Percutaneous Thermal Ablation for Treatment of T1a Renal Cell Carcinomas

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KEYWORDS

• Thermal ablation • Cryoablation • Radiofrequency ablation • Microwave ablation • Percutaneous ablation • Minimal invasive surgery • Partial nephrectomy • Radical nephrectomy

KEY POINTS

- Based on Surveillance, Epidemiology, and End Results (SEER) studies, most renal cancers are low grade and slow growing. Since 1996, percutaneous thermal ablation (TA) techniques such as cryoablation, radiofrequency ablation, and microwave ablation have gained widespread acceptance for treatment of renal masses less than 3 cm in patients who are not surgical candidates.
- There are now long-term single-center studies showing excellent outcomes for T1a renal cell carcinoma (RCC), comparable to partial nephrectomy without affecting renal function and with much lower rates of complications.
- However, there are no multicenter randomized controlled trials of multiple ablative modalities or comparison with partial nephrectomy, and most studies are single-arm observational studies with short-term and intermediate follow-up.
- For treatment of stage T1a RCC, percutaneous TA is an effective alternative to surgery with preservation of renal function, low risk, and comparable overall and disease-specific survival. Ideally, randomized phase 3 trials should compare surgical resection with ablative techniques.

INTRODUCTION

Over the past 30 years, the recognition of the importance of renal function preservation has led to the development or adoption of several nephron-sparing treatment options of clinical stage T1a (<4 cm) renal masses, including (open, laparoscopic, and robotic) partial nephrectomy (PN), thermal ablation (TA), and active surveillance (AS).[1–4] The procedure risk, underlying renal function is always weighed against the patients' cardiovascular morbidity and mortality.[3–6] Since initial case reports in 1996 and 1997, the adoption of TA for the treatment of clinical T1a renal masses has increased dramatically with favorable safety, efficacy, and preservation of renal function, as a minimally invasive alternative therapy for poor surgical candidates.[7–10] TA has now evolved to become an alternative to surgery for treatment of clinical T1a renal masses in 2019 National Comprehensive Cancer Network guidelines.[1]

More sophisticated understanding of the biology and natural history of solitary incidentally detected renal masses has led to an improved and less-invasive overall management paradigm. AS is now frequently recommended because of recognition of slow tumor growth rates, and wide prevalence of low tumor grade and low risk of adverse metastases.[11] Overall, patient care and counseling have improved with a multidisciplinary approach.[12]

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Clinical considerations for TA therapy include patient age, comorbidities, and life expectancy as well as risk of developing renal failure or chronic kidney disease and the potential need for dialysis.[13] In patients with multifocal or bilateral renal masses, or any positive family history of renal neoplasm, genetic susceptibility needs to be considered.[11,14] This article reviews the performance of different TA modalities and the goals of ablation therapy for treatment of renal cell carcinoma (RCC).

WHAT IS THE IMAGE-GUIDED THERMAL ABLATION?

Percutaneous image-guided tumor ablation refers to a group of minimally invasive treatment options using primarily ultrasound (US) and/or computed tomographic (CT)-guided needle-based thermal energy applicators to destroy focal malignancies.[4] Over the past 24 years, these techniques have proliferated and become routine for treatment of renal tumors.[14]

TA techniques eradicate malignant cells by inducing irreversible thermal cellular injury.[3] In TA therapy, the total projected energy delivered to the target is proportional to the radius^3 of the lesion target. Thus, the overall required energy for small lesions (1–2 cm) is significantly less than for intermediate (2–3 cm) and larger (3–5 cm) lesions, fundamentally limiting the utility of TA for large lesions.[2] The main goal of ablation procedures is to remove all viable malignant cells by treating the designated target and beyond into the visible tumor margin, typically the normal surrounding parenchyma up to 0.5 cm.[15]

TA techniques for treatment of renal tumors are either cold (cryoablation) or heat (electromagnetic [ie, radiofrequency [RF], microwave, laser] or US) based.[15–17] Cryoablation, first described for renal tumor ablation in 1996, induces cell death and apoptosis with a dual freeze-thaw cycle causing intracellular and extracellular ice formation (visualized as an "ice ball" on imaging). The goal is to reach to less than −140°C in the center of the lesion, −40°C at the margin of the lesion, and 0°C at the edge of the ice ball to create a near spherical ablation.[18] Subsequently, the thaw cycle ruptures the osmotic cellular phospholipid membrane.[15] The available cryoprobes are 13- to 17-G needles with internal shafts that circulate compressed argon gas, which produces dramatic cooling by dropping the gas pressure, called the Jewell-Thompson effect.[4] Helium gas is used for the thaw cycle. An array of up to 8 probes can create a large fused ice ball to treat lesions up to 5 to 6 cm, generally much larger than radiofrequency ablation (RFA) or microwave ablation (MWA)[19] (**Fig. 1**).

