Chapter

Guideline Based Algorithmic Approach for the Management of Renal and Ureteric Calculi

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Abstract

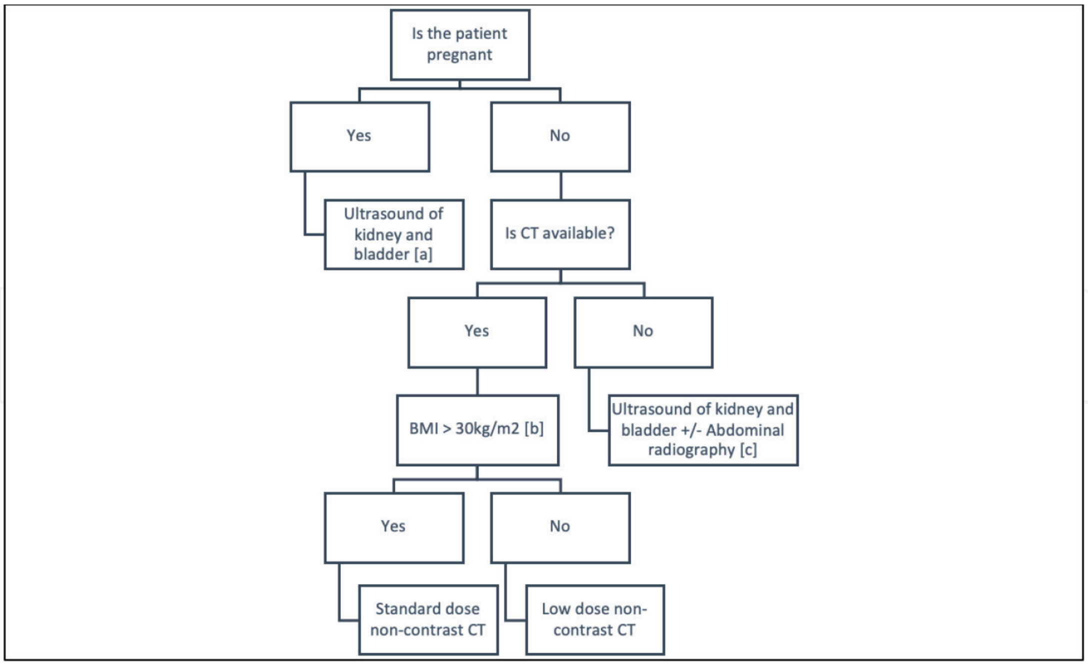
Urolithiasis is a global pathology with increasing prevalence rate. The surgical management of kidney and ureteral stones is based on the stone location, size, the patient's preference and the institutional availability of various modalities. To date, the available modalities in the management of urolithiasis includes external shock wave lithotripsy (ESWL), percutaneous nephrolithotomy (PNL), ureterorenoscopy (URS) including flexible and semirigid ureteroscopy. Tremendous technological advancement in the urological armamentarium has happened since its inception leading to multiple acceptable modalities for the treatment of a particular stone. In accordance with the available recommendations from various institutions and the newer evidence we recommend that the initial choice of modality for the treatment of a renal calculus depends on the stone size and whether the location is lower pole or not. For lower pole stones upto 20 mm PNL and RIRS is efficient irrespective of location while ESWL should only be considered for lower pole stones upto 10 mm. For stones larger than 20 mm mini PNL is effective for stones upto 40 mm while RIRS holds acceptable efficiency for stones not larger than 30 mm. For stones larger than 40 mm standard PNL only should be considered if single stage treatment is attempted.

Keywords: PNL, nephrolithiasis, urolithiasis, SWL, RIRS, URS

1. Introduction

Urolithiasis is a common urinary tract condition with a prevalence of approximately 14% [1]. There are multiple factors which influence an individual's propensity for formation of urinary tract calculi, the most common of which are age, sex, and ethnicity [1, 2]. Anatomically they can have origin in the upper tract or the lower tract of which those originating in the upper tracts are more common while approximately 5% are found within the bladder [3]. They present a significant clinical and economic burden to the healthcare systems [4, 5]. In an attempt to bring uniformity in management worldwide, many institutions have developed extensive guidelines to aid in the evaluation and management of urolithiasis.

Once the diagnosis of urolithiasis is confirmed, the goal of a diagnostic evaluation is to identify, efficiently and economically, the differences present in the patient's metabolic physiology to guide effective preventive strategies for recurrence and



a) For pregnant patients in the third trimester who have intractable pain or fever and in whom the results of an ultrasound of the kidneys and bladder are inadequate, a low-dose, noncontrast CT under guidance of an obstetrician can also be considered to detect suspected nephrolithiasis.

b) In patients with obesity (BMI >30 kg/m^2), standard-dose CT is preferred since low-dose CT may be less reliable for detecting small stones (<2 mm) and ureteral stones.

c) Ultrasound reliably detects hydronephrosis, and radiography can be used to measure stone size and location. However, compared with CT, both ultrasound and radiography are less sensitive for detecting stones.

Figure 1.
A stepwise approach for the diagnostic evaluation of suspected nephrolithiasis.

better assessment of prognosis. The extent of evaluation depends on the factors like: severity and type of stone disease; new stone formation or recurrent stone formation; co-existence of any systemic disease and/or risk factors for recurrent stone formation; family history of nephrolithiasis and last but not the least patient's interest in stone prevention (**Figure 1**).

Technological advancements in the endourological armamentarium have happened at a rapid pace since its inception and is still going on. As a result, the search for the *best* treatment modality for any given stone undergoes a frequent shift from one modality to other in accordance with the newer available evidence. The aim of this chapter is to highlight and summarize in the form of an algorithmic approach the best possible treatment of renal and ureteric calculi in accordance with the recommendations from various urological institutions worldwide along with the newer available evidence.

