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Staghorn Morphometry: A New Tool for Clinical Classification and Prediction Model for Percutaneous Nephrolithotomy Monotherapy

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Abstract

Background and Purpose: Staghorn stone volume and its distribution within the collecting system, "staghorn morphometry," predicts the requirement of tract and stage for percutaneous nephrolithotomy (PCNL) monotherapy. The purpose of the study was to develop a CT urography staghorn morphometry-based prediction algorithm to predict tract(s) and stage(s) for PCNL monotherapy and classify staghorn accordingly.

Material and Methods: A retrospective case-control design of 94 units was used. CT software calculated the total stone volume (TSV) with absolute volume and percentile volume in the pelvis, planned entry calix, favorable and unfavorable calix. Entry calix was the optimum calix chosen, keeping the relations of the ribs and adjoining viscera that could clear maximum stone volume. Unfavorable calix was defined as having an acute angle from the entry calix and infundibular width of ≤ 8 mm. A prediction model with odds ratio (OR) (95% confidence interval) was constructed on univariate and multivariate regression factors.

Results: On univariate analysis, TSV ($P = 0.013$), unfavorable calix stone volume (0.007), and percentile distribution of stone in pelvis (0.026), pelvis and entry calix (< 0.001), and unfavorable calix (0.001) predicted tracts while total stone (< 0.001), pelvic stone (0.0046), and unfavorable calix stone (< 0.001) volume and percentile volume in pelvis (0.04), pelvis and entry calix (0.005) and unfavorable calix ($P < 0.001$) predicted stage. Multivariate analysis showed that unfavorable calix stone percentile volume predicted tract (area under the curve [AUC] – 0.91) while TSV and unfavorable calix stone percentile volume (AUC – 0.846) predicted stage. The OR-based prediction model suggested a need for single tract and stage PCNL *vs* multiple tract and stage PCNL for TSV and unfavorable calix percentile stone volume of (< 5,000 mm^3 and 5%) and (> 20,000 mm^3 and 10%), respectively.

Conclusion: The model predicts the tract and stage for PCNL monotherapy. Staghorn morphometry differentiates staghorn into type 1 (single tract and stage); type 2 (single tract-single/multiple stage, or multiple tract-single stage), and type 3 (multiple tract and stage).

Introduction

Percutaneous nephrolithotomy (PCNL) has been a standard treatment for patients with renal staghorn calculus for the last decade.[1,2] Unfortunately, there is no consensus on the precise definition of staghorn calculus.[1] Consequently, the term "staghorn" is often used to define any branched stone occupying more than one portion of the collecting system. Furthermore, the designation of "partial" or "complete" staghorn calculus also does not imply any specific criteria of volume.[1] Stone-free rates after PCNL monotherapy or sandwich therapy have been found to be highly dependent on the stone burden.[3] More important than stone burden is the term "staghorn morphometry," defined as the staghorn stone volumetric burden distribution in the collecting system.

CT urography (CTU) with its three-dimensional (3D) volume rendering gives us an additional tool to better define the type of staghorn calculi based on morphometry and to correlate the therapeutic significance of PCNL monotherapy in terms of tract and stage requirement for complete stone clearance.[4,5] It also adds to a new armamentarium to clinically define the staghorn into a more operatively relevant classification important for planning PCNL monotherapy.

Material and Methods

A total of 170 renal units in 163 patients after clinically relevant evaluation were diagnosed to have staghorn calculi and were given treatment during the study period from September 2009 to December 2010. Of these, 76 renal units,

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consisting of 38 patients with renal insufficiency, 18 patients with nonfunctioning renal units, 6 pediatric patients, 6 renal malformations, and 8 patients who were lost to follow-up after PCNL were excluded from the study. The remaining 94 renal unit patients met the inclusion criteria for current study and were subsequently treated with either single or multiple (two and more than two) tract PCNL monotherapy in either single stage or multiple (two and more than two) stages.

All patients in this study underwent 16 slice CT scan (BrightSpeed Elite Select,™ GE Healthcare, Waukesha, WI) before definitive surgical therapy and subsequently underwent PCNL monotherapy by two expert surgeons (RBS and MRD). The techniques of the PCNL were described in our earlier publications.[6,7] Specifically, all attempts were made to completely clear the stones using bare minimum tracts possible with judicious use of rigid and flexible nephroscopes/ureteroscopes in the prone and Valdivia position. When needed, the procedure was staged by limiting nephroscopy to 90 minutes according to our hospital protocol. Stone-free status was assessed after the completion of surgery and subsequent follow-up after 3 months.