Heat-based ablation was once synonymous with RFA and was first described in 1997 for treatment of RCC.[4] RF energy is an electrical impedance-controlled pulsed current, generally at 500 MHz, which induces tissue heating around straight or expandable multitined needle electrodes placed within the target. Current passes from the generator through the electrode into the target tissue and is grounded through pads on the patient's skin, resulting in active frictional heating to greater than 60°C by rapidly oscillating water molecules at areas of high current density near the electrode, resulting in immediate coagulative necrosis of heated tissue. Nonelectric thermal diffusion (conductive heating) also occurs and results in a larger volume of cell death than beyond direct electric heating.[20] Conductance is an important property of RFA, and tissue heating resulting in charring can decrease conductance, reducing effectiveness. A variety of RF needle designs include expandable multitined hooklike electrodes and straight internally cooled needles that allow for up to 3 probe placements simultaneously.[19]

MWA, approved for use in the United States and used for RCC treatments since 2008, is a newer needle-based TA that heats target tissues to greater than 100°C because of more efficient frictional heating of water molecules by wavelike electromagnetic energy at either 915 MHz or 2450 mHz.[21] Microwave energy is produced by generating dielectric hysteresis (rotating dipoles) at either 915 MHz or 2.45 GHz from the exposed tip of a needlelike probe (antenna) into surrounding tissue, resulting in more efficient and robust frictional heating of water molecules in tissue to greater than 100°C.[19] Because of the wave property of MWA, permittivity is a useful metric determining efficacy, and marked differences in permittivity between tumors and surrounding tissue may allow better treatment with MWA. Unlike RFA, MWA is also not affected by carbonization or impedance and does not require grounding pads.[15] In addition, diffusion of microwave energy is enhanced in neoplastic tissues because permittivity is generally greater in neoplastic tissues than in normal tissues.[22] MWA is much less dependent on electrical conductivity of tissue because the energy delivery is less limited by the exponential rising electrical impedances of heated tissue in contrast to RFA.[4] For successful ablation, the tissue temperature should be maintained in a range of 100°C to 120o̲C to ablate lesion adequately and avoid carbonization around the needle tip because of excessive heating.[23] The severity of the thermal damage depends on tissue perfusion,

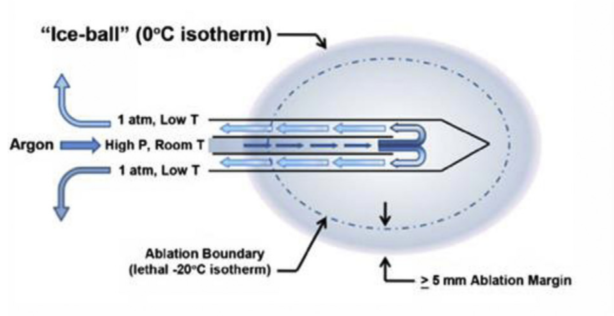

Fig. 1. Cryoablation probe design with ability to create different ice-ball sizes: High-pressure argon gas depressurizes and equilibrates with ambient pressure at the tip of the probe and supercools with resulting ice ball by Joule-Thomson effect. The edge of the ice ball is nonlethal. The lethal isotherm at −20°C is 5 mm deep to the outer edge, varying with probe design. Generally, ice-ball size is proportional to probe thickness (gauge) because larger gauge size allows for faster gas flow. P, pressure; T, temperature. (*From* https://oncohemakey.com/cryoablation-mechanism-of-action-and-devices/ and *Courtesy of* Kemal Tuncali, MD, Nobuhiko Hata, PHD, and Stuart G. Silverman, MD; https://ncigt.org/mri-guided-cryoablations-liver-and-kidney-tumors; with permission.)

tissue temperature, and the duration of heating[12] (**Figs. 2** and **3**). MWA occurs more rapidly than RFA and cryoablation.

WHAT ARE THE IMPORTANT FACTORS THAT CAN INFLUENCE THE RESULT OF THE ABLATION?