2. Evaluation of suspected nephrolithiasis

The entire diagnostic workup can be broadly categorized into two categories viz. biochemical and systemic assessment by various laboratory parameters and secondly, imaging specific to nephrolithiasis which will aid in treatment planning [6].

2.1 Biochemical and systemic evaluation

The main aim of biochemical evaluation is identification of any systemic adverse effects secondary to the urinary tract calculi along with a baseline workup of patient as a part of preparation for definitive surgical therapy. This baseline assessment should include evaluation of basic hematological parameters, renal function, urinalysis along with an abbreviated metabolic workup for hypercalcemia, hyperuricemia and hyperphosphatemia. Every attempt should be made to diagnose and treat any urinary tract infection (UTI) prior to definitive surgical therapy to avoid the risk of urosepsis [7].

2.2 Diagnostic imaging

The aim of diagnostic imaging is to confirm the presence of urinary tract calculi and to guide the decision making for the specific modality to be undertaken for treatment. Factors that influence the choice of treatment modality include stone size, location, density and composition, condition of contralateral kidney and presence or absence of complications of stone disease.

2.3 Selection of modality

CT of the abdomen and pelvis without contrast performed using low-radiation-dose protocols is that the gold standard imaging modality for adults with suspected urinary tract calculi, if not contraindicated. In the case of unavailability of CT scan, ultrasonography of the kidneys and bladder in combination with abdominopelvic radiography should be performed [8]. However, in the presence of small radiolucent stones there will be high fraction of stones that will miss the diagnosis. Other imaging modalities like intravenous urography (IVU) and magnetic resonance imaging (MRI) are not preferred as first line investigations and have specific and limited indications.

CT scan also accurately describes stone size and location for treatment planning as it also provides accurate information on the size and number of other stones in the kidneys. If available, there are very few contraindications to perform a low-dose CT [9, 10].

- If the patient is pregnant, an ultrasound is the preferred modality and CT is contraindicated because of risk of teratogenicity to the developing fetus.

- If the patient has a body mass index (BMI) >30 kg/m^2, then a standard-dose CT is preferred because of better exposure.

Computed tomography (CT) of the abdomen and pelvis without contrast reliably detects hydronephrosis and demonstrates the best diagnostic performance for nephrolithiasis. Sensitivity and specificity of CT for detecting ureteral calculi, using conventional radiation doses is, greater than 94% and 97% respectively [11–14]. CT done using low dose protocols is also highly sensitive and specific for detection of >2 mm calculi with a sensitivity and specificity of 97% and 95% respectively [9, 11, 12, 15–17]. Low-dose CT may be less reliable for detecting small stones (<2 mm) and ureteral stones in patients with obesity (BMI >30 mg/k^2). Patients with urolithiasis are at increased risk of recurrent stone formation and also may require repeat imaging sessions. Therefore, low dose CT, if not contraindicated, should be the standard of care to minimize the cumulative radiation exposure to the patients as the sensitivity for detection of stones >3 mm is high and comparable to the standard dose CT in non-obese patients [18, 19]. For the estimation of stone size, low and standard dose CT yield equivalent measurements [20].

3. Surgical treatment of nephrolithiasis

3.1 Goals of surgical therapy

As a part of shared decision making as recommended by American Urology Association, the following factors should be discussed and explained to the patients and the choice of surgical modalities should be made keeping the following factors into consideration along with the patients' preferences.

3.1.1 Stone clearance

Treatment success for ureteral or kidney stone surgery is generally defined in terms of stone clearance rates. Although the definition successful stone clearance is not having unanimous acceptance globally, the absence of residual stones or the presence of residual stone fragments ≤4 mm in size are generally considered a successful outcome. Achieving a stone-free status is important, since small residual stone fragments, particularly those >4 mm, may act as a nidus leading to aggregation and recurrent stone formation. Many centres also evaluate the need for re-treatment or additional procedures for complete stone clearance and consider it as another important measure of efficacy of any modality of treatment.

3.1.2 Risk of adverse events

The benefits of surgical stone removal must be balanced against the risk for adverse events and complications. Procedures that offer the highest stone clearance rates (such as ureteroscopy [URS] and percutaneous nephrolithotomy [PNL]) are also believed to have higher complication rates. The decision making should incorporate a detailed discussion with the patient regarding the possible adverse events and the subsequent need for ancillary treatments.

3.1.3 Effect on quality of life (QoL)

The treatment planning should also take into account the patients' perspective regarding the treatment and the subsequent overall impact on patient's quality of life depending upon factors like patient's perception of pain and other discomforting symptoms, the total number of hospital visits and admissions and the overall healthcare related economic impact on the patient.

4. Choice of surgical approach

The factors that play a role in the selection of a modality for surgical treatment of nephrolithiasis can be divided into patient factors (comorbidities, body habitus, pregnancy, infection, bleeding diathesis and patient preference) and factors related to the stone like size, location and composition of stone. Choice of the treatment modality should be a part of shared decision making between the patient and the healthcare provider. However, it can broadly be classified into two categories depending on whether the indication of procedure is emergency or a planned intervention.

4.1 Emergency surgery

Urgent decompression of the collecting system with either PNL or ureteroscopy (URS) with urinary diversion should be done if UTI is ruled out and emergency intervention is indicated [21]. On the other hand, in the presence of suspected or confirmed UTI urgent drainage of the collecting system by a ureteral stent or percutaneous nephrostomy tube should be instituted along with empirical antimicrobial therapy till urinary culture specific antibiotics can be instituted. Definitive stone management should be done once the infection is treated because stone manipulation in the presence of active UTI may lead to life-threatening urosepsis and should therefore be avoided [22]. Mortality has been found to be lower in patients who are treated with urgent surgical decompression followed by delayed definitive management compared with those who are taken up for upfront definitive treatment and lack of surgical decompression [22]. There is no specific recommendation regarding the choice of modality for urinary diversion as both the modalities, i.e. indwelling double J stents and percutaneous nephrostomy tubes, have been shown to be equally effective at drainage in one randomized trial [21].