CTU of all patients depicting the staghorn morphometry and pelvicaliceal anatomy was subsequently analyzed by the primary research fellow (SKM) using CT scan volumetric assessment software (3D-DOCTOR™; Able Software Corp., Lexington, MA). The inference obtained by the CTU analysis was then retrospectively applied to clinical per operative data to identify correlation between the staghorn morphometry to tract(s) and stage(s) needed to obtain complete clearance.

The CTU protocol followed at the institute consisted of unenhanced and enhanced images obtained from the dome of the liver to the pubic symphysis at 5-mm section thickness. The nephrogram phase was taken at 90 seconds after starting intravenous administration of 100 to 140 mL of iodinated contrast material. Abdominal compression was applied after completion of early-enhanced CT scans. The intrarenal collecting system was typically well distended by 8 minutes after intravenous contrast material injection, at which time urographic images were studied. The ureters were generally well visualized on the 10-minute decompression image. Opacified bladder images were optional. Additional urographic images including prone and oblique projection and delayed views were obtained when necessary. The patients were considered stone free if there was no evidence of any residual stone fragment on 3-month follow-up on plain skiagram and ultrasonography kidneys-ureters-bladder study.

3D-DOCTOR™ software, is an advanced 3D image rendering, processing, and analyzing software. The software works by extracting object boundaries using 3D image segmentation functions and creating 3D surface volume rendering for visualization, object measurement, and quantitative analysis. 3D-DOCTOR's user interface is similar to other Windows software programs. All the CTU data generated on a digital imaging and communications in medicine (DICOM) viewer compact disc were fed to the software installed on a computer desktop. 3D-DOCTOR has five main types of display windows; Single image plane view to show a single image slice at a time; montage view to display all slices from a 3D image; volumetric view to display volume rendered images; surface view to display 3D surface models; and plot window to display histograms and measurements. Volume rendering creates a 3D display using both the 3D image and the boundaries. Voxels are ray-traced to show the image in a 3D space. From the tools bar generated after volume rendering, the command calculates 3D volumes of surface models for all objects (Fig. 1). The volume calculation is based on the current surface geometry and calibrated parameters.

Staghorn morphometry assessment

All the measurements made for volumetric assessment were performed after 3D image rendering on the software program. Because of the lack of any previous published literature relating to the utilization of stone morphometry on CTU for planning PCNL monotherapy for staghorn calculus, various definitions were introduced. To facilitate understanding, readers are advised to follow the legend of Figure 2. TSV is defined as the stone volume calculated by reconstructing the entire stone image on the software. Pelvic stone volume is defined as the volume calculated by reconstructing the component of the stone present in the pelvis. Pelvic stone percentile volume is the percent of the pelvic to the TSV.

The researcher decided the entry calix for planning staghorn based on the main tract concept proposed by Ganpule and associates.[6] Specifically, it consisted of the optimum calix chosen, keeping in view the relations of the ribs and adjoining viscera that could clear the maximum stone burden. The stone volume amenable for clearance through the entry calix is the volume present in it, pelvis, and any of the favorable calices. The percentage volume of the stone in the entry calix is defined as entry calix stone percentile volume. A percentage of the pelvic and entry calix stone to the TSV constitutes the pelvic and entry calix stone percentile volume.

The rest of the caliceal stone distribution is classified as being in either favorable calix or unfavorable calix. The assessment of favorable and unfavorable calix is done on the image plane view of the software. The toolbars command on the image view is used to calculate the infundibular width and the angle of the entry calix to the desired calix. A favorable calix is defined as a calix containing stone that is at an obtuse

FIG. 1. 3D-Doctor software showing a volume rendered staghorn with tool bar command of volume given.