The complete and adequate cell destruction by TA requires that the entire target and an ablative margin of 0.5 to 1 cm reach to the optimal cytotoxic temperatures.[24] However, the ability to heat or cool the tissue, particularly for large volumes, is influenced by several factors like the amount of energy deposited (number of probes), tissue perfusion, the absolute temperature achieved at any point of target, and the heterogeneity of tissues.[25]

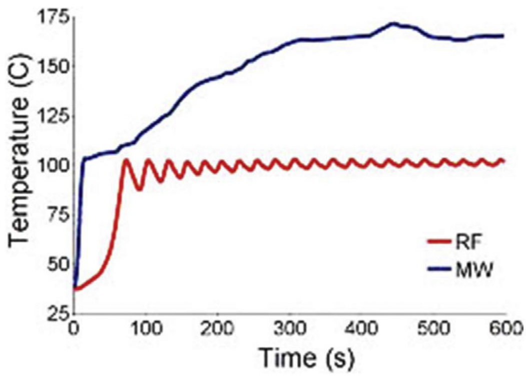

Fig. 2. The temperature differences between an MWA system and the RFA. As it shows, microwave energy is hotter and faster than RF. (*From* Hinshaw JL, Lubner MG, Ziemlewicz TJ, Lee FT, Jr., Brace CL. Percutaneous tumor ablation tools: microwave, radiofrequency, or cryoablation–what should you use and why? Radiographics 2014;34(5):1344-1362; with permission.)

Typically, TA times are based on the size and location of the lesions. Small exophytic renal lesions require the least time and energy, and large central lesions require the most time and energy because of low- and high-thermal dissipation, respectively, from surrounding heat sink inducing large central blood vessels and high and low insulation, respectively, from surrounding perinephric fat.[17]

For treatment planning, the 5-parameter nephrometry score is useful for classifying the complexity of renal masses for PN and adapted for percutaneous ablation based on anatomic characteristics: tumor size, proximity to collecting system or renal sinus, and location (exophytic or endophytic, anterior or posterior, and orientation to polar lines).[26–29] These parameters are for planning but are not associated with oncologic outcomes independently.[30] McClure and colleagues[29] first showed that higher nephrometry scores had a small adverse effect on efficacy of RFA, and this was later confirmed by Camacho and colleagues[26] for RFA and by Ierardi and colleagues[31] and Klapperich and colleagues[32] for MWA. However, in our previous study[30] this relationship was not found for MWA (**Fig. 4**).

PREFERENCE AND CHOICE OF ABLATION MODALITY

Cryoablation is the dominant percutaneous TA treatment modality for T1a RCCs because of its efficacy and ability to clearly visualize the zone of ablation (ice ball) under CT or MR guidance.[33,34] The ice ball is the near spherical ablation zone with sharply demarcated margins encompassing the target renal mass with 5- to 10-mm surrounding margin so that the margin of the lesion is at the

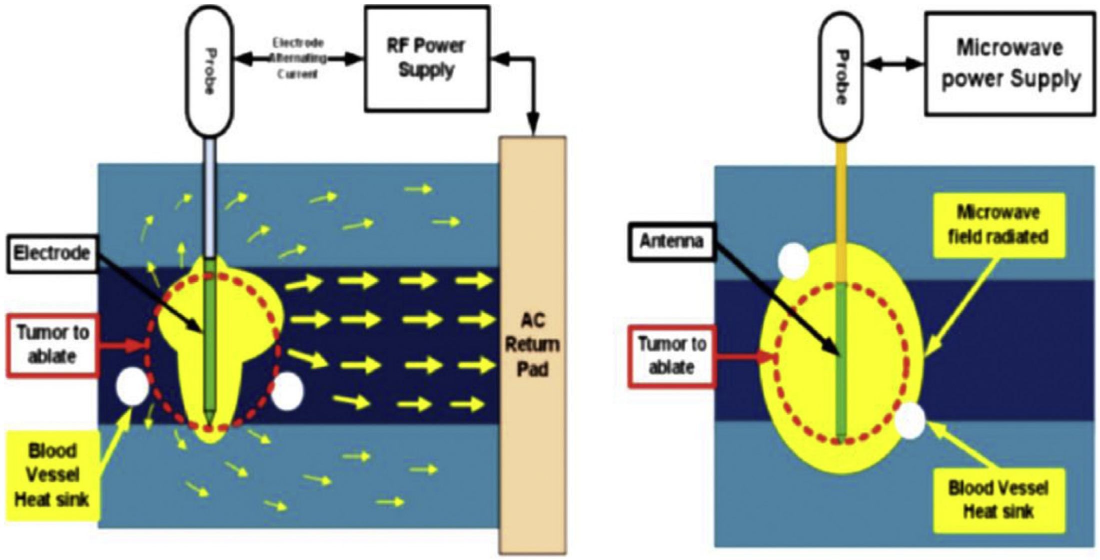

Fig. 3. Comparison of RFA and MWA: RFA (*left*) is a current-based system that often results in smaller and more irregular, scattered ablation zones because of uneven current flow, relatively low thermal temperatures, heat dissipation in perfused tissue, and poor propagation in charred tissues. MWA (*right*) is a much more efficient wave-based heating process with high thermal temperatures, much less heat dissipation, and less heat sink resulting in more homogeneous and larger ablation zones in shorter time. AC, Alternating current.

