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Review

Morphometry scores: Clinical implications in the management of staghorn calculi

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Abstract Due to their large size, rapid growth, and attendant morbidity, staghorn calculi are complex clinical entities that impose significant treatment-related challenges. Moreover, their relative heterogeneity—in terms of both total stone burden and anatomic distribution—limits the ability to standardize their characterization and the reporting of surgical outcomes. Several morphometry systems currently exist to define the volumetric distribution of renal stones, in general, and to predict the outcomes of percutaneous nephrolithotomy; however, they fall short in their applicability to staghorn stones. In this review, we aim to discuss the clinical utility of morphometry systems and the influence of pelvicalyceal anatomy on the management of these complex calculi.

1. Introduction

While the term "staghorn" traditionally refers to any complex, branched calculus that occupies multiple portions of a collecting system, there exists ambiguity in this definition owing to the anomalous morphology of these stones. Traditionally, staghorns are designated as "partial", occupying part, but not all of the collecting system, or "complete", occupying virtually all of the collecting system [1]. This morphologic definition is highly subjective with prior investigation demonstrating considerable overlap in the reported total stone burdens of staghorn calculi categorized as partial or complete [2]. The earliest classifications of staghorn stones were largely based on anatomic characteristics. Other factors incorporated included size or stone burden, presence of collecting system dilation, intra- versus extrarenal pelvis position, and functional status of the renal parenchyma [3—6]. Many of these systems have failed to gain widespread acceptance due to their relative complexity and subjectivity.

Over time, the growing availability and affordability of computerized tomography (CT) imaging have allowed for more accurate radiologic evaluation of staghorn stones. The qualitative and quantitative assessment of a stone by

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CT are integral to surgical planning. Information regularly obtained can influence decisions on patient positioning, location of percutaneous access, number of tracts obtained, tract size, and type of energy used for lithotripsy. Stone volume, in particular, has been identified as the strongest predictor of treatment success following extracorporeal shockwave lithotripsy [7] and is highly associated with stone-free rates (SFR) following percutaneous nephrolithotomy (PCNL) [8]. The use of CT with three-dimensional (3D) reconstruction remains the most accurate method for calculating stone volume (Fig. 1) [2,9]. However, this technique can be cost-prohibitive and is dependent on specialized imaging protocols and software. Understanding the importance of total stone burden on treatment decision-making and patient outcomes, several groups have attempted to identify formulas that accurately calculate stone volume based on information available from standard, non-contrast CT [10,11]. Unfortunately, no universal equation exists as the accuracy of such calculations decreases with increasing maximum diameter and the associated increase in stone asymmetry [10].

Based on guideline recommendations of the American Urological Association (AUA), the first-line treatment for staghorn stones is PCNL monotherapy [1]. These recommendations are largely based on level I evidence of PCNL superiority over extracorporeal shockwave lithotripsy (ESWL) monotherapy and combination therapy, as well as comparable stone clearance to open surgery with a more favorable complications profile [12,13]. While numerous authors [14,15] have demonstrated excellent postoperative outcomes following PCNL for staghorn stones, these patients tend to suffer from lower SFR and higher morbidity rates in comparison to their non-staghorn counterparts [16]. Moreover, there is considerable variability in the reported outcomes of different groups, underscoring the lack of consensus definition for staghorns (as well as for "stone-free"). Anatomy of the pelvicalyceal system, location of the stone, total stone burden, timing and modality of postoperative imaging, residual fragment size criteria, surgeon experience, and institutional volume, among other factors, potentially influence the reported surgical outcomes for staghorn patients [17,18].

Given the inherent surgical complexity of staghorn stones, there is a glaring need to standardize the nomenclature by which they are characterized. Herein, we review the utility of existing stone morphometry systems for describing and guiding the treatment of staghorns, as well as discuss the clinical implications of pelvicalyceal anatomy on the management of these complex calculi.

