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REVIEW ARTICLE

Image-guided cryoablation of endophytic renal tumors: technical considerations and current clinical outcomes—a narrative review

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ABSTRACT

Image-guided percutaneous cryoablation (CA) has become an increasingly accepted nephron-sparing treatment for small renal masses, including complex endophytic tumors. This narrative review synthesizes current evidence on technical considerations, oncologic outcomes, and safety profiles of CA for endophytic renal cell carcinoma (RCC), with critical evaluation of factors influencing local tumor control and complications. Dedicated endophytic cohorts report primary 5-year local tumor progression-free survival of approximately 64%–75%, improving to 87%–89% after re-ablation, with excellent cancer-specific survival and minimal impact on renal function. However, high anatomical complexity, size, and proximity to vascular or collecting system structures that suggest more endophytic locations pose significant technical challenges; furthermore, they are associated with increased risk of incomplete ablation and major complications compared with exophytic or mixed tumors. Advances in procedural techniques—including hydrodissection, pyeloperfusion, transarterial embolization, and selective arterial balloon occlusion—have expanded the boundaries of safely treatable disease. CA demonstrates similar safety and renal function preservation vs. partial nephrectomy, without the increase in rates of major adverse events or longer hospitalization. For appropriately selected patients with clinical T1 endophytic RCC, image-guided CA provides a safe and effective therapeutic option with durable oncologic outcomes and substantial quality-of-life benefits. Ongoing multicenter registry data and prospective studies are needed to refine risk stratification and optimize procedural strategies for challenging tumor locations.

KEYWORDS

Cryoablation, renal carcinoma, endophytic, hilar, interventional radiology

Renal cell carcinoma (RCC) represents approximately 2%–3% of all adult malignancies, and its incidence continues to rise due to the widespread use of cross-sectional imaging and the increasing rate of incidental detection. A substantial proportion of these lesions are classified as small renal masses (SRMs), most of which are localized (< 4 cm, cT1a) and amenable to nephron-sparing strategies.

Partial nephrectomy (PN) or robot-assisted PN (RAPN) is the reference standard for SRMs, preserving renal function and reducing the risk of chronic kidney disease progression.[1,2] However, endophytic renal tumors—defined as lesions with ≥ 50% of their volume embedded within the renal parenchyma—pose specific technical challenges.[3] These include limited visualization, restricted surgical access, and difficulties in achieving negative margins, which contribute to higher perioperative complication rates compared with exophytic lesions.[4]

Image-guided percutaneous cryoablation (CA) has emerged as a minimally invasive alternative, particularly suited for patients with significant comorbidities, solitary kidneys, bilateral lesions, or those unfit or unwilling to undergo surgery.[5,6] For SRMs in general, CA achieves technical success rates of 97%–99%, with long-term oncologic outcomes approaching those of PN.[7,8]

Major international guidelines, including those of the National Comprehensive Cancer Network (NCCN) (2026), European Association of Urology (EAU) (2025), and European Soci-

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ety for Medical Oncology (ESMO) (2024), now recognize thermal ablation as an acceptable alternative to PN for appropriately selected patients with clinical T1 RCC. These recommendations particularly endorse CA for patients who are frail, have high surgical risk, solitary kidneys, pre-existing renal impairment, hereditary RCC syndromes, or multiple bilateral tumors, with mandatory pre-ablation biopsy for histological confirmation.[9-11]

Despite the growing body of evidence supporting CA for localized RCC, endophytic tumors have traditionally been regarded as challenging or even contraindicated for percutaneous ablation.[12] Proximity to the collecting system raises theoretical concerns regarding urothelial injury, urinoma formation, and urinary fistulization;[13] adjacency to central vascular structures can create a heat sink effect, potentially compromising complete ablation,[7] and deeper intraparenchymal location increases risk of injury to surrounding organs during probe insertion.[14]

Main points

- Image-guided percutaneous cryoablation (CA) achieves high primary technical efficacy (86%–100%) and durable local control for T1 endophytic renal cell carcinoma (RCC), with most local tumor progression occurring in larger, more complex, or centrally located lesions.
- Careful patient selection using anatomical complexity scores (e.g., RENAL nephrometry score, ABLATE/sABLATE scores), detailed cross-sectional imaging, and mandatory pre-ablation biopsy is essential to identify suitable candidates and to triage high-complexity endophytic tumors to high-volume centers.
- Successful and safe treatment of endophytic tumors relies on careful technical planning, including optimized cryoprobe configuration, regular ice ball margin control, and systematic use of protective maneuvers, such as hydrodissection, pyeloperfusion, and, in selected cases, transarterial embolization or temporary renal artery balloon occlusion.
- Compared with partial nephrectomy, CA offers a similar safety profile as well as preservation of renal function, without the increase in major complication rates or hospital stay, which is particularly important in solitary kidneys and patients with baseline chronic kidney disease.
- Although anatomical complexity, size, and proximity to vascular or collecting system structures pose significant technical challenges and are associated with increased risk of incomplete ablation and complications, repeat CA provides effective salvage in most cases; metastatic progression is rare, and cancer-specific survival remains excellent, supporting CA as a first-line option for appropriately selected patients with T1a endophytic RCC.