−40°C isotherm, whereas the center is ideally less than −140°C.[18] This ability to visualize the ablation zone is not possible with many heat-based systems under CT guidance, but the echogenic cloud of ablation can be seen with US guidance.[18] However, radiologists who are unfamiliar with US monitoring prefer the CT-based monitoring with the ice ball. Also, current systems can power up to 8 cryoprobes simultaneously, which increases volume and efficacy of cryoablation for treating both T1a and T1b renal masses.[35] Like all TA modalities, cryoablation efficacy is limited by dissipation of cryoenergy (cold sink) from tissue perfusion by large arteries or veins. Large-volume cryoablation uniquely has a small but elevated risk for cryoglobulinemia or cryoglobulinuria, with associated risk of transient acute tubular necrosis. There is also an approximately 10-fold higher risk of hemorrhage relative to RFA and MWA.[17,36] Despite this, radiologist training, equipment preference, and experience are frequently the primary drivers of decisions regarding selection of TA type. Cryoablation is preferred for treating metastatic renal cancer lesions in the renal bed, adjacent to the spine or bowel, in the retroperitoneum, pleura, and subcutaneous tissue.[17,36] Other complication rates (besides bleeding) for cryoablation are similar to other ablation modalities.[37]

Cryoablation, RFA, and MWA rely on skills of US and/or CT guidance to precisely place probes into renal lesions while avoiding adjacent normal tissues like vessels, bowel, renal pelvis, and ureter.[24] Probes are placed into the deepest portion of the tumor initially and then retracted. RF and MW probes may have to be repositioned at opposite margins or may need to be circumferentially placed within larger tumors (>3 cm) to create larger overlapping zones of ablation. With cryoablation, up to 8 probes may be inserted within larger tumors. Continuous US monitoring during RF and MW ablation is important, because the operator monitors the rapidly forming heat generated release of water vapor and nitrogen, creating an echogenic cloud (“heat ball”), similar to the intermittent CT or MR imaging of the much slower forming ice ball of cryoablation. Both are surrogate markers of efficacy for TA.

The best marker of efficacy for any technique is to immediately perform a CT scan and/or MR imaging to see the predictable changes of TA. These changes include a smaller nonenhancing dense lesion on CT, T1 hyperintense or T2 hypointense lesion on MR imaging, and echogenic lesion on contrast US with a surrounding V-shaped nonenhancing region owing to thermal infarction of the segmental artery.[4]

One of the limitations of RF ablation is related to carbonization of tissues adjacent to the electrode, which decreases conductivity and increases tissue impedance owing to high temperatures greater than 60°C. A variety of strategies have been developed to compensate, including water

RENAL Nephrometry score

	1pt	2pts	3pts
(R)adius (maximal diameter in cm)	≤4	>4 but <7	≥7
(E)xophytic/endophytic properties	≥50%	<50%	Entirely endophytic
(N)earness of the tumor to the collecting system or sinus (mm)	≥7	>4 but <7	≤4
(A)nterior/posterior	No points given. Mass assigned a descriptor of a, p, or x		
(L)ocation relative to the polar lines[a] [a]Suffix 'h' asisigned if the tumor touches the main renal artery or vein	Entirely above the upper or below the lower polar line	Lesion crosses polar line	>50% of mass is across polar line (a) or mass crosses the axial renal midline (b) or mass is entirely between the polar lines (c)

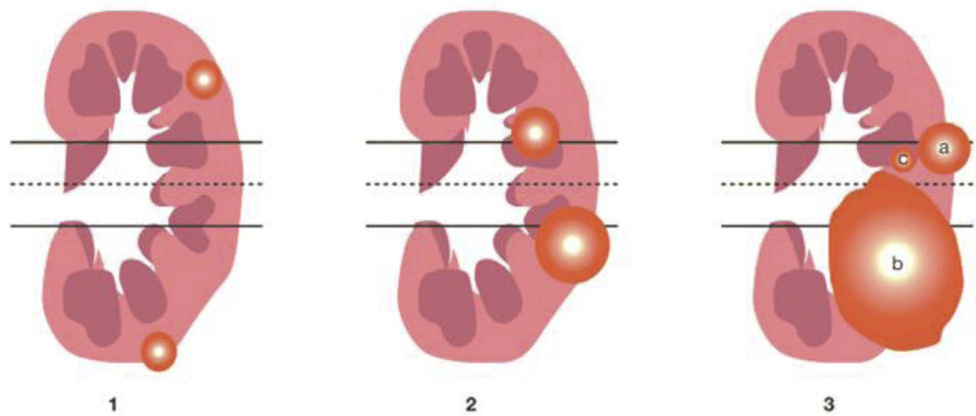

Fig. 4. Nephrometry score; the scale from 4 to 12 based on the anatomic location of the tumor in 5 categories. (*From* Kutikov A, Uzzo RG. The R.E.N.A.L. nephrometry score: a comprehensive standardized system for quantitating renal tumor size, location and depth. J Urol 2009;182(3):844-853; with permission.)

