81.8)           | 6 (18.2)                |        |
| GSS, median (IQR; range)         | 2 (1–4; 1–4)  | 2 (1–2)             | 4 (2.5–4)               | <0.001 |
| S.T.O.N.E. score, median (IQR; range) | 7 (6–9; 5–11) | 6 (6–7) | 10 (8–11) | <0.001 |
| Predicted success rate on CROES nomogram,%, median (IQR; range) | 75 (65.5–89; 33–90) | 83 (75–90) | 63 (53.5–69.5) | <0.001 |
| Re-look PCNL, n (%)              | 7 (14.6)      | 2 (28.6)            | 5 (71.4)                | N.A.   |
| Operative time, min, median (IQR; range) | 90 (60–120; 35–270) | 72.5 (60–90) | 120 (90–142.5) | <0.001 |
Application of percutaneous nephrolithotomy scoring systems

There were Grade I complications in six patients, Grade II complications in eight patients and Grade IIIa complications in five patients. All the models were found to have a weak correlation with the Clavien–Dindo grade of complications (GSS \( r = 0.29, P = 0.045 \); S.T.O.N.E. score, \( r = 0.40, P = 0.005 \); CROES nomogram \( r = -0.295, P = 0.04 \)).

Discussion

Many factors have been identified to predict clearance rates after PCNL such as stone burden, composition, number and location, HU, BMI, skin-to-stone distance (SSD), abnormal renal anatomy etc. However, a significant predictor alone is not a predictive tool in itself and thus various models have been developed by various authors combining various such parameters [9–11,15–18]. A few of such models include the GSS [9], Staghorn Morphometry [16], Seoul National University Renal Stone Complexity Scoring system [15], S.T.O.N.E. Nephrolithometry score [10], and recently developed acute E. score with the postoperative SFS. Both the above findings were consistent with our present study (median score 6 vs 10, \( P < 0.001 \)).

We also found all three scoring systems were correlated with Clavien–Dindo complications grade. This is consistent with Mandal et al. [20] and Vicentini et al. [21] who showed significant associations between the GSS and post-PCNL complications; however, the correlation in our present study was weak and might not be of clinical importance. This might be the effect of the small sample size of our study population. Also, Tho-

![ROC Curve](image)

**Fig. 1** ROC curves for the scoring systems: the AUCs for GSS, S.T.O.N.E. score and CROES nomogram were 0.858, 0.923 and 0.931 (1.00–0.69), respectively. Increasing values of GSS and S.T.O.N.E. score predict poorer chances whereas increasing scores on CROES nomogram predict better chances of being stone free.
| PCNL scoring system and reference | No. of patients | Study design | Preoperative imaging method | Postoperative imaging used | Timing of postoperative imaging, weeks | Threshold size of residual fragments, mm | Comments |
|--------------------------------|----------------|-------------|----------------------------|---------------------------|--------------------------------------|------------------------------------------|----------|
| **GSS** Thomas et al. (2011) [9] | Validated in 100 | Prospective | Variable (X-ray, CT, IVU) | X-ray (NCCT/US for radiolucent) | 6 | <4 | Variable imaging |
| **Validation studies of GSS** Mandal et al. (2012) [20] | 200 | Prospective | Variable (X-ray, IVU, US, NCCT) | Variable | 4 | <4 | Variable imaging |
| Ingimarsson et al. (2014) [22] | 166 | Retrospective | NCCT | X-ray/NCCT | Day 1 | <2 on CT and 0 on CT/X-ray | Variable definition and SFR imaging |
| Vicentini et al. (2014) [21] | 155 | Partial retrospective | NCCT | NCCT | Day 1 (if ancillary procedure, then on final CT) | <4 | All supine PCNL |
| **S.T.O.N.E. score** Okhunov et al. (2013) [10] | 117 | Prospective validation | NCCT | Intraoperative nephroscopy or US at 12 weeks | Intraoperative nephroscopy or US at 12 weeks | Vague definition and variable timing of SFR |
| **Validation studies of S.T.O.N.E. score** Okhunov et al. (2013) [24] | 58 | Retrospective | NCCT | NCCT | ≤2 (mostly day 1) | <2 | Checked inter-observer reliability in application of score |
| Akhavein et al. (2015) [25] | 122 | Retrospective | NCCT | NCCT | | | |
| **CROES nomogram** Smith et al. (2013) [11] | 2806 Multicentric (96) | Prospective | X-ray (US/CT patients excluded from the study) | | <4 | Low sensitivity of X-ray |
| **Comparative studies** Labadie et al. (2015) [5] (GSS vs S.T.O.N.E. vs CROES) | 246 (3 institutes) | Retrospective | NCCT | NCCT | At discharge or at ≤12 | <2 | Variable timing |
| Noureldin et al. (2015) [26] (GSS vs S.T.O.N.E.) | 185 | Retrospective | X-ray (NCCT for radiolucent) | 12 | <4 | Variable imaging |
| **Present study** (GSS vs S.T.O.N.E. vs CROES) | 50 | Prospective | NCCT | NCCT | 12 | <4 | |

