



Review

Preoperative imaging in staghorn calculi, planning and decision making in management of staghorn calculi



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Abstract *Objective:* Staghorn calculi present a particular and challenging entity of stone morphology. Treatment is associated with lower stone-free rates and higher complication rates compared to non-staghorn stones. In this review we looked for the most relevant data on preoperative imaging and access planning to help decision making for percutaneous surgery with this complex condition.

Methods: We conducted a PubMed search of publications in the past 2 decades that include relevant information on the planning for management of staghorn stones. Non-contrast computerized tomography (NCCT) is indeed the standard imaging tool for percutaneous nephrolithotomy (PCNL); additional tools such as three-dimensional computed tomography (CT) reconstruction of the staghorn calculus may help plan access in complex cases. Ultrasound guided percutaneous access may be considered for staghorn stones when planning upper pole access in kidney malposition or complex intrarenal anatomy or with complex body habitus. Wideband doppler ultrasound and real-time virtual sonography can assist. New technologies to improve kidney access such as Uro Dyna-CT or electromagnetic sensor have been reported, but have not shown utilization in staghorn cases. Staghorn morphometry-based prediction algorithms may predict the number of tract(s) and stage(s) for PCNL monotherapy. Lower pole access can be equally effective as upper pole when planning for staghorn and complex stones, with significantly less complications rate; Stone-Tract length-Obstruction-Number of involved calyces-Essence of stone density (STONE) nephrolithometry seems to be the best system to predict outcomes of PCNL in staghorn cases. There is a growing trend of endoscopic combined intrarenal surgery (ECIRS) in concordance with PCNL to treat larger stones. Conservative management of staghorn calculi is an undesired option, but can be an alternative for a carefully selected group of high-risk patients.

Conclusion: Staghorn stones may lead to deterioration of renal function and life-threatening urosepsis. This entity should be managed aggressively with planning ahead for surgery using the different tools available as the cornerstone for a successful outcome.

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1. Introduction

Staghorn stones are a specific entity of kidney stones that branch out and fill the renal pelvis and part or all of the intrarenal calyceal system. This particular form of stone can present with a complete or partial configuration. It is usually unilateral and more prevalent in females [1].

Traditionally, staghorn stones have close association with urinary tract infections caused by urea-splitting organisms and consist of pure magnesium ammonium phosphate (struvite) or a mixture of struvite and calcium carbonate apatite [1]. These "infection stones", if left untreated, grow rapidly and may lead to deterioration of renal function, end-stage renal disease, and life-threatening urosepsis [2].

Percutaneous nephrolithotomy (PCNL) represents the standard of care for staghorn stones [2]. A large series of patients with staghorn stones proves that PCNL has a lower stone-free rate (SFR) compared to non-staghorn stones, higher complication rate, with increased operation time and length of hospitalization [3]. We herein provide an overview of the preoperative planning and decision making to be considered in the management of staghorn calculi.

2. Preoperative imaging

Successful PCNL relies on meticulous preoperative planning and optimal percutaneous access. Computed tomography (CT) has become the standard imaging modality for PCNL planning. Preoperative CT allows the selection of the optimal percutaneous renal access. Intraoperative fluoroscopy and/or ultrasound (US) are necessary to carry out directed percutaneous renal puncture and the following tract dilation before endoscopic inspection of the collecting system. Finally, postoperative imaging (CT, US or kidneys, ureters and bladder [KUB]) determines the presence and volume of residual fragments to ascertain the need for second-look flexible nephroscopy.

Safe and efficient percutaneous access and stone removal require that endourologist has a clear and accurate understanding of the pelvicalyceal system anatomy as well as stone location with respect to infundibular and calyceal system. This is even more crucial in patients with various anatomic abnormalities such as morbid obesity, kyphoscoliosis and ectopic or mal-rotated kidneys that are in greater risk for a poor access, incomplete stone removal, and injury to adjacent organs.

Since spiral CT was first introduced into clinical practice in the late eighties, it has become the standard imaging tool for PCNL. Advantages of non-contrast CT (NCCT) before renal

stone surgery have become increasingly evident and include localizing peripheral stones to anterior or posterior calices, determining the direction of calyceal extensions of staghorn calculi, evaluating the thickness of the parenchyma that overlies calculi, and visualizing even stones that are poorly seen on plain radiograph [4]. The development of helical CT with the elimination of respiratory artefacts has improved image reconstruction even further while analyzing the surrounding structures in order to plan the access and further demonstrated the safety of supracostal access with the patient in the prone position [4].

