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TOPIC PAPER

Management and prevention of renal ablative therapy complications

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Abstract
Introduction The increasing diagnosis of incidental small renal masses has contributed to energy ablative techniques being increasingly utilized as a primary surgical modality. Despite promise associated with thermal ablation, complications related to both cryoablation (CA) and radiofrequency ablations (RFA) do occur.
Methods Contemporary literature on renal ablative procedures (CA and RFA) was reviewed to highlight diagnosis, management, and prevention of complications associated with these procedures.
Results While morbidity for renal thermal ablation is typically less than extirpative renal surgery, a range of complications of varying severity may exist. Such complications can include sequelae from choice of access site, procedural bleeding, visceral injury, or damage to the collecting system or ipsilateral ureter.
Conclusions An understanding of complications secondary to renal ablation is essential for urologists and radiologists to facilitate prompt diagnosis, appropriate management, and future prevention.

Keywords Radiofrequency ablation (RFA) · Cryoablation · Thermal ablation · Complications · Renal cell carcinoma (RCC) kidney

Introduction

Widespread use of abdominal cross-sectional imaging has contributed to a stage migration toward diagnosis of incidental small renal masses (SRMs) [1]. Many of these SRMs, present at an early stage, are generally slow growing and are almost universally confined to the kidney at diagnosis [2]. Furthermore, the highest incidence of these lesions were present in elderly patients with comorbid conditions.

It is now apparent that radical nephrectomy represents significant overtreatment for many SRMs. Nephron-sparing techniques confer equivalent oncologic and functional outcomes to that of radical nephrectomy for patients with renal tumors smaller than 4 cm. Nephron-sparing surgery (NSS), however, is not without associated technical challenges, perioperative complications, and patient morbidity. This is particularly true for minimally invasive approaches which require an advanced laparoscopic skill set as well as well as dexterity for time-sensitive intracorporeal suturing without renal hypothermia [3].

Cryoablation (CA) and radiofrequency ablation (RFA) represent the newest frontier for active treatment of SRMs. Reported advantages of thermal ablation over surgical extirpation includes minimal parenchymal loss, shorter hospital duration, decreased patient morbidity, and an improved convalescence. SRMs are particularly good targets for ablative technology as these lesions are typically spherical, unifocal, and surrounded by homogenous renal parenchyma and perirenal fat. Furthermore, the entire surface of the kidney is fairly accessible via either laparoscopic or percutaneous approaches with real-time monitoring of tissue destruction accomplished by intraoperative thermometry, ultrasonography, computed tomography (CT), or magnetic resonance imaging (MRI).

Despite promise associated with thermal ablation, complications inevitably exist with this treatment modality. A clear understanding of associated complications and sequelae are essential for practicing urologists and radiologists. Here, we review the literature to highlight diagnosis,

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management, and prevention of complications associated with ablative therapy.

Access-related complications

Either a laparoscopic or a percutaneous approach can be employed for thermal ablation of renal tumors. The particular approach is at the discretion of the treating surgeon. In general, however, tumors located anteriorly or medially with close proximity to bowel or adjacent organs are typically managed laparoscopically, while tumors oriented more posteriorly and laterally can be treated by percutaneous ablation.

Laparoscopy

The complication rate for laparoscopic urologic procedures has been fairly well defined.

In 1999, Fahlenkamp et al. [4] highlighted an overall complication rate of 4.4% when reviewing outcomes from over 2,400 laparoscopic or retroperitoneoscopic procedures performed at 4 German centers. Furthermore, when specifically considering surgery for renal pathology, the authors noted an 8.2% complication rate for nephrectomy and/or heminephrectomy cases, and a 3.5% rate for renal cyst resection. Similar observations were made by Cadeddu et al. [5] who observed an overall complication rate of 11.9% when reviewing data from 13 centers with surgeons who had a minimum of 12 months of training in urologic laparoscopy. When specifically considering laparoscopic renal thermal ablation, the complication rate is comparable to the above-mentioned series. In 2004, Johnson et al. [6] reported on complications of CA and RFA in a multi-institutional experience of 271 patients. In the subgroup of 90 laparoscopic procedures, 8 complications occurred (8.9%), of which 3 were specifically attributable to the laparoscopic technique (3.3%).