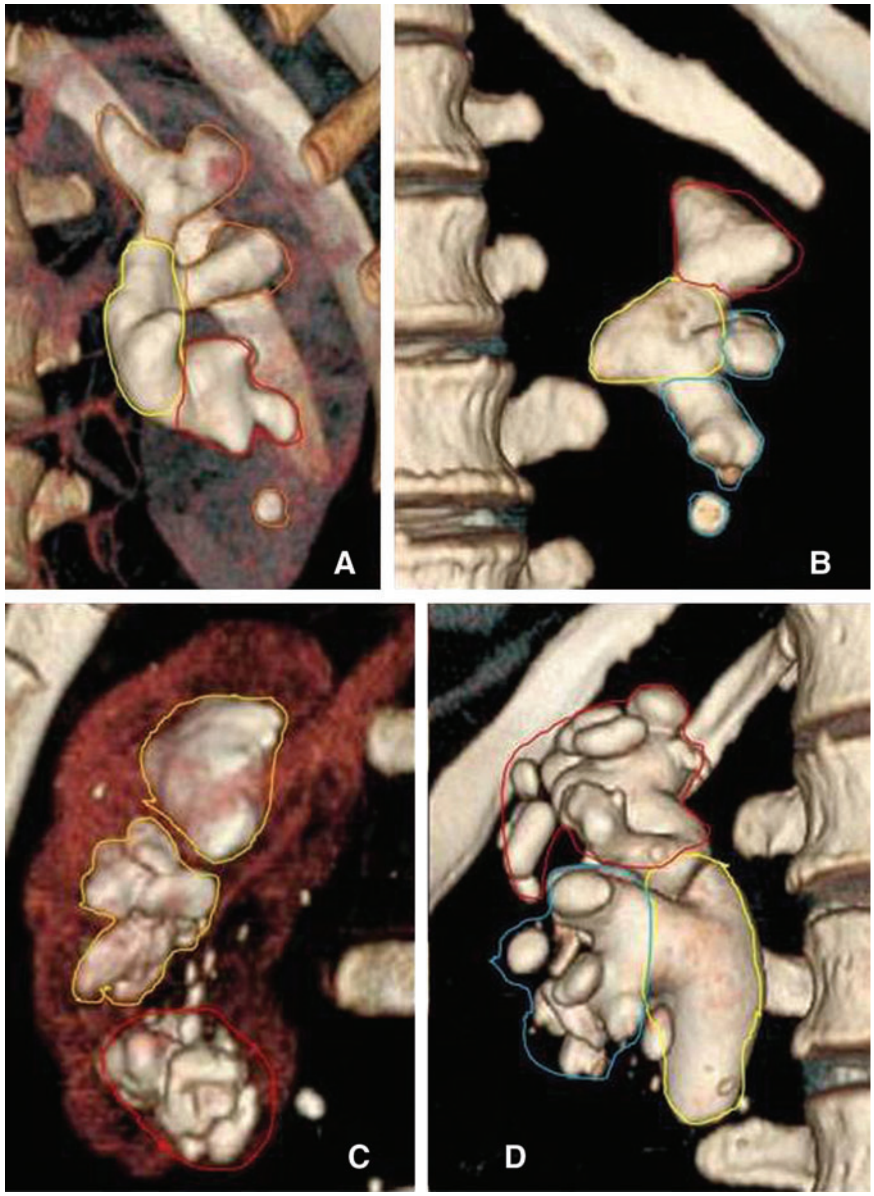

FIG. 2. Reconstructed CT urography showing different staghorn calculi. Staghorn morphometry depicted in the following categories; Yellow = pelvic stone volume, red = entry calix stone volume, blue = favorable calix stone volume, orange = unfavorable calix stone volume. **A** and **B** needed single stage percutaneous nephrolithotomy (PCNL) with three and one tracts, respectively, while **C** and **D** needed two stage PCNL with three and single tracts, respectively. The volumetric data are as follows: **(A)** Total stone volume (TSV) – 22,327 mm^3, pelvic stone volume – 5520 mm^3, pelvic stone percentile volume – 25%, entry calix volume – 5368 mm^3, entry calix and pelvic stone percentile volume – 48.7%, unfavorable calix stone volume – 11,449 mm^3, unfavorable calix stone percentile volume – 51.3%. **(B)** TSV – 6693 mm^3, pelvic stone volume – 4214 mm^3, pelvic stone percentile volume – 63%, entry calix stone volume – 1140 mm^3, entry calix and pelvic stone percentile volume – 80%, favorable calix stone volume – 1339 mm^3, unfavorable calix stone percentile volume – 0%. **(C)** TSV – 8240 mm^3, pelvic stone volume – 100 mm^3, pelvic stone percentile volume – 1%, entry calix stone volume – 1996 mm^3, entry calix and pelvic stone percentile volume – 25.4%, unfavorable calix stone volume – 6144 mm^3, unfavorable calix stone percentile volume – 74.6%. **(D)** TSV – 52,929 mm^3, pelvic stone volume – 26,591 mm^3, pelvic stone percentile volume – 50%, entry calix stone volume – 14,996 mm^3, entry calix and pelvic stone percentile volume –78.6%, favorable calix stone volume – 11,342 mm^3, favorable calix percentile stone volume – 21.4%.

angle to the entry calix and has an infundibulum more than 8 mm. An unfavorable calix, on the contrary, has an acute angle and infundibular width of less than 8 mm.