4.2 Elective surgery

Ureteral stones — If emergency management of ureteric stones is not required, the choice of treatment modality for planned removal of stone depends upon stone factors, anatomical factors and patient factors [7]. Stone factors include the total stone size and total stone burden, location of stones and the density of stones (assessed by the Hounsfield units of the stone). Anatomical factors include the urinary tract anatomy, presence of any distal obstruction or any congenital anatomical anomaly. Patient factors include the factors like pregnancy, bleeding diathesis and obesity.

For proximal and mid-ureteric stones ≤10 mm, SWL or URS is the most commonly performed procedure. For >10 mm stones in the same location, SWL is not recommended and URS is considered the first-line therapy. For **distal ureteric** stones, irrespective of the size, URS is considered the first-line treatment option. SWL is not suitable in patients with obesity, pregnancy, uncontrolled bleeding diathesis, abnormal urinary tract anatomy, and in stones with high attenuation (i.e., >900 Hounsfield units on preoperative CT scan). PNL, laparoscopic, robot-assisted, and open surgery are generally reserved for patients in whom SWL and/or URS are unsuccessful, or in patients with a complex kidney or ureteral anatomy. However, in patients who are planned to undergo concomitant open or reconstructive surgery for coexisting anatomical anomalies (e.g., ureteropelvic junction [UPJ] obstruction or ureteral stricture), the procedure can be combined with stone retrieval prior to reconstruction.

The rationale for this above mentioned approach is based on the results of multiple meta-analyses of randomized trials that have shown that URS offers higher stone-free rates (SFRs) and requires fewer retreatments and secondary procedures as compared to SWL, but with a higher rate of complications [23–27]. A 2016 systematic review that evaluated the efficacy of URS and SWL for the treatment of ureteral stones reported that the overall SFR with URS is significantly greater than that with SWL [23]. This difference in SFR with URS was also noted for subgroup of patients with stones ≤10 mm at all locations in the ureter and also for stones >10 mm in mid and distal ureter. For stones >10 mm in the proximal ureter, SFR was comparable between URS and SWL [23]. Complication rates for all the complications were comparable between both the groups except for ureteric perforation which was higher in the URS group [23]. However, another meta-analysis by Aboumarzouk et al. has reported higher procedure related complication rate with URS as compared to SWL [24]. The number of retreatments required with URS is lower than that required with SWL [28].

Kidney stones — SWL, URS, and PNL are the most commonly used surgical modalities for patients with kidney stones. In patients where emergency management of renal calculi is not indicated, modality for elective management is selected based on multiple stone factors, anatomical factors and patient factors as is the case with ureteric stones. Stone factors include the total stone size and total stone burden, location of stones and the density of stones (assessed by the Hounsfield units of the stone). Anatomical factors include the urinary tract anatomy, presence of any distal obstruction or any congenital anatomical anomaly. Patient factors include the factors like pregnancy, bleeding diathesis and obesity.

Traditionally, PNL has been associated with maximum stone clearance with the disadvantage mainly associated to the invasive nature of procedure with risk of hemorrhage. Advancements in technology has focused on minimizing the morbidity associated with PNL by reducing the diameter of sheath size and nephroscopes resulting in lesser invasion of renal parenchyma. This miniaturization has evolved from the first description of minimally invasive techniques by Lahme et al., which used an access sheath with outer diameter of 18F (inner diameter of 15F) and a 12F nephroscope, to the micro-PNL described by Bader et al. which uses a 4.85F "all seeing needle" only along with laser fragmentation and dusting of the stone. Other modifications include ultra-mini PNL first described by Desai et al. using a 11F amplatz and 6F nephroscope and super-mini PNL described by Zeng et al. which uses an active irrigation and suction mechanism attached to a miniaturized PNL system where the fragment evacuation is done by the so called "vacuum cleaner effect" [29].