Complications attributable to the laparoscopic technique can occur at any point of the procedure. Obtaining pneumoperitoneum by any method (Veress needle, optical trocar access, or Hasson) carries an inherent risk for bowel or vascular injury. Bishoff et al. [7] reviewed the literature to highlight a 0.13% incidence of laparoscopic bowel injury of which 50% was caused by electrocautery and 32% occurred during Veress needle or trocar insertion. Thermal injuries to the bowel during ablative procedures are uncommon unless extensive cauterization is used during tumor localization or bowel is in close proximity to the thermal probe during the ablation itself. Inadvertent non-thermal (penetrating) injuries from laparoscopic instrumentation necessitates prompt intraoperative repair when identified. Unfortunately, many small or large bowel injuries are unrecognized at the time of initial surgery. As such, surgeons must have a heightened sense of suspicion for patients who fail to progress as expected following a laparoscopic procedure. Cardinal signs and symptoms indicative of bowel injury include persistent and/or increased pain at the trocar site closest to the injured bowel, nausea, diarrhea, anorexia, low-grade fever, persistent bowel sounds, and a low or normal white blood cell count [7]. Appropriate imaging is necessary and exploration and repair of the injured segment of bowel is required in these cases.

Access-related abdominal wall hematomas secondary to epigastric vessel injuries or other superficial vasculature have been reported. Furthermore, abdominal wall hernias from both bladed and non-bladed trocars may occur and rarely may result in significant sequelae, such as incarcerated or strangulated bowel. The likelihood of both of these entities can be minimized by careful inspection of the trocar sites at the conclusion of the operative case with fascial re-approximation using closure devices as necessary. Injuries to other visceral organs including the liver, spleen, and pancreas are less likely to occur with laparoscopic CA and RFA because of limited dissection, mobilization, and traction during these procedures. Similarly, vascular complications at the level of the renal hilum are rarely encountered during laparoscopic CA and RFA as extensive hilar dissection is typically unnecessary.

Percutaneous

While percutaneous approaches typically avoid access-related visceral injuries, a central complication of this approach relates to pain and neuromuscular paresthesias due to local trauma to the flank or paraspinal musculature. Specifically, Johnson et al. [6] reported that pain or paresthesia at the percutaneous probe insertion site was the most common complication in their series accounting for 46% of all complications and occurring in 5% of all ablation cases. Similarly, when specifically considering percutaneous RFA procedures, Bhayani et al. [8] reported that 3 out of 48 patients (6%) had neuromuscular complications.

Ablation of posterior tumors may result in direct trauma or thermal injury to the psoas muscle, paraspinal musculature, diaphragm, retroperitoneal fascia, or any of several different nerves coursing through the retroperitoneum (subcostal, iliohypogastric, ilioinguinal, or genitofemoral). The genitofemoral nerve originating from the upper portion of the lumbar plexus and descends laterally along the psoas muscle is particularly at risk for thermal injury. While neuromuscular injuries can be a permanent complication, most resolve transiently with conservative therapy over a period of time [8].

There is an increased appreciation of strategies to prevent and minimize the likelihood of probe-related pain and paresthesia. First, pain may be minimized by selecting a probe that accurately matches the size of the tumor being ablated. This in turn contributes to a higher likelihood that the active portion of the probe is in the tumor itself while minimizing the potential for collateral thermal injury due to an unnecessarily large ablation zone [9]. Second, when deployed within the tumor, the probe itself can be used as a lever/fulcrum to elevate that specific portion of the kidney off of the posterior structures [10]. Third, hydrodissection with a fluid medium can be used to widen the space between the target lesion and psoas muscle [11]. This same strategy has been employed to displace anteriorly located bowel structures and will be subsequently discussed in greater detail. Finally, an additional strategy to optimize pain control for RFA in particular involves reducing the delivery power while lengthening the ablation duration. Of note, Allaf et al. [12] have observed that image-guided percutaneous cryoablation of small (≤4 cm) renal lesions appeared to require less analgesia than RF ablation. As such, cryoablation may be recommended for patients who are intolerant of pain and are unable to undergo general anesthesia.