However, over the past decade, increasing clinical and technical evidence has demonstrated the feasibility and safety of CA for endophytic renal lesions. Advances such as hydrodissection, pyeloperfusion, transarterial embolization (TAE), and temporary renal artery balloon occlusion have expanded the boundaries of safe ablation for complex tumor locations.[15-17] Furthermore, recent prospective studies and dedicated endophytic cohorts have reported encouraging long-term oncologic control and renal function preservation.[12,18] Experimental and histopathological data have also shown that urothelial integrity is maintained even when the ice ball extends adjacent to the collecting system, alleviating prior safety concerns.[13]

Recent comparative analyses have refined the role of CA among ablative techniques. A comprehensive meta-analysis of 133 studies involving 8,910 patients reported a 5-year local control rate of 90% for CA, compared with 95% for stereotactic body radiotherapy, 92% for radiofrequency ablation (RFA), and 86% for microwave ablation, with grade 3–4 adverse events[19] occurring in only 3% of CA cases.[20]

This narrative review synthesizes contemporary evidence on CA of endophytic renal tumors, evaluating technical success, oncologic and functional outcomes, and complication profiles, emphasizing factors influencing treatment success and safety. Finally, we provide evidence-based technical guidance for procedural planning, protective measures, intraoperative execution, and post-ablation surveillance. This review aims to equip interventional radiologists and multidisciplinary teams with the knowledge necessary to treat endophytic renal tumors safely and effectively using CA.

Methods

This narrative review synthesizes contemporary evidence on image-guided CA of endophytic renal tumors. A comprehensive literature search was performed using the PubMed and Scopus databases for publications between January 2012 and September 2025, employing keywords including CA, RCC, kidney tumor, endophytic, hilar, central, intraparenchymal, image-guided, and percutaneous. Additional literature was identified through manual review of reference lists and current clinical practice guidelines from NCCN (2026), EAU (2025), and ESMO (2024). Study selection was performed independently by two reviewers, with disagreements resolved by consensus. Studies were selected based on relevance, quality of evidence, and contribution to understanding technical success, oncological outcomes, or complication profiles. Emphasis was placed on dedicated endophytic tumor cohorts, comparative analyses, large prospective registries, and translational studies evaluating protective techniques and their mechanisms of action.

Technical considerations

This section provides evidence-based guidance for each phase of the procedure, with emphasis on strategies specific to endophytic tumor management.

Histological confirmation

Current guidelines[9-11] strongly recommend that a biopsy of lesions is performed prior to ablation to confirm diagnosis and guide ablation strategies.

Imaging assessment and tumor characterization

Contrast-enhanced computed tomography (CT) with arterial, nephrogenic, and excretory phases remains the standard for pre-procedural imaging, providing critical information on tumor vascularity, collecting system anatomy, and relationship to central vessels.[7] The minimum distance from tumor margin to collecting system should be measured precisely, as proximity <4 mm typically necessitates protective techniques.[15,16]

Magnetic resonance imaging (MRI) offers superior soft tissue contrast and may be preferred for purely endophytic tumors with a limited exophytic component, providing excellent visualization of the collecting system and assessment of tumor–ureter relationships.[18]

Risk stratification using anatomical complexity scores

The RENAL nephrometry score assigns points based on tumor radius, exophytic/endophytic properties, nearness to the collecting system, anterior/posterior location, and location relative to polar lines.[3] This score has been validated for CA outcomes prediction.[21] The ABLATE score, specifically designed for thermal ablation, demonstrated superior predictive value for ablation outcomes compared with the RENAL score.[22] A simplified version, the sABLATE score, maintains predictive accuracy while improving clinical practicality.[23]

For endophytic tumors specifically, high complexity scores (RENAL ≥ 10) should prompt consideration of referral to high-volume centers with extensive experience in complex ablations.[12]

Patient selection criteria

Ideal candidates for CA of endophytic tumors include patients with T1a lesions, comorbidities precluding surgery, solitary kidneys requiring maximal nephron preservation, or strong patient preference for minimally invasive treatment.[9-11] Percutaneous ablation is suitable for SRMs ≤ 3 cm and is an option for clinical T1b masses in selected patients not eligible for surgery.[10]

Image guidance selection

CT guidance remains the standard approach for renal CA, clearly delineating the relationship between the developing ice ball and critical structures, including the collecting system, renal sinus vessels, and adjacent organs.[7,12] Real-time visualization of ice ball formation, precise measurement of ice ball margins, and excellent spatial resolution for probe placement are key advantages.

MRI guidance is particularly valuable for purely endophytic tumors with poor CT visualization and offers superior soft tissue contrast without radiation exposure. In a dedicated study of 31 purely intraparenchymal tumors treated with MRI-guided CA, primary technical efficacy (PTE) was 94% with secondary technical efficacy of 100%, supporting MRI as a viable alternative when CT visualization is suboptimal.[18]

Patient positioning and anesthesia

Patient positioning depends on tumor location: prone for posterior tumors, lateral decubitus for lateral tumors, and supine for anterior lesions. General anesthesia (GA) is recommended for endophytic tumors due to anticipated longer procedure times and the need for patient immobility during critical probe manipulations.[6,12]

For right upper pole endophytic tumors inaccessible via the standard posterior approach, transhepatic access represents a viable alternative with secondary efficacy rates of 95%. Notably, the transhepatic approach eliminates pneumothorax risk, unlike superior intercostal approaches.[14]

Cryoprobe placement strategy

The number of cryoprobes correlates directly with tumor size and complexity.[21,24] For endophytic tumors, probe configuration must balance adequate tumor coverage with avoidance of collecting system injury. Hydrodissection is employed in approximately 39% of endophytic tumor procedures and should be considered mandatory when the collecting system is within 4 mm of the tumor margin.[12,15,16]

However, the number of probes has important safety implications. Analysis demonstrated that the use of more than three cryoprobes independently predicted major complications.[25] This association likely reflects both increased procedural complexity and greater collateral thermal injury to adjacent structures.

Freeze–Thaw protocol

The standard protocol consists of a double freeze–thaw cycle: initial freeze for 10 minutes, active thaw for 8 minutes, second freeze for 10 minutes, followed by passive thaw.[7] The target temperature at the tumor margin should reach −40°C to ensure complete cell death. Ice ball margins must extend 5–10 mm beyond the visible tumor to account for the peripheral transition zone where temperatures may not achieve lethal levels.[26]

Real-time monitoring of ice ball progression is critical for endophytic tumors.