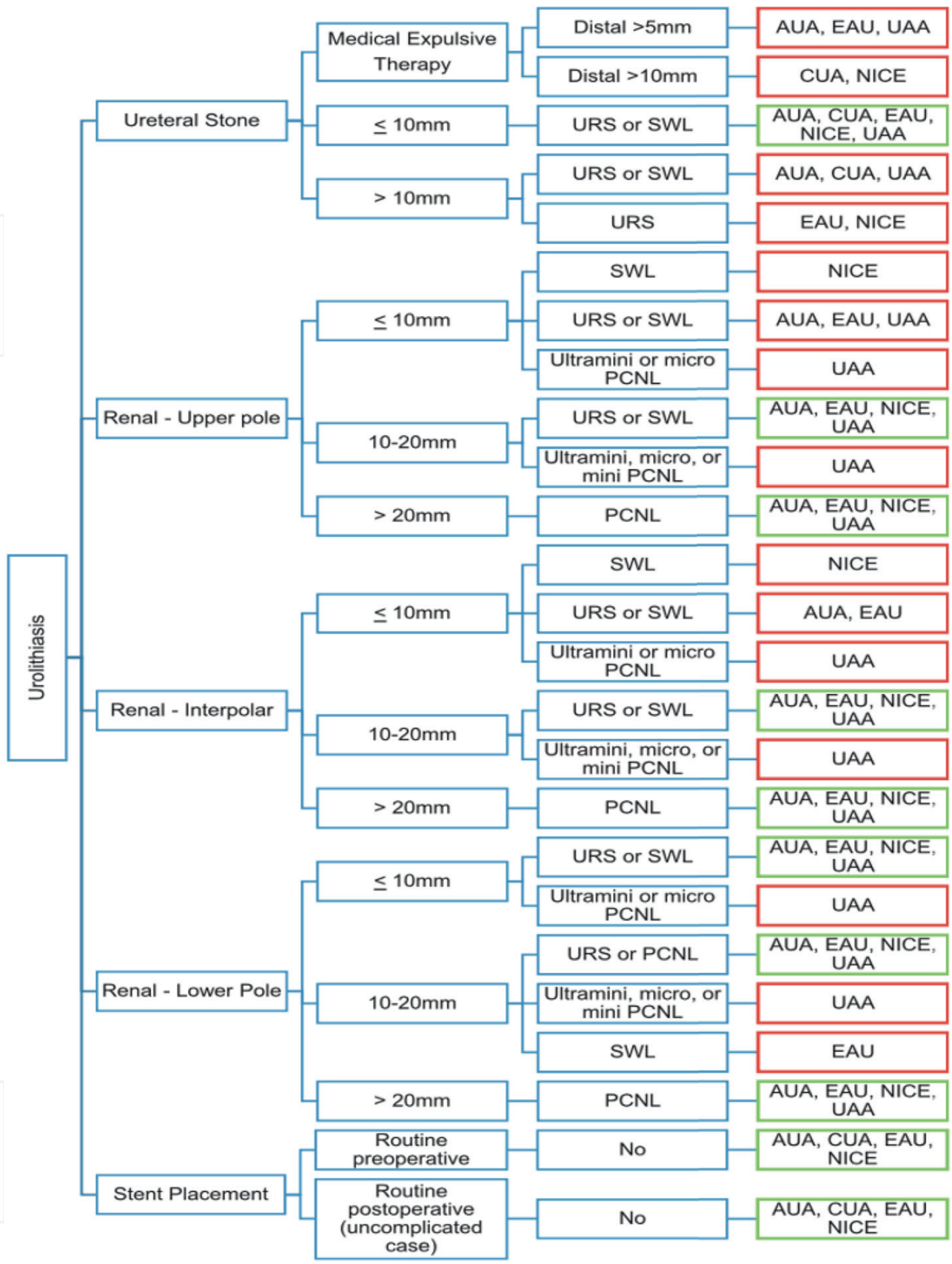
The current prevalent approach to the choice of surgical modality, largely in accordance with the 2016 American Urological Association/Endourological Society and 2018 European Association of Urology guidelines [23, 30], is as follows:

For ≤20 mm superior calyceal, middle calyceal or pelvic calculi, SWL or URS is the preferred modality while for inferior calyceal stones, URS or PNL is preferred. SWL is not preferred for inferior calyceal stones keeping in mind the poor stone clearance rates of SWL for lower pole stones. For stones that are >20 mm, PNL is considered the first-line option irrespective of the stone location. If PNL is not available or contraindicated, staged URS (i.e., performed in separate planned sessions) can be a viable alternative. The evidence guiding the rationale for this approach is based upon several randomized trials and meta-analyses [23, 31–42]. Collectively, these studies have shown that SFR for both SWL and URS gradually decreases with the increasing stone size, whereas efficacy of PNL in terms of stone clearance is minimally affected with the stone burden [31]. For stones <20 mm located in upper pole, middle calyx, or pelvis of the kidney, SWL and URS offer SFRs of roughly 50 to 80 percent [31, 43]. In a meta-analysis comparing SWL to URS for renal calculi of size 10 to 20 mm, URS provided improved SFR and lower retreatment rate without an increase in complication rates [32]. For lower pole renal calculi URS and PNL offer significantly improved stone clearance rates compared to SWL, with a moderate increase in the rate of complications. These findings are corroborated by the results of a systematic review, for lower pole renal calculi of size 10 to 20 mm, which showed highest SFR for PNL followed by URS and SWL [23]. For stones >20 mm, SFR for SWL was as low as 10 percent [23]. The reason for this reduction in SFR of SWL with increasing stone burden in the lower pole is mainly because of poor clearance of stone fragments post disintegration rand not due to poor efficiency of disintegration which is not much affected by the stone location within the kidney.

5. Evidence based recommendations and comparison of various guidelines regarding choice of surgical procedure: a summary of available guidelines

Recommendations from the American Urological Association guidelines when analyzed in comparison to the guidelines from Canadian Urological Association, European Association of Urology, National Institute for Health and Care Excellence guidelines and Urological Association of Asia revealed a high level of consensus surrounding the medical management of urinary tract calculi [44]. For surgical management, there was noted to be a high level of consensus regarding certain aspects of treatment of ureteral stones, including not pre stenting for uncomplicated ureteroscopy and employment of either ureteroscopy or shockwave lithotripsy as first line treatment. Jiang et al. [44] performed a qualitative review of the available major guidelines on the management of nephrolithiasis and noted a consensus on most of the factors but a discordance was also noted in certain stone categories. Also only UAA guidelines distinguish between the indications for traditional PCNL vs. mini-PCNL, micro-PCNL or ultramini-PCNL. The risk of complications, especially postoperative hemorrhage, after PCNL had traditionally limited its use as a first line surgical option only for bigger calculi (>20 mm) or lower pole calculi >10 mm. However, with the continued technological advancements in endourology and development of miniaturized techniques of PCNL have led to lesser renal parenchymal loss and lesser hemorrhage. The increasing use of these miniaturized PCNL techniques has led to availability of better quality of evidence regarding their safety and efficacy when compared to the other available options like SWL and RIRS. As can be seen in the below mentioned algorithm comparing the recommendations of various guidelines for the choice of modality of surgical treatment of renal calculi, the miniaturized PCNL techniques which are gradually replacing standard PCNL are not taken into consideration (**Figure 2**).