perfusion of the electrode shaft, multiple electrode placement with rapid switching,[16] and slow ramp-up of energy delivery.[19] RF ablation is less effective for tumors larger than 3 cm due to the large amount of energy required, centrally located tumors due to large heat sink, and tumors near the ureteropelvic junction of the collecting system due to heating-related stricture risk[38,39] (**Fig. 5**). For larger lesions greater than 4 cm, a combination of embolization and RFA is more effective because energy dissipating tissue perfusion is eliminated or decreased.[33,34,40]

MWA is a faster and more efficient wave-based heating technique that relies on rapid heating of tissue water because of antenna and generator design and also properties such as wavelength, frequency, power, and cooling. MWA leads to much faster, hotter, and efficient heating of tissues than RFA. It is much less susceptible to heat-sink effects from adjacent renal vessels but can also cause faster and more severe thermal injury than RFA. Tumor size and location are also important factors because larger lesions and central lesions are more challenging to ablate for MWA albeit to a lesser degree than RFA. Ablation of tumors located close to the ureteropelvic junction and ureter increase risk of thermal injuries, such as stricture or leak or thermal injury to the collecting system.[31] On average, fewer applicators are needed, and ablative margins are easier to obtain[32] (**Fig. 6**). Moreover, multiple studies have shown that MWA could effectively treat 5-cm lesions with similar efficacy to 3-cm lesions treated with RFA.[14,15,41–43] Major complications of MWA occur in approximately 4% and include bleeding, infection, urine leak, stricture, and nontarget ablation, including skin burn if the target is within 3 cm of the skin.[21,31,42–46]

WHAT ARE THE ADVANTAGES OF PERCUTANEOUS THERMAL ABLATION OVER PARTIAL NEPHRECTOMY?

The simplicity, efficacy, repeatability, minimal risk, favorable complication profile, and lack of general