These parameters are evaluated on the contrast excretory phase of CTU. Based on this parameter, stone volume present in these favorable and unfavorable calices is defined as favorable calix and unfavorable calix stone volume, respectively. The percent of the stone in these calices to the TSV is similarly defined as favorable calix and unfavorable calix stone percentile volume, respectively. A note of the

Table 1. Clinical Correlates of Tract for Percutaneous Nephrolithotomy Monotherapy

Domain	Single tract	Two tract	More than two tracts
Number of renal units	41	26	27
Age (mean ± SD); y	41 ± 8.9	39 ± 9.2	56 ± 8.9
Sex (male: female)	9:32	7:19	8:19
Laterality (left: right)	27:14	11:15	13:14
BMI (average); kg/m^2	23.8	26.3	21.9
Position (prone: Valdivia)	35:6	17:9	26:1
Access calix (upper: middle: lower)	6:11:24	7:8:11	5:8:14
Stone-free rate (%)	98.6	97.8	88.1
Hemoglobin drop (mean ± SD); g%	0.7 ± 1.2	0.9 ± 1.2	2.8 ± 2.4
Hospital stay (mean ± SD); d	5.2 ± 3.6	8.1 ± 2.7	9.3 ± 6.6
Complications			
Clavien I	8	4	6
Clavien II	0	1	3
Clavien III	1	0	2
Clavien IV	0	0	0

SD = standard deviation; BMI = body mass index.

pelvicaliceal anatomy in terms of Sampaio classification was also taken.

Statistical analysis

The study was planned as a retrospective case control series. Univariate analysis was performed using paired *t* test for continuous data and chi-square test for categorical data. Multivariate conditional logistic regression analysis with forward selection was performed of the possible strong factors from univariate analysis to determine adjusted odds ratios (ORs). A multiple receiver operating characteristic (ROC) curve for significant factors was then drawn for tracts, and stages with area under the curve (AUC) calculated for the combined risk factor. For each possible cutoff limits of the multivariate factor, a prediction model of ORs with 95 percentile confidence intervals was constructed. *P* value less than 0.04 was considered statistically significant.

Results

The clinical correlates of the PCNL monotherapy are seen in Table 1. Most preoperative demographic parameters were comparable in the three groups. The multiple tract group had lesser stone-free rates, more hemoglobin drop and hospital stay. The complications were also marginally higher in the multiple tract group.

The staghorn morphometry correlating with tract needed for PCNL monotherapy is seen in Table 2. There was not much difference in TSV when single or two tracts were compared but there was significant increase for more tracts. The pelvic stone volume, favorable calix, and entry calix stone volume were not significantly different in either group. Pelvic, favorable calix, and pelvic and entry calix stone percentile volume, however, were significantly lower in the multiple tract group. Unfavorable calix stone and unfavorable calix stone percentile volume were significantly less in single and two tract(s) compared with the more than two tract group. Sampaio classification subgroups were comparable in single and two tract(s). The more than two tracts group had more B1 subgroup, however. The multiple tract groups had significantly lesser single stage clearance and more multiple stage clearance.

Table 2. Staghorn Morphometry Correlation with Tract Requirement for Pcnl Monotherapy

	Single tract (n = 41)	Two tract (n = 26)	More than two tract (n = 27)	Single vs two	Two vs more than two	Single vs more than two
Total stone volume (mm^3) (mean ± SD)	13163 ± 13576	13836 ± 14997	23834 ± 20958	0.85	0.05	0.013*
Pelvic stone volume (mm^3) (mean ± SD)	7724 ± 9869	7304 ± 7947	8761 ± 8145	0.85	0.65	0.51
Pelvic stone % volume	59 ± 24	59 ± 12.25	41	1.00	0.0006*	0.0026*
Entry calix stone volume (mm^3) (mean ± SD)	3130 ± 4601	2693 ± 2864.4	3471 ± 3060.8	0.66	0.34	0.73
Pelvic and entry calix stone % volume	83 ± 19.8	75 ± 10.8	60 ± 23.6	0.064	0.0047*	< 0.001*
Favorable calix stone volume (mm^3) (mean ± SD)	1856 ± 2675	1364 ± 1239.2	1262 ± 2086.1	0.38	0.83	0.33
Favorable calix stone % volume	14 ± 19.2	13 ± 9.8	66 ± 24.31	0.80	< 0.001*	< 0.001*
Unfavorable calyx stone volume (mm^3) (mean ± SD)	453 ± 1663.1	2476 ± 5242.3	10339 ± 17737	0.0245*	0.035*	0.0007*
Unfavorable calix stone % volume	3 ± 9.1	12 ± 12.2	34.4 ± 24.3	0.001*	0.0001*	< 0.0001*
Sampaio subgroups						
A1	8	7	6	0.55	0.75	0.045*
B1	15	8	17	0.79	0.028*	0.047*
B2	18	11	4	1.00	0.035*	0.016*
PCNL Stage clearance						
Single	37	19	6	0.09	0.0003*	< 0.0001*
Two	4	7	16	0.09	0.026*	< 0.0001*
More than two	0	0	5	1.00	0.05*	0.007*

* = statistically significant.
SD = standard deviation; PCNL = percutaneous nephrolitotomy.