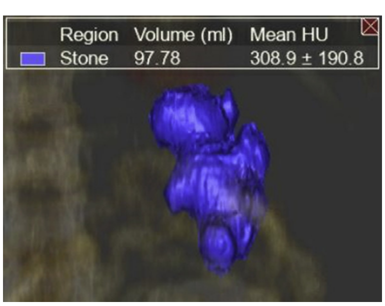

Figure 1 Computerized comography-based three-dimensional reconstruction of a staghorn calculus with volumetric analysis.

2. Stone morphometry scoring systems

Where morphology and volume calculations independently fall short, morphometry attempts to objectively define the complexity of a staghorn calculus by meshing both shape and size. An ideal classification system should be easy to use, reproducible, guide surgical planning, and accurately predict the rate of both surgical success and complications following PCNL. To date, several groups have attempted to standardize the relative complexity of renal stones on the basis of their volumetric distribution (Table 1). Despite their contrasting methods for incorporating staghorn morphology into overall stone complexity, none of these systems specifically characterize the morphometry of a staghorn calculus (Table 2).

2.1. Guy's stone score (GSS)

GSS is a prospectively validated grading system first described in 2011 by Thomas et al. [19] that categorizes the complexity of PCNL into one of four grades (I—V) based on patient and imaging characteristics. Neither of grades I/II pertain to patients with a staghorn calculus. Grade I denotes a solitary stone in a mid/lower pole calyx or a solitary stone in the renal pelvis with simple anatomy. Grade II stones are either solitary in the upper pole, multiple in a collecting system with uncomplicated anatomy, or solitary in an anatomically abnormal kidney. Grade III includes the presence of a partial staghorn (or calyceal or multiple stones in a patient with abnormal anatomy). Grade IV is designated for a complete staghorn stone (or any stone in a spinal injury or spina bifida patient). Notably, the system does not specify what constitutes a partial versus a complete staghorn.

The primary strengths of GSS include its relative ease of use and ability to reproducibly estimate SFR [23]. However, the scoring system was designed based on various imaging modalities (not exclusively CT) and does not account for stone size; therefore, underestimation of collecting system complexity and/or failure to visualize residual fragments may lead to overestimation of predicted SFR. Further, the ability of the GSS to predict the risk of complications has not been consistently demonstrated [24].

More pertinent to the current discussion, the GSS is limited by only two grades—III and IV—accounting for the presence of a staghorn. Moreover, these grades are inclusive of other clinical scenarios making conclusions about PCNL outcomes difficult to link directly to the staghorn morphology. Finally, the lack of standardized definitions for "partial" versus "complete" introduces considerable subjectivity to the characterization of a staghorn creating risk for clinical overlap between grades III and IV.

2.2. S.T.O.N.E. nephrolithometry score

The S.T.O.N.E. score is a morphological scoring system that aims to characterize and categorize renal stone complexity [20]. Points are assigned based on five stone or collecting

Table 1 Comparison of stone scoring systems on the basis of staghorn classification.

Scoring system	Pertinent staghorn criteria	Limitations to applicability in staghorn patients
GSS [19]	Grades I/II: Not applicable Grade III: Partial staghorn (or calyceal or multiple stones in a patient with abnormal anatomy) Grade IV: Complete staghorn (or any stone in a spinal injury or spina bifida patient)	- No standardized definitions of "partial" or "complete" staghorn stones - Inclusion of other clinical variables within staghorn grading categories (grades III/IV) obscures interpretation of outcomes - Does not account for staghorn volume or stone hardness
S.T.O.N.E. score [20]	Maximum 3 points are assigned under "*n*" (number of calyces) for presence of a staghorn calculus	- No clinical definition of "staghorn" provided - Pools all staghorn stones together; does not subdivide by size and/or shape
CROES nomogram [21]	"Presence of staghorn" represents 1 of 6 nomogram parameters; reduces probability of being stone-free after PCNL	- No clinical definition of "staghorn" provided - Pools all staghorn stones together; does not subdivide by size and/or shape - Does not account for stone hardness or variant/complex renal anatomy
S-ReSC [22]	No specific criteria. Staghorn morphometry is indirectly accounted for by number of calyces involved by stone	- Does not specifically characterize staghorn complexity - Does not account for variant/complex renal anatomy, stone hardness, or stone volume

