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Review

Prevention of complications in endourological management of stones: What are the basic measures needed before, during, and after interventions?

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Abstract *Objective:* This narrative review aims to describe measures to minimise the risk of complications during percutaneous nephrolithotomy (PCNL), ureteroscopy, and retrograde intrarenal surgery.

Methods: A literature search was conducted from the PubMed/PMC database for papers published within the last 10 years (January 2012 to December 2022). Search terms included "ureteroscopy", "retrograde intrarenal surgery", "PCNL", "percutaneous nephrolithotomy", "complications", "sepsis", "infection", "bleed", "haemorrhage", and "hemorrhage". Key papers were identified and included meta-analyses, systematic reviews, guidelines, and primary research. The references of these papers were searched to identify any further relevant papers not included above.

Results: The evidence is assimilated with the opinions of the authors to provide recommendations. Best practice pathways for patient care in the pre-operative, intra-operative, and post-operative periods are described, including the identification and management of residual stones. Key complications (sepsis and stent issues) that are relevant for any endourological procedure are then be discussed. Operation-specific considerations are then explored. Key measures for PCNL include optimising access to minimise the chance of bleeding or visceral injury. The role of endoscopic combined intrarenal surgery in this regard is discussed. Key measures for ureteroscopy and retrograde intrarenal surgery include planning and technique to minimise the risk of ureteric injury. The role of anaesthetic assessment is discussed. The importance of specific comorbidities on each step of the pathway is highlighted as examples.

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Conclusion: This review demonstrates that the principles of meticulous planning, interdisciplinary teamworking, and good operative technique can minimise the risk of complications in endourology.

1. Introduction

The incidence of urolithiasis is rising [1,2], leading to more endourological interventions [3]. The incidence and impact of complications for these procedures may be underestimated [4]. This is particularly the case when the definition of complications is taken to include complications that may be considered "minor" but can have significant impact on quality of life, such as stent symptoms [5].

This article describes measures to minimise the risk of complications during percutaneous nephrolithotomy (PCNL), ureteroscopy (URS), and retrograde intrarenal surgery (RIRS). The best practice pathways for patient care in the pre-operative, intra-operative, and post-operative periods are mapped out. Then, two key complications (sepsis and stent issues) that are relevant for any endourological procedure are discussed. Operation-specific considerations then are explored. Key measures for PCNL include optimising access to minimise the chance of bleeding or visceral injury. The role of endoscopic combined intrarenal surgery (ECIRS) in this regard is discussed. Key measures for URS and RIRS include planning and technique to minimise the risk of ureteric injury. Finally, the role of anaesthetic assessment is discussed.

2. Methods

This paper constitutes a narrative review of the literature. A literature search was conducted from the PubMed/PMC database for papers published within the last 10 years (January 2012 to December 2022). Search terms included "ureteroscopy", "retrograde intrarenal surgery", "PCNL", "percutaneous nephrolithotomy", "complications", "sepsis", "infection", "bleed", "haemorrhage", and "hemorrhage". Articles included were written in English. Papers were screened for relevance to the topic. Key papers were identified and included meta-analyses, systematic reviews, guidelines, and primary research. The references of these papers were searched to identify any further relevant papers not included above. As a narrative review, the evidence is assimilated with the opinions of the authors to provide recommendations for best practice.

3. Best practice care pathways

There are three key principles which underline the care pathways required to prevent complications for endourology patients [6,7].

a. There are general measures to prevent complications, but within this framework there should be bespoke measures related to the individual patient, their comorbidities, and stone burden.
b. Preparation to understand the individual stone and patient factors is key.
c. Inter-disciplinary teamworking is essential at every step.

3.1. Pre-operative measures

The correct procedure must be selected for the stone size, stone location, stone type (where known), and patient characteristics. In addition, surgeon's skills, armamentarium availability, and hospital facilities (such as prompt access to an interventional radiology service) need to be taken into consideration. Where there are equivocal options, the patient must be fully informed and involved in selecting a management plan with a risk profile that is appropriate for their specific circumstances and wishes. The first consideration must always be whether the patient requires surgical or conservative treatment and what the risks and complications may be—including potential risks of no intervention. There are a range of approaches to ensuring informed consent. Written and signed consent is strongly recommended to facilitate and document shared decision-making, even if it may not be the standard in many countries [8].

