Percutaneous Renal Surgery
Edited by
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Percutaneous renal procedures are highly complex and require a great deal of surgical skill. Improve your patient care with this outstanding instruction manual from the experts.

Clinically-focused throughout, the three major conditions managed by percutaneous renal surgery – large renal calculi, transitional cell cancer and renal cell cancer – are expertly covered by the world’s leading surgeons and urologists. Well-illustrated with over 100 top-quality surgical photos and with reference to the leading society guidelines in this area, inside you’ll find coverage of:
- Evidence-based outcomes for percutaneous management
- Patient selection and informed consent
- Preparing the patient for surgery
- Instrumentation used in surgery
- Surgical technique and patient safety
- Pre-and post-op counseling

In addition, 10 high-quality videos offer an excellent visual guide to best practice and surgical tips and tricks of the trade.

Percutaneous Renal Surgery is the perfect multi-media teaching tool, providing urologists, nephrologists and surgeons with the knowledge, confidence and clinical skills required to perform these complex and difficult surgical procedures safely and effectively.

Of related interest

This book is accompanied by a companion website: www.wiley.com/go/monga/percutaneous

The website includes:
- 10 video clips

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Percutaneous Renal Surgery
To our parents:

Uma and Trilok Monga
Snehalata and Murali Rane
Percutaneous Renal Surgery

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As medical students, we learn that the kidney receives 20% of the cardiac output. The thought of making a 1 cm hole in the kidney and relying on the forces of nature for hemostasis is understandably met with trepidation. Yet, the foresight, innovation, and courage of our predecessors have paved our path towards minimally invasive percutaneous approaches to renal diseases.

In this book we explore both the novel developments in percutaneous renal surgery and percutaneous ablative techniques, recognizing that the overlap in anatomical considerations, radiological and surgical skill sets, instrumentation and technique present an opportunity for collaboration and synergy.

Manoj Monga
Abhay Rane
About the Companion Website

This book is accompanied by a companion website:

www.wiley.com/go/monga/percutaneous

The website includes 10 video clips.
SECTION 1
Introduction
Introduction

Percutaneous nephrolithotomy (PCNL) has evolved to become the preferred minimally invasive approach for treating large-burden renal stones. This approach has replaced open renal surgery for stones. It has also evolved into a treatment option for treating noninvasive urothelial tumors of the upper urinary tract. Current percutaneous access techniques involve fluoroscopic or ultrasound guidance with a small-gauge needle for initial access. In selected cases, computed tomography (CT) guidance or blind access by anatomical landmarks may be indicated. The complications of PCNL are minimal and the associated morbidity is far less than for open renal surgery.

History

In 1865 at the Great Ormond Street Hospital, a case report by Thomas Hillier of therapeutic percutaneous renal decompression in a 4-year-old boy with congenital obstruction of the ureteropelvic junction was the first such case of percutaneous nephrostomy [1]. Through the course of the following 5 years, he performed multiple nephrostomies to relieve the recurring abdominal distension from the obstructed kidney. However, there was no suitable trocar available with which to create a permanent nephrocutaneous fistula. The child subsequently died at the age of 8 after a febrile illness.

The history of modern percutaneous renal surgery began with the first image-guided renal biopsy performed in 1944 by Nils Alwall by means of needle aspiration using a simple radiograph and retrograde pyelogram to localize the kidney with the patient in the sitting position. The procedure was performed at the University of Lund, Sweden. While the initial procedure was performed in 1944, the experience was not published until 1952 [2]. Subsequent series of percutaneous renal biopsy had the patient positioned prone, and the kidneys were localized using landmark distances between the vertebral spinous processes and the 11th and 12th ribs, and palpation for kidney movement [3].

The next reported description of percutaneous renal access was in 1955. Goodwin, Casey, and Woolf presented their experience at Harbor General Hospital of the University of California, Los Angeles, in 16 patients with hydronephrosis managed with percutaneous nephrostomies for drainage. All cases were performed under local anesthesia [4]. This technique followed as a natural extension of their initial report of percutaneous antegrade pyelography [5]. The authors noted in their technique that the procedure should be limited to patients with severe hydronephrosis since it was easier to puncture a larger hydronephrotic sac. The punctures were made with 12–14 gauge needles. It is of interest to note that the authors fashioned polyethylene tubings with several additional lateral holes to increase urinary drainage, allowing 2–4 inches of that portion of the tubing to coil in
the renal pelvis. These early modifications are now the
standard design of pigtail nephrostomy tubes that are
currently available.