CROES, Clinical Research Office of the Endourology Society; GSS, Guy's Stone Score; PCNL, percutaneous nephrolithotomy; S-ReSC, Seoul National University Renal Stone Complexity; S.T.O.N.E, stone size, tract length, obstruction, number of involved calices, and essence or stone density.

system characteristics. The acronym "S.T.O.N.E." refers to stone size (S), tract length (T), obstruction (O), number of involved calices (N), and essence or stone density (E). Ranging from 5 to 13, the nephrolithometry score determines stone complexity as follows: Low complexity (score = 5), moderate complexity (score = 6–8), and high complexity (score = 9–13).

The S.T.O.N.E. score is a clinically practical system as it relies on the most readily accessible information from preoperative CT imaging without any reliance on specialized software or scanning protocols. It has been shown to accurately predict SFR with high reproducibility regardless of user training level. Additionally, the incorporation of tract length may serve as a surrogate for patient body mass index, a clinical factor associated with increased risk of complications [25]. This unique feature of the S.T.O.N.E. score likely contributes to its ability to risk-stratify patients and aids in surgical decision-making. Recognized disadvantages of the scoring system include subjectivity in the degree of hydronephrosis and non-standardization of stone size and number of calyces, contributing to potential interobserver variability [24].

Similar to GSS, this system incorporates the presence of a staghorn stone into its scoring, but does not specifically characterize staghorn anatomy. Under "N" (number of involved calyces), the maximum three points are assigned for a staghorn calculus without specification of partial versus complete morphology. Unlike other scoring systems, both volumetric stone burden and hardness are encompassed.

2.3. Clinical Research Office of the Endourology Society (CROES) nomogram

The CROES nomogram, described by Okhunov and colleagues [20] in 2013, makes use of a risk estimator model to rank stone complexity on a continuous scale. Specifically, the nomogram incorporates six patient-, stone-, and surgeon-dependent factors found to be independently predictive of SFR. These variables include stone burden, stone location, prior stone treatment, presence of a staghorn stone, number of stones, and surgeon case volume per year. Each variable is assigned a particular numeric value weighted based on its relative predictive strength. Scores are summed to a final score, which is used to determine the probability of being stone free (<4 mm) following PCNL.

Based on numerous external validations, the nomogram has been proven highly accurate for determining SFR [26–29] and strongly correlated to complication rates, estimated blood loss, operative time, and length of hospital stay [30]. However, along with being cumbersome to calculate, the nomogram requires patient-related and institutional information that might not be readily available limiting its widespread clinical practicality.

The presence of a staghorn stone accounts for one of the six nomogram parameters where "absence of staghorn" is positively predictive of being stone-free following PCNL. Specifically, the absence of a staghorn raises the calculated total score by 20 points, thereby increasing the probability of treatment success. Sharing similarities with the GSS and S.T.O.N.E. score, the CROES nomogram accounts for staghorn morphology, but does not specifically incorporate stone complexity in its scoring. All staghorn calculi are treated the same without addressing specific anatomy of the stone, hardness, or volumetric distribution.

2.4. Seoul National University Renal Stone Complexity (S-ReSC) score

In 2013, Jeong and colleagues [22] developed the S-ReSC score on the basis that stone distribution within a

Table 2 Comparative studies evaluating morphometry systems in staghorn patients.

