Review

Percutaneous Image-guided Thermal Ablation for Renal Cell Carcinoma

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Abstract

Nephrectomy is the gold standard for the treatment of renal cell carcinoma (RCC). However, some patients are not suitable candidates for nephrectomy because of high surgical risk, reduced renal function, or the presence of multiple renal tumors. Percutaneous image-guided thermal ablation, including cryoablation and radiofrequency ablation, is a minimally invasive and highly effective treatment and can be used to treat RCC in patients who are not good candidates for surgery. This article will review percutaneous image-guided thermal ablation for RCC, covering treatment indications, ablation modalities and techniques, oncologic outcomes, and possible complications. In addition, the characteristics of each ablation modality and its comparison with nephrectomy are also presented.

Key words: Renal carcinoma, radiofrequency ablation, cryoablation

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INTRODUCTION

Kidney cancer is the 14th most common cancer in the world, with more than 400,000 patients having been newly diagnosed with the disease in 2018 [1]. Among the types of kidney cancer, renal cell carcinoma (RCC) is the most commonly diagnosed one. The frequency of RCC diagnosis has increased in part because of the widespread use of various imaging modalities such as ultrasonography, computed tomography (CT), and magnetic resonance imaging (MRI) [2, 3]. Most cases of incidentally diagnosed RCC are early-stage, small tumors [3, 4].

Nephrectomy has been the gold standard for the treatment of early-stage RCC [5-8]. Partial nephrectomy, especially, is recommended for patients with small RCC tumors to preserve postsurgical renal function. If partial nephrectomy proves to be technically challenging, radical nephrectomy may also be performed. However, some patients are unsuitable candidates for both partial and radical nephrectomy due to high surgical risks, reduced renal function, or the presence of multiple renal tumors.

Recently, percutaneous image-guided thermal ablation has been increasingly adopted for the treatment of small RCC tumors [9, 10]. In contrast to nephrectomy, thermal ablation is associated with a lower rate of complications, shorter recovery time, and good preservability of renal function as well as patient quality of life [9, 11-13]. Moreover, recent studies have suggested that percutaneous thermal ablation has the potential to provide oncologic outcomes similar to those of nephrectomy and that it could be the next therapeutic option to turn to after partial nephrectomy [10, 14].

This article describes the current state of percutaneous image-guided thermal ablation for RCC, considering treatment indications, ablation modalities and techniques, complications, and oncologic outcomes. The characteristics of each ablation modality and their comparison with nephrectomy are also discussed.

Treatment Indications

Existing guidelines recommend nephrectomy as a stan-

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dard therapy [5-8]. Percutaneous thermal ablation is recommended for patients with small RCC tumors (≤3-4 cm) and high surgical risk due to advanced age and/or comorbidities. Patients unwilling to undergo surgery, those with impaired renal function, and those with hereditary RCC (e.g., Von Hippel-Lindau disease) are also potential candidates for thermal ablation. The National Comprehensive Cancer Network clinical practice guidelines published in 2017 contended that ablation techniques, including radiofrequency (RF) ablation and cryoablation, can be considered for selective patients with clinical stage T1a renal lesions who are not candidates for other surgery [5]. Other clinical practice guidelines for RCC advocated for by the European Society for Medical Oncology in 2019 suggest that partial nephrectomy is appropriate for T1a tumors, but thermal ablation is a reasonable treatment option for patients with small tumors (≤ 3 cm) who are at high risk for adverse outcomes following surgery or those who present with a solitary kidney, compromised renal function, hereditary RCC, and/or multiple bilateral tumors [6]. Similarly, the American Urological Association guidelines, updated in 2017, support that thermal ablation should be considered as an alternative approach for the management of clinical stage T1a renal masses measuring less than 3 cm in diameter, wherein a percutaneous approach is preferred [15]. These guidelines also recommend the biopsy of renal tumors in patients who undergo thermal ablation [5, 6, 15].

Thermal Ablation Modalities

Various thermal ablation modalities, such as cryoablation, RF ablation, and microwave (MW) ablation, have been employed for the treatment of RCC. Cryoablation is a hypothermal ablation technique that destroys target cells by way of rapid tissue-cooling. The mechanism of cryoablation is mainly based on promoting crystal formation, osmotic change, and thrombus formation in micro-vessels [16]. Importantly, the lethal temperature for cells could vary among both normal tissues and malignant tissues in different parts of the body [16, 17]. Georgiades et al. reported that the lethal temperature for treating RCC is –40 ℃ and that an ice-ball should be made to extend 5.36 mm or larger beyond the target edge in order to bring the entirety of the tumor below –40 ℃ [17]. The key advantage of cryoablation over other hyperthermal ablation modalities is the good visibility of the ablative zone during the procedure. Ice-ball formation during the cryoablation procedure is visible using CT, MRI, and ultrasonography; thus, the operator can more easily avoid not only causing collateral damage to nearby critical structures but also incomplete ablation [18-22] (**Fig. 1**). Another advantage of cryoablation is that it is less painful compared to heat-based thermal ablation techniques such as RF ablation and MW ablation. Indeed, previous studies have found that patients undergoing cryoablation required a lower dose of fentanyl than those receiving RF ablation [23, 24]. In addition, cryoablation does not use an electric current and can therefore be safely performed for patients with implanted electrical medical devices such as cardiac pacemakers and implantable cardioverter-defibrillators.