In 1975, Stables published a case series in which he
described a technique to convert a standard temporary
percutaneous nephrostomy to prolonged or permanent
nephrostomy drainage with Foley catheters [6]. This was
thought to be of benefit in the management of obstructive
nephropathy in cases where the primary lesion was not
readily amenable to surgical repair. In a larger series and
review of the literature, Stables described the application
of the percutaneous nephrostomy in supravesical urinary
obstruction, urinary fistulas, and renal calculi [7]. He
reported a success rate of over 90% with percutaneous
nephrostomies, with major complications limited to 4%
and minor complications to 15%. This represented a
significant advance because open nephrostomy had been
associated with such complications as uremia, hemor-
rhage, infections, sepsis, and at times difficult access to
the renal pelvis.

In another series, Hellsten et al. reported performing
percutaneous nephrostomy in 32 patients. Of these, eight
patients were for permanent drainage and 24 for tempo-
rary drainage. Malignant obstruction of the distal ureter
was the most common indication [8]. Access to the renal
pelvis was obtained with the aid of fluoroscopy and/or
ultrasound. Change to larger catheters was achieved
using the Seldinger technique. The most common com-
plication reported was hemorrhage in five patients.

Percutaneous nephrolithotomy

In 1976, Fernstrom and Johannson reported on the first
percutaneous image-guided nephrolithotomy [9]. The
tract was dilated coaxially with graded plastic dilators
over the course of a few days. The tract was then used for
renal manipulation using grasping tools and Dormia bas-
kets after allowing the tract to mature. Following shortly
thereafter in 1979, Smith et al. from the University of
Minnesota reported on their experience [10]. By 1984,
they reported results from their first 100 patients [11].
Interestingly, the complication rate decreased to 5% as
their experience with the procedure grew, with a reported
stone-free rate of 91% for the most recent patients in that
series. One year later in 1985, the same group reported on
a further 400 patients. This time, the stone-free rate had
improved to 99% for patients with renal stones and 94.5%
for ureteral stones [12]. Their results compare very favor-
ably to stone-free and complication rates from more
modern PCNL series.

Percutaneous transitional cell
carcinoma resection

In 1984, Orihuela, Crowley, and Smith from the Long
Island Jewish Medical Center in New York extended the
techniques for percutaneous renal access to the treatment
of upper tract urothelial carcinomas. Two years later, they
became the first to report their experience at the annual
meeting of the American Urological Association in 1986
[13]. The initial series of patients was a highly selected
group suitable for renal-sparing surgery for solitary
kidney, bilateral synchronous disease, renal insufficiency,
poor surgical risk for open surgery or biopsy evidence of
a solitary low-grade superficial tumor. The authors’ tech-
nique involved an initial resection through a percutaneous
nephrostomy, followed by a second-look procedure 2–28
days later to assess the completeness of the initial resection
and to remove any residual tumors. Of note, with this
initial series of patients, the authors used adjuvant topical
therapy through the nephrostomy tube with mitomycin C
and bacillus Calmette–Guerin (BCG). Subsequently, the
same group published results on their experience with
their first nine patients [14]. Other authors emulated the
technique and reported similar success [15].

Percutaneous endopyelotomy

The percutaneous renal access technique was also adapted
treatment of the obstructed ureter. With percutaneous
renal access, the ureteropelvic junction is easily accessible
and made endoscopic incision feasible, avoiding the need
for open surgery. In 1983, Whitfield et al. described a
procedure of percutaneous incision of the ureteropelvic
junction using a modification of the Davis intubated ure-
terostomy technique. The authors reported a success rate
of 64% with their technique [16]. In 1984, Smith reported
on the various adaptations of the nephrostomy tract to renal surgery [17]. He demonstrated that the nephrostomy tract permits antegrade insertion of ureteral stents, ureteral dilation, and insertion of ureteral catheters to which other instruments such as stone baskets, steel styles, etc. could be attached, thus facilitating controlled stone manipulation, ureteral meatotomy, and retrograde stent insertion. He adapted the technique reported by Whitfield et al. and termed it endopyelotomy. In 1986, Badlani et al. reported on their initial experience in the treatment of ureteropelvic junction obstruction using this modified technique in 31 patients with a cold knife direct-vision urethrotome inserted through a percutaneous nephrostomy tract [18]. A success rate of 87.1% was reported by the authors. Notably, eight of these patients were undergoing endopyelotomy after previous failed open pyeloplasty.