Noncontrast three-dimensional (3D) CT reconstruction of the staghorn calculus for planning access has also been evaluated in several studies with the thought that 3D reconstruction of the renal stone can help determine access site and intraoperative orientation. Hubert et al. [5] used this method in 27 renal calculi of whom 23 staghorn stones found that the access site was altered in a third of patients to what would have been adopted if the corresponding axial CT and intravenous urography (IVU) had been used. Li et al. [6] performed PCNL successfully with the assistance of a 3D model in 15 patients with complex stones, and eight partial/complete staghorn were managed with one-stage SFR of 93.3%.

There may be a role also for contrast enhanced CT scans for patients with staghorn stones. Thiruchelvam et al. [7] assessed a modified technique of multidetector computed tomographic urography (CTU) to map the pelvicalyceal system (PCS) for complex renal calculi. Of the 10 CTUs performed, three were for staghorn stones. These showed good infundibular anatomy and provided a good map of the stones in relation to the PCS. With reconstructed images, subjectively the 3D imaging provided an advantage over conventional imaging in optimizing nephrostomy placement. Authors suggested reducing radiation exposure by performing CTU with no preceding unenhanced CT as all the stones detected on the CTU after contrast injection were visualized on the unenhanced CT.

Mishra et al. [8] suggested a CT urography staghorn morphometry-based prediction algorithm to predict tract(s) and stage(s) for PCNL monotherapy and to use it to classify the staghorn stone accordingly. They used a retrospective case-control design of 94 renal units. CT software calculated the total stone volume (TSV) with absolute volume and percentile volume in the pelvis, planned entry calix, favorable and unfavorable calix. This model of staghorn morphometry differentiated staghorn stones 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).

3. Planning on the access calyx and number of tracts

PCNL represents the standard of treatment for large renal stones. Even though it is not a complication free procedure, it is still considered a minimally invasive procedure providing high success rate and safety profile [8,9]. Complete removal of stones is crucial for preventing recurrence and morbidity. The most favored approaches when performing PCNL for staghorn stones are the upper pole (UP) access and multiple tract access. Literature favors the UP caliceal access as the one that allows better entry into the entire pelvicalyceal system thereby allowing better approach to the stone burden, better SFRs, fewer kidney percutaneous tracts needed, and less manipulative trauma compared to lower pole (LP) or multiple tracts access [10,11].

While the UP calyx allows direct access to the intrarenal collecting system and potential greater stone clearance rate, one should keep in mind that the complication rates, especially thoracic complications and bleeding, are significantly more common with this approach. Tefekli et al. [12] reviewed 4 494 patients from the data collected by the Clinical Research Office of the Endourological Society (CROES) from consecutive patients at 96 centers globally. The upper pole access group was utilized for more staghorn stones (21.7% vs. 15.5%, $p < 0.001$). Overall perioperative complication rates were higher in the UP-access group compared to LP (23.5% vs. 16.1%, $p < 0.001$). Pulmonary complications (hydrothorax) were significantly more common in the UP access (5.8% vs. 1.5%, $p < 0.001$). Transfusion rate was also significantly higher for the UP access compared to LP (7.3% vs. 4.0%, $p < 0.002$).

In a recent report, Blum et al. [13] looked at total of 76 patients with complete staghorn stones. The lower pole was accessed in 59 (77.6%) patients, and they found similar efficacy with decreased morbidity compared to UP access in patients in prone position. They did not find any difference in the ability of completing the surgery utilizing a single tract as opposed to multiple tracts (74.6% of LP patients vs. 76.5% of UP patients). SFRs for LP and UP access were similar (74.5% vs. 70.5%, respectively [$p = 0.760$]) and the complication rates were lower for LP access vs. UP access (3.4% vs. 23.5%, $p = 0.02$).

The debate continues over the use of single tract PCNL with complimentary flexible nephroscopy and/or ureteroscopy, versus multiple tracts [14]. Akman et al. [15] retrospectively reviewed the records of 413 patients with partial or complete staghorn stones. Single access was performed in 244 (59%) patients and multiple accesses were necessary in 169 (41%) patients. Mean durations of fluoroscopy and operative times were significantly longer in the multiple tract group. Success after one stage PCNL was achieved in 70.1% with single tract and in 81.1% after multiple tracts ($p = 0.012$). The most common complication was bleeding for both groups, and it was higher for the multiple tract group (hemoglobin drop 2.1+1.7 in the single tract vs. 2.5+1.6 in the multiple tract group, $p < 0.0001$). Turna et al. [16] retrospectively analyzed the data of 193 PCNL procedures, and they found that staghorn stones ($p = 0.006$) and multiple tracts ($p = 0.038$) were associated

with increased renal hemorrhage during PCNL on multivariate analysis. Decrease in renal function is another factor to consider when planning single or multiple tracts. We recently reported that multiple per cutaneous access is associated with a small reduction in the differential renal function on the operated kidney when compared to a single access approach. We identified 110 cases in which renography was performed before surgery and between 1 month and 1 year after PCNL and found a significant 2.28% decrease in renal function on the affected kidney in patients who received multiple tracts ($p < 0.01$) [17].