At this time, RF ablation is the most widely used thermal ablation technique for the treatment of solid cancers in the world. It employs a high-frequency oscillating electrical current of 375-500 kHz that travels between the needle and grounding pads on the skin in a monopolar system or among needles in a multipolar system [18, 25-28]. The alternating current derived from RF ablation devices induces ionic agitation of intracellular molecules and frictional heating, leading to the coagulation of the target lesions. A tissue temperature of 42-45 ℃ for 30 to 60 minutes is reported to cause irreversible cellular damage, while temperatures exceeding 60 ℃ can induce immediate cell death [26].

Separately, MW ablation uses an alternating electromagnetic field, typically at 900-2,500 MHz, to facilitate the continuous realignment of polar molecules, leading to tissue heating [18, 25, 29]. Theoretically, MW ablation has several advantages over RF ablation including reduced dependence on electrical tissue conductivity and higher intratumoral temperatures [30]. However, in comparison with the aforementioned modalities, MW ablation is a relatively new technology, and as a result, the available clinical data on its safety, efficacy, and indications are more limited. As such, this article focuses on the use of cryoablation and RF ablation in the treatment of RCC.

Image Guidance

Percutaneous thermal ablation is performed under close image guidance. CT, MRI, and ultrasound (US) are used for needle placement and periodic monitoring of the treatment area during the procedure [18, 20, 22, 25, 31,32]. CT is a widely applied imaging modality in the guidance of thermal ablation (**Figs. 1** and **2**). Though it involves the risks of radiation exposure and artifacts from the needles appearing on and obscuring images, CT supports good objective images of needle positioning [33]. CT fluoroscopy is particularly useful for achieving objective and almost real-time imaging [19, 28, 32, 34]. In RF ablation, the ablative zone is not visible on CT images during the procedure. On the other hand, during cryoablation, the ice-ball can be visualized as a hypodense area on CT images [21, 22]. MRI is also a useful modality for image guidance, especially during cryoablation because of the good visibility of the ice-ball. On the other hand, MRI is not considered suitable to assist RF ablation because of the limited RF applications that are compatible with MRI [35]. US can provide real-time imaging without radiation exposure and is thus sometimes useful at the time of needle insertion. However, the quality of image resolution with this modality depends upon the depth of the target lesion. Moreover, images can be further impaired due to the presence of air pockets or calcification [34]. Therefore, even if US is being employed, monitoring of the ablative zone during the procedure using CT or MRI is mandatory to

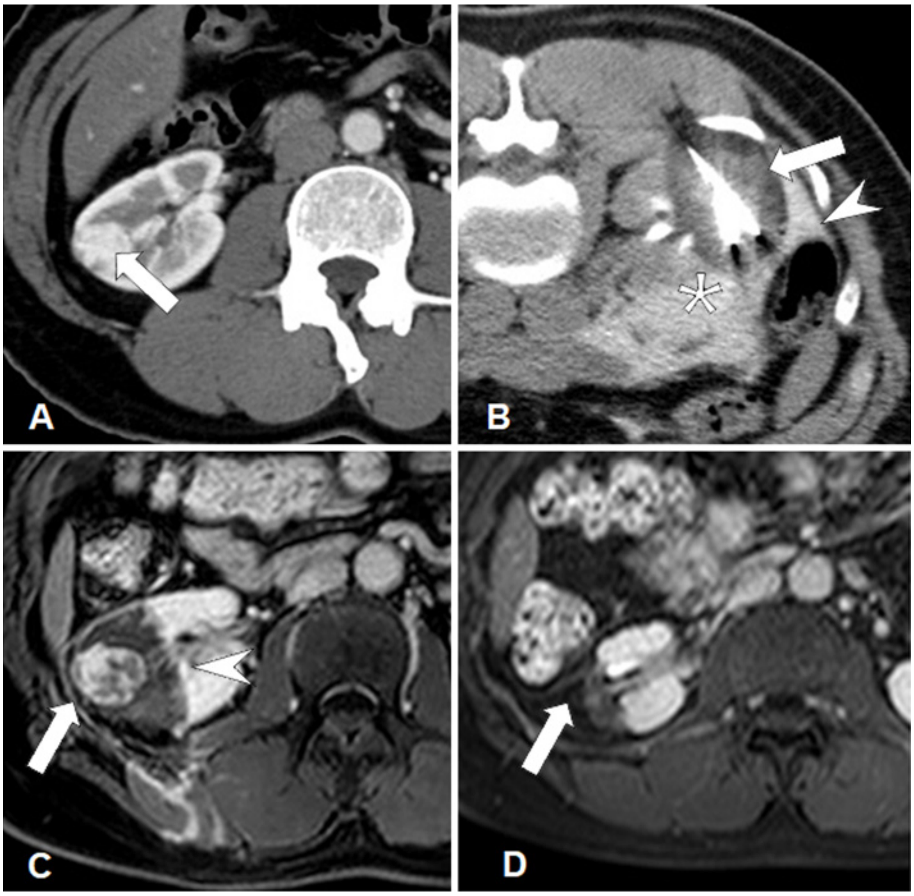

Figure 1. A female patient in her 50s with a biopsy-proven RCC (maximum tumor diameter, 2 cm) in the right kidney. A. Contrast-enhanced CT image shows RCC with homogeneous enhancement (arrow) in the right kidney. B. CT image during cryoablation clearly shows an ice-ball as a low attenuation area around the needles (arrow). The colon (arrowhead) was dislocated using hydrodissection fluid (asterisk). A small amount of iodinated contrast medium was mixed with the hydrodissection fluid. C. MR image obtained 6 days after cryoablation shows residual heterogeneous tumor enhancement (arrow) inside the non-contrast-enhancing ablative zone (arrowhead). D. MR image obtained 1 year after cryoablation shows no tumor enhancement and shrinkage of the ablative zone (arrow). The patient did not develop local tumor progression during follow-up.

avoid complications.