Adjunctive techniques

Hydrodissection and air dissection

Hydrodissection involves the injection of fluid (typically normal saline or 5% dextrose in water) into the perinephric or peritoneal space.[16] An 18–20-gauge needle is placed under imaging guidance into the space between the tumor and the structure to be protected, with fluid injected incrementally (typically 100–500 mL total) and repeat imaging to confirm adequate separation (target > 10 mm).[16] For better visualization, a contrast medium can be added (Figure 1).

Carbon dioxide can also be used (Figure 2), offering advantages of the gas properties, such as thermal insulation and tendency to rise.[15]

In selected cases, gelatin-based hemostatic agents may also be used as a semi-solid insulating barrier, providing both mechanical protection and hemostatic effect (Figure 2). These materials are particularly useful when hydrodissection is technically limited or when a more stable separation between the kidney and adjacent structures is required.

Comprehensive analysis of protective techniques confirmed the safety and efficacy of hydrodissection and pyeloperfusion approaches.[16]

Pyeloperfusion and the role of ureteral catheters

For tumors within 4 mm of the collecting system or ureteropelvic junction, pyeloperfusion provides active thermal protection through continuous warm saline irrigation.[17] The technique requires cystoscopic placement of a 5–7 French ureteral catheter or antegradely placed nephrostomy tube, with continuous perfusion of warmed normal saline (approximately 37°C) during freeze cycles and placement of a Foley catheter in the bladder to drain excess fluid. There is currently no universally defined or validated recommendation for perfusion flow rate; however, perfusion under a pressure of approximately 80 cm H_2O has been suggested in the literature as a pragmatic technical reference rather than a standardized protocol.[27,28]

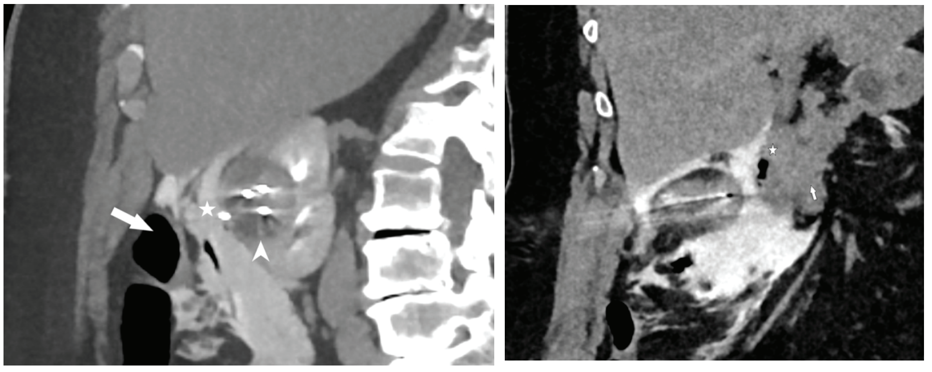


Figure 1. Use of contrast-opacified normal saline to protect critical structures. In the left picture, the forming ice ball (arrowhead) is separated by hydrodissection from the large bowel (arrow). The 18G needle used for the application of hydrodissection is also visible (asterisk). In the right picture, the ice ball is separated by hydrodissection from the duodenum (asterisk) and pancreas (arrow). The original image is from Národný onkologický ústav, Bratislava.

Evidence from one prospective cohort[6] showed that placement of double-J ureteral stents was statistically significantly associated with major complications after renal CA. However, this finding was not adjusted for anatomical complexity (e.g., RENAL score), and the stent is therefore best interpreted as a surrogate marker of challenging tumor location rather than an independent causal driver of complications. The authors recommend that double-J stents are reserved for cases in which ureteral protection is indispensable, and they should be removed as soon as feasible after CA to minimize stentrelated morbidity.

Transarterial embolization

TAE performed prior to CA is indicated for highly vascular tumors, large endophytic lesions (> 3.5 cm), or tumors with central location and concern for the heat sink effect from major vessels.[17,29] Pre-ablation embolization reduces tumor blood supply, eliminates the heat sink effect, may improve ice ball propagation, and reduces intraoperative hemorrhage risk.[17]

Gelatin sponges represent the preferred embolic agent based on technical efficacy comparable with ethanol but with considerably less intraprocedural pain.[29] Importantly, TAE does not negatively impact renal function, with no significant change in estimated glomerular filtration rate (eGFR) following combined TAE and CA.[17]

Temporary renal artery balloon occlusion

For selected cases of central endophytic tumors with major renal artery or vein proximity, temporary balloon occlusion during freeze cycles represents an advanced technique (Figure 3). Experimental studies demonstrate that arterial occlusion increases ice ball volume by 80% and achieves significantly lower temperatures.[30] Clinical application demonstrated 93% PTE, though major complications occurred in 21% of cases, higher than standard CA.[31] This technique should therefore be reserved for the most challenging central endophytic tumors where standard approaches are deemed inadequate.

Post-procedural management

Immediate post-ablation care includes tracking ablation to prevent bleeding along the cryoprobe paths, followed by immediate contrast-enhanced imaging to assess ice ball coverage and identify complications.[7,12] Standard cases typically require only overnight observation, with a mean hospitalization of 0.39 days reported in endophytic cohorts.[12]

Follow-up imaging with contrast-enhanced CT or MRI is recommended at 1, 3, 6, and 12 months, then annually.[7,8] Assessment focuses on the identification of residual unablated tumor (enhancement at 1–3-month imaging) vs. local tumor progression (LTP) (new or enlarging enhancement after initial complete ablation).