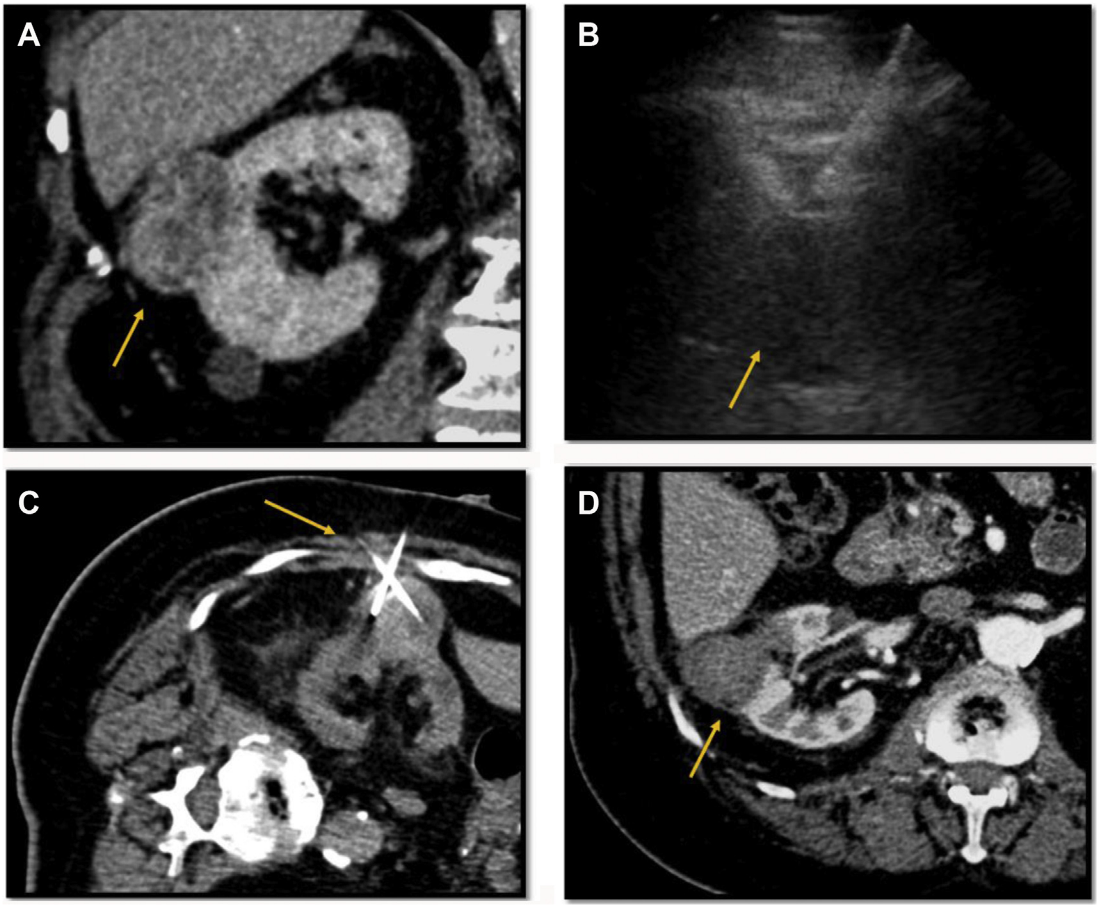

Fig. 5. An 86-year-old man with 4.5-cm exophytic clear cell RCC in the right kidney (*arrows*). Preablation CT (nephrographic phase) shows tumor enhancement (*A*). Two RF probes placed into the tumor under US and CT guidance (*B*, *C*). Postablation CT (corticomedullary phase) confirms successful ablation with no residual enhancing tumor (*D*).

anesthesia are some the many benefits of percutaneous TA over PN in patients with and without preexisting renal parenchymal injury.[4,25,34]

Traditionally, renal tumors treated by TA were generally smaller and of lower anatomic complexity than those treated by PN.[10] Accordingly, guidelines have emphasized that TA should ideally be reserved for tumors ≤3 cm in size with a slightly increased risk of complications and decreased efficacy for TA of lesions greater than 3 cm[12] (**Tables 1** and **2**). However, T1b lesions are well treated by more contemporary ablation techniques, such as MWA alone or combination with renal arterial embolization.

Studies comparing TA and PN tend to be retrospective and fail to account for operator expertise and equipment. In 2017, Long and colleagues[47] reported results with a mean follow-up of 43.2 months for 172 (mostly open) partial nephrectomies and 38 months follow-up of 112 (mostly RFA) TAs; the percentage of estimated glomerular filtration rate decrease was similar in the 2 groups. Five-year local radiologic recurrence-free survival was better for PN (92 vs 74%). Mean time of recurrence was 13.1 months for TA and 39.4 for PN, but metastatic recurrence was similar, 89% versus 85%.[47] They found that PN had worse outcomes than TA in terms of transfusion rate, length of stay, and complication rate, but PN was necessary to manage larger and more complex tumors while providing a better local control and similar renal function loss. Other studies have shown no significant differences with regard to local recurrence rate or overall disease-free survival and distant metastases in RFA and MWA versus PN.[29,48–50]

Some studies have shown a 2.3-fold increased rate of renal and cardiovascular events and 5-fold increased rate of thromboembolic events for PN over TA,[51] whereas some other studies found no difference.[52]