Ablation Technique

Standard ablation protocol

Miyazaki et al. have reported the expert consensus on renal ablation protocols [36]. In this report, the recommended initial electric power of RF ablation is 30-40 W increased by 10 W per minute. Two breaks/roll-offs were also recommended during ablation. In cryoablation, the recommended protocol was 2 cycles of 10-15 minutes freezing with 5 minutes thawing.

Patient positioning

Prior to ablation, it is important to select the optimal body position for the patient to be placed in during the thermal ablation procedure. Patients should be positioned in a manner that allows for needle insertion to be done safely and easily. The prone position is preferred in most cases, because it facilitates renal tumor access and is generally more comfortable for patients [37-39]. It is important to pay attention to the surrounding organs, because they can move according to body position. Air in the digestive tract and lungs is also affected by the body position, while gas inside the colon and duodenum can expand the cavity and shift the organs toward the kidney in the prone position (**Fig. 1**). Moreover, the lower lobes of the lungs can become inflated in the prone position as compared with the spine position, increasing the risk of transpulmonary needle insertion, which can lead to pneumothorax, especially when the RCC tumor is located in the upper pole of the kidney [38, 40, 41]. In this context, the ipsilateral decubitus position (ablation-side down) can assist in avoiding transpulmonary puncture [34, 38, 39].

Hydrodissection

Hydrodissection is commonly incorporated to avoid col-

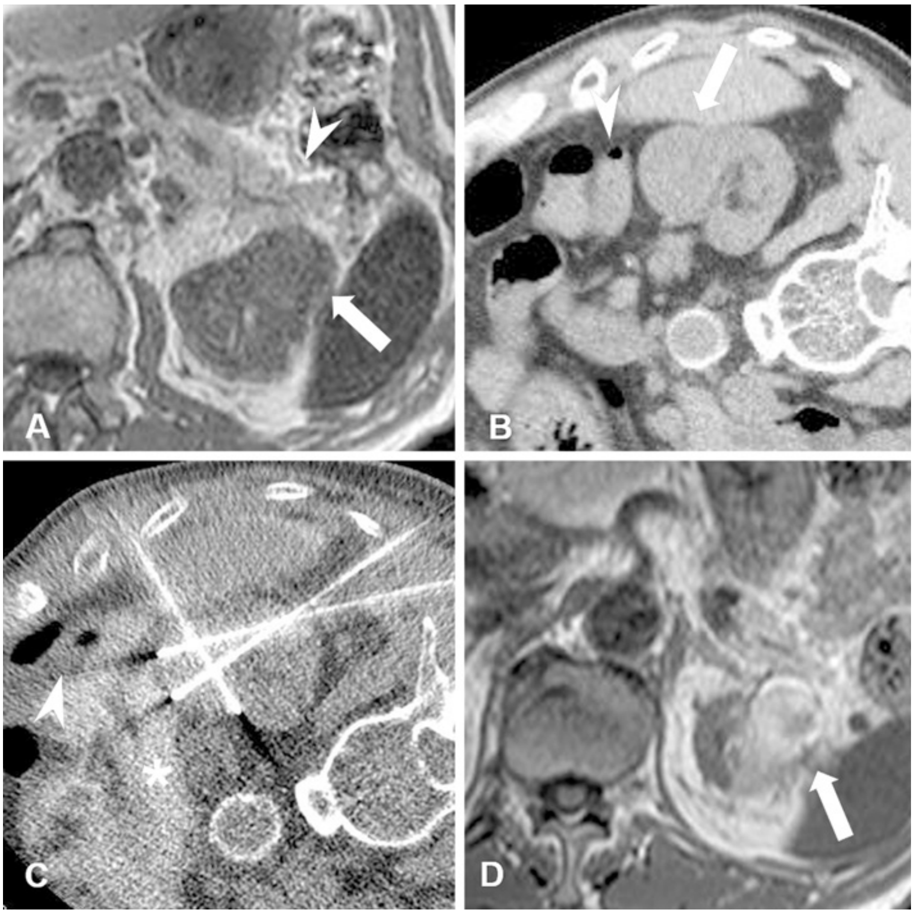

Figure 2. A male patient in his 70s with chronic kidney disease (estimated GFR: 21.7). Biopsy-proven RCC (maximum tumor diameter, 3.2 cm) is seen in the left kidney. A. Non-contrast-enhanced MRI T1-weighted scan shows RCC (arrow) adjacent to the pancreas (arrowhead). B. CT image obtained in the right lateral decubitus position (ablation-side up). In this position, the pancreas is positioned away from the RCC but the colon (arrowhead) is adjacent to the tumor (arrow). C. CT image obtained during RF ablation shows the colon (arrowhead) dislocated using hydrodissection fluid (asterisk). Iodinated contrast medium was mixed in with the hydrodissection fluid. D. Non-contrast-enhanced MRI T1-weighted scan obtained at six months after RF ablation shows shrinkage of the ablated RCC (arrow) and no thermal damage to surrounding organs.