Oncologic and functional outcomes

Primary technical efficacy

PTE, defined as complete ablation at initial follow-up imaging, ranges from 86% to 100% across dedicated endophytic tumor cohorts, as shown in Graph 1.[12,18,31,32] In the largest multicenter analysis from the European Renal Cryoablation Ablation registry, which evaluated risk factors for residual unablated tumor, PTE overall was 97%, whereas tumors adjacent to vessels (usually centrally located/complex) had PTE of 90%.[7]

Incomplete ablation typically manifests as focal residual enhancement at the tumor margin detected on first follow-up imaging within 3 months. Risk factors for residual tumor include proximity to central renal vessels, nearness to the collecting system of < 4 mm, large tumor size > 4 cm, and high RENAL nephrometry scores ≥ 10. The rates of exophytic or endophytic portions of the tumor, as well as the anterior/posterior location of the tumor and the use of GA, did not reach significance. Importantly, central vessel contact, particularly with the main renal artery or

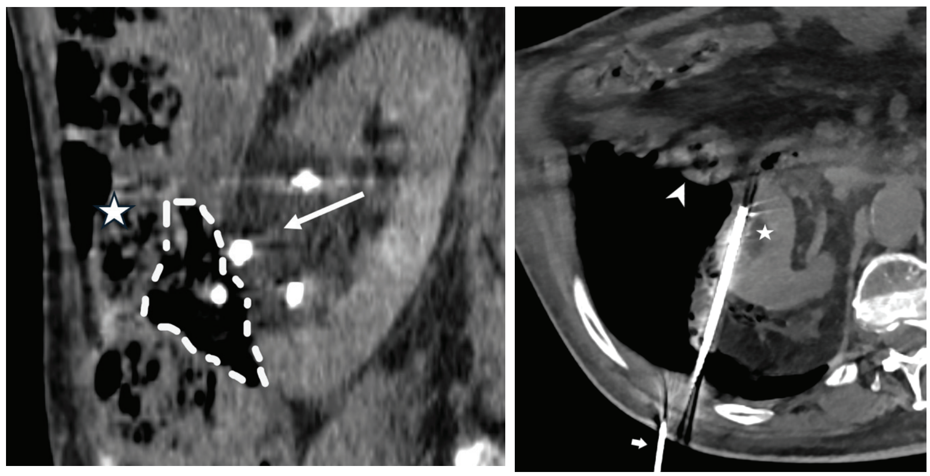


Figure 2. On the left, gelfoam (dotted line) is used to separate the large bowel (asterisk) from the ice ball (arrow). On the right, carbon dioxide is used to protect the large bowel (arrowhead) from the ice ball (asterisk). An 18G needle used for insufflation is also visible (arrow). The original image is from Národný onkologický ústav, Bratislava.

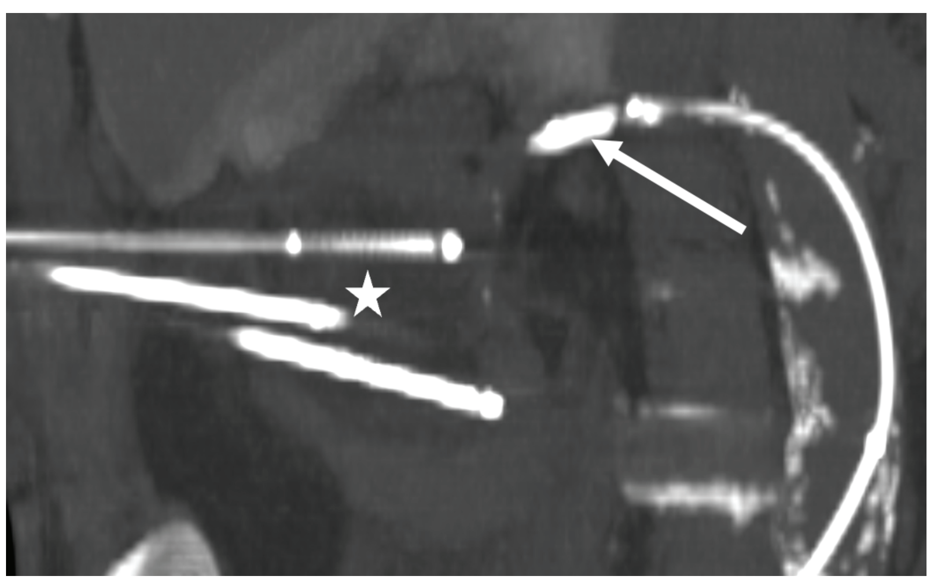


Figure 3. A balloon (arrow) is used to occlude the renal artery to increase the ice ball volume (asterisk). The original image is from Národný onkologický ústav, Bratislava.

vein, is the strongest independent predictor of incomplete ablation, with an odds ratio of 5.29 and a PTE of 90%.[7] This phenomenon reflects the heat sink effect whereby blood flow prevents adequate freezing temperatures at the perivascular tumor margin.

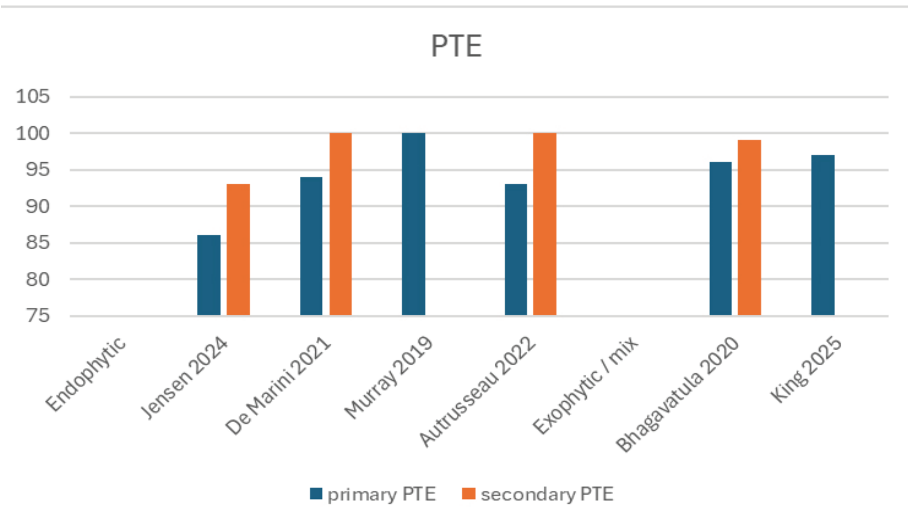
When residual enhancement is detected, repeated CA is a safe and effective salvage strategy. Secondary ablation following incomplete primary treatment achieves complete ablation in 93%–100% of cases without significantly increased complication risk.[12,18,31,33]