**Other applications**

The next application of the nephrostomy tract was the attempt to dissolve stones by chemolysis. The instillation of acetylcysteine together with sodium bicarbonate through a nephrostomy tube into the renal pelvis was highly effective for dissolving cystine stones. Subsequently, renacidin was used to dissolve struvite stones. Blaivas et al. attempted chemical dissolution of residual stone fragments in 12 instances via nephrostomy tube irrigation [19]. Solutions containing either hemiacidrin or sodium bicarbonate were used for struvite and uric acid stones respectively, with a 75% success rate (complete dissolution of stones) reported. Pfister and Dretler also reported a considerably higher success rate in the management of renal and ureteral calculi with chemolytic drug irrigation through a percutaneous nephrostomy catheter [20]. Struvite, apatite, and carbonate stones were dissolved with an acidic solution (hemiacidrin, Suby solution G) and cystine stones were dissolved with an alkaline agent (Tham-E, acetylcysteine). A success rate of 85% in more than 150 stones cases was reported. This was particularly advantageous in medical conditions (cardiac, metabolic) where oral alkalinization with sodium bicarbonate or potassium citrate may be contraindicated. However, it took about 3–4 weeks of continuous irrigation to dissolve a stone. Chemolysis has since fallen out of favor due to the excellent outcomes from percutaneous nephrolithotomy.

**Conclusion**

The evolution of percutaneous renal access became the highway. The early innovations in minimally invasive urological surgery have evolved into what has today become the standard of care for many urological diseases. Those experiences propelled minimally invasive urology in great leaps and bounds. Not long after the early days of percutaneous renal surgery, in 1991 Ralph Clayman, one of the early pioneers, performed the first laparoscopic nephrectomy [21]. That endeavor has driven the evolution of urological surgery to a craft that is accomplished primarily through minimally invasive techniques.

**References**

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CHAPTER 2

Interventional Imaging and Radiation Safety

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Introduction

Medical imaging plays an essential role during the diagnosis, treatment, and follow-up of patients undergoing percutaneous renal surgery. As minimally invasive surgery has employed smaller and less invasive techniques for renal surgery, surgeons have increasingly relied upon interventional imaging to provide the information regarding anatomical relationships and pathology which previously could be directly seen or felt during open surgery. These imaging modalities have allowed surgeons to gain percutaneous access to the kidney for stone treatment, treat upper tract transitional cell carcinoma (TCC) in an endoscopic manner and perform percutaneous renal ablative surgery for small renal tumors. However, this increased reliance upon medical imaging during diagnosis, treatment, and follow-up has increased the radiation exposure received by patients. It is important that the surgeon performing minimally invasive renal surgery is facile with interventional imaging, knowledgeable regarding basic radiation physics and fully appreciates the differences between imaging modalities. Finally, the surgeon must use this knowledge to select diagnostic, therapeutic and follow-up imaging in a manner that will provide the optimal outcome and patient safety while minimizing the radiation exposure to the patient, surgeon, and staff.

Basic radiation physics

A fundamental understanding of the biological effects of radiation in the patient is essential in order to optimally utilize diagnostic and therapeutic imaging. The term “absorbed dose” refers to the amount of energy deposited per unit mass and is a way to determine the probability of biological effect (Box 2.1). Absorbed dose is measured in units of gray (Gy) or milligray (mGy). One gray is equal to 1 joule per kilogram of tissue (J/kg). Entrance skin dose refers specifically to the measure of radiation dose absorbed by the skin where the x-ray beam enters the patient. Finally, organ dose describes the amount of radiation to the organs of a patient [1, 2].

The two types of biological effects observed in patients following radiation exposure include immediate deterministic effects and delayed stochastic effects. Deterministic effects typically have a short latency period and are characterized by nonlinear dose–responses with a threshold dose (> 0.1 Gy) [3]. At lower doses, these deterministic effects (i.e. erythema and epilation) will completely resolve but above 10 Gy permanent damage may result [4].

The stochastic effects of radiation include the development of secondary malignancies. Unlike deterministic effects, there are no data to support a threshold below which stochastic effects will not occur [3]. The development of secondary malignancies is thought to be due to misrepair...
of damaged DNA that results in a genetic transformation. This damage is directly correlated with the total radiation absorbed by organs and tissues [5]. Since intentionally exposing patients to high levels of radiation would be unethical, much of our understanding of radiation's stochastic effects is inferred from the effects observed in atomic bomb survivors. However, since atomic bomb survivors also received neutrons, protons, and other radioactive materials for which the biological effects are not as well characterized, this may not be the most accurate comparison [6,7]. At the present time the linear no-threshold model is felt to best represent the risk for stochastic injury.