lateral damage at the time of image-guided ablation [23, 34, 38, 42] (**Figs. 1** and **2**). It can be used to displace heat-sensitive critical organs, such as the colon, intestine, duodenum, pancreas, and ureter, away from designated ablation zone. During this procedure, small needles (i.e., 18- or 21-gauge) are inserted into the perinephric space and fluid injection is performed. To avoid collateral damage, the desirable distance between the ablation zone and organs not receiving treatment is 2 cm or more [34, 38]. Although normal saline or dextrose in water can be used for hydrodissection, a nonionic solution of dextrose in water is preferred over saline solution during RF ablation [34, 38, 43, 44]. Addition of a small amount of an iodinated contrast medium is useful for increasing the attenuation of the fluid and improving differentiation between the hydrodissection area and adjacent organs, as well as for identifying hemorrhage [45] (**Figs. 1** and **2**).

Ureteral stent placement and pyeloperfusion

Pyeloperfusion is a technique used to protect the renal collection system and ureter from thermal damage during renal ablation. A ureteral stent should be placed prior to pyeloperfusion, with the distal end located in the renal pelvis and the proximal end directed outwards from the urethra and connected to a water bag containing sterile saline or 5% dextrose for perfusion [34, 38, 43, 44, 46, 47]. No randomized prospective study has analyzed the effectiveness of pyeloperfusion; however, Dai et al. reported a 10% rate of hydronephrosis or urinoma as major complications after RF ablation combined with pyeloperfusion [48]. Careful patient selection is therefore required.

Combination treatment with arterial embolization

Most RCCs are hypervascular, and it is sometimes difficult to achieve complete ablation because of the effect of

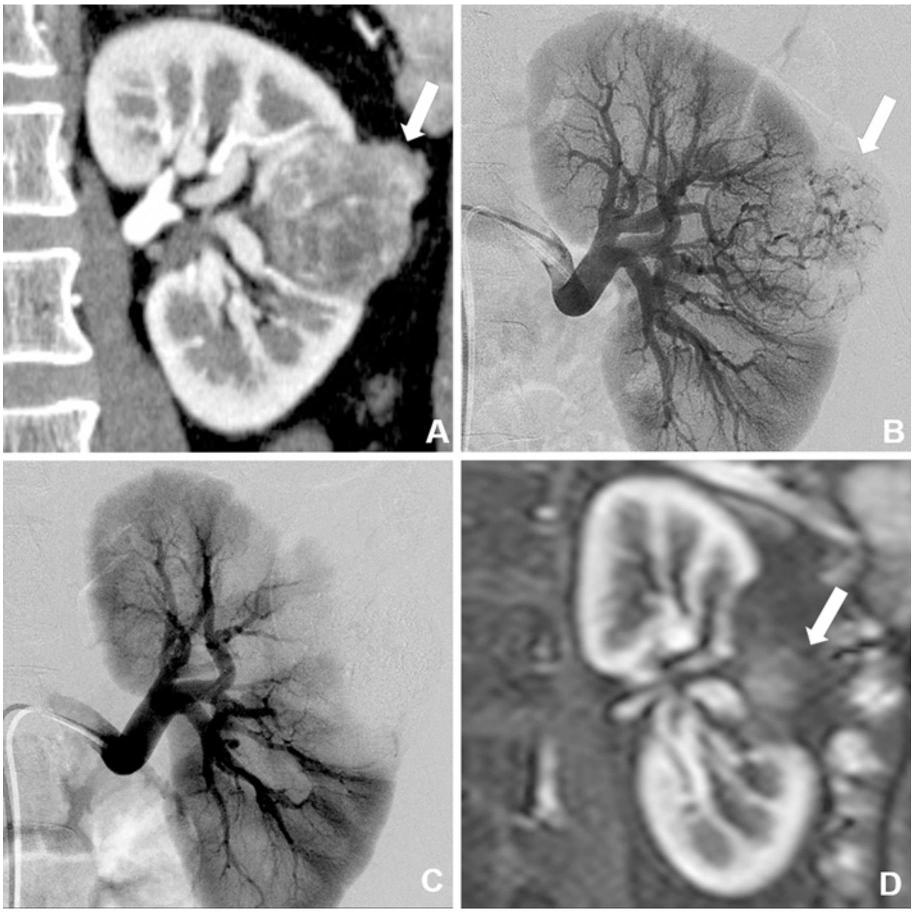

Figure 3. A male patient in his 30s with biopsy-proven RCC (maximum tumor diameter, 5.0 cm). A. Contrast-enhanced CT image shows a heterogeneous enhanced tumor (arrow) in the left kidney. B. Arteriography image of the left kidney showing tumor staining (arrow) in the left kidney. C. Arteriography image obtained just after selective transarterial embolization (TAE) using ethanol and ethiodized oil mixture shows no tumor staining. Cryoablation was performed one month after TAE. D. Contrast-enhanced MRI scan obtained six months after cryoablation shows no enhancement and shrinkage of the treated RCC.

blood flow. In such cases, conducting renal artery embolization prior to thermal ablation is a useful method to reinforce favorable treatment effects [19, 25, 49-55]. Embolic material, including particles, ethanol mixed with lipiodol, coils, and balloons, can be used to embolize the renal artery [25] (**Fig. 3**). Yamakado et al. treated 12 RCC tumors larger than 3.5 cm in 11 patients by combining the use of renal artery embolization and RF ablation, achieving tumor control in all cases during a mean follow-up period of 13 months [52]. The combination with renal artery embolization is also helpful in avoiding hemorrhagic complications at the time of ablation [55]. On the other hand, recent propensity score matching analysis showed no significant difference in technical success rate, complication rate, blood loss, and number of needles between patients treated with cryoablation combined with arterial embolization and cryoablation alone [56]. Further investigation is needed to evaluate the role of arterial embolization prior to thermal ablation.