Local tumor progression-free survival

LTP-free survival (LTPFS) is defined as the time from the ablation to the first radiologically confirmed LTP (i.e., new contrast enhancement within a previously completely ablated zone). LTP occurs in up to 17% and 36% of endophytic tumors at 1 and 5-year followup, respectively, compared with 5% and 10% in mixed tumor cohorts. After re-ablation, the proportion of patients with LTP decreases up to 7% and 25% at 1 and 5 years, as shown in Table 1.[12,18,20,31-33] The cumulative incidence of local progression thus continues to rise with extended surveillance, underscoring the importance of longterm imaging followup after renal CA.

In the study by Bhagavatula et al.,[33] LTPFS remained stable beyond 5 years, with LTPFS of 95% at both 10 and 15-year followup. However, this cohort consisted of mixed renal tumors; therefore, these longterm outcomes cannot be directly extrapolated to purely endophytic tumor populations.

It is critical to recognize that many presumed late local recurrences may actually represent initially incomplete ablations that were not detected on early imaging due to benign postablative enhancement mimicking complete treatment.[34] This highlights the importance of expert radiological assessment of initial postablative imaging with particular attention to perivascular margins.



Graph 1. Comparison of primary and secondary technical efficacy in endophytic and exophytic cohorts of tumors. PTE, primary technical efficacy.

Metastasis-free survival and cancer-specific survival

Metastasis-free survival (MFS) and cancer-specific survival (CSS) are difficult to characterize for purely endophytic lesions, as only two dedicated series have reported these endpoints. In the cohort by Jensen et al.,[12] comprising 56 endophytic RCCs with a mean followup of 996 days, no patient developed metastatic disease or died from RCC, yielding 100% MFS and CSS within the available followup window. In contrast, De Marini et al.[18] observed distant metastases in 5 of 31 patients (16%), corresponding to 1, 3, and 5-year MFS estimates of 93%, 83%, and 75%, respectively, although no deaths attributable to RCC occurred during followup, resulting in 100% CSS in that series as well.

Together, these limited data suggest that metastatic progression after CA of endophytic T1 RCC is uncommon, although larger cohorts with longer surveillance are required to define longterm systemic control more precisely.

Overall survival must be interpreted in the context of patient comorbidity. Given that CA cohorts include elderly patients and those with significant medical comorbidities, overall survival rates of 91%–97% at 3 years reflect competing risks of mortality from cardiovascular and other systemic diseases rather than renal cancer.[8,33]

Table 1. Local tumor progression-free survival in endophytic and mixed renal tumors treated with cryoablation, showing improved longterm (5 year) outcomes after reablation in endophytic cohorts, approaching the rates observed in mixed tumors[12,18,20,31-33]

Follow-up	1 year	2 or 3 years	5 years
Endophytic			
De Marini et al.,[18] 2021 (primary)	83%	64%	64%
De Marini et al.,[18] 2021 (secondary)	93%	89%	89%
Jensen et al.,[12] 2024 (primary)	93%	87%	74%
Jensen et al.,[12] 2024 (secondary)	96%	93%	87%
Murray et al.,[32] 2019	100%	90%	75%
Autrusseau et al.,[31] 2022 (primary)	93%	86%	N/A
Autrusseau et al.,[31] 2022 (secondary)	100%	100%	N/A
Exophytic/mix			
Huang et al.,[20] 2025	95%	94%	90%

N/A, not applicable.

Renal function preservation

Preservation of renal function represents an important advantage of CA. Among studies specifically focused on endophytic tumors, only three have reported longitudinal eGFR data, describing relative declines of approximately 17%–20% or a decrease of 2.2 mL/minute after CA.[12,18,31] In the series by De Marini et al.,[18] application of the Kidney Disease: Improving Global Outcomes chronic kidney disease classification showed that 13 patients (42%) experienced a onestage decline in renal function and 2 patients (6%; both with a solitary kidney) a two-stage decline, with only 1 of 31 patients (3%) ultimately requiring hemodialysis because of severe renal impairment.[18] Jensen et al.[12] documented a mean eGFR change of 2.2 mL/minute, with no patients requiring dialysis. In larger mixed cohorts, authors report only modest reductions in renal function, typically within 9% of baseline eGFR.[8,15] Taking into account that the day-to-day biological variation of creatinine clearance is approximately 10% even in otherwise healthy individuals, these modest eGFR changes appear clinically acceptable for a nephronsparing procedure such as CA.[15]

In comparative analyses, CA appears to preserve renal function at least as well as PN. In a systematic review and metaanalysis, Patel et al.[35] found no significant difference in postoperative eGFR between PN and thermal ablation. For patients with solitary kidneys or baseline chronic kidney disease, this nephron-sparing advantage becomes clinically critical in preventing progression to dialysis dependence.

Complications

Safety profile and complication rates

CA of endophytic renal tumors demonstrates a reasonable safety profile when performed by experienced operators with appropriate use of protective techniques. The overall complication rate ranges from 23% to 36% across contemporary series, with major complications (Clavien–Dindo grade 3 or higher)[36] occurring in 3%–10% of procedures.[12,18,25,32]

In a dedicated prospective multicenter comparative study evaluating complications following PN vs. CA for T1 RCC, Junker et al.[25] documented a similar overall complication rate after PN or CA (23%).