The greatest discordance among various guidelines for the choice of surgical treatment modality can be seen in the upper pole and interpolar calculi of size <10 mm and 10 - 20 mm where the first line options as proposed by various guidelines differ. For upper pole calculi of size upto 10 mm SWL is the recommended modality by NICE guidelines while AUA and EAU guidelines recommend for URS or SWL for stones upto 20 mm. UAA guidelines, on the other hand, take into account the newer miniaturized options of ultra-mini or micro PCNL and recommend it to be the modality of choice for stones upto 20 mm. For stones larger than 20 mm all guidelines unanimously recommend for PCNL irrespective of stone location. Discordance in recommendations is also seen for lower pole stones of size 10-20 mm and in this regard, the AUA appears to favor the use of PCNL but does not necessarily mandate its use over RIRS [23]. Instead, they insist that patients should be informed about the improved SFR of PCNL with increased risk of adverse events. On the other hand, the EAU guidelines very clearly recommend the use of PNL for lower pole calculi >20 mm and suggest that it should be *highly considered* for stones in the 10 - 20 mm range as well (**Table 1**) [45]. These recommendations have not specifically mentioned about the use of mini, ultra-mini or super mini PCNL (**Figure 2**).



Abbreviations used in Figure 2	
AUA [American Urological Association]	NICE [National Institute for Health and Care Excellence]
CT [Computerized Tomography]	PCNL [Percutaneous Nephrolithotomy]
CUA [Canadian Urological Association]	SWL [Shockwave Lithotripsy]
EAU [European Association of Urology]	UAA [Urological Association of Asia]

Figure 2.
Comparative description of recommendations of various guidelines for selection of modality for surgical management of nephrolithiasis [44].

Guideline	Stone size	SWL	RIRS	PNL
AUA	10 mm	Preferred	Preferred	Discouraged
	10-20 mm	Discouraged	Allowed	Preferred
	>20 mm	Discouraged	Allowed	Preferred
EAU	10 mm	Preferred	Preferred	Discouraged
	10-20 mm	Allowed	Allowed	Allowed
	>20 mm	Discouraged	Discouraged	Preferred

Table 1.
Recommendations for the surgical management of lower pole stones based on current AUA and EAU guidelines.

A meta-analysis of randomized controlled trials by Feng et al. [46] concluded that mPCNL had a higher SFR than standard PCNL and there was no significant difference between the two groups regarding ≥2 cm renal calculi. Besides, mPCNL has been noted to be associated with significantly less bleeding and a lower transfusion rate. Further, a multi-institutional comparative study by Liu et al. [47] showed SMP to be safe and highly effective for renal calculi upto 4 cm with lesser postoperative complications as compared to standard PCNL. However, for stones larger than 4 cm the stone clearance by SMP was lower than standard PCNL. The better efficacy of mini PNL in terms of stone free rates and improved stone clearance has been corroborated by a recent network meta-analysis of randomized trials by Tsai et al. [48] Another network meta-analysis by Chungh et al. [49] comparing PCNL, RIRS and SWL showed PCNL to have the maximum stone free rates followed by RIRS. SWL was shown to have the least stone free rates. Subgroup analysis for lower pole stones showed similar results. Complications (in SWL, PCNL, and RIRS were 12.5%, 20.2%, and 15.0%, respectively) were greater in the patients undergoing PCNL but the major complications (15.4% in SWL, 13.8% in PCNL, and 18.3% in RIRS) were comparable between the three groups.

6. PCNL as a day-care procedure?

PNL is traditionally conducted as a procedure that necessitates hospitalization rather than outpatient care. However, there is significant pressure to use health care resources as effectively as possible in order to continuously improve medical quality and patient satisfaction with as little medical expenditure as possible. This attempt for optimal utilization of hospital resources, particularly in the publicly funded health care system, is one of the primary indications to attempt to cut down the costs associated with the hospitalization required for PCNL. Complications after PCNL and the length of hospital stay have already been steadily declining mainly attributable to the less invasive approaches and advancements in postoperative pain management [50]. Discharging the day of procedure or no later than 24 hours following surgery is referred to as day-care PCNL [51–53] and is regarded as a potential viable option for some patients, supported by emerging evidence [51–55]. Grade I and II complications following PCNL are the most common and may usually be managed conservatively or in a brief course [56]. The early studies were conducted on tiny cohorts, and in 2005, Singh et al. published their initial findings on a small series of the day-care PCNL that included 10 patients. The reported readmission rates for day-care PCNL have ranged from 0 to 10% [51]. Jones et al. conducted a systematic review on the safety and efficacy of day-care PNL and concluded that it is a safe procedure when preoperative preparation and patient selection are done judiciously [51]. However, there still is a lot of concern about patient safety, which keeps this approach from being incorporated into routine practice. Furthermore, there aren't many research that compare day-care and inpatient results and formal cost-effectiveness assessments. There is still lack of good quality evidence which comprehensively evaluates the safety and efficacy of day-care PCNL along with the advantage of cost effectiveness and this gap needs to be bridged before formal incorporation of day-care PCNL for management of renal calculi can be done for global acceptance.

7. Conclusion

We therefore, based on the newer evidences on the miniaturized modifications of PCNL and their comparative analysis with RIRS and SWL, recommend the following approach for the appropriate selection of surgical modality for renal and ureteral calculi.

For renal calculi upto 20 mm, the choice of surgical modality should be based on the stone location. For lower pole stones of size upto 10 mm, super mini or ultra-mini modifications of PCNL can be considered the first line modality because of proven safety and improved efficacy in terms of stone clearance. However, RIRS and SWL can also be considered in case of unavailability of SMP or UMP. For lower pole stones of size 10-20 mm, SMP or UMP should be preferred if available due to the already mentioned factors. SWL for stones 10–20 mm in lower pole should be avoided given the increased propensity of requirement of repeat procedure due to poor stone clearance in one session.