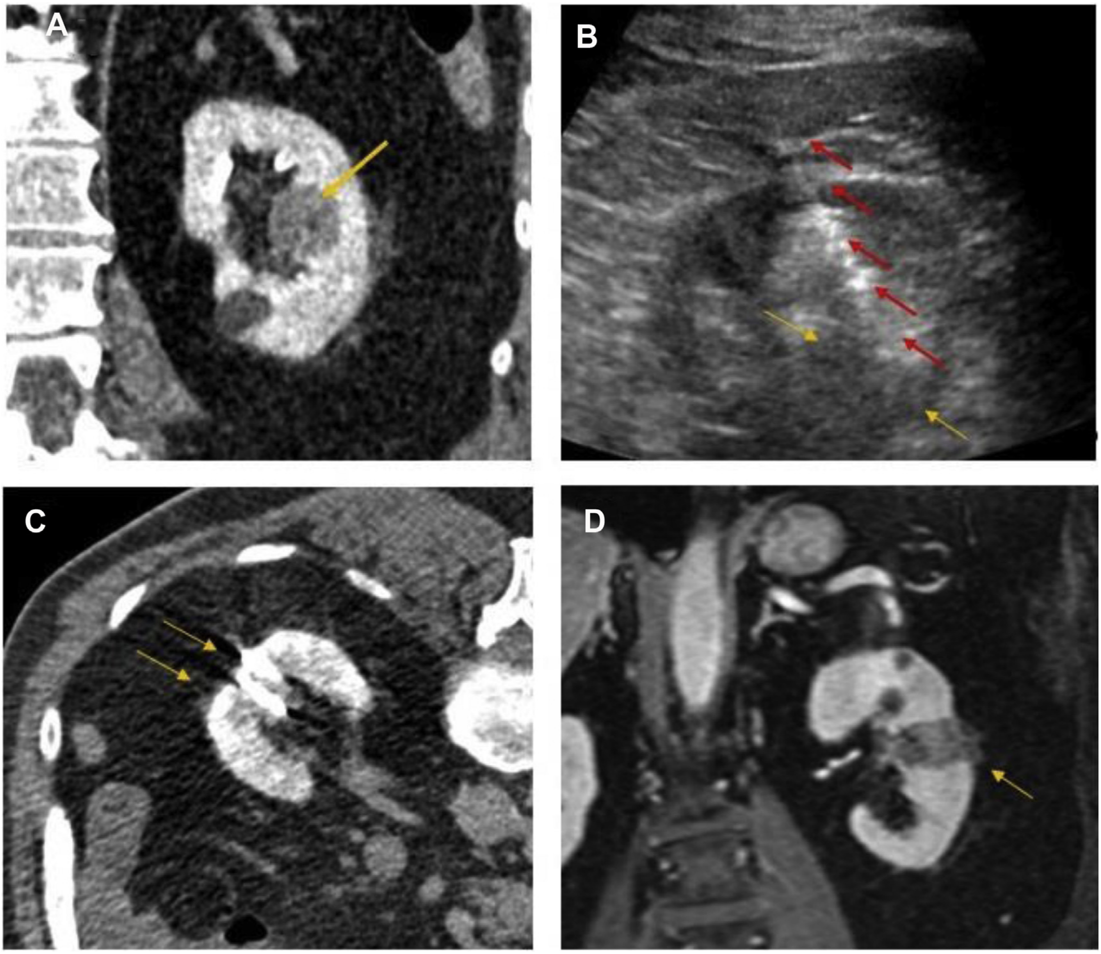

Fig. 6. A 62-year-old man with 4-cm clear cell RCC. Two microwave probes (*red arrows*) placed into the tumor (*yellow arrows*) with multidetector CT (corticomedullary, nephrographic, and excretory phases) (*A–C*). After the procedure, MR confirmation on coronal view shows the successful ablation with no residual tissue (*D*).

Local tumor recurrence and incomplete ablation are the principal complications of TA in larger tumors (>3 cm).[3] Tanagho and colleagues[53] found that tumor size greater than 2.5 cm was an independent predictive factor in local recurrence for cryoablation. Moreover, some studies of renal cryoablation compared with PN for clinical T1b RCCs reported that the rate of local recurrence was significantly higher for cryoablation versus PN (P = .019).[54] However, they showed there was no significant difference in cancer-specific mortality or overall mortality between the CA and PN groups.[54,55]

Notably, because the postoperative complications of TA are not higher than the PN, second ablation for tumor recurrence or incomplete removal can provide a solution.[12] The rate of second ablation procedures used is reported from 4% to 8% for T1a RCC.[22,29] Based on the authors' previous studies, the primary and secondary efficacy rates were 90% to 92% and 100% in 125 RCCs with RFA and 69 RCCs, respectively, using MWA. RFA tumor recurrence rate was 8%, versus 5.8% for MWA.[30,56]

Interestingly, there is evidence suggesting that tumor histology may play a role in predicting efficacy in percutaneous RFA.[9] Clear-cell RCC had a primary, secondary, and total technique efficacy of 76.4%,14.5%, and 90.9%, whereas non-clear-cell RCC had a primary, secondary, and total technique efficacy of 97.8%, 2.2%, and 100%.[9]

In a cost comparison study of PN versus RFA, Lotan and Cadeddu[57] found that for T1a RCCs minimally invasive methods (RFA) can decrease morbidity, along with significant cost benefits. They reported RFA was significantly cheaper to perform (US$4454 ± $US938), compared with both laparoscopic PN (US$7013 ± US$934) and

Table 1
Characteristics of single-center studies with different ablation modalities in renal cell carcinomas

	Reference	No. of Patients	Type of the Study	Time Period	Treatment Modality	Outcomes
1	Johnson et al,[59] 2019	106	Retrospective study	2000–2007	Outcomes of RFA in RCCs in 10-y follow-up	RFA is a safe and effective treatment option for RCCs <3 cm with good 10-y CSS 94% and OS 49% rates
2	Psutka et al,[60] 2013	185	Retrospective study	During 5 y	Outcomes of RFA in RCCs in 5-y follow–up	RFA is an effective treatment in RCCs, and the higher stage correlates with a decreased disease-free survival
3	Marshall et al,[56] 2019	100	Retrospective study	2004–2015	Outcomes of RFA in RCCs in 5-y follow-up	RFA is a safe and effective treatment for RCCs with a low LTP and has good 5-y CSS 92%, OS 68% rates
4	Leveillee et al,[61] 2013	274	Prospective study	2001–2011	Outcomes of RFA in RCCs in 5-y follow-up	RFA is a clinically effective and safe treatment of RCCs with high OS rate
5	Wah et al,[62] 2014	165	Prospective study	2004–2012	Outcomes of RFA in RCCs in 5-y follow-up	RFA is a safe and effective treatment for RCCs with a low rate of recurrence and has good 5-y CSS rate
6	McClure et al,[29] 2014	100	Retrospective study	2004–2011	Outcomes of RFA in RCCs in 2-y follow-up	RFA is a clinically effective and safe treatment of RCCs with 97.6% OS and 100% CSS rates
7	Kim et al,[63] 2015	70	Retrospective study	2007–2014	Outcomes of Cryo in RCCs in 10-y follow-up	Recurrence-free rate was 83.0% and the CSS rate was 100%. The 5- and 10-y OS rates were both 100%
8	Larcher et al,[52] 2015	174	Retrospective study	2000–2013	Outcomes of Cryo in T1a RCCs in 10-y follow-up	The 10-y LPR free was 100% and the 10-y disease relapse-free survival rate was 81%. The CSS; 100%, OS; 61%