Further information or imaging may aid the decision-making process. For example, 4%—14% of patients who underwent URS for ureteric stone had a "negative" URS with no stone found [9,10]. Pre-operative imaging (either computed tomography, plain X-ray of kidney-ureter-bladder, or ultrasound) reduced the likelihood of negative URS by over 50% [11].

Reduced function of the stone-bearing kidney may be suspected from the history (such as an asymptomatic obstructing stone that may be longstanding), imaging appearance (such as thin parenchyma), and/or blood test (such as reduced estimated glomerular filtration rate). Where reduced function is suspected, isotope function tests should be considered. If the kidney is non-functional, then the correct procedure may be a nephrectomy rather than an endourological procedure. Furthermore, if there is no pre-operative demonstration of reduced split function, then this could incorrectly be attributed to the operation itself if the reduced function is identified after the operation.

Detailed preparation to understand the individual factors should inform the decision regarding the correct procedure. Selection of the correct procedure is underpinned by a detailed understanding of each individual case. The size and location of the stone may suggest certain operative strategies, but these must be matched up to the patients and their comorbidities. For example, a large stone over 20 mm in a lower pole is more likely to be cleared in one operation with a PCNL, and is, therefore, recommended as a first-line treatment [12—14]. However, for patients who are at high risk from a PCNL specifically (for example, with bleeding disorders), then the risk of a more invasive operation needs to be balanced against the risk of multiple anaesthetics [12—14].

Parallel to a decision about the correct operation, there should be decisions about the "right time, right place, right team". Complex patients or complex operations are better managed in highly specialised centres in order to minimise the risk of complications [15]. The volume-outcome relationship describes that high-volume centres have lower complications and mortality [16—18]. However, not all patients can or should be managed in tertiary or quaternary centres. Patients for less complex procedures are likely to be better served in a timely manner in their local surgical units [19]. The solutions to this paradigm will vary according to the healthcare system. In the UK, "urology area networks" are being developed to ensure that patients are managed at the right time, in the right place, and by the right team [19].

Effective interdisciplinary teamwork is essential for detailed planning to minimise the risk of complications. One effective strategy for coordinating input from urology, radiology, and microbiology is a planning meeting. Considerations for operative planning include correct operation, operative strategy, criteria for success, and post-operative drainage options. This will be discussed in more detail below. This also provides an opportunity to assess the latest imaging and microbiology, and assess whether more up to date results are required. Formal pre-operative assessment occurs under the remit of the anaesthetic team, and is discussed in more detail below.

3.2. Intra-operative measures

Intra-operative measures to prevent complications rely on communication, protocol, monitoring, and good operative technique.

There is increasing understanding of the role of human factors in preventing complications [20]. Lessons from the aviation industry [21], enshrined in the WHO surgical checklist, are well documented. A key principle is to facilitate good communication. Communication issues contribute to 52% of surgical errors [22]. Bad communication contributes to "error causation" and complications, whilst good communication contributes to "error capture" and prevention of complications [23]. A culture of open communication must be encouraged within the operating room—in other words, a "flattened hierarchy". Any staff member who identifies an actual or potential risk or complication should feel able to speak openly in order to manage the risk in real-time [24]. The WHO checklist mandates that all staff have introduced themselves by name. However, data suggest that this is often performed in a cursory manner and seen as a bureaucratic hurdle [25].

The WHO checklist forces communication between the surgical, scrub, and nursing team. The aim is to identify, and take appropriate measures to prevent risks and complications related to anaesthesia, operation, and equipment available [26]. This will include an opportunity to confirm whether medications can and should be given at induction to reduce the risk of complications. Specifically, this involves antibiotics to minimise the risk of sepsis and tranexamic acid to minimise the risk of bleeding after a PCNL [27].

Intra-operative monitoring takes various forms, and its value depends on good communication as outlined above. Physiological disturbances picked up by the anaesthetist may be the portent of current or impending complication, such as sepsis or bleeding. Shared decisions can be made about whether to stop or modify the operation. Inversely, the surgeon may ask for anaesthetic manoeuvres to aid the operation, such as modifying tidal volume in a mobile kidney during RIRS.