An additional complication that is related to the percutaneous approach is iatrogenic pneumothorax during ablation of upper pole renal lesions. Contemporary series suggest an incidence of 2–4% for both percutaneous RFA and CA procedures [13, 14]. Unlike the laparoscopic approach, where the diaphragm can be visualized and the kidney can be appropriately mobilized, percutaneous ablation carries a greater risk of lung injury from adjacent probe placement or the thermal effect. CT fluoroscopy is one modality whereby "real time" visualization of the renal lesion and lung spaces can be performed to optimize placement of percutaneous probes. Furthermore, the use of general anesthesia allows for more precise control of respiratory excursion thereby improving the accuracy of probe placement. Post-procedure radiography is essential for these cases to ensure that pneumothoraces are promptly diagnosed and managed. Most mild pneumothorax cases are asymptomatic and can be conservatively managed with observation, serial imaging, and supplemental oxygen. A moderate or severe pneumothorax, however, necessitates thoracostomy drainage.

Hematoma/Hemorrhage

Hematoma is a common minor complication following thermal ablation via either laparoscopic or percutaneous approaches with a reported incidence of 6–8% in several series [9, 13]. It is likely that the true incidence is higher as many cases of subclinical hematomas occurring following laparoscopic ablation cases may be undetected in the absence of immediate retroperitoneal imaging [6]. The hematoma may occur in the subcapsular, perinephric, or paranephric spaces and may range from minimal to significant volumes. Acute hematoma typically manifests as a hyperdense fluid collection on CT images with decreasing density over time as the blood becomes more organized. In most cases, hematomas are small, self-limiting, and spontaneously absorbed. It is important, however, to recognize that larger hematomas may result in compression of the renal parenchyma with resultant renin-mediated hypertension from a Page kidney phenomenon.

Hemorrhage or significant bleeding requiring blood transfusion has a reported incidence of 1–8% following cryoablation or RFA [14–16]. In their multi-institutional series of 271 cases, Johnson et al. [6] noted that only 1 patient (0.4%) required a blood transfusion following percutaneous cryoablation. Similar rates were noted by both Zagoria et al. and Gervais et al. [14, 17] who reported transfusion requirements of 1 and 2%, respectively, following percutaneous RFA of renal lesions. Other groups, however, have noted substantially higher transfusion rates. Specifically, Finley et al. [15] recently noted that 7 out of 37 patients (19%) required a mean transfusion of 3 units of packed red blood cells following percutaneous or laparoscopic cryoablation. These authors do note, however, that all cases of hemorrhage occurred in cases where multiple cryoprobes were necessary suggesting that larger lesion size may in part contribute to these higher observed rates.

Bleeding following thermal ablation procedures can be multifactorial. Earlier technology necessitated use of larger probes which were associated with greater difficult in placement and higher rates of renal parenchymal fracture with resultant bleeding. This appears to occur more commonly with cryoablation and is attributed to suboptimal probe entry (i.e. non-orthogonal) into the tumor or renal parenchyma [3]. One advantage of RFA is the ability to minimize tract bleeding by coagulating the puncture tract during probe withdrawal. In this regard, significant bleeding appears to be less common following RFA. Beyond probe damage itself, mechanical injury to major vascular structures including the aorta, vena cava, or main renal vascular pedicle can contribute to bleeding. Avoidance of these complications necessitates meticulous monitoring of the probe position using either ultrasound or CT fluoroscopy particularly when managing hilar tumors which are in close proximity to such structures. Delayed bleeding may be sequelae of an arteriovenous fistula [18]. In most cases, transfusion is sufficient to manage bleeding although urologists must consider angioembolization or surgical exploration if bleeding remains refractory.

Bowel injury

Injury to the small or large bowel can occur during thermal ablation (either CA or RFA) performed by laparoscopic or percutaneous approaches. Diagnosis and management of laparoscopic bowel injuries were discussed earlier in this review article. Thermal injury during percutaneous ablation can occur during treatment of anterior or medial renal lesions that are abutting or closely approximating visceral structures. In this regard, careful lesion selection is paramount to avoid significant complications. Weizer et al. [19] illustrated this point when presenting complications on 24 high-risk patients with 32 renal tumors treated by percutaneous RFA. This series highlighted 5 complications including 2 perinephric hematomas, 1 persistent urinoma associated with a proximal ureteral stricture, and 2 colonic injuries. When specifically considering the colon injuries, 1 patient developed a colonic perforation 48 h following percutaneous RFA of a 7 cm left anterior renal lesion in a solitary kidney. Procedural CT scanning demonstrated that the colon was within 1 cm of the ablation tract. The second patient was treated for a 1.8 cm left anterior upper pole lesion in a solitary kidney and 7 days later developed colonephric fistula. On statistical analysis, anterior lesions were 5 times more likely than posterior lesions to have complications following percutaneous RFA (80% vs. 16%, $p < 0.0001$).