For renal calculi of size greater than 20 mm, decision should be made depending on further stratifying the stone size of less than 4 cm or more than 4 cm. Stones up to 4 cm can be efficiently cleared by miniaturized PCNL and therefore it should be the

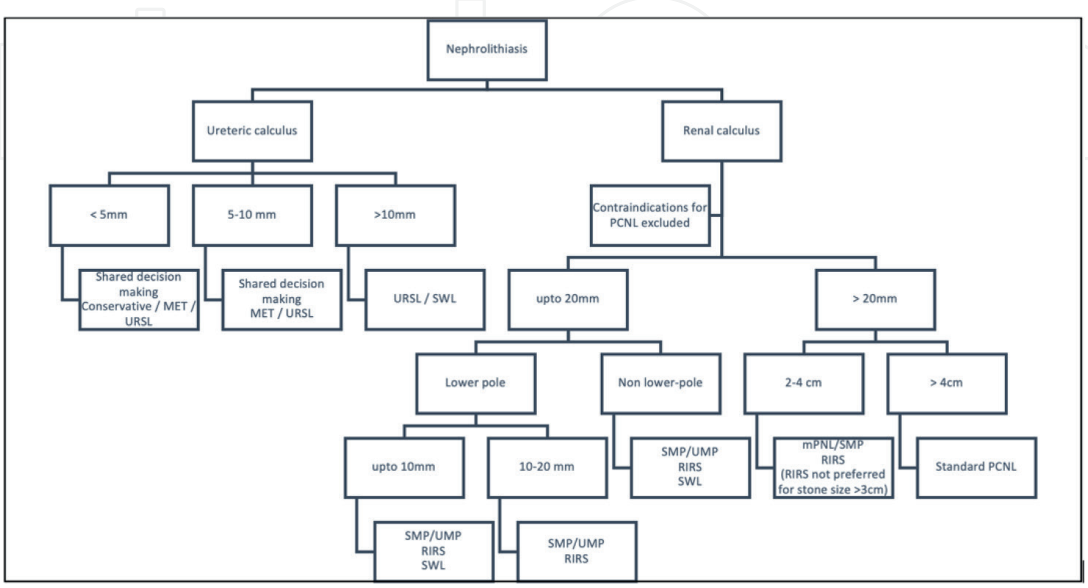


Figure 3.
Approach for surgical management of nephrolithiasis.

preferred modality due to improved safety profile as compared to standard PCNL. However for stones larger than 4 cm, the clearance has been sub-optimal using miniaturized techniques and standard PCNL should be the preferred approach (**Figure 3**).

As is easily understood by the discussion, the technical advancements and miniaturization of PCNL is leading to its increased use and applicability to the various domains which were previously being primarily managed by other less invasive modalities like RIRS and SWL. Given its increasing safety profile and comparable efficacy to standard PCNL, it can now be used for almost all stone categories except for very large stones without the risk of significant complications and therefore is becoming a promising modality to replace the standard PCNL as the gold standard modality for treatment of nephrolithiasis.

Conflict of interest

None.

Notes/thanks/other declarations

None.

Acronyms and abbreviations

CT	Computerized Tomography
IVP	Intravenous Pyelography
MRI	Magnetic Resonance Imaging
BMI	Body Mass Index
CI	Confidence Interval
SFR	Stone Free Rate
PNL	Percutaneous Nephrolithotomy
URS	Ureterorenoscopy
UTI	Urinary Tract Infection
SWL	Shockwave Lithotripsy
UPJ	Ureteropelvic Junction
AUA	American Urological Association
CUA	Canadian Urological Association
EAU	European Association of Urology
NICE	National Institute for Health and Care Excellence

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References

[1] Curhan GC. Epidemiology of stone disease. The Urologic Clinics of North America. 2007;**34**:287-293

[2] Rukin NJ, Siddiqui ZA, Chedgy ECP, Somani BK. Trends in up- per tract stone disease in England: Evidence from the hospital epi- sodes statistics database. Urologia Internationalis. 2017;**98**:391-396

[3] Schwartz BF, Stoller ML. The vesical calculus. The Urologic Clinics of North America. 2000;**27**:333-346

[4] Geraghty RM, Jones P, Hermann TRW, Aboumarkzouk O, Somani BK. Ureteroscopy is more cost effective than shock wave litho- tripsy for stone treatment: Systematic review and meta-analysis. World Journal of Urology. 2018;**36**:1783-1793

[5] Geraghty RM, Cook P, Walker V, Somani BK. Evaluation of the economic burden of kidney stone disease in the UK: A retrospec- tive cohort study with a mean follow-up of 19 years. BJU International. 2020;**125**:586-594

[6] Pak CY, Britton F, Peterson R, et al. Ambulatory evaluation of nephrolithiasis. Classification, clinical presentation and diagnostic criteria. The American Journal of Medicine. 1980;**69**(1):19-30

[7] Wang CJ, Hsu CS, Chen HW, Chang CH, Tsai PC. Percutaneous nephrostomy versus ureteroscopic management of sepsis associated with ureteral stone impaction: A randomized controlled trial. Urolithiasis. Oct 2016;**44**(5):415-419. DOI: 10.1007/s00240-015-0852-7. Epub 2015 Dec 11. PMID: 26662171

[8] Ulusan S, Koc Z, Tokmak N. Accuracy of sonography for detecting renal stone: Comparison with CT. Journal of Clinical Ultrasound. 2007;**35**:256

[9] Niemann T, Kollmann T, Bongartz G. Diagnostic performance of low-dose CT for the detection of urolithiasis: A meta-analysis. AJR. American Journal of Roentgenology. 2008;**191**:396

[10] Jung SI, Kim YJ, Park HS, et al. Sensitivity of digital abdominal radiography for the detection of ureter stones by stone size and location. Journal of Computer Assisted Tomography. 2010;**34**:879