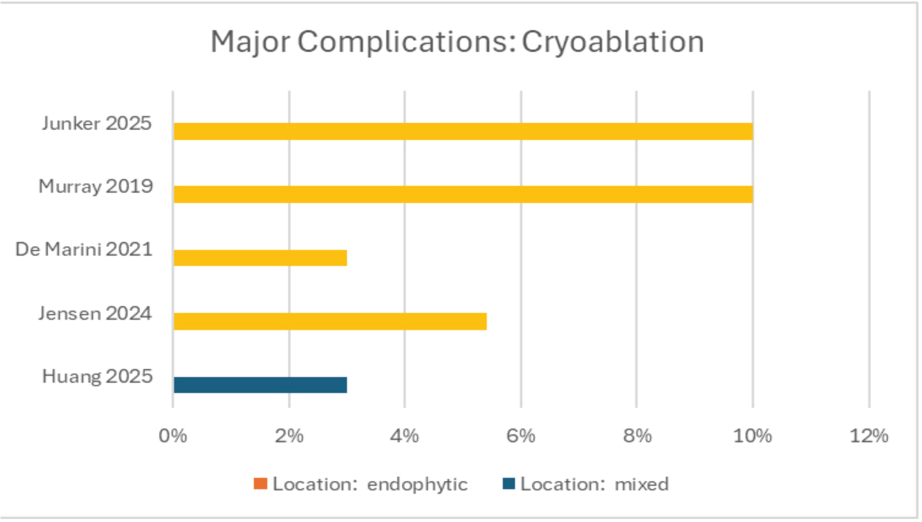
More severe complications (Clavien–Dindo grade 3 or higher) account for 3% after CA without specification of tumor complexity,[20] as shown in large meta-analyses with 3,726 patients. In the studies dedicated to the specific subgroup of completely endophytic tumors, major complications account for 5.4%,[12] 3%,[18] 10%,[32] and 10%,[25] although the number of patients was limited (Graph 2).[20]

Minor complications are mostly represented by self-limited perinephric hematoma (5%–8%).[12,37] Other minor complications are pain, post-ablation syndrome, abscess, urinary tract infection, and pyelonephritis. The latter two occur in 1%–2% of cases, more frequently in procedures requiring pyeloperfusion or ureteral stent placement.[6,25]

Among major complications, the most frequent is significant hemorrhage requiring transfusion or angiographic embolization (2%), followed by creation of an abscess, requiring drainage (Figure 4).[6,37]

Collecting system injury manifesting as urinoma, hematuria (Figure 5), or urinary fistula occurs rarely despite the proximity of endophytic tumors to the renal pelvis. In Jensen et al.'s[12] dedicated endophytic cohort, only 1 of 56 patients (1.8%) developed a urinoma requiring percutaneous drainage. This low rate of urothelial complications validates experimental data demonstrating preservation of collecting system integrity despite ice ball involvement.[13]

Bowel injury represents a potentially catastrophic but rare complication (Figure 6).



Graph 2. Major complication rates after cryoablation for endophytic/high-complexity vs. mixed renal tumors, highlighting higher rates in the endophytic group.

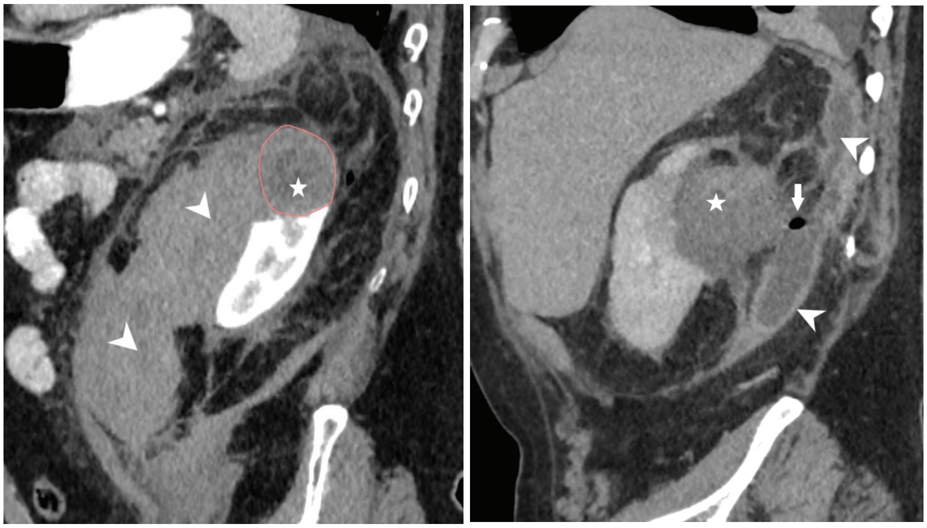


Figure 4. On the left, the formation of hematoma (arrowheads) directly connected to the ice ball (red line, asterisks) can be seen. On the right, the creation of an abscess (arrowhead) with a gas bubble (arrow) in the tract of needles can be seen. The postablation zone is also depicted (asterisk). Národný onkologický ústav, Bratislava.