Table 3 shows the correlation between stage and CTU related factors. Increasing stone volume resulted in increasing stages. The single stage procedure had significantly lesser TSV and pelvic stone volume. Unfavorable calix stone volume and percentile stone volume was more in multiple stage procedures. There was no major impact of the Sampaio subgroup in defining stages.

Multivariate logistic regression analysis for the significant factors found on univariate analysis is seen in Table 4. Unfavorable calix stone percentile volume (area under ROC curve [AUC] – 0.91) predicted the number of tracts. TSV and unfavorable calix stone percentile volume (AUC – 0.846) predicted the number of stages needed. Both TSV and unfavorable calix stone percentile volume (AUC – 0.884) predicted combined number of tracts and stages for PCNL monotherapy for staghorn calculus.

Multiple ROC curves were drawn of significant factors derived by paired analysis to identify their individual importance. Chances of clearing the stone in a single tract is in a staghorn that has a low TSV, high pelvic and entry calix percentile volume, and a low unfavorable calix percentile volume (Fig. 3). Chances of clearing the stone in multiple stages (Fig. 4) are in a staghorn that has large TSV, a low pelvic and entry calix stone volume, and a large unfavorable calix stone volume/percentile volume.

A model based on multiple logistic regression analysis was made with ORs for possible various cutoff limits of TSV and unfavorable calix stone percentile volume (Table 5). Based on this model, there is a likelihood for single tract and stage PCNL for staghorn TSV less than 5000 mm^3 and unfavorable calix stone percentile volume of less than 5% and a multiple tract and stage PCNL for a staghorn TSV more than 20,000 mm^3 and unfavorable calix stone percentile volume of more than 10%. For stones more than 5000 mm^3, an unfavorable calix stone percentile volume of less than 2% could be cleared with a single tract.

Discussion

The concept of tract(s) and stage(s) is clinically relevant for planning PCNL monotherapy for staghorn calculus. For staghorn calculus, there is scant evidence that single tract renders optimum access for clearing all the caliceal extensions.[6,8,9] It use is advocated for mainly small burden staghorn stones.[10,11] It has lesser morbidity but is limited by suboptimal stone-free rates.[9] Multiple tracts are often needed for large burden staghorn and have been demonstrated to be feasible and safe in expert hands.[7,12,13] The stone clearance rates have been demonstrated to be superior to single tract access.[6] Although the amount of renal functional loss[14] is similar in multiple *vs* single tract, it is significantly associated with more hemorrhagic complications.[10,12–15] Therefore, its use is under scrutiny and limited to high volume centers.[6]

Measures that have been advocated to reduce the short-term morbidity of multiple tracts PCNL are use of multiple small tracts[16] and PCNL in stages.[7,15] Staging the procedure is associated with lesser fluid absorption and decreased blood loss.[15,17] Fluid absorption may be an important consideration for large burden stones where staging becomes safer.[15,17] The other advantage of staging, either in single or multiple tract, is to increase the stone-free status under the same hospital stay by doing second look nephroscopy.[7,8,18–20]

The disadvantages of PCNL monotherapy performed in multiple stages are an increased hospital stay, patient costs, and decreased hospital turnover. Therefore, it is pertinent to

Table 3. Staghorn Morphometry Correlation with Stage Requirement for Percutaneous Nephrolithotomy Monotherapy