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**Box 2.1 Radiation sources and recommendations**

### Radiation conversions

<table>
<thead>
<tr>
<th>Radiation</th>
<th>Equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 mGy</td>
<td>100 mrad</td>
</tr>
<tr>
<td>1 mSv</td>
<td>100 mrem</td>
</tr>
<tr>
<td>1 mGy*</td>
<td>1 mSv*</td>
</tr>
<tr>
<td>1 rad*</td>
<td>1 rem*</td>
</tr>
<tr>
<td>1 Gy</td>
<td>100 roentgen</td>
</tr>
<tr>
<td>10 mSv</td>
<td>1/1000 develop cancer; 1/2000 fatal cancer [107]</td>
</tr>
<tr>
<td>100 mSv</td>
<td>1% increase in cancer in a population [108]</td>
</tr>
<tr>
<td>1 Sv</td>
<td>Onset of early radiation effects [109]</td>
</tr>
<tr>
<td>2 Sv</td>
<td>Threshold for early death [109]</td>
</tr>
<tr>
<td>4 Sv</td>
<td>50% chance for survival [109]</td>
</tr>
</tbody>
</table>

### Environmental exposures

- Natural background radiation per year: 2.72 mSv [110]
- Cosmic radiation per year: 0.28 mSv [110]
- Radiation from airport scanners (50 kVp): 0.9 μSv [111]
- Airplane flight from New York to London: 0.1 mSv [112]
- Within 3 km of Hiroshima detonation: 50–100 mSv [112]
- 237 onsite Chernobyl workers at meltdown: 1–16 Sv [113]

### Medical imaging exposures

- Kidney, ureter and bladder (KUB) 0.7 mSv [47]
- Chest x-ray 2 view: 0.05–0.24 [47]
- Voiding cystourethrogram: 0.2–8.5 mSv [114]
- Intravenous pyelogram: 3–9 mSv [56,115]
- Noncontrast CT abdomen or pelvis (1 phase): 10 mSv [112]
- CT urogram: 14.8–36.1 mSv [56,116]
- Nuclear renal scan DTPA: 1.8 mSv [47]
- Nuclear renal scan MAG 3: 2.6 mSv [47]
- Nuclear renal scan DMSA: 3.3 mSv [47]
- Bone scan: 6.3 mSv [47]
- PET scan: 14.1 mSv [47]
- Low-dose CT abdomen and pelvis: 2.1 mSv [117]
- Ultra low-dose CT abdomen and pelvis: 0.95 mSv [112]
- Percutaneous cryoablation: 120 mSv [118]

### Exposure recommendations

- Maximum occupational radiation exposure: 20 mSv/year averaged over 5 years with no more than 50 mSv in any one year [119]
- Allowable exposure to the lens of the eye/yr: 150 mSv [119]
- Hands and feet/yr: 500 mSv [119]

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* = when discussing x-rays, gamma rays, and beta radiation.

CT, computed tomography; DMSA, dimercaptosuccinic acid; DTPA, diethylene triamine pentaacetic acid; KUB, kidney, ureter and bladder; MAG 3, mercaptoacetyltriglycine 3; PET, positron emission tomography.
following radiation damage. It has been documented that solid cancer rates will increase by 35% per Gy for men and 58% per Gy for women after exposure at age 30 if they live to 70 years of age [8]. The likelihood that exposing patients to ionizing radiation will result in cancer is dependent upon how much radiation they absorb, the type of radiation they are exposed to, and the sensitivity of the organ exposed.

Humans receive radiation from a variety of natural and iatrogenic sources (see Box 2.1). During the diagnosis, treatment, and follow-up of patients undergoing percutaneous renal surgery, patients may receive substantial radiation exposure. Most of this imaging is essential to allow safe and effective patient treatment. However, it has been estimated that of the 80 million computed tomography (CT) scans performed annually, 20–40% may be unnecessary [9]. Medical imaging currently contributes to approximately 50% of overall radiation exposure in the United States compared to 15% in 1980 [9]. It was recently estimated that 29,000 tumors may result from the 70 million CT scans performed in the United States in 2007 alone and this may account for 2% of US cancers [10]. In 2010, the Food and Drug Administration (FDA) issued a White Paper calling for a reduction in the radiation exposure received by patients during medical imaging and specifically recommended reductions in radiation from CT, fluoroscopy, and nuclear medicine imaging [11].

Percutaneous renal surgery for stones

Preoperative imaging
The treatment of large renal stones with percutaneous nephrostolithotomy (PCNL) begins by obtaining an appropriate characterization of the preoperative stone volume and location, anatomical relationships and at least indirect information to suggest the presence of adequate renal function. Although a plain abdominal radiograph (KUB), intravenous pyelogram (IVP), nuclear renography, and renal ultrasound (US) are sometimes used, CT imaging is the most commonly employed modality in the evaluation of staghorn calculi. CT acquires images rapidly, is nearly universally available, and provides important anatomical relationships. CT imaging can also create three-dimensional (3D) reconstructions to assist in tract site planning [12], although the benefits of the 3D reconstructions are not uniformly accepted [13]. Furthermore, in some patients with complicated anatomy, the nephrostomy tube may have to be placed using CT guidance [14].