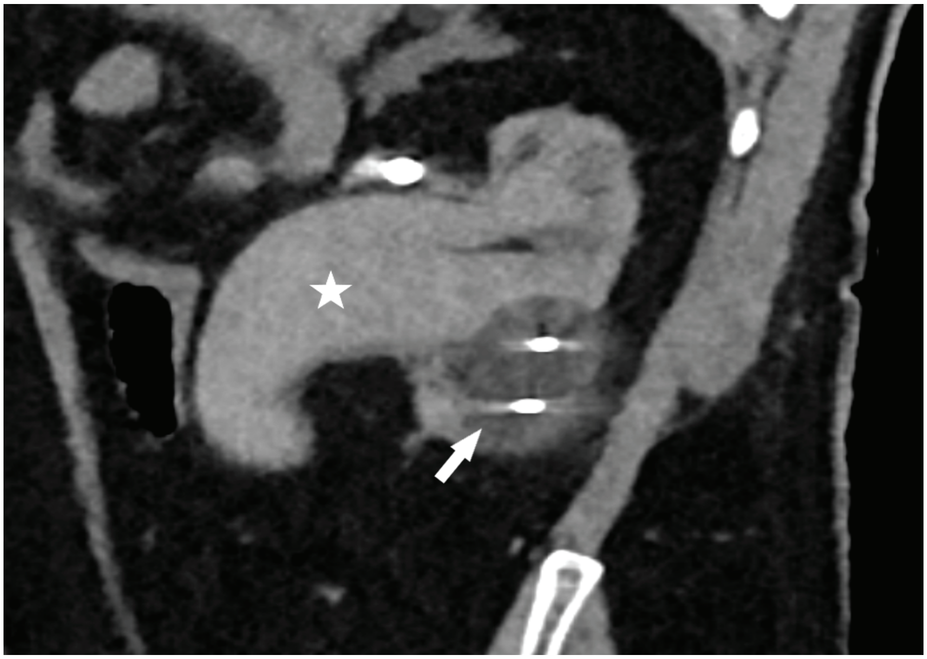


Figure 5. A hemorrhage in the collecting system and its widening are seen (asterisk), directly caused by the trajectory of the needle. The ice ball is also visible (arrow). Národný onkologický ústav, Bratislava.

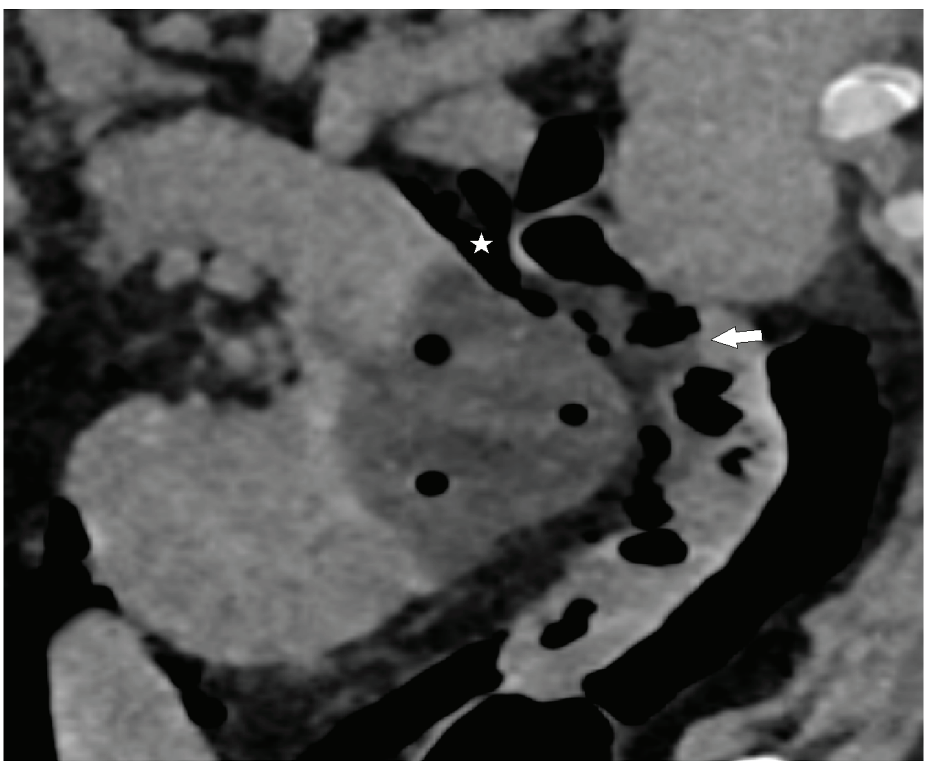


Figure 6. The ice ball directly involves the wall of the large bowel (arrow). Air dissection was used but with insufficient effect (asterisk). Národný onkologický ústav, Bratislava.

Proper patient positioning, hydrodissection to displace adjacent organs, and careful probe trajectory planning minimize this risk to <0.5% in experienced hands.[16,37] When bowel injury does occur, early recognition and surgical intervention are mandatory.

Predictors of complications

Use of more than three cryoprobes independently predicts major complications, likely reflecting both tumor complexity and increased collateral tissue injury.[25] Placement of double-J ureteral stents was associated with a higher rate of major complications;[6] however, this likely reflects the complexity of the treated lesion rather than a direct harmful effect of the stent itself. High RENAL nephrometry scores (≥ 10) and hilar tumor location increase complication risk 2- to 3-fold compared with peripheral exophytic lesions.[21,22] Patient factors, including obesity (body mass index ≥ 35), chronic kidney disease (eGFR ≤ 60 mL/min), and anticoagulation therapy similarly elevate complication risk.[6,37]

Comparative safety

When compared with PN, CA demonstrates similar safety across multiple comparative analyses, although the CA cohorts include older, frailer patients deemed unfit for surgery. A prospective multicenter study by Junker et al.[25] documented a similar overall complication rate after PN or CA (23%). More severe complications (grade 3 or higher according to the Clavien–Dindo classification)[36] account for 3% after CA without specification of tumor complexity,[20] as shown in large meta-analyses with 3,726 patients, whereas in subgroup of completely endophytic they account for 5.4%,[12] 3%,[18] 10%,[32] and 10%,[25] although the number of patients were limited (56, 31, 47, and 61, respectively). In comparison, a multicenter analysis comparing complications after RAPN pointed out that after resection of an endophytic tumor, Clavien–Dindo grade ≥ 3 complications occurred in up to 5% of patients, compared with 3% for mesophytic or 1% for exophytic tumors.[4] Despite these higher rates in endophytic lesions, the overall incidence of Clavien–Dindo grade ≥ 3 complications after both CA and RAPN remains low. However, given the limited sample sizes and the lack of direct head-to-head comparisons, randomized trials comparing CA and RAPN specifically for completely endophytic renal tumors are warranted.