US, ultrasonography.
mas et al. [9], Okhunov et al. [10] and Noureldin et al. [26] did not find any correlation of the GSS and S.T. O.N.E. score with complications.

Problems faced in the practical application of the scoring systems and how we found our way out!

Calculating stone burden

Nowhere in either of the Okhunov et al. [10,24] studies or in the studies of the authors who validated the S.T. O.N.E. score [5,25,26] is there a description of the formula for stone burden calculation, so they might or might not have used the same equation as Okhunov et al., thus we do not know for sure if the model was actually reproduced in the same way as Okhunov et al. built it. We measured stone burden using the formula: maximum length × maximum width × π × 0.25, on axial cuts, as the same equation has been used by Smith et al. [11] in the CROES nomogram. Both these dimensions could be reliably determined for a smooth

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Fig. 2  (a) Dimensions of solitary oval stone reliably measured. (b) Irregular shape staghorn calculus on a coronal section of CT scan. (c) and (d) Same stone in two different axial cuts. Measurement of dimensions of this stone on axial images will produce incorrect stone size. (e) Coronal section of CT scan of another patient depicting two stones: one in pelvis and the other in the inferior calyx. (f) Calculation of tract length/SSD: the stone farthest from the skin (pelvic stone in this case) chosen from the above coronal section. On axial section, centre of the stone marked and three lines drawn at 0, 45 and 90° posteriorly intersecting the skin. These three distances measured and mean value taken. (g) Coronal section of CT scan showing two stones with different HU. Higher HU value was taken for the calculation in view of higher score (more difficult) given for >950 HU in the S.T.O.N.E. scoring system.
ovoid/rounded stone but not large/complex staghorn stones. For example in Fig. 2a the dimensions of a solitary oval stone can be reliably measured (Burden = $\pi \times 0.25 \times 21 \text{ mm} \times 19 \text{ mm} = 313.6 \text{ mm}^3$). Fig. 2b shows an irregular shaped staghorn stone on a coronal CT section. Fig. 2c and d shows the same stone in two different axial cuts calculating dimensions on which will produce an incorrect stone size. Further, the stone burden is best measured as volume on three-dimensional (3D)-reconstructed CT rather surface area especially in large/asymmetric/staghorn stones [27,28]. This is because larger/staghorn stones tend to conform to the pelvicalyceal system and develop protrusions/excrescences that result in irregular, asymmetric, and less geometric configurations. But 3D-CT is costly, complicated and not available in all urological clinics and probably is the reason most models have used surface area and not volume. Another inherent disadvantage is the measurement of exact dimensions of each and every stone especially in multiple secondary stones, which are so closely stacked to each other that making an exact count and dimension measurement is unfeasible.

**Tract length and grade of hydronephrosis**

Although the term ‘tract length’ has been used, it cannot be known preoperatively; as it will depend on the calyx punctured and thus can only be ascertained intraoperatively. Measurement is not difficult for a solitary stone but for multiple stones, which stone is to be chosen to measure the SSD presented as a dilemma in few cases. Thus, in cases of multiple stones, we chose the farthest stone from the skin in coronal sections and measured its distance on axial cuts, assuming it to be the most difficult target. For example, Fig. 2e shows a coronal section of a NCCT depicting two stones: one in the pelvis and the second in inferior calyx. The stone farthest from the skin (pelvic stone in this case) chosen from the above coronal section and centre of the stone marked on the axial section and three lines drawn at 0, 45 and 90° posteriorly intersecting the skin. These three distances were measured in millimetres and the mean value taken as the SSD (Fig. 2f).

The grades of hydronephrosis are subjective, non-quantitative and not clearly demarcated especially in mild vs moderate. For example, in Fig. 2f, one may grade it ‘mild’, while another may grade it ‘moderate’ hydronephrosis thus adding inaccuracy to the entire predictive model.