Other studies favor a more aggressive approach when treating staghorn calculi by showing the safety and efficacy of multiple tracts. Singla et al. [18] retrospectively analyzed 164 renal units in 149 patients with 2–6 tracts per unit. Complete stone clearance rate of 70.7% was achieved after a single session of PCNL and increased to 89% after a second-look procedure and extracorporeal shock wave lithotripsy. The complications described included blood transfusion in 46 patients, sepsis in eight and hydrothorax in seven.

4. Fluoroscopy versus ultrasound guided PCN access

Fluoroscopy is the most commonly used modality for PCN access. Several techniques have been described, and all have proved to be efficient. The election of the technique should be merely decided based on the surgeon experience. The main disadvantages for fluoroscopy access are the single plane projection and the radiation exposure to the patient and the staff in the operating theatre.

US guided percutaneous access has several advantages compared with fluoroscopic access. US is a readily available, non-expensive and portable unit in OR; it provides a tridimensional orientation and provides guidance for access in multiple planes, longitudinal, transverse and oblique; it allows to measure the stone to skin distance; it avoids the risk of lesions to adjacent organs mainly colon, liver or spleen and the risk of transthoracic puncture. Doppler/US may prevent the puncture to important vascular structures and allows a real-time monitoring of the needle tip placement reducing significantly radiation exposure during surgery. While US guided access can be used for any patient, indications where US has clear advantage over fluoroscopy are upper pole access, kidney malposition, complex intrarenal anatomy, complex patient body habitus, reconstructed urinary tract post urinary diversion or when retrograde contrast injection cannot be performed.

Several studies have compared fluoroscopy versus US guided access during PCNL. Andonian et al. [19], in another of the CROES publications on PCNL, analyzed whether the image modality used for percutaneous renal access made a difference. The study included 453 (13.7%) patients where US guided access was utilized and 2 853 (86.3%) patients accessed with fluoroscopy. In the univariate analysis they found that there was a significant reduction in the risk of transfusion in favor of US (6.0% versus 13.1% for fluoroscopy, $p = 0.001$). On the multivariate analysis they found that the risk of bleeding was associated to the size of the tract with an increase of 4.91 times when using 27–30 Fr sheaths compared to a sheath smaller than 24 Fr and the

number of tracts with an increase of 2.6 times for multiple versus single tracts.

Liu et al. [20] conducted a systemic review and found no significant difference in SFR, operation time, hospital and success rate of tract creation between ultrasonography and fluoroscopy. Access with US did offer shorter puncture time (mean difference [MD]: -4.71 ; 95% confidence interval [CI]: -6.43 to -3.0 ; $p < 0.0001$), higher success rate of first puncture (RR: 1.16; 95% CI: 1.04 to 1.3; $p = 0.01$), less blood loss (MD: -0.42 , 95% CI: -0.81 to -0.02 ; $p = 0.04$), and less transfusion requirement (relative risk [RR]: 0.73; 95% CI: 0.33–1.6; $p = 0.44$).

There has been a recent interest on performing X-ray-free ultrasound access to the kidney. Usawachintachit et al. [21] reported on their technique of X-ray-free ultrasound-guided PCNL. They looked at 96 consecutive patients and concluded that the ideal candidate for a completely X-ray-free ultrasound-guided PCNL should have a hydronephrotic collecting system with no staghorn stone present.

Inoue et al. [22] evaluated the efficacy and safety of wideband Doppler ultrasound-guided mini-endoscopic combined intrarenal surgery (mini-ECIRS) for large renal stones. This method displays a clearer image of the path of the blood vessels in real time than conventional color Doppler and therefore can be used to accurately visualize peripheral vascular flow. Forty one patients with a mean stone size of 45.5 mm, of which 41.4% were staghorn stones were included. The mean total operative time was $158.4 + 51.3$ min. SFR was defined as residual fragments smaller than 4-mm on X-ray and ultrasonography on 1 day and 1 month postoperatively. Initial SFR of 73.2% was reported with mean hemoglobin drop of 0.54 g/dL and three (7.3%) postoperative modified Clavien grade II complications.