Studies[a]	Stone-free definition	Key study features	Scoring systems	Major findings
Sfoungaristos et al. [34]	No fragments >4 mm on CT at 4−6 weeks	• 73 patients • Complete 26 (35.6%) • Partial 47 (64.4%) • Single-stage PCNL • Mean stone burden: 1 253.5 mm^2	GSS S.T.O.N.E. CROES	• Overall SFR = 65.8% • Overall complications rate = 42.5% • S.T.O.N.E. score was the only independent predictor of SFR • AUCs GSS = 0.635 CROES = 0.687 S.T.O.N.E. = 0.743
Choi et al. [35]	No fragments >4 mm on KUB on postoperative day 1 (or CT if radiolucent stones)	• 217 patients • Complete 106 (48.8%) • Partial 111 (51.2%) • Some patients underwent staged procedures • Mean stone burden: 1 358.3 mm^2	GSS S.T.O.N.E. CROES	• Overall SFR = 70.1% • Overall complications rate = 32.7% • Independent predictors of SFR: NIC, pre-existent UTI, S.T.O.N.E. score • AUCs GSS = 0.678, CROES = 0.627 S.T.O.N.E. = 0.746
Yarimoglu et al. [36]	No fragments ≥4 mm on KUB at 1 month (or CT if radiolucent stones)	• 160 patients • Complete 76 (47.5%) • Partial 84 (52.5%) • Mean stone burden: 952.9 mm^2	GSS S.T.O.N.E. CROES S-ReSC	• Overall SFR = 58.8% • Overall complications rate = 36.2% • GSS and S-ReSC were independently predictive of SFR • Did not calculate AUC for scoring systems

Complete = occupies ≥80% of the collecting system; Partial = occupies the renal pelvis and ≥2 calyces.
AUCs, area under the curves; CROES, Clinical Research Office of the Endourology Society; CT, computerized tomography; GSS, Guy's Stone Score; KUB, kidneys, ureter, and bladder; NIC, number of involved calyces; PCNL, percutaneous nephrolithotomy; S-ReSC, Seoul National University Renal Stone Complexity; SFR, stone-free rates; S.T.O.N.E, stone size, tract length, obstruction, number of involved calices, and essence or stone density.

[a] All studies adopted the same definition for staghorn stones.

pelvicalyceal system is the most significant determinant of renal stone complexity. In this 9-point system, one point is assigned to each of nine different pelvic or calyceal locations if affected by calculus. The scoring does not distinguish by stone size, hardness, or number. The nine designated sites are: Renal pelvis (#1), superior and inferior major calyceal groups (#2–3), and anterior and posterior minor calyceal groups of the superior (#4–5), middle (#6–7), and inferior calyx (#8–9). Scoring can be categorized by degree of stone complexity: Low (score=1–2), moderate (score=3–4), and high (score=5–9).

S-ReSC has the advantage of being purely an image-based scoring system devoid of extensive calculations without reliance on patient-related or other stone-related factors. Evaluated as both a continuous and categorical variable, the score demonstrates an inverse relationship with SFR, findings that have been externally validated by multiple groups [31–33]. Although the primary authors found a correlation between score and complications rate, this relationship was not statistically significant and has not been otherwise proven.

S-ReSC does not specifically address the presence of staghorn calculi. Instead, it indirectly characterizes staghorn morphometry via anatomic distribution of stone involvement without distinguishing between staghorn morphology or the presence of multiple renal stones occupying multiple sites in the collecting system. Moreover, it does not account for stone hardness, total stone burden, or variant/abnormal pelvicalyceal anatomy.

2.5. Comparison studies

Despite a wealth of literature evaluating these previously described scoring systems for renal stones treated with PCNL, comparative studies for staghorn calculi are limited. Sfoungaristos et al. [34] compared the relative accuracy of the GSS, S.T.O.N.E. score, and CROES nomogram for predicting SFR following PCNL for staghorn stones. Complete staghorns were defined as those occupying at least 80% of the collecting system, while partial staghorns occupied the renal pelvis and two or more calyces. The study cohort was comprised of 73 consecutive staghorn patients who underwent a single-stage PCNL by a fellowship-trained endourologist. Mean stone burden was 1 253.5 mm^2; overall SFR and complications rate were 65.8% (48/73) and 42.5% (31/73), respectively. All three scoring systems were significantly associated with postoperative SFR, as were stone burden ($p=0.0005$) and number of involved calyces (NIC, $p=0.0005$). However, S.T.O.N.E. score was the only independent predictor of SFR on multivariate analysis. Using receiver operating characteristic analysis to calculate predictive ability, the area under the curve (AUC) was the highest for S.T.O.N.E. score (0.743), compared to CROES (0.687) and GSS (0.635).