	Single stage (n = 62)	*Two stage (n = 28)*	*More than two stage (n = 4)*	*Single vs two*	*Two vs more than two*	*Single vs more than two*
Total stone volume (mm^3) (mean ± SD)	10789 ± 10536	21975 ± 14691	64682 ± 24233	< 0.0001	< 0.0001	< 0.0001
Pelvic stone volume (mm^3) (mean ± SD)	6073 ± 7886	10454 ± 8812	18474 ± 12948	0.02*	0.11	0.0046*
Pelvic stone % volume	56 ± 19	46 ± 21.7	35 ± 26	0.03*	0.36	0.04*
Entry calix stone volume (mm^3) (mean ± SD)	2413 ± 2980	4245 ± 4460	5901 ± 6508	0.024*	0.51	0.04*
Pelvic and entry calix stone % volume	79 ± 17.3	67 ± 22.9	45 ± 29.9	0.007*	0.09	0.0005*
Favorable calix stone volume (mm^3) (mean ± SD),	1537 ± 2279	1635 ± 2031.9	1135 ± 2269	0.84	0.65	0.73
Favorable calix stone % volume	14 ± 16.7	8 ± 8.42	3 ± 6.94	0.07	0.26	0.19
Unfavorable calix stone volume (mm^3) (mean ± SD)	765 ± 1622	5462 ± 6650	31972 ± 34698	< 0.0001	0.0005	< 0.0001
Unfavorable calix stone % volume	7 ± 11.3	25 ± 23.8	51 ± 34.3	< 0.0001	0.06	< 0.0001
Sampaio subgroups						
A1	15	4	2	0.41	0.31	0.63
B1	20	16	4	0.02*	1.0	0.17
B2	27	6	0	0.09	1.0	0.07
PCNL tracts						
Single	37	4	0	< 0.0001	1.00	0.014*
Two	19	7	0	0.80	0.56	0.31
More than two	6	16	5	< 0.0001	0.04	< 0.0001*

* = statistically significant.
SD = standard deviation; PCNL = percutaneous nephrolithotomy.

Table 4. Staghorn Morphometry: Multivariate Regression Analysis for Tract and Stage

	Variable	Odds ratio	95% CI	AUC
PCNL tracts	Unfavorable calix stone percentile volume	1.1783	1.087 to 1.277	0.910
PCNL stages	Total stone volume	1.0001	1.000 to 1.0001	0.846
	Unfavorable calix stone percentile volume	1.0659	1.027 to 1.106	
PCNL tracts and stages	Total stone volume	1.0001	1.0000 to 1.0001	0.884
	Unfavorable calix stone percentile volume	1.0845	1.0403 to 1.1306	

CI = confidence interval; AUC = area under the curve; PCNL = percutaneous nephrolithotomy.

reduce the tract(s) and stage(s) as and when required while maintaining the highest achievable stone-free rate.

The major determinant for tract and stage is staghorn morphometry. A collecting system with favorable anatomy, thereby implying a wide capacious system with wide infundibuli, may permit single tract easy nephroscopy navigation into each calix.[18] Similarly, a compact collecting system with narrow infundibuli may not permit easy nephroscopy through a single tract. A friendly collecting system with a large TSV and a corresponding large stone volume in an unfavorable calix still necessitates a separate tract for clearing the unfavorable caliceal stone bulk. There is currently a lack of an operational definition of staghorn calculus where these two factors demand planning for success.

Table 5. Odds Ratio Based Prediction Model for Tract and Stage of Percutaneous Nephrolithotomy Monotherapy for Staghorn Calculus

Risk parameter for stage		*Cases*	*Single stage*	*Multiple stage*	*Odds ratio*
Total stone volume					
< 5000 mm^3		14	14	0	0.06
5000–10,000 mm^3		30	23	7	0.58
10,000–15,000 mm^3		16	13	3	0.44
15,000-–0,000 mm^3		10	7	3	0.83
> 20,000 mm^3		24	5	19	7.36
Risk parameter for tracts		*Cases*	*Single tract*	*Multiple tract*	*Odds ratio*
Total stone volume					
< 5000 mm^3					
Unfavorable calix	< 2%	9	8	1	0.09
	2–5%	3	1	2	1.54
	> 5%	4	0	4	6.98
5000-10,000 mm^3					
Unfavorable calix	< 2%	14	13	1	0.059
	2–5%	4	0	2	3.87
	> 5%	12	1	11	8.50
10,000-15,000 mm^3					
Unfavorable calix	< 2%	9	8	1	0.096
	2–5%	2	1	1	0.77
	> 5%	7	0	7	11.6
15,000-20,000 mm^3					
Unfavorable calix	< 2%	3	2	1	0.38
	> 2%	7	0	7	11.6
> 20,000 mm^3					
Unfavorable calix	< 5%	6	5	1	0.154
	5–10%	3	2	1	0.386
	10%	15	0	15	24.0

There are no prognostic tools at present that could predict tract(s) and stage(s) for PCNL monotherapy for staghorn. The prediction based on an OR may also prognosticate the different types of staghorn. There is a need for a clinical definition of staghorn that could classify patients in either of the two ends of the treatment spectrum for PCNL monotherapy. At the one end is the so-called easy staghorn that could clear in a single tract and stage while at the other end is the difficult staghorn necessitating multiple tract and stage.

As one ascends the treatment spectrum, the complications, recurrence, and patient costs increase and at the same time, the stone-free and hospital turnover rates decrease. It is also anticipated that insurance cover may vary at different scales of the treatment spectrum. From the surgeon's perspective, to know on what scale of the treatment spectrum the patient lies is also important.