The scrub team will be in charge of monitoring operating time, by logging the start time. This may also involve the use of a stop-clock. Anaesthetic time is an independent risk factor for anaesthetic complications [28]. Operating time is also a key risk factor for complications including sepsis and bleeding, as discussed below [13,14]. Objective measurement of intra-operative time supplements the surgeon's and anaesthetist's subjective sense of how prolonged or complicated an operation, or specific steps of the operation are. This allows for real-time modification of strategy if required.

High intra-renal pressure (IRP) or temperature (IRT) can lead to complications including tissue damage and sepsis. Measures must be taken to optimise these factors. In the future these may be monitored and optimised in real-time. Optimal pressure and temperature rely on low pressure and temperature influx, constant flow, and adequate efflux [29,30].

Physiological IRP is from 5 cmH_2O to 10 cmH_2O (1 $cmH_2O = 0.098$ kPa) [31]. The pressure above 40 cmH_2O increases risk of complications including sepsis, bleeding, and perirenal collections [32]. Pressure is best standardised with a fixed-pressure irrigation system [33]. This reduces rates of sepsis and pain compared to a hand pumped system which can lead to extremely high IRPs [29]. All irrigation systems can lead to extremely high IRPs [34] and must be used with care.

The mechanism of ensuring adequate efflux depends on the specific operation. For URS and RIRS, use of a ureteric access sheath (UAS) reduces pressure. Larger UAS reduces pressure further [29], in keeping with Poiseuille's Law. This is further facilitated by use of a small calibre scope [31]. This translates to lower sepsis rates with larger UAS [35]. However, artificial kidney studies suggest that there is a negligible further pressure reduction from a 10/12 Fr to a 12/14 Fr UAS [31].

UAS facilitates irrigation levels to be increased by up to 80% whilst maintaining the same pressure [36]. This may partly explain the reduced operating time with UAS [37]. When UAS is not used, and a manual pressure pump is used to maintain vision, extremely high pressures up to 300 mmHg (1 mmHg = 0.133 kPa) can be measured [38].

The benefits of UAS needs to be balanced against the risk of ureteric injury, particularly with larger 12/14 Fr sheaths. Specific risk factors include increasing age and male gender [39]. Therefore, decision to use UAS represents another example of a tailored approach suitable to the specific patient and their stone burden. The American Urological Association (AUA) guidelines recommend the UAS use during flexible URS for large stone treatment, to lower operative time and complications rates [40]. The European Association of Urology Section of Urolithiasis (EULIS) and International Alliance of Urolithiasis (IAU) consensus recommend using UAS routinely during RIRS, although not necessarily in the treatment of small stones [41].

Similarly, during PCNL, increasing pressure increases the risk of complications including sepsis [42].

Nevertheless, standard PCNL rarely involves raised IRP above 40 cmH_2O due to the large calibre sheaths used [43]. Mini-PCNL with an open control sheath can keep intrarenal pressure to 20 cmH_2O, even with inflow up to 125 cmH_2O [44]. Suction devices were later developed that can keep the IRP down to 5.58 cmH_2O [45] or 2.72 cmH_2O [46]. Suction has been demonstrated to reduce post-operative complications, sepsis, blood loss, and operative time, whilst improving the stone-free rate (SFR) [47,48].

Energy for intracorporeal lithotripsy can be converted to heat energy which can raise the IRT. Temperatures over 40 °C can promote tissue damage and cellular death [49]. The ureter threshold for tissue damage is 43 °C for 120 min, 50 °C for 56 s, or 56 °C for 0.9 s [50]. As for pressure, optimising temperature depends on not only influx parameters, flow, and adequate efflux, but also optimal technique for laser usage. Room temperature or cooled irrigation fluid should be used [51]. The scrub team should be alert to ensure that there is continuous irrigation fluid [52] and any issue is managed promptly. Even a momentary pause to irrigation can cause exponential rise in temperature during laser lithotripsy [53]. Higher power laser lithotripsy should be matched with higher irrigation flow [53,54]. In particular, power above 30 W during RIRS is at risk of critical temperature spikes (with flow up to 100 mL/min) [51]. The laser should be activated intermittently as pauses allow the fluid to cool [53]. Holmium:yttrium-aluminium-garnet (Ho:YAG) laser and thulium fibre laser provide similar temperature changes at equivalent power settings [55].