Oncologic Outcomes

Accumulating evidence has suggested that thermal ablation has the potential to provide a similar level of local control to that of nephrectomy for treating small RCC tumors (**Table 1**). For T1a RCC, the local tumor control rate of partial nephrectomy was reported to be 95% to 100% [49, 57-61]. In contrast, with cryoablation and RF ablation, the local control rates of T1a RCC were reported as 76.8% to 100% [61-64] and 91% to 100% [49, 57, 61, 62, 64], respectively. Among larger RCC tumors, thermal ablation can also provide a good level of local control in selected patients: for T1b RCC, the local tumor control rate of partial nephrectomy was reported as 91% to 100% [60, 61, 65], while cryoablation and RF ablation had reported rates of 84% to 100% [19, 53, 60, 61, 65] and 91% [19], respectively. Tumor size and location are considered as important factors affecting local control. Yamanaka et al. and Blute et al. reported that a deeper tumor location was associated with

Table 1. Oncologic outcomes after thermal ablation and partial nephrectomy

Author	Year	No. of Patients	No. of Lesions	Age (years)	T stage	Tumor Size (cm)	Follow-up Period	Local Tumor Control Rate	Overall Survival Rate	Recurrence-free Survival Rate	Cancer-related Survival Rate
Partial nephrectomy											
Takaki et al.[49]	2010	10	10	mean 64	T1a	mean 1.9	mean 26 mo	100%	5-y: 100%	3-y: 75%	3-y: 100%
Malley et al.[58]	2006	15	15	mean 76	T1a	mean 2.5	mean 10 mo	100%	(-)	(-)	(-)
Andrew et al.[61]	2019	1055	1055	median 62	T1a	median 2.4	median 9.4 y	5-y: 98%	5-y: 92%	5-y: 98%	5-y: 99%
Olweny et al.[57]	2012	37	37	median 55	T1a	median 2.5	median 6 y	5-y: 95%	5-y: 100%	5-y: 89%	5-y: 100%
Thompson et al.[60]	2015	1057	1057	mean 60	T1a	mean 2.5	(-)	97%	3-y: 95%	(-)	(-)
Chang et al.[59]	2015	45	45	mean 53	T1a	(-)	median 72 mo	5-y: 98%	5-y: 93%	5-y: 89%	5-y: 98%
Caputo et al.[65]	2017	31	31	median 68	T1b	median 4.6	median 13 mo	100%	(-)	5-y: 100%	5-y: 100%
Andrew et al.[61]	2019	324	324	median 61	T1b	median 5.0	median 8.7 y	5-y: 93%	5-y: 90%	5-y: 94%	5-y: 98%
Thompson et al.[60]	2015	326	326	mean 61	T1b	mean 5.1	(-)	94%	3-y: 93%	(-)	(-)
Fraisse et al.[81]	2019	177	177	mean 60	T1a+b	mean 2.8	median 39 mo	5-y: 95%	(-)	(-)	(-)
Cryoablation											
Camacho et al.[64]	2015	47	56	median 69	T1a	mean 2.3	mean 35 mo	77%	(-)	(-)	(-)
Zhou et al.[62]	2019	26	26	mean 68	T1a	mean 2.4	2 y	2-y: 100%	(-)	2-y: 100%	2-y: 100%
Murray et al.[63]	2019	47	49	mean 64	T1a	mean 2.5	median 54 mo	3-y: 95%, 5-y: 90%	3-y: 91%, 5-y: 88%	(-)	(-)
Andrew et al.[61]	2019	187		median 72	T1a	median 2.8	median 6.3 y	5-y: 96%	5-y: 77%	5-y: 100%	5-y: 100%
Thompson et al.[60]	2015	187	187	mean 72	T1a	mean 2.9	(-)	98%	3-y: 88%	(-)	(-)
Caputo et al.[65]	2017	31	31	median 68	T1b	median 4.3	median 30 mo	84%	(-)	(-)	(-)
Hasegawa et al.[19]	2018	23	23	median 67	T1b	mean 4.6	median 23 mo	100%	5-y: 82%	(-)	5-y: 100%
Atwell et al.[53]	2015	46	46	mean 73	T1b	mean 4.8	(-)	97%	(-)	(-)	3-y: 94%, 5-y: 94%
Thompson et al.[60]	2015	53	53	mean 75	T1b	mean 4.8	(-)	98%	3-y: 74%	(-)	(-)
Andrew et al.[61]	2019	52	52	median 77	T1b	median 4.8	median 6.0 y	5-y: 95%	5-y: 56%	5-y: 90%	5-y: 91%
Fraisse et al.[81]	2019	177	177	mean 70	T1a+b	mean 2.6	median 63 mo	5-y: 85%	(-)	(-)	(-)
Georgiades et al.[69]	2014	246	265	mean 68	T1a+b	median 2.8	(-)	3-y: 99%, 5-y: 97%	5-y: 98%	3-y: 99%, 5-y: 97.0%	5-y: 100%
Breen et al.[68]	2018	433	484	median 68	T1a+b	mean 3.3	median 24 mo	98%	3-y: 92%, 5-y: 79%	(-)	(-)
RF ablation											
Camacho et al.[64]	2015	40	45	median 65	T1a	mean 1.7	mean 35 mo	91%	(-)	(-)	(-)
Andrew et al.[61]	2019	180	180	median 72	T1a	median 1.9	median 7.5 y	5-y: 96%	5-y: 72%	5-y: 94%	5-y: 96%
Olweny et al.[57]	2012	37	37	median 64	T1a	median 2.1	(-)	5-y: 92%	5-y: 97%	5-y: 89%	5-y: 97%
Thompson et al.[60]	2015	180	180	mean 71	T1a	mean 2.1	(-)	96%	3-y: 82%	(-)	(-)
Mimura et al.[31]	2016	33	33	mean 61	T1a	mean 2.1	mean 15 mo	CR: 93%	1-y: 97%, 2-y: 92%	(-)	(-)
Takaki et al.[49]	2010	51	51	mean 69	T1a	mean 2.4	mean 34 mo	100%	5-y: 75%	5-y: 98%	5-y: 100%
Zhou et al.[62]	2019	244	244	mean 73	T1a	mean 2.4	2 y	2-y: 100%	(-)	2-y: 100%	2-y: 100%
Chang et al.[59]	2015	45	45	mean 53	T1a	(-)	median 66 mo	5-y: 95%	5-y: 90%	5-y: 87%	5-y: 96%
Hasegawa et al.[19]	2018	23	23	median77	T1b	median 4.4	median 33 mo	91%	5-y: 78%	(-)	5-y: 100%
Iannuccilli et al.[32]	2016	203	203	mean 73	T1a+b	mean 2.5	mean 34 mo	87%	5-y: 80%	(-)	(-)
Takaki et al.[28]	2013	33	33	mean 71	T1a+b	mean 2.9	mean 20 mo	100%	1-y: 97%	1-y: 97%	1-y: 100%
Dai et al.[48]	2017	30	31	mean 74	T1a+b	mean 3.7	mean 83 mo	96%	3-y: 100%, 5-y: 96%	(-)	(-)