Although magnetic resonance imaging (MRI) provides excellent soft tissue imaging, its use in the evaluation of staghorn calculi has been limited due to poor visualization of stones, high cost, long acquisition time, and degradation with motion artifact [15,16]. Ultrasound is able to accurately detect renal calculi, determine parenchymal thickness and access for hydronephrosis without ionizing radiation. A KUB is also routinely performed to give an overview of the stone size and location, and to determine whether the stone is radiopaque (Figure 2.1). A nuclear renogram may be helpful to access renal function in staghorn patients, particularly in those with long-standing hydronephrosis, parenchymal thinning or prior interventions [17].

Imaging for establishing nephrostomy tract
The most common imaging modality employed intraoperatively in the treatment of staghorn calculi is fluoroscopy. Appropriate utilization of fluoroscopy
during PCNL provides an important understanding of anatomical and spatial relationships that leads to a decrease in the complexity and improved procedure safety. The cinematic images are particularly helpful for advancing the guidewire past the stone into the ureter prior to tract dilation [18].

Computed tomography-guided percutaneous access to the kidney can also be employed. It is slower and more cumbersome than nephrostomy placement under fluoroscopy but may be helpful in identifying a retrorenal colon and the location of the lung, pleura, liver, and spleen in upper pole access. Some of the indications for CT-guided percutaneous access include spinal dysraphism, morbid obesity, and abnormal anatomy [19–21]. The success of CT-guided percutaneous nephrostomy tube placement approaches 100% and may minimize the risk of major complications like bowel and visceral injury [22,23].

The use of US guidance during nephrostomy tube placement has some potential advantages compared to fluoroscopy and eliminates the need for ionizing radiation. US may result in shorter procedure times, fewer punctures, real-time visualization of surrounding structures, easier identification of posterior and anterior calyces and the ability to visualize and avoid the lung, pleura, and bowel [24]. Using ultrasound, successful nephrostomy placement has been reported in 91–100% of patients [25–27]. Major complications occurred in about 5% of patients [27].

**Radiation implications of percutaneous stone surgery**

The imaging used and the manner in which that imaging is employed may have significant effects upon the radiation exposure for patients during PCNL. Lipkin and colleagues used a validated phantom model to determine the effective dose during PCNL. The effective dose for left and right PCNL was 0.021 mSv/s and 0.014 mSv/s, respectively. These corrections were multiplied by the median fluoroscopy time of 386.3 and 545 sec for left and right PCNL, respectively. The effective dose received by the patient was 8.11 mSv on the left and 7.63 mSv on the right [28].

The fluoroscopic radiation exposure received by the patient is dependent upon patient factors, fluoroscopy settings, and the specifics of the machine. Newborns have a 3× higher risk of developing cancer compared to adults due to their longer life expectancy and greater susceptibility to the effects of ionizing radiation [29,30]. A patient of medium build may typically receive a skin entrance dose of 30 mGy/min [31]. Obesity increases radiation exposure due to poor radiation penetration and the x-ray source being closer to the patient [32]. An obese patient may receive a dose as high as 10–50× that of an individual with normal build [33,34].

There are several radiation reduction strategies that can be employed during the diagnosis, treatment, and follow-up of stone patients, including avoiding ionizing imaging, spacing out imaging intervals, and the use of intraoperative behavioral and technical modifications. Alternative imaging strategies may include the use of US to place the nephrostomy tube and to monitor stone fragmentation. Behavioral changes include shorter pedal activations, use of last image hold, maintaining appropriate distance from the radiation source, and monitoring and recording fluoroscopy time. There are also technical modifications to reduce radiation exposure, including maintaining an optimal fixed and intentionally lowered kVp and mA instead of using automatic brightness control settings, use of a laser guided C-arm, use of pulsed instead of continuous fluoroscopy, and the use of shielding and collimation.

Early C-arm machines provided only real-time images and if the foot pedal was not depressed, there was no screen image. Last image hold allows the physician to scrutinize the last image and develop an appropriate management plan without exposing the patient to additional doses of radiation [35]. Although some steps during percutaneous nephrolithotomy, such as placing the guidewire past an obstructing stone, may require dynamic fluoroscopy, most tasks can be effectively performed by viewing a static image. This maneuver may reduce radiation exposure by up to 60% [36].