In a single-center, retrospective study, Choi et al. [35] reviewed the cases of 217 patients with available preoperative CT imaging who underwent PCNL for a staghorn calculus—111 (51.2%) partial *vs.* 106 (48.8%) complete staghorn. The GSS, S.T.O.N.E. score, and CROES nomogram were calculated for each patient. The overall SFR was 70.1% as some patients underwent staged procedures; overall complications rate was 32.7%. In addition to NIC, the authors found higher S.T.O.N.E. score and pre-existent urinary tract infection (UTI) to be independently predictive of lower SFR. The AUCs for GSS, CROES, and S.T.O.N.E. were 0.678, 0.627, and 0.746, respectively. These values were consistent with those found by Sfoungaristos et al. [34] (0.635, 0.687, and 0.743, respectively) and both studies found S.T.O.N.E nephrolithometry to be the only scoring system independently predictive of treatment success. By contrast, the study from Sfoungaristos et al. [34] failed to identify any individual preoperative factors predictive of SFR, unlike the significance of NIC and pre-existent UTI by Choi et al. [35]. The high accuracy of the S.T.O.N.E. score is possibly related to its incorporation of NIC, tract length, presence of obstruction, and stone density. Whereas the advantages of the GSS come at the cost of its simplicity, and the CROES nomogram places greater weight on surgeon experience and prior stone treatments, the inclusion of these parameters may provide S.T.O.N.E. with the ability to better characterize the true complexity of a staghorn calculus and its treatment.

In the only known study comparing all four stone scoring systems for staghorn calculi, Yarimoglu et al. [36] evaluated 160 patients with a staghorn stone (partial: Occupying the renal pelvis and $\geq$2 calyces; complete: Occupying >80% of the collecting system). Stone-free was defined as no residual fragments $\geq$4 mm on plain radiography of the kidneys, ureter, and bladder (KUB). Mean stone burden was 952.9 mm^2. The overall SFR was 58.8% (94/160) and overall complications rate was 36.2% (58/160). The study demonstrated both the GSS and S-ReSC to be independently predictive of SFR. Given their relative ease of use and reproducibility, this would support their widespread use for evaluating patients undergoing PCNL for a staghorn calculus. Yet, such a conclusion must be tempered by the somewhat contradictory results of prior comparative studies in which the GSS failed to accurately predict SFR. Furthermore, neither S.T.O.N.E. score ($p=0.794$) nor CROES ($p=0.760$) were significant, whereas Choi et al. [35] and Sfoungaristos et al. [34] both found S.T.O.N.E. score to be significantly predictive of SFR. The authors concluded that the most important predictor of being stone-free is the stone distribution of a staghorn. This would explain the accuracy of S-ReSC as distribution is the sole parameter of the system, but not GSS.

These collective findings must be cautiously interpreted in the context of the individual study limitations and contrasting methodologies. Several key themes include the recurring significance of NIC and systems that place a large emphasis on NIC and pelvicalyceal stone distribution. Taken together, it is apparent that all four scoring systems are limited in their characterization of staghorn morphometry. Nonetheless, they each provide clinical value and the aforementioned limitations should be taken into consideration but not preclude their use.