Adequate flow and efflux are facilitated by use of a UAS. The UAS allows for safe IRT even at higher power laser settings. In a porcine model, IRT rose to a hazardous level using 20 W Ho:YAG for only 20 s, without a UAS. This temperature rise was not hazardous when a UAS was used. For high power settings up to 60 W, high flow irrigation ensured safe IRT [30]. As discussed above, the UAS facilitates the safe use of higher irrigation pressure, by ensuring that high pressure does not translate to very high IRP.

Care should be taken to position and prepare the patient appropriately, in order to prevent related peri-operative complications. Nerve injury is a rare but potentially devastating peri-operative complication, caused by traction or compression associated with incorrect positioning [56]. Teams placing prone patients placed in the "swimmer's position" must be meticulous to avoid traction on the brachial plexus. The arm should only be manoeuvred in physiological movements, and with the arm placed at less than 90° from the torso [56]. Lithotomy position should involve hips at 80—100 degrees of flexion and legs at 30—45 degrees abduction to avoid sciatic or obturator nerve traction [57] Pressures points should be identified and padded.

3.3. Post-operative measures

Measures to prevent complications after intervention include appropriate monitoring, physiological support, and post-operative planning.

The pre-operative planning and/or intra-operative course will determine which patients will benefit from high dependency unit or intensive care input. These are patients who will benefit from close monitoring and/or organ support. Patients identified pre-operatively will include those with significant cardiac or respiratory comorbidities who may require organ support. Suitable patients identified intra-operatively will include those who suffer from an intra-operative anaesthetic or surgical complication.

A clear post-operative plan is needed to mitigate risk in the short- and long-term. Patients who would benefit from intravenous fluids and antibiotics post-operatively should be identified. An assessment of venous thrombo-embolism risk should be made and mitigated with stockings and/or low molecular weight heparin where appropriate. A clear follow-up plan is essential, particularly where a stent is left *in situ*.

3.4. Residual stones

For endoscopic procedures, the surgeon and patient should discuss the definition of "success" for the operation. Specifically, the presence of significant residual stone fragments should be discussed as a possible complication.

There is a lack of consensus regarding imaging and what constitutes a significant residual stone. The threshold varies from zero to 4 mm [58].

With this in mind, the SFR after a PCNL for a staghorn stone was 79%—90.5% [58]. The SFR for staged RIRS for stones of >2 cm (mean 2.7 cm) was 91%, with a mean of 1.45 procedures per patient [59].

Due to limited high-quality data, European Association of Urology (EAU) recommends that the threshold for further intervention, and modality and timing of imaging, are up to the discretion of the surgeon. Fragments over 2 mm are more likely to grow than small ones, although this is not associated with increased intervention rate at 1 year [60]. Stones over 5 mm are more likely to require intervention [61]. CT provides higher sensitivity for residual fragments than ultrasound or X-ray, although this involves a high false positive rate as over half of patients with residual fragments on CT may not experience a stone-related event [62]. The EAU guidelines recommend deferred imaging (for example at 4 weeks), although do not recommend a specific timeframe due to a lack of data.

There is limited definitive evidence for intra-operative measures to optimise the SFR. The application of suction during PCNL [48] or RIRS [63] may improve the SFR by directly clearing dust and fragments as well as optimising vision. The EAU and IAU guidelines recommend that further evidence is required [12,14].

For PCNL, tranexamic acid at induction may also improve the SFR [27]. The position (prone *vs*. supine) [64], tract size (mini *vs*. standard) [12], and imaging guidance method (sonography *vs*. fluoroscopy) [65] have not been demonstrated to influence the SFR.

For RIRS, UAS does not appear to improve the SFR [37]. However, if UAS is used, smaller calibre flexible scopes may improve the SFR [66]. Peri-operative factors to dilate or relax the ureter also improve SFRs. A course of tamsulosin given pre-operatively can increase the success rate for intra-operative ureteral navigation as well as the SFR [67]. Post-operative tamsulosin can decrease colic episodes as well as improving the SFR [68]. Pre-stenting improves the SFR for RIRS [69], although EAU guidelines urge surgeons to weigh up the benefit of a further procedure with attendant additional risk, including stent symptoms in the interim [12]. Factors that have not had a definitive effect on the RIRS SFR demonstrated include single versus re-useable scopes [70], "Moses" effect technology [71], laser energy source (thulium fibre laser or Ho:YAG laser) [72], and dusting versus fragmenting strategy [73].