No, number; mo, month; y, year; RF, radiofrequency

increased rates of local tumor progression after cryoablation [41, 66]. Yamanaka et al. also reported that an ice-ball margin of less than 6 mm was another risk factor for local tumor progression [66]. With RF ablation, Gervais et al. found that both tumor size and tumor location were independent predictors of complete necrosis after a single ablation session [67]. Similarly, Breen et al. determined that a significant factor influencing local tumor control after RF ablation was a tumor size of 3 cm or less [50]. Finally, Camacho et al. reported that the R.E.N.A.L. nephrectomy score is useful in predicting local tumor progression after thermal ablation. The results of their study suggest that local tumor progression was significantly frequent in patients with R.E.N.A.L. nephrectomy scores of eight points or more 64].

Overall survival (OS) rates after thermal ablation have been reported to be lower than those after partial nephrectomy (**Table 1**). OS rates in patients with T1 RCC at three and five years after partial nephrectomy were reported to be 93% to 100% and 90% to 100% [49, 57, 59-61], respectively. On the other hand, OS rates among patients with T1 RCC after cryoablation and RF ablation were reported to be 74% to 92% and 79% to 100% at three years and 56% to 98% and 72% to 97% at five years, respectively [19, 31, 32, 48, 49, 59-61, 63, 68, 69]. However, these differences may be mainly due to variations in patient backgrounds. Indeed, cancer-specific survival rates were similar among partial nephrectomy, cryoablation, and RF ablation procedures. In the literature, cancer-specific survival rates of patients with T1 RCC were reported to range from 98% to 100% at five years after partial nephrectomy [57, 59, 61, 65], 91% to 100% at five years after cryoablation [19, 53, 61, 68], and 96% to 100% at five years after RF ablation [19, 49, 57, 59, 61] (**Table 1**). Liao et al. also reported, in subset analysis of their recent large-scale study, that partial nephrectomy and cryoablation showed similar outcomes regarding overall and cancer-specific survival in patients with RCC tumors 2 cm or smaller [70].