Image-guided CA has evolved from a niche technique reserved for poor surgical candidates to an evidence-based first-line option for appropriately selected patients with endophytic renal tumors. Contemporary data demonstrate that technical challenges can be successfully overcome through meticulous procedural planning, use of protective and adjunctive techniques, and advanced expertise in renal tumor ablations.

The oncologic outcomes synthesized in this review suggest that CA achieves local tumor control broadly comparable with that reported after PN for T1a endophytic RCC. Across the endophytic CA series, PTE ranges from 86%–100%, with 3 and 5-year-LTPFS of 64%–87% and 64%–75%, respectively; after re-ablation of residual or recurrent tumor, pooled estimates improve to 93%–100% technical efficacy and 89%–100% and 87%–89% secondary LTPFS at 3 and 5 years.[12,31,32] These figures compare favorably with contemporary surgical cohorts of completely endophytic tumors, in which tumor recurrencefree survival is approximately 94% at a median 3-year followup after PN.[38]

Direct comparison of the safety profile of CA for endophytic renal tumors with that of RAPN remains challenging because dedicated studies are lacking. Surgical series of RAPN show that endophytic lesions carry a significantly higher postoperative complication risk than mesophytic or exophytic tumors, underscoring the technical complexity of these cases.[4] A similar pattern is observed in CA cohorts, where complication rates rise in purely endophytic series, albeit with wide confidence intervals due to limited sample sizes.[12,18,25,32] In the prospective nonrandomized study by Junker et al.,[25] overall and major complication rates were comparable between PN and CA for cT1 RCC in a mixed population, suggesting that minimally invasive ablation can achieve a safety profile similar to surgery;[6] whether this equivalence also holds specifically for deeply endophytic tumors remains to be confirmed in future comparative studies.

Renal function preservation constitutes a longterm aratalım long-term yapaım benefit of CA. For endophytic tumors, changes in eGFR have been reported in only three small series totaling 101 patients; in the largest of these, Jensen et al.[12] observed a mean eGFR decline of just 2.2 mL/minute at a mean 114day followup, with no patients requiring dialysis. These findings contrast with surgical series of endophytic tumors, in which the proportion of patients experiencing > 25% loss of renal function at 12 months ranges from approximately 12% after RAPN to 26% after open PN.[38] For patients with bilateral tumors, hereditary RCC syndromes, or preexisting chronic kidney disease, such nephron preservation may delay or prevent progression to dialysis dependence and thereby substantially improve longterm quality of life.

Direct comparative data between different thermal ablation modalities in predominantly or completely endophytic renal tumors are not available. Existing head-to-head studies in unselected T1a SRMs suggest that RFA, CA, and microwave ablation achieve comparable short to intermediateterm oncologic control and preservation of renal function, with similar overall complication rates.[20,39] However, central and endophytic tumors appear more challenging for RFA, whereas CA may offer technical advantages due to improved visualization of the ice ball and reduced susceptibility to perfusion-mediated heat sink effects. In addition, CA appears safer for the collecting system wall; collecting system injuries have been reported more frequently with RFA than with CA in clinical series.[13,37,40]

Limitations of the current evidence base must be acknowledged. Most published series comprise relatively small cohorts from high-volume centers with extensive ablation expertise, potentially limiting generalizability. Long-term oncologic data > 5 years remain limited, though available 10-year data from mixed cohorts suggest durable local control. Randomized controlled trials directly comparing CA with PN specifically for endophytic tumors are lacking, and selection bias inherent to observational studies precludes definitive comparative conclusions.

Given that CA is preferentially offered to frail patients, patients with solitary kidneys, or patients with baseline renal impairment, and in view of its nephronsparing nature, CA of endophytic or otherwise complex tumors may ultimately emerge as a preferred option for this high-risk subgroup, provided ongoing research validates its longterm safety and efficacy.

It is essential that high-complexity endophytic cases are concentrated in high-volume centers with established expertise in renal tumor ablation. Advanced protective maneuvers (such as hydrodissection, pyeloperfusion, or arterial balloon occlusion) during percutaneous renal ablation are associated with a steep learning curve and require substantial operator experience, which may limit their widespread adoption.

Future investigations should also focus on the precise identification of high-risk centrally located lesions with the greatest propensity for local progression after ablation, continued refinement of protective strategies for hilar and deeply endophytic tumors to expand the anatomical limits of safely treatable disease, and structured postablation surveillance in collaboration with experienced genitourinary radiologists, with particular attention to perivascular and collecting-system-adjacent regions. Moreover, establishing multicenter prospective registries with standardized outcome definitions, uniform reporting of local control, and extended longitudinal followup is essential for generating highquality evidence and consolidating the role of CA as a definitive treatment option for endophytic RCC.

CA has evolved into a robust option for endophytic RCC when performed in appropriately selected patients and in experienced centers. Across contemporary endophytic cohorts, CA achieves high primary and secondary technical efficacy, durable 3–5 year local tumor control, low rates of metastatic progression, and excellent CSS, while generally preserving renal function and maintaining an acceptable complication profile. Higher risks can be mitigated through rigorous preprocedural imaging assessment, use of validated anatomical complexity scores, careful procedural planning, and systematic application of protective maneuvers, such as hydrodissection, pyeloperfusion, TAE, or temporary renal artery balloon occlusion, in selected cases. For selected patients, particularly those with significant comorbidities, solitary kidneys, hereditary syndromes, or baseline chronic kidney disease, CA should be considered alongside RAPN as a frontline nephronsparing strategy, offering a favorable balance between oncologic efficacy, procedural safety, and longterm renal function preservation. Ongoing multicenter registries and prospective comparative studies remain essential to refine risk stratification, optimize technical approaches, and clarify the longterm role of CA in the management algorithm for endophytic renal tumors.

Footnotes

Conflict of interest disclosure

The authors declared no conflicts of interest.

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