If a significant residual stone is identified, the surgeon and patient should consider all relevant options, including observation, lifestyle interventions, and medical and surgical treatment. Biochemical analysis of the stone will facilitate a bespoke management strategy [12,74].

4. Sepsis

Post-operative fever occurs in 4.3%—12.8% of the patients undergoing PCNL [13] and 4.9% of the patients undergoing RIRS [75]. Sepsis is the most common cause of death after URS or RIRS [76]. Using the framework described above, we will explore the measures to minimise the risk of sepsis.

Pre-operative measures aim to minimise the bacterial load in the urine, and maximise the patient's physiological reserve and immunity. A urine sample must be sent for culture; results should be corroborated with patient symptoms; and management should be in tandem with microbiology advice. Overtly septic patients should be managed with emergency drainage by stent or nephrostomy [77]. Patients with acute symptomatic urine infection should be treated and re-tested. Asymptomatic bacteriuria does not preclude a safe operation. Stones that are colonised may mean that urine samples will never reliably be completely free of bacteriuria. For these patients, the aim is to minimise the bacterial load for the operation. One regime is a "run-in" course of antibiotics before the operation [13,14]. A single dose of antibiotic should be given at induction for all patients, according to local protocol. There are limited data, with a systematic review finding only four trials and 500 patients, and a trend towards a reduction in febrile episodes [78].

Pre-operative planning is identified as a key factor in preventing sepsis. Planning and pre-operative assessment will identify comorbidities that can impede patient immunity. There may need to be multidisciplinary discussion and teamwork to decide when, to what extent, and how the patient can be optimised. For example, a patient may have diabetes newly diagnosed with an HbA1c blood test at pre-operative assessment for an elective procedure on an asymptomatic renal stone. The balance of risk is likely such that the patient should have optimal diabetic control before proceeding. As an alternative example, a patient undergoing a long course of neutropenic chemotherapy may present with an acute ureteric stone. This patient may require more urgent treatment and the oncology team will be involved to find an optimal chemotherapy "window" and/or support with granulocyte colony-stimulating factor as required.

Certain risk factors for sepsis such as age, frailty, female gender, neurogenic bladder, and history of recurrent UTIs are non-modifiable [6]. However, it is important to identify these patients as this informs pre-operative planning and intra-operative decision making regarding the operative strategies.

As discussed above, increasing the IRP correlates to increasing risk of sepsis [13,14]. This is likely related to pyelovenous backflow, driving any bacterial load into the blood stream. Measures to optimise the influx parameters were described above (UAS for RIRS, or PCNL with suction), and the pros and cons should be weighed according to the individual patient and stone burden.

Operating time also correlates to risk of sepsis [6]. URS of less than 1 h has three times lower risk of sepsis than one of over 3 h [79]. Pre-operative planning should account for stone and patient factors to determine the operative strategy that will minimise the risk of sepsis for selected patients [6,7]. In general, a more expedient operation involves lower risk of sepsis. However, other factors must also be considered. For example, for infected struvite stones, any remaining particles may act as a nidus for rapid reformation of the stone; therefore, the surgeon may consider it a priority to wash out all stone fragments and dust. For a large stone burden, decisions should be made early about whether staged procedures will be required [7]. These decisions should be started during pre-operative planning but will depend on how the operation progresses in reality. EULIS and IAU recommend that a single stage RIRS should not exceed 90 min [41]. Similarly, a decision should be made regarding whether to send the stone for microbiological analysis, particularly for high-risk patients. In one study, 73% of patients who developed sepsis after RIRS or PCNL had positive stone cultures in the absence of positive preoperative midstream urine culture [80]. In another, 25% of post-operatively septic patients had positive stone culture; 67% had renal pelvic urine culture; none had positive midstream urine culture [81].