Bowel injuries following percutaneous ablation are a direct result of thermal energy-induced adjacent tissue necrosis. Quite simply, such complications can be minimized (and even avoided) by ensuring adequate distance between bowel (or other visceral structures) and the renal lesion being treated. Animal models of liver RFA have shown that colonic injury is increased when lesions within 1 cm of bowel are treated [20]. Postablation CT scanning should be performed whenever bowel injury is clinically suspected. Patients must be closely observed or surgically explored if there are any concerns of a related bowel injury.

Multiple strategies can be employed to avoid and prevent bowel-related complications from percutaneous ablation. In 2002, Ogan et al. [21] reported that 2 out of 15 patients scheduled for percutaneous RFA had bowel within millimeters of the target lesion when the patients were placed in the full and modified (30°) prone position. This was not readily apparent on preoperative imaging performed in the supine position. These authors recommend imaging prior to the procedure in the prone position to confirm an adequate safe margin between the target lesion and visceral structures. An additional protective technique involves using the probe itself as a lever or fulcrum when deployed in the lesion to orient it away from adjacent bowel [22]. This same strategy was discussed early to minimize thermal injury to posterior neuromuscular structures.

An increasingly popular technique involves instillation of fluid or CO_2 to displace bowel away from the treatment lesion. Bodily et al. [23] recently reported on percutaneous hydrodisplacement during the course of percutaneous CA for 50 renal tumors. These authors reported using this technique in 24% of percutaneous CA overall (50 of 206 lesions) to displace structures including the colon, body wall, duodenum, jejunum/ileum, ureter, and psoas muscle. The overall success rate was 96% in displacing the critical structure from its initial location by a mean distance of 16 mm (range 3–46 mm). They further emphasized continuous infusion was often necessary to maintain displacement during the procedure. Other groups have made similar observations [24]. While there is no consensus regarding the optimal medium, several authors advocate use of 5% dextrose in water due to its non-ionic and iso-osmolar nature [25].

Finally, in cases where bowel anatomy is not favorable for percutaneous ablation, surgeons should have a low threshold for employing a laparoscopic approach.

Ureteral and collecting system injury

Thermal ablation of renal tumors in close proximity or abutting the renal pelvis, ureteropelvic junction (UPJ), or proximal ureter presents a higher risk scenario for ureteral or collecting system injury with resultant obstruction or renal loss. Such observations have been more clearly delineated for RFA, although several reports note similar observations for CA. Johnson et al. [6] noted that 1 out of 271 (0.4%) patients in this multi-institutional series developed a UPJ obstruction following laparoscopic RFA for a 2.3-cm tumor near the hilum and renal pelvis. While initial observation failed to note any abnormalities, subsequent imaging revealed delayed renal excretion with the patient eventually requiring a nephrectomy for poor function. These authors have subsequently recommended use of ultrasonography to avoid collecting system puncture during laparoscopic probe placement and selecting a modality other than RFA to treat tumors neighboring the renal pelvis. Weizer et al. [19] had similar observations with 1 out of 24 patients (4%) in this series developing a persistent urinoma and proximal ureteral stricture 1 month following RFA treatment for 2 separate tumors, the largest of which was 3 cm and abutting the renal pelvis. These authors similarly concluded that RFA in lesions that abut the renal pelvis or UPJ significantly increases the risk of ureteral stricture disease. While less published, CA can certainly contribute to ureteral injuries as well. In 1976, a bovine study clearly demonstrated that direct cryoablation of the ureter can cause stricture disease and urinary obstruction [26]. Additional human cases of ureteral strictures following CA have been reported [27].

As with bowel injuries described previously, proximity between the urinary collecting system and the ablation zone plays a key role in preventing complications. Postablation CT urography should be performed if a ureteral injury is suspected. Importantly, a urine leak may not be obvious in the acute setting. Rather, secondary signs of inflammation and injury including increased ureteral wall thickness, periureteral stranding, or hydronephrosis may be the only early presentation [9]. Management of injury may be conservative, although most necessitate active interventions including nephrostomy tube placement, antegrade ureteral stent, or nephrectomy.