[11] Fulgham PF, Assimos DG, Pearle MS, Preminger GM. Clinical effectiveness protocols for imaging in the management of ureteral calculous disease: AUA technology assessment. The Journal of Urology. 2013;**189**:1203

[12] Pfister SA, Deckart A, Laschke S, et al. Unenhanced helical computed tomography vs intravenous urography in patients with acute flank pain: Accuracy and economic impact in a randomized prospective trial. European Radiology. 2003;**13**:2513

[13] Smith RC, Verga M, McCarthy S, Rosenfield AT. Diagnosis of acute flank pain: Value of unenhanced helical CT. AJR. American Journal of Roentgenology. 1996;**166**:97

[14] Ulahannan D, Blakeley CJ, Jeyadevan N, Hashemi K. Benefits of CT urography in patients presenting to the emergency department with suspected ureteric colic. Emergency Medicine Journal. 2008;**25**:569

[15] Kim BS, Hwang IK, Choi YW, et al. Low-dose and standard-dose unenhanced helical computed

tomography for the assessment of acute renal colic: Prospective comparative study. Acta Radiologica. 2005;**46**:756

[16] Liu W, Esler SJ, Kenny BJ, et al. Low-dose nonenhanced helical CT of renal colic: Assessment of ureteric stone detection and measurement of effective dose equivalent. Radiology. 2000;**215**:51

[17] Tack D, Sourtzis S, Delpierre I, et al. Low-dose unenhanced multidetector CT of patients with suspected renal colic. AJR. American Journal of Roentgenology. 2003;**180**:305

[18] Ciaschini MW, Remer EM, Baker ME, et al. Urinary calculi: Radiation dose reduction of 50% and 75% at CT--effect on sensitivity. Radiology. 2009;**251**:105

[19] Poletti PA, Platon A, Rutschmann OT, et al. Low-dose versus standard-dose CT protocol in patients with clinically suspected renal colic. AJR. American Journal of Roentgenology. 2007;**188**:927

[20] Sohn W, Clayman RV, Lee JY, et al. Low-dose and standard computed tomography scans yield equivalent stone measurements. Urology. 2013;**81**:231

[21] Pearle MS, Pierce HL, Miller GL, et al. Optimal method of urgent decompression of the collecting system for obstruction and infection due to ureteral calculi. The Journal of Urology. 1998;**160**:1260

[22] Borofsky MS, Walter D, Shah O, et al. Surgical decompression is associated with decreased mortality in patients with sepsis and ureteral calculi. The Journal of Urology. 2013;**189**:946

[23] Assimos D, Krambeck A, Miller NL, et al. Surgical Management of Stones: American urological association/ Endourological society guideline, PART II. The Journal of Urology. 2016;**196**:1161

[24] Aboumarzouk OM, Kata SG, Keeley FX, McClinton S, Nabi G. Extracorporeal shock wave lithotripsy (ESWL) versus ureteroscopic management for ureteric calculi. Cochrane Database of Systematic Reviews. May 2012;**16**(5):CD006029. DOI: 10.1002/14651858.CD006029.pub4. PMID: 22592707

[25] Matlaga BR, Jansen JP, Meckley LM, et al. Treatment of ureteral and renal stones: A systematic review and meta-analysis of randomized, controlled trials. The Journal of Urology. 2012;**188**:130

[26] Cui X, Ji F, Yan H, et al. Comparison between extracorporeal shock wave lithotripsy and ureteroscopic lithotripsy for treating large proximal ureteral stones: A meta-analysis. Urology. 2015;**85**:748

[27] Drake T, Grivas N, Dabestani S, et al. What are the benefits and harms of Ureteroscopy compared with shock-wave lithotripsy in the treatment of upper ureteral stones? A systematic review. European Urology. 2017;**72**:772

[28] Preminger GM, Tiselius HG, Assimos DG, et al. 2007 guideline for the management of ureteral calculi. The Journal of Urology. 2007;**178**:2418

[29] Lahme S. Miniaturisation of PCNL. Urolithiasis. 2018;**46**(1):99-106. DOI: 10.1007/s00240-017-1029-3

[30] http://uroweb.org/guideline/urolithiasis/

[31] Srisubat A, Potisat S, Lojanapiwat B, Setthawong V, Laopaiboon M. Extracorporeal shock wave lithotripsy (ESWL) versus percutaneous nephrolithotomy (PCNL) or retrograde

intrarenal surgery (RIRS) for kidney stones. Cochrane Database of Systematic Reviews. Nov 2014;**24**(11):CD007044. DOI: 10.1002/14651858.CD007044.pub3. PMID: 25418417

[32] Pearle MS, Lingeman JE, Leveillee R, et al. Prospective, randomized trial comparing shock wave lithotripsy and ureteroscopy for lower pole caliceal calculi 1 cm or less. The Journal of Urology. 2005;**173**:2005

[33] Preminger GM. Management of lower pole renal calculi: Shock wave lithotripsy versus percutaneous nephrolithotomy versus flexible ureteroscopy. Urological Research. 2006;**34**:108

[34] Zheng C, Yang H, Luo J, et al. Extracorporeal shock wave lithotripsy versus retrograde intrarenal surgery for treatment for renal stones 1-2 cm: A meta-analysis. Urolithiasis. 2015;**43**:549

[35] Karakoyunlu N, Goktug G, Şener NC, et al. A comparison of standard PNL and staged retrograde FURS in pelvis stones over 2 cm in diameter: A prospective randomized study. Urolithiasis. 2015;**43**:283

[36] Zheng C, Xiong B, Wang H, et al. Retrograde intrarenal surgery versus percutaneous nephrolithotomy for treatment of renal stones >2 cm: A meta-analysis. Urologia Internationalis. 2014;**93**:417