Recently, Deng et al. and Rivero et al. shared the results of a meta-analysis wherein the outcomes of thermal ablation and partial nephrectomy were compared: study findings suggested that thermal ablation significantly increased all-cause mortality and cancer-specific mortality rates in comparison with partial nephrectomy [14, 71]. Yoon et al. and Deng et al. noted that the local recurrence rates and risk of metasta-

Table 2. Complications after thermal ablation and partial nephrectomy

Author	Year	No. of Patients	Age (year)	T stage	Tumor Size (cm)	Major Complication Rate	Minor Complication Rate
Partial nephrectomy							
Takaki et al.[49)]	2010	10	mean 64	T1a	mean 1.9	0%	10%
Malley et al.[58)]	2006	15	mean 76	T1a	mean 2.5	13%	7%
Chang et al.[63)]	2015	45	mean 53	T1a	(-)	4%	(-)
Caputo et al.[65)]	2017	31	median 68	T1b	median 4.6	13% (Clavien Grade 3,4)	29%
Cryoablation							
Zhou et al.[62)]	2019	26	mean 68	T1a	mean 2.4	0% (Modelate complication)	15%
Murray et al.[63)]	2019	47	mean 64	T1a	mean 2.5	10%	(-)
Atwell et al.[53)]	2015	46	mean 73	T1b	mean 4.8	15%	2%
Georgiades et al.[69)]	2014	246	mean 68	T1a+b	median 2.8	6%	(-)
RF ablation							
Mimura et al.[31)]	2016	33	mean 61	T1a	mean 2.1	0%	88%
Takaki et al.[49)]	2010	51	mean 69	T1a	mean 2.4	0%	5%
Zhou et al.[62)]	2019	244	mean 73	T1a	mean 2.4	1% (Modelate complication)	16%
Chang et al.[59)]	2015	45	mean 53	T1a	(-)	2%	(-)
Takaki et al.[28)]	2013	33	mean 71	T1a+b	mean 2.9	0%	9%
Dai et al.[48)]	2017	30	mean 74	T1a+b	mean 3.7	13%	31%

RF, radiofrequency

sis were significantly higher for thermal ablation compared with those for partial nephrectomy, but Rivero et al. reported no significant difference in these rates between thermal ablation and partial nephrectomy [14, 71, 72]. One important limitation of these studies was the lack of prospective randomized trials comparing thermal ablation and nephrectomy.

Change in Renal Function

An approximately 10% decrease in renal function has been reported after thermal ablation of T1 RCC tumors [19, 23, 62, 63, 65, 68, 73]. More specifically, the percentage decrease in renal function [i.e., glomerular filtration rate (GFR) or estimated GFR] after thermal ablation was reported to be 8% to 12% in patients with T1a RCC [49, 59, 73]; in patients with T1b RCC, the percentage decrease in renal function after thermal ablation was 7% to 27% [19, 65]. A recent meta-analysis reported that significantly better preservability of renal function was achieved following thermal ablation than after partial nephrectomy [14]. Therefore, thermal ablation may be appropriate to avoid having to pursue hemodialysis in patients with poor renal functional reserves. Gobara et al. reported on the effects of cryoablation among patients with T1a RCC in stages 4 or 5 of nondialysis chronic kidney disease [73]. In their study, although renal function showed a gradual decrease after treatment, no patient required early initiation of hemodialysis. It is also known that lower renal function can provoke cerebrovascular and cardiovascular events [40, 74]. Therefore, preserving renal function is important not only to avoid hemodialysis but also to reduce the risk of all-cause mortality [40, 74-76].

Complications

Reported complication rates are similar for partial nephrectomy and thermal ablation, although older patients and those with high-risk comorbidities are more frequently treated using thermal ablation. Major complication rates following the treatment of T1 RCC were 0% to 13% for partial nephrectomy [49, 58, 59, 65], 0% to 15% for cryoablation [53, 62, 63, 69], and 0% to 13% for RF ablation [28, 31, 48, 49, 59, 62] (**Table 2**).

Hemorrhage is the most frequent complication seen after thermal ablation, with an incidence of 1% to 18% [23, 53, 77]. However, 81% to 100% of cases of hemorrhage seem to be self-limiting [23, 32, 55]. The incidence of major hemorrhage requiring additional procedures such as arterial embolization is reported to be 1% to 7% [53, 63, 77].

Urothelial injury is a complication more frequently noticed after RF ablation than following cryoablation. The reported incidence rates of urothelial injury after RF ablation and cryoablation are 2% to 8% and 0.4% to 1%, respectively [23, 48, 68]. Urothelial injuries sometimes require additional treatment, including nephrostomy, ureteral stent placement, percutaneous drainage, or nephrectomy [32, 37, 69, 77, 78] (**Fig. 4**). Urothelial injury may even develop in