Post-operative measures involve identifying patients who are at high risk of sepsis, and communicating a clear plan for their monitoring and management. High dependency placement may be considered for patients who are at a high risk of sepsis and also have significant comorbidities that would mean that a septic episode could be catastrophic. Otherwise, the ward team should be informed and appropriate monitoring implemented. Pre-emptive discussion with microbiology for a "rescue" plan will allow prompt treatment if the patient does deteriorate. There should be a low threshold for escalation as up to 30% who display signs and symptoms of systemic inflammatory response syndrome after PCNL eventually need intensive care support [82].

Post-operative antibiotic prophylaxis is not indicated in all patients [83,84], but should be considered in high-risk patients. The long-term risk of sepsis should also be considered, and the key risk factor for this is prolonged stent dwell time [6].

5. Stents and drainage

Stent complications are common, can be subjective and/or objective, and have a significant impact on patient quality of life. Up to 88% of patients report stent symptoms [85]. Increased stent dwell time risks sepsis, and if prolonged for a significant period of time, may encrust, calcify, and obstruct [86].

As with the decision to operate in the first place, the only absolute strategy to avoid stent symptoms is to avoid placing a stent in the first place. Uncomplicated URS or RIRS does not necessitate the placement of a stent, including cases where UAS is used [87]. Pre-operative planning and counselling should include a discussion of the options for drainage and the alternatives to a standard double-J stent insertion, such as ureteric catheter or a "stent on a string".

A key factor in pre-operative counselling is to explain clearly and in detail to the patient what stent symptoms are to be expected, the mechanisms, and what steps can be taken [88,89]. Symptoms should be framed as side-effects rather than a complication. In our experience, this is often the difference between patients who manage symptoms at home or those who re-attend for symptom control.

Intra-operative measures to minimise stent symptoms involve selecting an appropriate stent for the patient. Bladder symptoms are exacerbated by a long length of redundant stent irritating the bladder [90,91], reducing quality of life [91]. Therefore, the surgeon should aim for the shortest length of stent that would be effective for the patient. Alternatively, pigtail suture stents are designed to minimise the amount of irritative material in the bladder by employing two strings to anchor in the bladder rather than plastic. These cause less symptoms than standard stents [92]. Silicone stents have been demonstrated to cause less stent symptoms than other materials [93].

Post-operative measures to minimise stent symptoms include reiterating and reinforcing the pre-operative counselling. Analgesia should be recommended or prescribed where appropriate. Alpha-blockers improve lower urinary tract symptoms and overall pain relief [94]. Solifenacin improves lower urinary tract symptoms, haematuria, and pain in the flank, abdomen, and urethra [95]. Combination therapy is additive in effect [96].

Post-operative measures to prevent "forgotten" stents are vitally important. Prolonged stent dwell time, over 1 month, is a key risk factor for sepsis [6,89]. A "Swiss cheese" method of multiple safety measures should be employed: the patient should be aware that a stent has been inserted and that it will need to be removed or exchanged. They should be enabled to contact the department if it has remained *in situ* for a prolonged period. There should be a clear post-operative plan for either relook procedure or removal of stent, with a specified time frame. Finally, there should be a "stent register" as a safety net to identify and prioritise patients with stents for theatre schedulers [89].

6. Operation-specific measures

Meticulous pre-operative planning and good intra-operative technique minimise the risk of damage to the genitourinary system or other structures. Pre-operative planning involves discussions about correct operation, strategy, criteria for success, and drainage options.

6.1. PCNL and ECIRS

Key complications related to PCNL involve risks of vascular or visceral injury. As always, the first measure is a decision on which operation is appropriate, and this depends on patient and stone factors. Mini-PCNL involves access of smaller or equal to 22 Fr, while "standard" PCNL involves access of 24 Fr or larger [97]. The SFR is equivalent, but mini-PCNL involves less bleeding, risk of visceral injury, and hospital stay [98,99]. This is counterbalanced by increased operating time. As discussed above, operating time correlates to risk of sepsis. Therefore, standard PCNL should be considered when a faster operation may be deemed more suitable on balance, for example, for large infected stones and/or patients at risk of sepsis.