Perhaps the most intuitive behavioral method of reducing radiation exposure is to reduce the amount of time that the fluoroscopy pedal is depressed [37]. Using shorter rather than longer periods of continuous fluoroscopy will reduce radiation exposure. By only obtaining images that are necessary for the surgery, the overall exposure is reduced. Substituting visual and tactile cues for fluoroscopic cues may significantly reduce radiation exposure [38]. An example of this technique is confirming...
placement of a safety guidewire by comparing its length to the original wire instead of employing fluoroscopy.

Surgeon monitoring and recording of activation times have been shown to result in a 24% reduction in fluoroscopy [39]. Also, employing the inverse square law between exposure and distance during fluoroscopy can lower radiation exposure to the patient, urologist, and ancillary staff. If the distance from the source is doubled, the radiation exposure decreases by a factor of 4. The fluoroscopy machine should always be used with the spacer at the source to prevent the operator from moving the source too close to the patient. All operating room members should work at the greatest distance from the source that allows the safe performance of their clinical duties.

There are also several easily implemented technical modifications that can reduce the radiation exposure during PCNL. In a review of 96 patients by Lipkin and colleagues, it was found that using air instead of contrast for the nephrostogram reduced the radiation exposure from 7.67 mSv to 4.45 mSv (p = 0.001). This reduction was thought to be due to the automatic brightness control (ABC) mode increasing settings to preserve image quality in response to dense contrast [40,41].

Another technique to reduce radiation exposure during PCNL is through intentional alteration of the fluoroscopy machine settings prior to the procedure. Fluoroscopy machines are routinely operated using ABC settings where the machine automatically adjusts the mA and kVp to provide optimal image quality based upon the density of objects within the field of interest [42]. One highly effective method for reducing radiation exposure is to maintain the kVp while decreasing the mA using fixed manual settings [43]. During fluoroscopy, guidewire and nephroscope position, stone fragmentation and nephrostomy position can all be determined using a relatively low-quality image. Use of intentionally lowered fixed settings also prevents the “whited out” image which can occur using automated settings if the C-arm sensor encounters dense structures such as the bar on the fluoroscopy table or a dense region of contrast [44]. These settings can be placed at the lowest level that will provide adequate image quality for the task at hand.

Another alteration that can be applied to the fluoroscopic machine is the use of pulsed rather than continuous fluoroscopy. In continuous fluoroscopy, x-rays are continuously created and captured on a video camera display at a rate of 30 frames/sec [45]. In contrast, the operator can manually adjust the number of frames/sec in pulsed fluoroscopy. It has been documented in the literature via phantom models that pulsed fluoroscopy at rates of 15, 10, 7.5, and 3.75 frames/sec were associated with radiation reduction of 22%, 38%, 49%, and 87%, respectively [46].

Collimation and shielding are other technical strategies for reducing the amount of radiation by restricting the radiation solely to the area of interest. Collimation occurs at the level of the machine and can be used to narrow the amount of radiation exposure escaping the machine, thereby reducing the x-rays to the areas of interest. In contrast, shielding is routinely placed between the x-ray source and the patient. Similar to collimation, shielding limits the radiation exposure to the area of interest and may reduce exposure by 80% [47,48].

In addition to taking measures to protect the patient, the surgeon should also be aware of methods to improve the safety for themselves and their staff. In an internet study, Elkousy and colleagues reported that only 68% of surgeons wore thyroid shields and 34.3% reported wearing dosimeters. Only 17.2% reported wearing lead-impregnated glasses and 9.7% used lead-impregnated gloves [49]. The reasons for noncompliance included unavailability, carelessness and denial, lack of knowledge of the hazards of radiation, inadequate knowledge of radiation protective measures, and discomfort of heavy lead aprons. Thyroid shielding should be utilized as the radiation exposure may be decreased by 23-fold [50]. Even though the National Council on Radiation Protection and International Commission on Radiological Protection reported that the lowest cumulative lens dose resulting in cataracts is 2 Gy, other evidence suggests that even centigray doses may cause cataracts [51], highlighting the importance of lead glasses.

A study performed by King and colleagues demonstrated that by using a disposable sterile bismuth drape the amount of scatter radiation to the surgeon was reduced 12-fold to the eyes, 25-fold to the thyroid and 29-fold to the hands. Yang and colleagues demonstrated that a 0.5 mm lead equivalent vinyl-coated sheet fastened to the operating table acting as a curtain to protect the surgeon decreased the radiation exposure 71–96% [52].
Interventional imaging and radiation safety for upper tract transitional cell carcinoma

Upper tract TCC accounts for approximately 12% of the diagnosed upper tract urothelial cancers [53]. Traditionally, hematuria patients underwent a cystoscopy and IVP [54]. More recently, the IVP has been replaced by a three-phase CT urogram (CTU) including noncontrast, early arterial and delayed phases (Figure 2.2). CT urography is more sensitive (93.5% versus 80.4%) and more specific (94.8% versus 81%) than IVP in the diagnosis of upper tract TCC [55], but is associated with greater radiation exposure. Nawfel and colleagues found a mean exposure of 14.8 mSv in eight CT urogram patients compared to 9.7 mSv in 11 patients undergoing IVP [56].