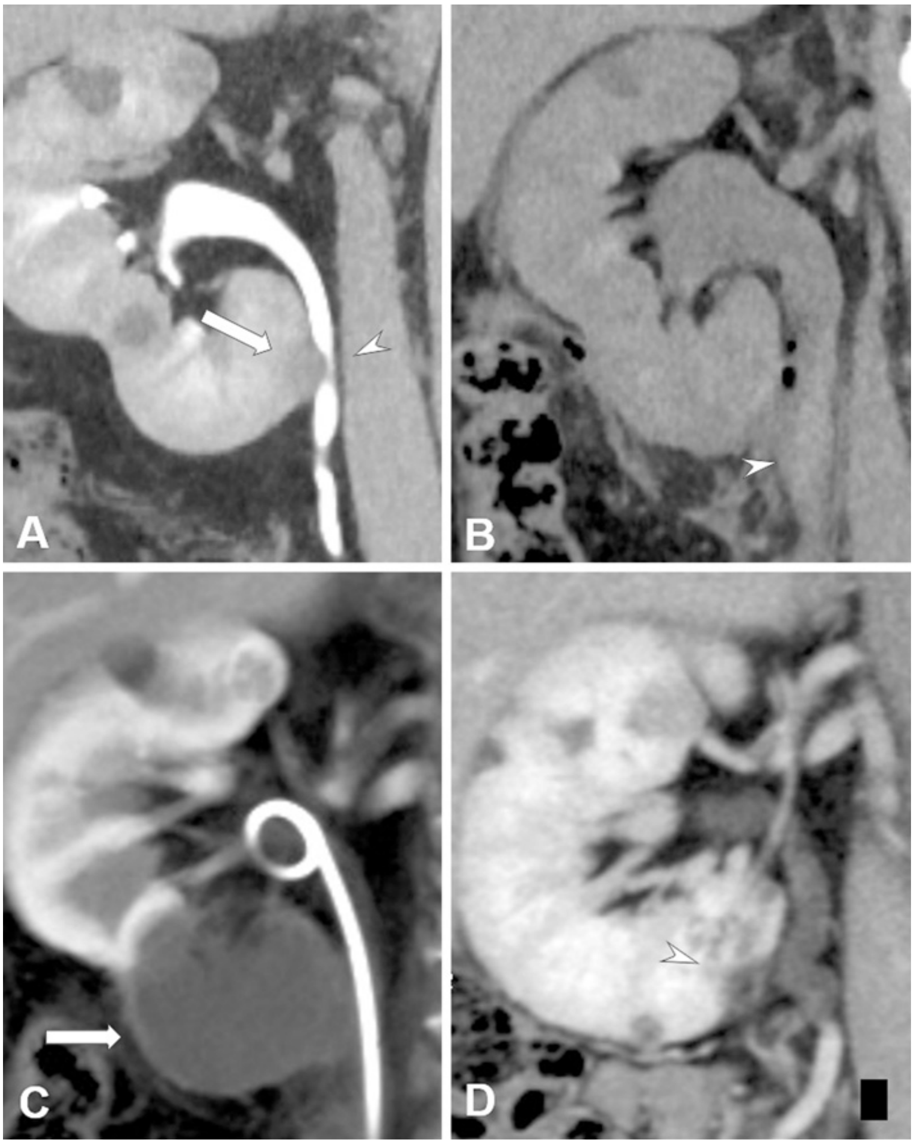

Figure 4. A male patient in his 50s with biopsy-proven RCC (maximum tumor diameter, 1.7 cm) in the right kidney. He had a history of radical nephrectomy of the left kidney because of RCC from von Hippel-Lindau disease. A. Contrast-enhanced CT image shows RCC (arrow) adjacent to the right urinary tract (arrowhead). B. Non-contrast-enhanced CT image obtained two days after cryoablation performed with pyeloperfusion and hydrodissection. Hydronephrosis in the right kidney and a high-density structure (arrowhead) in the urinary tract, which is considered to be an example of hematuria, can be seen. Retrograde urinary stent placement was performed to prevent renal failure. C. Contrast-enhanced CT image obtained at one month after cryoablation shows complete necrosis of the RCC (arrow). Improvement in hydronephrosis because of urinary stent placement can be observed. D. Contrast-enhanced CT image obtained at two years after cryoablation shows shrinkage of the ablated RCC (arrowhead). Hydronephrosis is not observable in this image.

patients using pyeloperfusion and may become evident as late as one month after thermal ablation [69, 78].

Thermal injury in the digestive tract wall, which can result in perforation or development of a fistula or abscess, is rare, but surgical treatment is needed if conservative treatment does not work [37, 38, 43, 54, 79].

Nerve injury is also reported to develop in 3.8% to 10% of patients after thermal ablation, though its occurrence is more frequent after RF ablation in comparison with cryoablation [42, 77].

Procedure-related death after thermal ablation was not reported in most studies [42, 48, 49, 53, 55, 69, 77, 78]. Nevertheless, Murray et al. and Breen et al. reported procedure-related death after cryoablation from sepsis and pulmonary embolization, respectively; procedure-related mortality rate in these studies was 0.2 and 2.1% [63, 68].

Rare but potentially life-threatening complications, including myocardial infarction, cerebrovascular accident, and cryoshock, may also appear after thermal ablation [48, 68]. Therefore, careful monitoring of patients during and after ablation is required.

Imaging Follow-up after Treatment

For the evaluation of treatment effects, cross-sectional imaging, including contrast-enhanced CT or MRI, at three- and six-months posttreatment followed by annual imaging for a period of two to five years is recommended [5, 6]. Emerging contrast enhanced masses located adjacent to the ablated area can be considered as local tumor progression [80, 81]. However, few reports of inflammatory masses mimicking tumor progression after RF ablation exist [67, 82]. Further, false-positive enhancement mimicking a residual tumor or positive enhanced necrotic fat tissue mimicking tumor seeding have been also reported after cryoablation [83, 84] (**Fig. 1**). Needle biopsy is a useful technique to confirm the diagnosis of local tumor progression after thermal ablation, especially in disputed cases.

CONCLUSIONS

Percutaneous image-guided thermal ablation is a safe and minimally invasive therapeutic option for the treatment of early-stage RCC. Oncologic outcomes of thermal ablation for small RCC tumors are comparable to those of partial nephrectomy; therefore, thermal ablation has the potential to replace nephrectomy for selected patients. However, the results of thermal ablation are highly dependent upon patient and technique selection. Therefore, careful patient selection, adequate understanding of the characteristics of each ablation modality, and appropriate application techniques are required to maximize positive patient outcomes.

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