Bleeding can occur during puncture, dilation, instrument manipulation, or lithotripsy itself. The risk of bleeding has decreased over the years with iterative improvements to technique. Around 0.5%—2.4% require surgical intervention [100]. In order to avoid peri-calyceal blood vessels, the access tract should be onto a posterior calyx, into the fornix of a papilla, via a short straight tract through Brodel's line [100]. Cadaveric models demonstrate that there is up to 68% of vascular injury with infundibular puncture, versus 8.3% in papillary puncture [101]. Failure to puncture according to these principles is a major risk factor for severe haemorrhage requiring embolization [102]. Nevertheless, non-papillary puncture has been described [103]. Reported complication levels are low, although a RCT comparing against papillary puncture had a small sample size of 55 patients in total [104]. The importance of planning access pre-operatively is emphasised by the correlation between multiple puncture attempts and increased risk of bleeding [105]. There is equivocal evidence regarding the method of dilation (balloon or serial dilation), imaging modality (fluoroscopy or ultrasound), and position (prone *vs.* supine), on the risk of bleeding [100]. Bleeding risk increases with increasing tract size [106]. Torque applied to the kidney should be minimised to avoid further shearing forces on the blood vessels during instrument manipulation and lithotripsy.

Pre-operative measures include identifying risk factors for vascular or visceral injury and incorporating this when planning the preferred access point(s). Pleural injury occurs in 0.3%—1% of patients [107]. Supracostal access is the major risk factor, with 16% of these patients having a pleural injury [108]. Injury to solid viscera is associated with abnormalities such as splenomegaly or hepatomegaly [107]. Hollow viscera injury occurs in 0.2%—1% [107]. Risk factors include history of abdominal surgery with resultant heterotopic bowel position, and thin body habitus.

The use of ultrasound during puncture allows visualisation of any organ interposing between skin and kidney. This may reduce the risk of perirenal organ injury [13]. Both prone and supine positions are safe and effective with no demonstrated effect on the risk of complications [13].

Supine position allows for the option of ECIRS [12,13]. There are theoretical advantages over PCNL, although evidence for the reduction of complications is equivocal [12,109,110]. ECIRS allows puncture under vision, although this advantage may be negated when image-guided puncture is performed by an experienced surgeon or interventionist [13,109]. The EAU guidelines state that the existing evidence regarding ECIRS is of low quality. Further work is required for evidence-based recommendations for the potential role of ECIRS in reducing complications.

Parallel to operative planning and technique, measures should be taken to optimise physiology and pharmacology in terms of coagulation. If the patient is on anticoagulant or antiplatelet medication, then this should be identified at pre-operative assessment and the haematology team should advise a peri-operative bridging plan. Anticoagulants should be withdrawn before PCNL with bridging for high thromboembolic risk patients. The timing of withdrawal depends on prothrombin time for vitamin K antagonists, and renal function for direct oral anticoagulants. In patients with a high risk of post-operative bleeding, reintroduction should be postponed for 48–72 h [13]. Antiplatelet therapy should be withdrawn for patients with low thrombotic risk (including primary prevention) depending on the medication (for example, aspirin 7–10 days, clopidogrel 5 days, and ticagrelor 3–5 days) [13]. PCNL should not be performed in patients with high thrombotic risk who cannot safely pause their antiplatelet therapy [13].

Tranexamic acid given at induction reduces the risk of bleeding. Tranexamic acid is also associated with a lower complication rate overall, reduced operative time, reduced time in hospital, and an increased SFR [27]. Intraoperative optimisation of body temperature is important for normal homeostasis and in particular, this includes normal coagulation. PCNL patients must be draped appropriately with waterproof drapes and the aperture sealed to ensure that water does not pool on the patient directly and cause hypothermia [111]. A Bair hugger should be used. Post-operatively, there should be a high threshold for the use of low molecular weight heparin in these patients.

If bleeding occurs during the operation, an assessment is required of how significant the bleeding is and in particular whether this is an arterial bleed. If there is minor bleeding partially obscuring the view, then a decision may be made to continue. However, if the vision is sufficiently obscured, then there is the risk of further damage either by torque or direct injury. The drainage plan should be carefully considered. If there is a suspicion of venous bleeding, then the tube should be clamped to provide further tamponade. In case of bleeding, a CT-angiogram should be carried out. If there is a suspicion of arterial bleed, then interventional radiology should be involved as soon as possible. If this is identified on the table, then there may be an opportunity for rapid embolisation. This highlights the principle outlined above of "right time, right place, right team" as specialist units with interventional radiology available on site have the opportunity to mitigate this risk more readily.