2.6. Stone morphometry in pediatrics

The management of staghorn stones in pediatric patients represents a significant challenge for the urologist owing to differences in kidney size and collecting system anatomy that vary with age, as well as a higher incidence of renal malformations relative to adults. As with all patient populations, there is considerable awareness to limit radiation exposure and the need for future procedures. Additionally, strong consideration must be given to preserve renal function and development in children. Attempts have been made to apply existing stone scoring systems to PCNL in the pediatric population with limited success [37]. This is compounded by the fact that CT scans are not regularly obtained on all children, limiting available data for scoring. Çitamak et al. [38] attempted to develop a scoring system to predict SFR and complications following PCNL in children. The model was simplistic, based on number of stones and average stone/kidney index (stone size/kidney size on longitudinal axis). Despite its practical simplicity and moderate utility for risk stratifying patients, the scoring system did not directly account for staghorn anatomy.

2.7. Staghorn morphometry

Standardized morphometric nomograms and scoring systems are essential tools for surgeons who perform PCNL because they provide a quantitative and consistent definition of stone complexity and surgical difficulty. This provides for improved patient counseling and preoperative planning. Despite being externally validated in large, general PCNL cohorts, the applicability of the aforementioned scoring systems to staghorn stones remains limited.

To date, only one group has attempted to create a staghorn-specific morphometry system [39]. Mishra and colleagues [39] sought to standardize staghorn complexity with a clinically relevant, operational definition of staghorn stones based on volumetric distribution within the collecting system. This novel system was designed with the intent of predicting the number of tracts and stages needed to best perform PCNL monotherapy. Acknowledging the inherent risks versus potential benefits of multiple accesses, tract sizing, and multiple procedures, such a system would guide clinical decision-making, helping surgeons to individualize treatment plans that maximize SFR while minimizing complications.

Briefly, the authors reviewed the cases of 94 renal unit patients who underwent PCNL for a staghorn calculus. Stones were classified into three categories of increasing complexity (or unfavorable morphometry) according to total stone volume (TSV) and unfavorable calyx stone percentile volume (UCSPV). TSV was calculated from CT-based 3D-reconstruction of the stone using a proprietary volumetric software (3D-DOCTOR™, Able Software Corp., Lexington, MA, USA). By definition, a stone-containing calyx with an infundibular width $\leq$8 mm or an acute entry angle was considered unfavorable. Type 1 staghorns had UCSPV $<$5% and TSV $<$5 000 mm^3, type 2 had UCSPV 5%—10% and TSV 5 000—20 000 mm^3, and type 3 had UCSPV $>$10% and TSV $>$20 000 mm^3. Stone-free status was defined as no residual fragments on CT imaging at 3 months following completion of treatment.

Based on this clinical classification, type 1 stones require a single tract and stage, while type 3 stones generally require multiple tracts over multiple stages. Type 2 stones represent a heterogeneous mix of staghorns with intermediate complexity. The authors concluded that they should be treated either with a single tract in single/multiple stages or with multiple tracts in a single stage procedure. In this scenario, the decision of surgical approach should be based on a combination of surgeon preference along with the relative contributions of TSV and UCSPV to the stone's morphometric classification. Despite some ambiguity in the morphometry definitions (*e.g.* how to classify a staghorn with a favorable TSV and an unfavorable UCSPV), the results of the multivariate analysis indicated that TSV was more predictive of number of stages needed (AUC 0.846), compared to UCSPV, which was more predictive of the number of tracts required (AUC 0.910). Ultimately, these findings provide the clinician with the important tools needed for surgical decision-making.

Though cumbersome to calculate and limited in utility outside of a research setting, the work of Mishra et al. [39] provides a clinically relevant tool for PCNL of staghorn stones, incorporating stone volume as well as pelvicalyceal anatomy. In doing so, it also demonstrates that stone volume does not necessarily correlate with renal complexity, a feature overlooked by other stone scoring systems. Moreover, it serves as a firm foundation for prospective validation of this tool and for the development of alternative staghorn morphometry classification systems.