**Dilemma of pelvic stones**

No score has been assigned to a pelvic location in the S. T.O.N.E. scoring model [10]. Thus, presuming the pelvis as one calyx and approaching it with the same difficulty level, we assigned the score ‘1’. But this is not in concordance with the literature, where pelvic stones have better clearance rates than calyceal stones [29]. Strangely, authors who have used the S.T.O.N.E. score have not commented on this issue to date [10,24–26].

**Essence: is it essential?**

Regarding stone density/essence, Okhunov et al. [10] have assigned a higher score to >950 HU stones suggesting poorer clearance, which is not in concordance with published data where stones with higher HU values had either equal or greater clearance rates compared to lower HU stones [29,30]. As with stone burden, HU of large/staghorn calculi is also not very accurately calculated owing to their lamellated structures, which leads to varying densities from centre to periphery. Also, nothing has been suggested about which HU to be taken where there are different HU of multiple stones. Fig. 2g depicts a coronal section of NCCT showing two stones with different HU. We took the higher HU value for the calculation in view of the higher score (more difficult) given for >950 HU in the S.T.O.N.E. scoring system. We found ‘essence’ to be insignificant in predicting SFR.

**Staghorn: poorly defined**

Even the term ‘staghorn’ is plagued by an unclear morphology [3]. Rassweiler et al. [31] and Di Silverio et al. [32] classified staghorn stones into: ‘borderline’, stones occupying pelvis and one calyx; ‘partial’, pelvis extending into two calyces; ‘complete’, pelvis extending into all major calyces, filling ≥80% of the pelvicalyceal system; and ‘gigantic’, whole pelvicalyceal system have stones and dilation occurs. But, this classification is not based on any specific volume criteria [3], as there is considerable overlap of stone burden between partial and complete staghorn stones. Other definitions of staghorn stone commonly used in literature are: stone located in the pelvis and in at least two of the calyces [33]; partial staghorn, pelvis and at least one infundibulum and calyx; and complete staghorn, occupying more than one portion of the collecting system [22]. We used the latter definition in our study.

**Variable imaging modality and timing**

Lastly, the imaging methods used (X-ray/ultrasonography/CT), sizes of residual fragments (0, 2, and 4 mm), and timing of imaging (day 1, 4, 6, and 12 weeks) to document SFR all varied in different studies (Table 2).

**Stone size, obstruction and number of involved calyces (S.O.N.) score**

During our present analysis, we found that among the five variables of the S.T.O.N.E. score, tract length and essence were not significant predictors of stone clearance. Tract length/SSD may be important only in morbidly obese patients where longer instruments are
needed to access the pelvicalyceal system and clear the fragments. Too few obese patients in our present study might also be the reason for inappropriate study of this variable. In the current era, almost all types of stones except matrix are breakable with the current energy sources and might not affect the SFR. Okhunov et al. [10] believe that ‘in a tertiary referral centre with substantial experience in PCNL, the tract length and stone density might have a lesser effect on perioperative outcomes when performed by an expert endourologist capable of compensating for factors that can increase the complexity of a case’. Thus, we calculated the S.O.N. score after omitting ‘T’ and ‘E’ from S.T.O.N.E. With a \( P < 0.001 \), it significantly affected the SFS. The AUC was almost consistent with the S.T.O.N.E. score (0.922 and 0.923, respectively; Fig. 3). However, this was not a significant increase \( (P = 0.99) \). Thus, both models were found to be equally effective in predicting the SFS. But this needs further validation in larger studies. And as with any study, the present study also had some limitations such as small sample size, absence of intraoperative flexible nephroscopy, and a lack of multiple observers in calculating the scores.

**Conclusions**

All three scoring tools were equally predictive of SFS and correlated weakly with complications after PCNL. A simplification of the S.T.O.N.E. score, i.e. S.O.N. score, is equally predictive and has the potential to bring the scoring system to preoperative counselling room in limited settings/non-obese patients. Further refinement in the definition, calculation and application of individual variables, clear cut definitions for staghorn stones, standardisation of the size of residual fragments, timing and mode of imaging to document SFS, and larger prospective studies are required to determine a single scoring system to be adopted for standardised academic reporting and preoperative prediction for PCNL outcomes.

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None.

**Conflicts of interest**

None.

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