6.2. URS and RIRS

Damage to the mucosa may occur in the ureter or pelvicalyceal system, may be minor to major (erosion, perforation, avulsion), and immediate or delayed (stricture). Good intra-operative technique during URS and RIRS minimises these risks [112]. This in turn is facilitated by meticulous pre-operative planning to select the correct equipment and operative strategies: "instruments should be adapted to the anatomy... and not vice versa" [112]. Each instrument must be used appropriately.

Whilst there are nuances with differences in technique from surgeon to surgeon, there is consensus that certain steps are recommended as routine. The IAU guidelines recommend that a safety wire is used routinely [14]. Semi-rigid URS is recommended to be performed at the start of the procedure to evaluate or dilate the ureter before accessing the kidney [41]. If a UAS is used, it should be removed under direct vision to assess for any injury [14].

Avulsion is the most severe form of ureteric injury, although it is rare (0.04%–0.09%). It is most often related to two errors related to equipment use. The first is the attempted retrieval of a fragment that is too large. Fragments should be small enough to be retrieved without damaging the mucosa. If a stone is stuck, the basket can be released by disassembling it or cutting it. Alternatively the the stone can be lasered *in situ*. The second is a broken flexible ureteroscope with locked deflection [112]. The operator must always be aware of the scope position and deflection [112], and the deflection should be tested prior to introduction. This also highlights the importance of a flattened hierarchy as detailed above—anyone in theatre who identifies this happened should feel able to communicate impending risk.

Pre-operative planning to identify operative strategy will minimise the risk of ureteric damage by informing intra-operative decisions. For example, a previously unoperated "virgin" ureter is more likely to preclude successful access, particularly in male patients [113]. Understanding this pre-operatively will engender an appropriate and safe low threshold to place a stent and return for a relook procedure, ideally around 1–3 weeks later [41], and prevent the risk of perforation by attempting to force a ureteroscope.

7. Pre-operative assessment and co-morbidities

Pre-operative assessment identifies comorbidities and should seek to optimise these in order to minimise the risk of complications. Furthermore, as detailed above, a complete picture of comorbid status has impact on the decision making before, during, and after operation. This includes decisions about whether a patient will require high dependency or intensive care monitoring or organ support post-operatively.

Pre-operative optimisation can directly impact the risk of complications. For example, diabetic control impacts on the risk of sepsis [114]. Smoking status increases morbidity by 1.5 times [115] and mortality by 1.38 times [116] across all operations. These can be identified and optimised in liaison with primary care.

Pre-operative assessment should identify and optimise known comorbidities and relevant medications, allowing for liaison with the appropriate team if required, identification and mitigation of associated risks of complications, and multi-disciplinary team discussion about risk/benefit of the options including no operation. Assessment can also identify and optimise important occult comorbidity, such as iron infusion for anaemia.

Specific examples of the importance of pre-operative assessment and their impact on measures before, during, and after operation have been discussed above and include:

a. Spina bifida or spinal cord injury or spinal deformity: anaesthesia (reduced respiratory function, or autonomic dysreflexia), surgery (contractures, positioning, or PCNL access);
b. Cancer patient on neutropenic chemotherapy: may need to time the operation with chemotherapy "window" to optimise the white cell count;
c. Diabetic patient with poor diabetic control: multi-disciplinary team approach to balance waiting to optimise control versus risk of waiting to operate;
d. High body mass index patient: anaesthesia (airway issues or post-op hypoxia), surgery (access), PCNL proning pressure or nerve injury;
e. Haematological disorder or anticoagulation: bridging advice.

8. Limitations

This article represents a narrative review of up to date literature and synthesis with author opinion. There are inherent limitations and advantages to consider. This article is not a meta-analysis, nor a systematic review; therefore, there is not a quantitative analysis of data. Nevertheless, the narrative review method allows for the latest available evidence to be synthesised with the experience of the authors, from various healthcare systems.

9. Conclusion

Meticulous planning, interdisciplinary teamworking (including radiology, anaesthetic team, microbiology, and the nursing team) and good operative technique can minimise the risk of complications in endourology.

Author contributions

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Drafting of manuscript: Eric Edison, Vimoshan Arumuham, Giorgio Mazzon, Simon Choong.
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Conflicts of interest

The authors declare no conflict of interest.

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