5. New technologies for percutaneous renal access

Performing the puncture of the renal collecting system is the major challenge step in PCNL, whether it is performed with the use of standard fluoroscopy or in combination with ultrasound-based maneuvers. The current challenge for PCN renal surgery is to improve accuracy of the puncture, using real time anatomic navigation system to reduce the puncture related complications and improve the procedure efficacy.

In recent years several novel techniques for percutaneous kidney access have been developed. Lima et al. [23] used a flexible ureteroscopy to insert an electromagnetic sensor to the optimal renal calyx for access. Then the selected calyx was punctured with a needle with a sensor on the tip guided by real-time 3D images observed on the monitor.

Rassweiler et al. [24] reported an iPad-assisted access that applies marker-based tracking for puncture of collecting system. A CT is performed in similar prone position on a PCNL-cushion with six colored radiopaque markers on the skin around the target area preoperatively and using a special software, virtual anatomy displayed on the iPad correlates with real anatomy and can be used for puncture.

Uro Dyna-CT (Siemens Medical Solutions, Erlangen, Germany) utilizes a digital angiography unit that rotates around the patient and creates 3D reconstruction of target structures [25]. Using a special software and based on “bull’s eye” technology, a laser light simulates the puncture line in any position of the C-arm that might be necessary during puncture. An obvious disadvantage of this technology is that the image acquisition uses higher radiation doses than standard fluoroscopy.

Real-time virtual sonography (RVS) is another technology suggested to assist in access to the kidney. This is a diagnostic imaging support system that synchronizes real-time US with CT or magnetic resonance imaging, via a magnetic navigation system, to provide volume and position data, side by side, in real time. It has been used for radio-frequency ablation for hepatocellular carcinoma, and biopsy and focal therapy for prostate cancer. Hamamoto et al. [26] evaluated it for percutaneous renal puncture during endoscopic combined intrarenal surgery. Thirty patients were divided half into the RVS-guided puncture and half for US guided puncture. In the RVS group, renal puncture was repeated until precise piercing of a papilla was achieved under direct endoscopic vision. The mean sizes of the renal calculi in the RVS and the US group were 33.5 mm and 30.5 mm, respectively. A lower mean number of puncture attempts for access was needed for the RVS compared with the US group (1.6 times vs. 3.4 times, $p = 0.001$). The RVS group had a lower mean postoperative hemoglobin decrease (0.93 vs. 1.39 g/dL, $p = 0.04$), but with no differences with regard to operative time, tubeless rate, and SFR and with no postoperative complications of a Clavien score ≥ 2 .

While these technologies represent promising ways to improve renal access and the final outcomes for the patients with renal stones, today, none of these alternatives have been approved for routine utilization during percutaneous surgery and none of them have been implemented for PCNL in staghorn stones in a large scale.

6. Patient position for PCNL of staghorn stone

PCNL can be accomplished via several patient positions: Prone position, flank position, supine position, and several modified supine positions. The debate in the literature has been long as to which one of the patient positions achieves better results and fewer complications. Yuan et al. [27] conducted recently the most updated meta-analysis including 6 881 patients. The study showed that prone position was associated with a higher rate of stone clearance than the supine position (odds ratio [OR]: 0.74; 95% CI: [0.65, 0.84]; $p < 0.00001$). A shorter mean operative time was observed in the supine groups (weighted mean difference [WMD]: -18.27 ; 95% CI: -35.77 to -0.77 ; $p = 0.04$) as well as a lower incidence of blood transfusions in favor of the supine group (WMD: 0.73; 95% CI: 0.56 to 0.95; $p = 0.02$).

Astroza et al. [28] on behalf of CROES analyzed the effect of supine versus prone position on the outcomes of PCNL in patients with staghorn stones. They looked at a total of 1 311 patients, 1 079 PNLs performed in prone and 232 in supine position, and found that SFR was higher for patients in the prone position (48.4% vs. 59.2%; $p < 0.001$).

Of note, upper pole access was significantly more utilized in prone position compared to supine (12.6% vs. 3.6%, $p < 0.001$), supporting the fact that accessing the upper pole is more challenging when patient is positioned in supine. Surgical time was shorter in the prone position (103.2 min vs. 123.1 min; $p < 0.001$); retreatment rate was higher in supine position (36.1% vs. 21.5%; $p < 0.05$); there were no differences in complication rates in both groups.