3. Influence of renal collecting system anatomy on staghorn management

3.1. Basic anatomical considerations

In addition to morphometry of the stone, the unique anatomy of the renal collecting system plays a major role in PCNL. There are approximately 20 papillary ducts that drain into each renal papilla, each of which drains into one calyx. A simple calyx has only one papilla, whereas a compound calyx has two or more papillae draining into it. The fornix of each calyx is the most peripheral location of the renal collecting system. This is the ideal location for percutaneous access in terms of both functionality and safety.

The heterogeneous anatomy of the pelvicalyceal system plays a major role in surgical planning and SFR. There are 5—14 calyces in each collecting system with a mean of 8 calyces (70% of kidneys have between 7 and 9) [40]. With a greater number of calyces, it becomes more difficult to be certain whether a patient's entire collecting system has been successfully visualized and rendered stone free during PCNL.

It is important to understand the classic grouping of calycesas well. The calyces are divided into three groups: Upper pole, lower pole, and interpolar calyces. The upper and lower poles usually have at least one compound calyx, while they are rare in the interpolar region. Instead, the interpolar calyces are usually simple calyces paired in an anterior and posterior orientation. In one third of kidneys, the interpolar calyces drain separately from the upper and lower poles, either into their own major calyx or directly into the renal pelvis.

3.2. Polarity

With the patient in the prone position, access into a posterior calyx allows direct entry into the renal pelvis and other moieties of the collecting system. Access into an anterior calyx, however, requires steep angulation which severely limits rigid nephroscopy. The upper pole calyces lie in a mediolateral orientation with negligible differences in anteroposterior relationship in 95% of cases [41]. This allows access into either the medial or lateral calyx to be suitable for nephroscopy. By contrast, the interpolar and lower pole calyces lie in an anteroposterior orientation in 100% and 95% of cases, respectively, making other methods of posterior calyx identification necessary. For one, understanding the common spatial orientations of calyces is useful. In the lower pole, the most inferior calyx is usually anterior and the next most cephalad calyx is usually posterior. Other techniques, such as instilling air in a retrograde fashion into the collecting system can assist in identifying a posterior calyx. Air will travel to the posterior areas of the collecting system with a patient in the prone position and this can be visualized by either fluoroscopy or retrograde ureteroscopy.

If percutaneous access is obtained in the upper or lower pole, the interpolar calyces pose the greatest challenge to visualize with both rigid and flexible nephroscopy due to steep angulation. This, in addition to the typical paired simple interpolar calyces, carries great risk of missing an isolated interpolar calyx with retained stones.

3.3. Infundibula

Major calyces drain through an infundibulum into the renal pelvis. The infundibula are the canals of the collecting system connecting calyces to the renal pelvis and other moieties of the collecting system. The two factors that impact maneuverability of the nephroscope most are infundibular angle and infundibular width. To measure infundibular angle from one calyx to another on preoperative CT, the surgeon draws two lines starting at the middle of the two calyces (the accessed calyx and the calyx of interest) passing through the middle of each infundibula (Fig. 2). If the angle is $<75^\circ$ then the likelihood of passage of a rigid nephroscope into the calyx of interest is 0% [42]. If the angle is $>95^\circ$, entry into the calyx of interest is 95% successful. Given this small separation of only 20°, a surgeon must make all efforts possible to obtain access parallel to the infundibulum of the accessed calyx. This eliminates additional angulation and torque to align a rigid nephroscope with the infundibulum of the entry calyx.