Magnetic resonance urography (MRU) has also been reported for the diagnosis and follow-up of upper tract TCC. MRU includes better tissue contrast resolution, greater ease of evaluation of vascular structures, and better identification of perivascular lymph nodes, and can provide greater information with regard to tissue properties than CT scan [57–59]. Typically, TCC has lower signal intensity than the high signal intensity urine on T2-weighted images and thus allows identification of the tumor in a dilated collecting system [60]. Conversely, TCC is essentially isointense with renal parenchyma on T1- and T2-weighted images. Hence, gadolinium is often required for accurate delineation and assessment of tumor extent [61].

A study performed by Jung and colleagues found that MRU had an 88% sensitivity and a 100% specificity for detection of ureteral tumors [61]. This is comparable to the 87% sensitivity and 98% specificity of CTU [62–64]. Therefore, MRU is a viable alternative to using ionizing radiation when evaluating patients for upper tract TCC. MRU may also be ideal in patients with an iodine allergy or in younger and healthier patients concerned about radiation exposure.

The process of obtaining percutaneous access to the kidney to manage upper tract TCC is similar to the process for obtaining percutaneous access to the kidney to manage staghorn calculi, except that the access is placed to allow inline treatment of the TCC without placing access directly through the tumor [65]. Compared to treatment of staghorn calculi, most of the treatment for endoscopic management of upper tract TCC is via direct visualization and therefore these patients tend to receive less radiation exposure. In addition, patients with upper tract TCC have a peak incidence in the seventh decade of life and often present with significant medical comorbidities. Although many of the same radiation principles discussed in the section on treatment of large renal stones are also applicable in this patient population, concerns for radiation-related morbidity are much less [66,67].

Intraoperatively, endoluminal ultrasound (EUS) may provide a promising new staging tool for upper tract TCC that does not require ionizing radiation. Matin and colleagues reviewed 15 patients being evaluated for suspected upper tract urothelial carcinoma. Six out of seven patients treated with nephroureterectomy were appropriately staged with EUS. In this study, the positive predictive value of endoluminal ultrasonography was 66.7% and the negative predictive value was 100% [68].

Similarly, the postoperative follow-up of upper tract TCC patients should be dictated by the provision of optimal follow-up and should not be overly concerned with radiation exposure. A wide variety of methods for follow-up of the upper tract have been reported including IVP, CT urogram, MR urogram, and endoscopic surveillance. The method selected for follow-up should be influenced by the availability and expertise at the treating institution. Similarly, follow-up interval and method should be dictated by the tumor biology and patient comorbidity [69–79].

Figure 2.2 CTU demonstrating a right filling defect in the renal pelvis due to upper tract TCC.
Interventional imaging and radiation safety for percutaneous renal mass ablation

The incidence of renal cell carcinoma in the United States has risen over the last 30 years [80,81]. This increase has been attributed to increased utilization of CT and US in the evaluation of abdominal symptoms as well as an increase in risk factors, such as obesity and hypertension [82,83]. Many patients who are poor surgical resection candidates are amenable to percutaneous ablative therapies.

When treated using percutaneous ablative techniques, patients with renal masses typically undergo multiple imaging tests in the pre-, intra, and postoperative periods. Therefore, it is important for the physician to understand the advantages and disadvantages of each imaging modality. While the clinical effect of radiation exposure in the older patient with multiple comorbidities may be minimal, reducing radiation exposure in younger, healthier patients with potential long-term survival is important.

Preoperative imaging of the small renal mass

Ultrasonography has the advantage of delivering no ionizing radiation, being relatively inexpensive, and is useful for differentiating solid and cystic lesions. However, ultrasound lacks the ability to provide detailed anatomical images, is operator dependent, and is inferior to CT in the identification of renal masses < 2.5 cm [84]. Magnetic resonance imaging is a reasonable alternative to CT in the evaluation of renal masses, particularly in patients with known iodine contrast allergy. Additionally, advances in MRI technology may help differentiate between oncocytomas and renal cell carcinoma and differentiate amongst the other histological subtypes of renal cell carcinoma [85]. Disadvantages of MRI include higher costs, the risk of nephrogenic systemic fibrosis with gadolinium administration in patients with renal failure, and decreased patient tolerance due to claustrophobia and anxiety [86].