The "best" treatment option for a particular condition in terms of healthcare economics is the one that achieves the desired outcome at the lowest cost.[21] There should be an optimum balance between monetary cost and treatment efficiency. Within a given geographical and socioeconomic region, the combination of local patient factors, surgical skill sets, purchasing power, and care pathways might make anatrophic nephrolithotomy a cheaper option than PCNL. This may be an option in spite of proven level 1 evidence that PCNL, single or multiple tract and stage, gives equivalent stone-free rates with the advantages of less morbidity, shorter hospital stay, and lesser collateral renal damage.[22]

To the best of our knowledge, stone morphometry in the collecting system has not been studied previously. Computer image analysis is accurate, rapid, and easy to perform. Software programs compatible with microcomputers are readily available, making assessment of stone morphometry practical and inexpensive. Bandi and colleagues[23] studied the volumetric data of nonstaghorn simple renal stones and found that stone volume is an optimal predictor of stone-free status after shockwave lithotripsy. Lam and coworkers[24] were the first to study stone burden and advocated the use of stone surface area by 3D CT for more accurate reporting of treatment results. They opined that the comparison of data between institutions would be more meaningful if stone surface area is used. In a recent global PCNL study in which data of 5803 patients were presented by de la Rosette and associates,[25] they found that 27% (1566) patients globally had staghorn of which only 464 (8%) needed multiple tracts. No absolute interpretation can be drawn from these data of staghorn because of the lack of stone volumetric correlates. It is possible that many patients might have had simple or partial staghorn, which resulted in the necessity of only one tract for clearance.

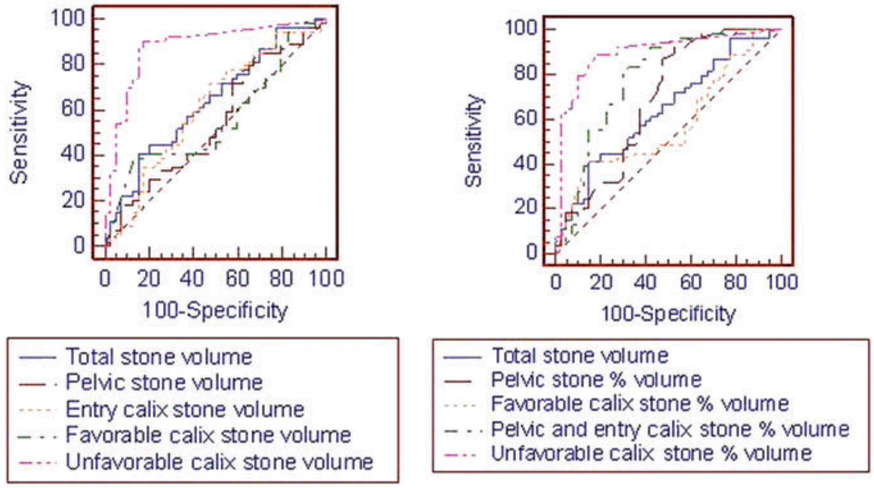

FIG. 3. Receiver operating characteristic curve for tract and staghorn morphometry parameters: A predictor with perfect discrimination would have a plot that passes through the left upper corner, where the positive fraction is 1 or 100 percentile and the false-positive fraction is 0. Quantitatively, the closer the plot is to the upper left corner, the higher is the overall predictive power of the criterion.

We require modalities that would offer accurate stone morphometric data. 3D CTU has an edge over the conventional intravenous urography in this regard for providing accurate morphometric data for standard PCNL planning. In our study, for a 3D image, the voxel size (image resolution) must be provided to 3D-DOCTOR software. This ensures that the 3D rendered image will have the correct scale in all the three dimensions and result in calibrated computation for all the reporting functions. For DICOM images, these parameters are normally provided in the header, as in our study. Olcott and colleagues[26] demonstrated that 3D CTU showed calculi more accurately than conventional radiographic technique despite correction for magnification error in traditional imaging methods. Routine 3D CT reconstruction, however, is not performed as part of the standard noncontrast CT examination, primarily because of the increased time and expenses for processing and interpretation.

The concept of stone morphometry by CTU has not been studied so far, with the probable reason of its being a time-consuming methodology for assessing stone volume. We extensively studied the volumetric stone distribution primarily by measuring stone volume each in the pelvis, entry calix, favorable calix, and unfavorable calices. This was possible because the primary assessment was performed by an urologist who was aware of the primary access tract. The radiologist while reporting may not necessarily be aware of the planning access concept. In an attempt to reduce the complexity, we also measured percentile volume of the caliceal stone burden. This was done on the assumption that the more cumbersome individual caliceal stone volume may not be needed if the percentile distribution was an effective prognostic variable. The radiologist may then suffice just by reporting TSV.