In order to achieve optimal access, the triangulation method may be utilized [43]. First, a mark is made in the skin overlying the calyx of interest while viewing the kidney with the C-arm in the anteroposterior (AP) orientation. Next, the C-arm is rotated 20° laterally and another skin mark is made overlying the new location of the target calyx. Then a mark is made 1 cm lateral and 1 cm cephelad or caudad (for upper or lower pole access, respectively) in a parallel line with the infundibulum of the calyx. The needle is advanced in the parallel plane of access to the infundibulum while in the 20° orientation of the C-arm. Once the needle has reached the lateral portion of the calyx of interest, the C-arm is rotated back to its 0° AP. The

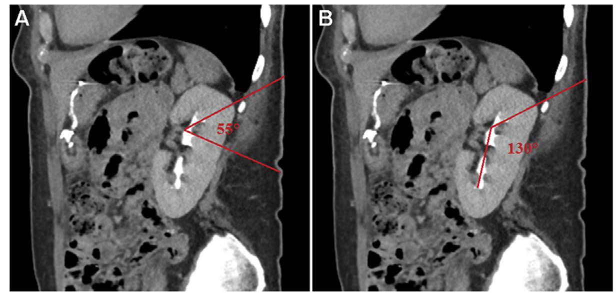

Figure 2 Influence of infundibular angle on nephroscope maneuverability during percutaneous nephrolithotomy. (A) Computerized tomography (CT) urogram with a theoretical supracostal upper pole access showing aninfundibular angle into an interpolar calyx of 55°, indicating low likelihood of entry by rigidnephroscopy; (B) CT urogram with a theoretical supracostal upper pole access showing an infundibular angle into a lower pole calyx of 130°, indicating high likelihood of entry by rigid nephroscopy.

needle is then advanced until the lateral portion of the calyx is accessed, which is ideally through the fornix of the calyx. This parallel entry into the infundibulum of a posterior calyx maximizes maneuverability of the nephroscope into the renal pelvis and other moieties of the collecting system.

When an infundibulum is narrow, it poses a significant obstacle for the urologist, especially with use of larger, rigid instruments. If a narrow infundibulum is encountered at the site of access, the surgeon should place a guidewire through the narrowed infundibulum, remove the rigid nephroscope, and dilate the infundibulum (over the guidewire) with a balloon dilator. This technique will allow passage of a rigid nephroscope with the least amount of trauma to the infundibulum.

3.4. Renal pelvis

The renal pelvis has also been shown to take several different anatomical shapes that impact PCNL. A renal pelvis can be singular or divided with occurrence rates of 58% and 42%, respectively (Fig. 3) [44]. A divided collecting system introduces added challenges to performing PCNL.

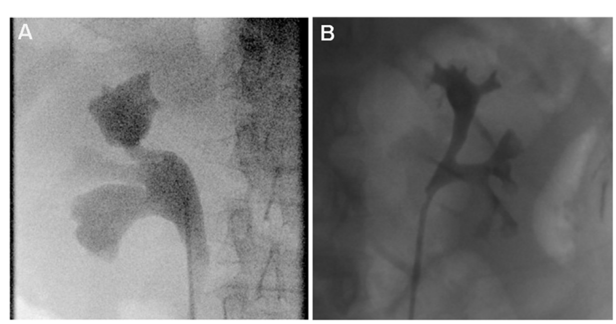

Figure 3 Influence of renal pelvis shape on percutaneous nephrolithotomy. (A) Singular renal pelvis draining all upper, lower, and interpolar calyces of the kidney; (B) Divided renal pelvis with one portion draining the upper pole and another-draining both the lower and interpolar calyces.

The lack of a normal sized renal pelvis creates additional angles to traverse along with less space within which to maneuver the nephroscope. Additionally, infundibular length may be longer in such a collecting system. Thus, a divided system significantly impedes the ability of the nephroscope to be maneuvered from one calyceal moiety to the next. Ultimately, this increases the likelihood of requiring multiple access sites if stone is present in separate moieties of the collecting system.

4. Conclusion

Despite limited attempts to standardize the characterization of staghorn complexity, further work is needed to create morphometry systems that guide surgical management, risk stratify patients, and standardize reporting of outcomes. Such systems, combined with a strong working knowledge of an individual's pelvicalyceal anatomy, hold the potential to greatly improve patient outcomes.

Author contributions

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Conflicts of interest

The authors declare no conflict of interest.

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