Gökçe et al. [29] looked at 48 patients operated in prone position and 39 patients operated in supine position and reported that multi-caliceal and intercostal access was more common in the prone position. Operation duration was significantly shorter and hemoglobin drop was significantly less in the supine group while the complication rates were similar in the two groups. SFR was similar (64.1% and 60.4% in the supine and prone groups, respectively; $p = 0.72$).

Prone and supine position are feasible and recommended to access the kidney during PCN renal surgery. This statement applies also for the management of staghorn stones, although the literature shows that upper pole access may be limited in some cases in the supine position. There are very limited restrictions for each one of the surgical approaches and there is not enough evidence in the literature to make strong recommendations on a superior position. The decision on the patient position modality to treat renal stones, including staghorn stones, depends strictly on the surgeon preference.

7. ECIRS

Another growing trend in the past decade is ECIRS, using both PCNL and RIRS to treat larger stones [30]. This approach has the apparent advantage of avoiding multiple tracts and therefore bleeding complications. Since then, several modifications to this approach have been published, including, among others, the use of mini-PCNL instead of standard PCNL and the use of semi-rigid URS.

This technique is becoming more popular and larger series will be needed to probe the benefits treating staghorn stones [31].

8. Predicting outcomes of PCNL for staghorn stones

There are currently three systems validated to predict prognosis of PCNL outcomes, the Guy's stone score (GSS), the CROES nomogram and Stone-Tract length-Obstruction-Number of involved calyces-Essence of stone density (STONE) nephrolithometry [32–34]. All three nomograms systems have shown high accuracy and proved to be reliable in predicting SFRs after PCNL [35,36].

Sfoungaristos et al. [37] analyzed a total of 73 staghorn calculi with mean Guy's, CROES and STONE scores of 3.34, 125.8 and 9.95, respectively. Postoperative SFR was 65.8% and STONE nephrolithometry was found to be the only predictor for SFR after PCNL for staghorn stones compared to Guy's and CROES nomograms.

Choi et al. [38] reached a similar conclusion when they examined 217 procedures, 111 (51.2%) patients with partial staghorn and 106 (48.8%) patients with complete staghorn stones. The initial and overall SFRs of PCNL were 53.9% and 70.1%, respectively. On a multivariate logistic regression analysis, independent predictors for SFR were number of involved calices, STONE nephrolithometry, and pre-existent urinary tract infection (UTI) (ORs = 1.311, 1.933, and 2.340, respectively).

9. Conservative management of a staghorn stone

The natural history of untreated staghorn stones is one of progressive morbidity and mortality. It destroys the kidney and causes life threatening risks from end stage kidney disease and infectious complications. This has been consistently shown in earlier and recent reports. Blandy and Singh [39] in 1976 reported a 10-year mortality rate of 28% with conservative treatment. Teichman and colleagues [40] in 1995 retrospectively reviewed 177 consecutive staghorn patients with an average follow-up of 7.7 years. They reported an overall rate of renal deterioration of 28% and 67% renal-related causes of the deaths for those who declined treatment.

Despite this evidence, ever so often clinicians face with the need of deciding for conservative treatment due to severe comorbidities, restrictions for renal access due to difficult anatomy and even patient or family decisions. Morgan et al. [41] described the overall outcomes in a cohort of patients with staghorn calculi treated conservatively. Fourteen out of a cohort of 29 patients were treated conservatively over a mean follow-up of 24 months. None of the study patients required hemodialysis or developed an abscess. There was only one related admission for pyelonephritis and one death from urosepsis of a patient that had been noncompliant with follow-up. Deutsch and Subramonian [42] evaluated the outcomes of 22 patients with unilateral or bilateral staghorn calculi conservatively managed. The rate of recurrent UTIs was 50%; the progressive renal failure rate was 14%; the disease-specific mortality rate was 9%; the dialysis dependence rate was 9%; the rate of hospital attendances attributable to stone-related morbidity was 27%. Therefore, conservative management of staghorn calculi can be an option for a carefully selected patients that should be counseled thoroughly regarding the risks entailed with this choice.

10. Conclusion

Staghorn stones are a renal disease that may lead to deterioration of renal function and life-threatening urosepsis. This entity should be managed aggressively and effectively and planning ahead for surgery using the different tools available is the cornerstone for a successful outcome. Proper consent is important so patients understand what to expect after treatment.

Author contributions

Study concept and design: Jorge Gutiérrez-Aceves.

Data acquisition: Ilan Klein.

Data analysis: Ilan Klein.

Drafting of manuscript: Ilan Klein.

Critical revision of the manuscript: Jorge Gutiérrez-Aceves.

Conflicts of interest

The authors declare no conflict of interest.

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