Prevention of UPJ or ureteral injury can be accomplished by careful lesion selection and appropriate use of laparoscopic versus percutaneous approaches. As mentioned earlier, hydrodissection with an aqueous medium can be employed during percutaneous procedures to displace the ureter from the renal lesion prior to therapy [23]. Froemming et al. [28] have recently reported on several cases of probe retraction during percutaneous CA to minimize direct ureteral injury. Their pilot experience was promising although a greater experience is necessary prior to broader implementation.

Deep, centrally located lesions have raised concern for increased risk of collecting system injury following probe ablative therapy. Janzen et al. [29] addressed this concern by reviewing the effects of intentional CA and RFA of the collecting system in a porcine model. These authors concluded that CA (and not RFA) spares the collecting system in the acute setting, although regrowth of urothelium may occur with time following RFA. These animal model observations were further supported by Hegarty et al. [30] who observed only one collecting system complication in 28 RFA-treated tumors that were adjacent to the renal sinus, calyces, or hilum. Furthermore, in this latter study, one urinary fistula also occurred following CA. Collectively, these imply that the specific ablation technique for centrally located tumors is less important than the precision with which the probes are placed to treat these tumors.

Conclusions

While fewer in number than extirpative surgery, complications following probe ablative therapy for renal cortical tumors can occur. While some are self-limiting, others can result in significant patient morbidity with the potential for renal loss or adjunctive surgical procedures. Many can be avoided by careful consideration of relevant anatomy coupled with a firm understanding of mechanisms underlying the ablative technique themselves.

Conflict of interest statement There is no conflict of interest.

References

1. Hollingsworth JM, Miller DC, Daignault S, Hollenbeck BK (2006) Rising incidence of small renal masses: a need to reassess treatment effect. J Natl Cancer Inst 98(18):1331–1334
2. Rendon RA, Stanietzky N, Panzarella T, Robinette M, Klotz LH, Thurston W et al (2000) The natural history of small renal masses. J Urol 164(4):1143–1147
3. Aron M, Gill IS (2005) Renal tumor ablation. Curr Opin Urol 15(5):298–305
4. Fahlenkamp D, Rassweiler J, Fornara P, Frede T, Loening SA (1999) Complications of laparoscopic procedures in urology: experience with 2, 407 procedures at 4 German centers. J Urol 162(31):765–770 discussion 70–71
5. Cadeddu JA, Wolfe JS Jr, Nakada S, Chen R, Shalhav A, Bishoff JT et al (2001) Complications of laparoscopic procedures after concentrated training in urological laparoscopy. J Urol 166(6): 2109–2111
6. Johnson DB, Solomon SB, Su LM, Matsumoto ED, Kavoussi LR, Nakada SY et al (2004) Defining the complications of cryoablation and radio frequency ablation of small renal tumors: a multi-institutional review. J Urol 172(3):874–877
7. Bishoff JT, Allaf ME, Kirkels W, Moore RG, Kavoussi LR, Schroder F (1999) Laparoscopic bowel injury: incidence and clinical presentation. J Urol 161(3):887–890
8. Bhayani SB, Allaf ME, Su LM, Solomon SB (2005) Neuromuscular complications after percutaneous radiofrequency ablation of renal tumors. Urology 65(3):592
9. Park BK, Kim CK (2009) Complications of image-guided radiofrequency ablation of renal cell carcinoma: causes, imaging features and prevention methods. Eur Radiol 19(9):2180–2190
10. Boss A, Clasen S, Kuczyk M, Anastasiadis A, Schmidt D, Claussen CD et al (2005) Thermal damage of the genitofemoral nerve due to radiofrequency ablation of renal cell carcinoma: a potentially avoidable complication. AJR Am J Roentgenol 185(6):1627–1631
11. Lee SJ, Choyke LT, Locklin JK, Wood BJ (2006) Use of hydrodissection to prevent nerve and muscular damage during radiofrequency ablation of kidney tumors. J Vasc Interv Radiol 17(12):1967–1969
12. Allaf ME, Varkarakis IM, Bhayani SB, Inagaki T, Kavoussi LR, Solomon SB (2005) Pain control requirements for percutaneous ablation of renal tumors: cryoablation versus radiofrequency ablation—initial observations. Radiology 237(1):366–370
13. Derweesh IH, Malcolm JB, Diblasio CJ, Giem A, Rewcastle JC, Wake RW et al (2008) Single center comparison of laparoscopic cryoablation and CT-guided percutaneous cryoablation for renal tumors. J Endourol 22(11):2461–2467
14. Zagoria RJ, Traver MA, Werle DM, Perini M, Hayasaka S, Clark PE (2007) Oncologic efficacy of CT-guided percutaneous radiofrequency ablation of renal cell carcinomas. AJR Am J Roentgenol 189(2):429–436
15. Finley DS, Beck S, Box G, Chu W, Deane L, Vajgrt DJ et al (2008) Percutaneous and laparoscopic cryoablation of small renal masses. J Urol 180(2):492–498 discussion 8
16. Malcolm JB, Berry TT, Williams MB, Logan JE, Given RW, Lance RS et al (2009) Single center experience with percutaneous and laparoscopic cryoablation of small renal masses. J Endourol 23(6):907–911