9	Georgiades & Rodriguez,[64] 2014	134	Retrospective study	5 y	Outcomes of Cryo in T1a RCCs in 5-y follow-up	Cryoablation in RCCs offers very high efficacy of 97%, with a more favorable safety
10	Choi et al,[65] 2018	567 (13 articles)	Review article	2012–2017	Technical and oncologic outcomes of MWA in RCCs	MWA showed favorable technical and oncologic outcomes with a low incidence of major complications
11	Mu et al,[66] 2016	140	Retrospective study	2006–2015	Outcomes of MWA in T1 RCCs in 5-y follow-up	MWA is a safe treatment for RCCs with 1-, 3-, and 5-y OS rates of 98.4%, 94.8%, 89.5%, respectively
12	Klapperich et al,[32] 2017	96	Retrospective study	2011–2015	Outcomes of MWA in RCCs in short-term follow-up	MWA is a safe treatment option for stage T1a RCC, regardless of tumor complexity
13	Shakeri et al,[30] 2019	56	Retrospective study	2013–2017	Outcomes of MWA in T1 RCCs in short-term follow-up	MWA appears to be an effective treatment in RCCs regardless of renal score and tumor location with high TS, CSS, OS rates
14	Wells et al,[67] 2016	29	Retrospective study	2013–2014	Outcomes of MWA in T1 RCCs in short-term follow-up	MWA is a safe and effective treatment regardless of tumor complexity

Abbreviations: CSM, cancer-specific mortality; CSS, cancer-specific survival; LPR, local progression rate; LTP, local tumor progression; OS, overall survival; RN, radical nephrectomy.

Table 2
Characteristics of larger population-based studies comparing kidney tumor ablation to other surgical management strategies

	Study	No. of Patients	Study Population	Time Period	Treatment Modality	Outcomes
1	Palumbo et al,[68–70] 2019	3946	SEER	2004–2015	Cryosurgery vs TA	TS >30 mm is an independent predictor of higher 5-y CSM in TA
2	Xing et al,[51] 2018	10,309	SEER	2001–2012	Comparison of complication rates and CSM,OS between PN, RN, TA, AS	TA showed CSM and OS similar to PN/RN with significantly fewer adverse outcomes at 1-y follow-up
3	Zhou et al,[48] 2019	297	Retrospective study	2006–2016	Comparison of therapeutic effects of RFA, MWA, and cryoablation	RFA, MWA, and cryoablation are equivalent for treatment of T1a RCC for renal function, and low adverse event rate at 2-y follow-up
4	Atwell et al,[7] 2013	385	Retrospective study	2000–2010	Comparison the efficacy and complication rates of RFA vs Cryo in RCCs $\leq$3 cm	Both RFA and Cryo are effective in the treatment of RCCs $\leq$3 cm. Major complications are infrequent
5	Guan et al,[46] 2012	102	Prospective randomized comparison study	2004–2006	Comparison of therapeutic effects of MWA and PN in T1a	MWA provides favorable results compared with PN with high efficacy and local free recurrence rate
6	Chang et al,[71] 2019	90	Retrospective study	2005–2009	Comparison outcomes of RF and PN in RCCs in 5-y follow-up	RFA is an effective treatment with 5-y oncologic outcomes and better preservation of renal function than PN

open PN (US$7767 ± $US1605). Accordingly, Castle and colleagues[58] reported that the 6-month cost of nephron-sparing surgery is lowest using RFA with either laparoscopic or CT-guided approach in comparison with the open or robot-assisted PN.

SUMMARY

Although partial or radical nephrectomy represents the reference standard of treatment of RCCs, TA therapies have been used increasingly with acceptable efficacy, high survival rate, and low complication rate. Since there are no strict criteria for patient selection, more randomized phase 3 trials comparing surgical resection with ablative techniques would be beneficial for improved decision making by treating physicians.

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