Computed tomography provides exceptional image quality and is currently the imaging method most widely used in the evaluation of renal masses. A major limitation, however, is the exposure to ionizing radiation and the possible subsequent increased risk of malignancy [87]. In an effort to reduce radiation exposure, Graser and colleagues utilized single-phase dual-energy CT. Radiation dose was reduced by nearly 50% while maintaining diagnostic accuracy of >95% for the evaluation of renal masses [88].

Use of the preoperative imaging modality to be employed during the ablation will allow the surgeon to predict the tumor appearance at the time of ablation. Understanding the advantages and disadvantages of each imaging modality will help guide the clinician in developing a management plan to maximize treatment success while minimizing patient risk.

Intraoperative radiation safety

Percutaneous ablative therapy of renal masses requires image guidance for probe placement and, in the case of cryoablation, active monitoring of treatment effect. As with preoperative imaging, CT, MRI or ultrasound can be employed, each with modality-specific advantages and disadvantages. Currently, CT is the imaging technique most widely used during percutaneous ablative therapy [89]. It provides rapidly acquired images with high resolution and the ability to characterize anatomical relationships. CT without contrast is usually adequate to guide probe placement and treatment. The major disadvantage with CT is patient exposure to ionizing radiation. Although there are currently no published reports comparing radiation exposure between the varying percutaneous ablative therapies, fewer CT scans are typically obtained during radiofrequency ablation (RFA) compared to cryoablation. This is due to the greater number of probes that are typically needed for cryotherapy and the resultant need for increased CT imaging used during probe placement. Additionally, repeated scans are needed for active monitoring of ice ball growth during cryotherapy (Figure 2.3a). In contrast, active image monitoring of RFA is not useful [90] (Figure 2.3b). In a retrospective review, Leng and colleagues reported a mean effective dose of approximately 120 mSv in 42 patients undergoing CT-guided cryoablation of a renal mass [91] (Figure 2.4).

Several techniques can be implemented to minimize radiation exposure when using CT for image guidance during percutaneous ablation. First, the extent of intraoperative CT images should be limited to 1 cm above and below the tumor and imaging should be performed within the same phase of respiration to assure accuracy in slice position. This reduces unnecessary imaging of tissue out of the treatment field. Additionally, while there are
no published reports of reduced radiation protocols in patients undergoing CT-guided ablation, image quality with reduced radiation settings may prove adequate for intraoperative monitoring [92]. Leng and colleagues utilized validated noise addition software to simulate reduced radiation dose exposure during acquisition of CT images obtained during monitoring of ice ball progression. They found that >94% of images were adequate for ice ball monitoring at a 50% reduction in radiation dosage [93]. Finally, the operating physician should continually monitor the images acquired, ensuring appropriate slice selection including only essential portions of the anatomy while using the lowest energy possible to obtain adequate images. Implementing these techniques will aid in keeping radiation exposure “as low as reasonably achievable.”

Magnetic resonance imaging is an attractive alternative to CT for intraoperative image-guided percutaneous treatment of renal masses due to the avoidance of ionizing radiation. Silverman and colleagues reported their experience with MR-guided cryoablation of 26 small renal masses in 23 patients. Twenty-three of the 26 tumors were completely treated in a single session at a mean follow-up of 14 months [94]. Active monitoring of the ice ball was accomplished with a rapidly acquired T2 image where the margin is clearly seen as a dark signal void. Image acquisition times ranged from 20 to 60 sec during monitoring of ice ball growth and total procedure time was between 3 and 4 h. In this study, gadolinium-based contrast was injected intravenously prior to ablation for patients who did not yet have a preoperative MRI of the abdomen. Limitations include the need for gadolinium, increased cost and the limited availability of open MR suites equipped to provide anesthesia in close proximity to strong magnetic forces.

Boss and colleagues have evaluated the use of MR-guided RFA using both a 0.2 T and 1.5 T MRI system [95,96]. Utilizing the 0.2 T MRI, 11/12 patients were successfully treated in a single session, with one recurrence found at 13-month follow-up. When using a 1.5 T MRI system, the authors noted improved image quality, faster acquisition time, and the ability to more clearly identify postablative low signal intensity consistent with coagulative necrosis. The mean operative time was approximately 5 h in their initial pilot study using the 0.2 T MRI and ranged from 3 to 4 h in the study using the 1.5 T MRI.

Although ultrasound lacks the anatomical detail of CT and MRI, it is widely available and has been shown to be adequate for image guidance for percutaneous ablative therapies. Bassignani and colleagues reported their experience in three patients who underwent US-guided percutaneous renal cryoablation of four masses [97]. There were no perioperative complications and follow-up imaging 6–7 weeks following cryoablation demonstrated no enhancement in any lesion. Veltri and colleagues