17. Gervais DA, McGovern FJ, Arellano RS, McDougal WS, Mueller PR (2005) Radiofrequency ablation of renal cell carcinoma: part 1, Indications, results, and role in patient management over a 6-year period and ablation of 100 tumors. AJR Am J Roentgenol 185(1):64–71
18. Park BK, Kim CK, Moo HL (2007) Arteriovenous fistula after radiofrequency ablation of a renal tumor located within the renal sinus. J Vasc Interv Radiol 18(9):1183–1185
19. Weizer AZ, Raj GV, O'Connell M, Robertson CN, Nelson RC, Polascik TJ (2005) Complications after percutaneous radiofrequency ablation of renal tumors. Urology 66(6):1176–1180
20. Hansen PD, Rogers S, Corless CL, Swanstrom LL, Siperstien AE (1999) Radiofrequency ablation lesions in a pig liver model. J Surg Res 87(1):114–121
21. Ogan K, Jacomides L, Dolmatch BL, Rivera FJ, Dellaria MF, Josephs SC et al (2002) Percutaneous radiofrequency ablation of renal tumors: technique, limitations, and morbidity. Urology 60(6):954–958
22. Park BK, Kim CK (2008) Using an electrode as a lever to increase the distance between renal cell carcinoma and bowel during CT-guided radiofrequency ablation. Eur Radiol 18(4):743–746
23. Bodily KD, Atwell TD, Mandrekar JN, Farrell MA, Callstrom MR, Schmit GD et al (2010) Hydrodisplacement in the percutaneous cryoablation of 50 renal tumors. AJR Am J Roentgenol 194(3):779–783
24. Park BK, Kim SH, Byun JY, Kim YS, Kwon GY, Jang IS (2007) CT-guided instillation of 5% dextrose in water into the anterior pararenal space before renal radiofrequency ablation in a porcine model: positive and negative effects. J Vasc Interv Radiol 18(12):1561–1569
25. Laeseke PF, Sampson LA, Brace CL, Winter TC 3rd, Fine JP, Lee FT Jr (2006) Unintended thermal injuries from radiofrequency ablation: protection with 5% dextrose in water. AJR Am J Roentgenol 186(5 Suppl):S249–S254
26. Bagley DH, Terrill R, Javadpour N, Beazley RM (1976) Cryosurgery of the ureter in dogs. Invest Urol 14(3):241–245
27. Littrup PJ, Ahmed A, Aoun HD, Noujaim DL, Harb T, Nakat S et al (2007) CT-guided percutaneous cryotherapy of renal masses. J Vasc Interv Radiol 18(3):383–392
28. Froemming A, Atwell T, Farrell M, Callstrom M, Leibovich B, Charboneau W (2010) Probe retraction during renal tumor cryoablation: a technique to minimize direct ureteral injury. J Vasc Interv Radiol 21(1):148–151
29. Janzen NK, Perry KT, Han KR, Kristo B, Raman S, Said JW et al (2005) The effects of intentional cryoablation and radio frequency ablation of renal tissue involving the collecting system in a porcine model. J Urol 173(4):1368–1374
30. Hegarty NJ, Gill IS, Desai MM, Remer EM, O'Malley CM, Kaouk JH (2006) Probe-ablative nephron-sparing surgery: cryoablation versus radiofrequency ablation. Urology 68(1 Suppl): 7–13