[37] Donaldson JF, Lardas M, Scrimgeour D, et al. Systematic review and meta-analysis of the clinical effectiveness of shock wave lithotripsy, retrograde intrarenal surgery, and percutaneous nephrolithotomy for lower-pole renal stones. European Urology. 2015;**67**:612

[38] Kumar A, Kumar N, Vasudeva P, et al. A prospective, randomized comparison of shock wave lithotripsy, retrograde intrarenal surgery and miniperc for treatment of 1 to 2 cm radiolucent lower calyceal renal calculi: A single center experience. The Journal of Urology. 2015;**193**:160

[39] Sener NC, Imamoglu MA, Bas O, et al. Prospective randomized trial comparing shock wave lithotripsy and flexible ureterorenoscopy for lower pole stones smaller than 1 cm. Urolithiasis. 2014;**42**:127

[40] Kumar A, Vasudeva P, Nanda B, et al. A prospective randomized comparison between shock wave lithotripsy and flexible Ureterorenoscopy for lower Caliceal stones ≤2 cm: A single-Center experience. Journal of Endourology. 2015;**29**:575

[41] Mi Y, Ren K, Pan H, et al. Flexible ureterorenoscopy (F-URS) with holmium laser versus extracorporeal shock wave lithotripsy (ESWL) for treatment of renal stone <2 cm: A meta-analysis. Urolithiasis. 2016;**44**:353

[42] Zhang W, Zhou T, Wu T, et al. Retrograde intrarenal surgery versus percutaneous Nephrolithotomy versus extracorporeal shockwave lithotripsy for treatment of lower pole renal stones: A Meta-analysis and systematic review. Journal of Endourology. 2015;**29**:745

[43] Khan SR, Pearle MS, Robertson WG, et al. Kidney stones. Nature Reviews. Disease Primers. 2016;**2**:16008

[44] Jiang P, Xie L, Arada R, Patel RM, Landman J, Clayman RV. Qualitative review of clinical guidelines for medical and surgical Management of Urolithiasis: Consensus and controversy 2020. The Journal of Urology. 2021;**205**(4):999-1008. DOI: 10.1097/JU.0000000000001478

[45] Türk C, Petřík A, Sarica K, Seitz C, Skolarikos A, Straub M, et al. EAU

guidelines on interventional treatment for urolithiasis. European Urology. 2016;**69**:475-482

[46] Feng D, Hu X, Tang Y, Han P, Wei X. The efficacy and safety of miniaturized percutaneous nephrolithotomy versus standard percutaneous nephrolithotomy: A systematic review and meta-analysis of randomized controlled trials. Investigative and Clinical Urology. 2020;**61**(2):115-126. DOI: 10.4111/icu.2020.61.2.115

[47] Liu Y, Cai C, Aquino A, Al-Mousawi S, Zhang X, Choong SKS, et al. Management of large renal stones with super-mini percutaneous nephrolithotomy: An international multicentre comparative study. BJU International. 2020;**126**(1):168-176. DOI: 10.1111/bju.15066

[48] Tsai SH, Chung HJ, Tseng PT, Wu YC, Tu YK, Hsu CW, et al. Comparison of the efficacy and safety of shockwave lithotripsy, retrograde intrarenal surgery, percutaneous nephrolithotomy and minimally invasive percutaneous nephrolithotomy for lower-pole renal stones: A systematic review and network meta-analysis. Medicine. 2020;**99**(10):e19403

[49] Chung DY, Kang DH, Cho KS, Jeong WS, Jung HD, Kwon JK, et al. Comparison of stone-free rates following shock wave lithotripsy, percutaneous nephrolithotomy, and retrograde intrarenal surgery for treatment of renal stones: A systematic review and network meta-analysis. PLoS One. 2019;**14**(2):e0211316. DOI: 10.1371/journal.pone.0211316

[50] Güler A, Erbin A, Ucpinar B, et al. Comparison of minia- turized percutaneous nephrolithotomy and standard percutaneous nephrolithotomy for the treatment of large kidney stones: A ran- domized prospective study. Urolithiasis. 2019;**47**:289-295. DOI: 10.1007/s00240-018-1061-y

[51] Jones P, Bennett G, Dosis A, Pietropaolo A, Geraghty R, Aboumarzouk O, et al. Safety and efficacy of day-case percutaneous nephrolithotomy: a systematic review from european society of uro-technology. European Urology Focus. Nov 2019;**5**(6):1127-1134. DOI: 10.1016/j.euf.2018.04.002. Epub 2018 Apr 12. PMID: 29657068

[52] Schoenfeld D, Zhou T, Stern JM. Outcomes for patients undergoing ambulatory percutaneous nephrolithotomy. Journal of Endourology. 2019;**33**:189-193. DOI: 10.1089/end.2018.0579

[53] Bechis SK, Han DS, Abbott JE, et al. Outpatient percuta- neous nephrolithotomy: The UC san diego health experience. Journal of Endourology. 2018;**32**:394-401. DOI: 10.1089/end.2018.0056

[54] Beiko D, Lee L. Outpatient tubeless percutaneous nephro- lithotomy: The initial case series. Canadian Urological Association Journal. 2010;**4**:E86-E90

[55] Singh I, Kumar A, Kumar P. "Ambulatory PCNL" (tube- less PCNL under regional anesthesia)—A preliminary report of 10 cases. International Urology and Nephrology. 2005;**37**:35-37. DOI: 10.1007/s1125 5-004-6706-9

[56] de la Rosette JJMCH, Opondo D, Daels FPJ, et al. Categorisation of complications and validation of the Clavien score for percutaneous nephrolithotomy. European Urology. 2012;**62**:246-255. DOI: 10.1016/j.eururo.2012.03.055