We also used CTU for assessing the angle of other calices with respect to the entry calix and the infundibular width. Although noncontrast CT may avoid further radiation, such a scan has limited collecting anatomy delineation mainly through maximum intensity projection images.

As per our detailed stone morphometric analysis, we introduce a clinically important definition of staghorn calculi based on the high odds probability of multiple tract(s) and stage(s). Type 1 staghorn has a TSV of less than 5,000 mm^3 with lesser than 5% unfavorable calix stone percentile volume while type 3 staghorn has a TSV of more than 20,000 mm^3 with greater than 10% unfavorable calix stone percentile volume. Type 2 staghorn is in between type 1 and 3. Based on our prediction model for achieving clearance by PCNL monotherapy, type 1 staghorn would necessitate single tract and stage; type 2, single tract-single/multiple stages or multiple tract-single stage; and type 3, multiple tract and stage.

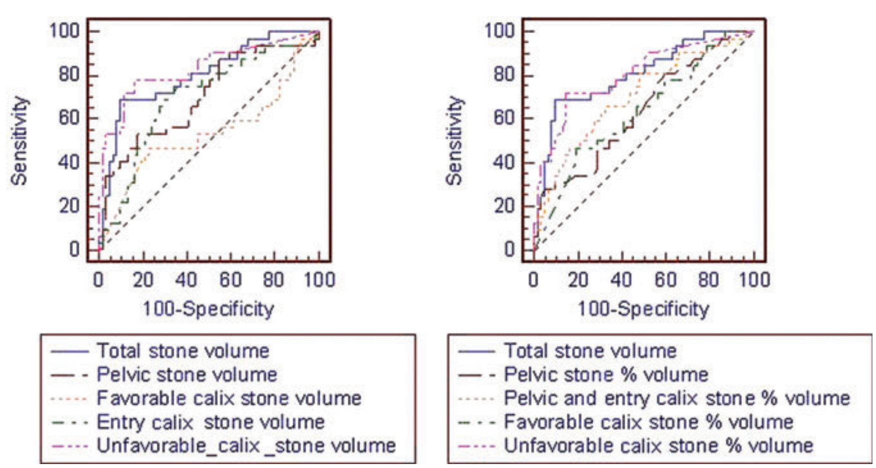

FIG. 4. Receiver operating characteristic curve for stage and staghorn morphometry parameters.

Most patients with type 1 are likely to have partial staghorn. Even with the higher unfavorable calix stone locations, most would clear easily in single stage with or without the use of flexible nephroscopy. Type 2 staghorn PCNL monotherapy may be individualized as per the operating team philosophy. Flexible nephroscopy may aid in single tract clearance, depending on the unfavorable calix stone volume. A smaller volume(<2% – type 2a) may result in single stage while larger volume(>2% – type 2b) may result in in multiple stages. If an aggressive multiple tract approach is used to avoid flexible instrumentation, the similar burden stone can still be cleared in single stage. Flexible nephroscopy for a large unfavorable calix stone volume may prolong the PCNL monotherapy by increasing the stage primarily by increasing the operative time.

Type 3 staghorn would ultimately test the patience and the skill of the surgeon. Most would result in multiple tracts and stages. Flexible nephroscopy has a limited role in such a variety of staghorn. During counseling of patients with the type 3 category, the clinician and patient should be aware of the cost implications, hospital stay, and marginally reduced stone-free state. These are also those patients in whom clearance may be suboptimal, leading to residual fragments causing recurrent stone formation.

The findings from this high-volume single-center experience of a retrospective case control design need further validation in a prospective manner. The strength of the article is the large number of patient data with mainly large bulk staghorn calculi. The treating surgeons were unaware of the researcher's interpretation, thereby avoiding a treatment bias. Each CTU was studied in detail with an enthusiastic urologist involved in the treatment program well aware of the renal access philosophy for managing staghorn calculus. The limitations would include the retrospective nature of the study, besides the still to be extensively validated time-consuming stone volume assessing apparatus. The time spent on assessing the staghorn morphometry at present is exhaustive. With its utility being explored, a need to develop specialized software measuring the morphometry is needed sooner rather than later.

Disclosure Statement

No competing financial interests exist.

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Abbreviations Used

AUC = area under the curve
CT = computed tomography
CTU = computed tomography urography
DICOM = digital imaging and communications in medicine
OR = odds ratio
PCNL = percutaneous nephrolithotomy
ROC = receiver operating characteristic
3D = three dimensional
TSV = total stone volume