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Meta-analysis of cryoablation versus microwave ablation for small renal masses: is there a difference in outcome?

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PURPOSE
We aimed to compare local and metastatic recurrence of small renal masses primarily treated by cryoablation or microwave ablation.

MATERIALS AND METHODS
The MEDLINE, CINAHL, and PUBMED databases were searched to review the treatment of small renal masses with cryoablation or microwave ablation. Fifty-one studies met the inclusion criteria.

RESULTS
Fifty-one studies representing 3950 kidney lesions were analyzed. No differences were detected in the mean patient age ($P = 0.150$) or duration of follow-up ($P = 0.070$). The mean tumor size was significantly larger in the microwave ablation group compared with the cryoablation group ($P = 0.030$). There was no difference between microwave ablation and cryoablation groups in terms of primary effectiveness (93.75% vs. 91.27%, respectively; $P = 0.400$), cancer-specific survival (98.27% vs. 96.8%, respectively; $P = 0.470$), local tumor progression (4.07% vs. 2.53%, respectively; $P = 0.460$), or progression to metastatic disease (0.8% vs. 0%, respectively; $P = 0.120$). Patient age was predictive of overall complications in the multivariate analysis ($P = 0.020$). Local tumor progression with cryoablation was predicted by the mean follow-up duration using univariate ($P = 0.009$) and multivariate regression ($P = 0.003$). Clear cell and angiomyolipoma were more frequent in the microwave ablation group ($P < 0.0001$ and $P = 0.03328$, respectively), and papillary, chromophobe, and oncocytoma were more frequent in the cryoablation group ($P < 0.0001$, $P < 0.0001$, and $P = 0.0004$, respectively). Open access was used more often in the microwave ablation group than in the cryoablation group (12.20% vs. 1.04%, respectively; $P < 0.0001$), and percutaneous access was used more frequently in the cryoablation group than in the microwave ablation group (88.64% vs. 37.20%, respectively; $P = 0.0021$).

CONCLUSION
There is no difference in local or metastatic recurrence between cryoablation- and microwave ablation-treated small renal masses.

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Over the past few decades, increased use of diagnostic imaging has led to a higher incidence of small renal masses through incidental discovery. From 1982 to 1997, the proportion of incidentally discovered renal tumors increased from 13% to 60%. Almost half of people with incidentally found renal masses were older than 65 years (1). As the incidence of renal cancers increases in our aging population, treatments with decreased morbidity are needed to address these smaller masses. The greater risk of end-stage renal disease after radical nephrectomy than with partial nephrectomy has encouraged the growth of elective nephron-sparing surgery (2). Excellent disease-specific survival rates have established partial nephrectomy as the reference standard of nephron-sparing surgery (3, 4). Laparoscopic partial nephrectomy results in less postoperative pain and more rapid recovery but is associated with a higher complication rate than open partial nephrectomy (5).

In the past few years, ablative therapies such as cryoablation (CA), microwave ablation (MA), and radiofrequency ablation (RFA) have become increasingly available and may provide a suitable alternative to partial nephrectomy in patients who are not suitable candidates for partial nephrectomy. The established ablative method for renal cell carcinomas (RCCs) is RFA, which shows comparable oncologic outcomes to partial nephrectomy with more preservation of nephron function (6–8). CA seems to offer the advantages of minimally invasive surgery with a significantly lower late complication rate than laparoscopic partial nephrectomy (2.2% vs. 16.3%, respectively) (9). A recent meta-analysis showed no difference in clinical efficacy or complication rates between RFA and CA, but there remains a lack of randomized clinical trial data comparing these two ablative methods (10). MA is now emerging in the literature; however, with the introduction of this novel technique, few studies have documented its efficacy and long-term outcomes.

RFA utilizes the flow of alternating electrical currents to induce thermal injury to a lesion (11). To accomplish this, a closed-loop circuit containing an electrical generator, a needle electrode, grounding pads, and a patient are required to complete the circuit. The patient acts as a resistor, and the grounding pads act as large dispersive electrodes. Advantages of RFA include its minimally invasive nature, a decrease in pain for the patient, and a shorter hospital stay. Peripheral, exophytic, and small (<3 cm) tumors are associated with improved efficacy. Disadvantages include the lack of long-term clinical data, the heat sink effect (blood flow from adjacent vessels causing heat loss), and charring, which leads to decreased ablation zones (11).

CA is used to decrease tissue temperatures to between -20°C and -50°C (12). This causes ice formation within the extracellular space that cre-

ates an osmotic gradient and vascular stasis, leading to cellular dehydration, cell membrane rupture, and local tissue ischemia. Peripherally and posteriorly located tumors improve efficacy, and central tumors may be ablated as well. Advantages include the ability to ablate tumors of any shape and the ability to control iceball margins during treatment, allowing better tumor coverage and limiting unintended injury to organs (12).

MA works by using a microwave generator to emit an electromagnetic wave (13). Electromagnetic microwaves agitate water molecules in the surrounding tissue, causing friction and heat and inducing cellular death via coagulation necrosis. Advantages include higher temperatures, larger tumor ablation volumes, shorter ablation times, and an improved convection profile (13).

The reasoning for choosing to compare CA and MA is multifold. Firstly, in a period of declining research funding and limited resources for clinical research, establishing whether MA has comparable outcomes to CA could help guide future clinical research and product development. Much about MA remains unknown, particularly in comparison to other ablative methods. To the authors' knowledge, no comparison of CA and MA exists in the scientific literature, whereas CA has been previously compared to RFA. Additionally, the nature of the statistical analysis for more than two populations is complex and beyond the scope of a meta-analysis, in which two techniques are traditionally compared. Therefore, the authors restricted the comparison to CA vs. MA and excluded RFA.

The purpose of the present study was to understand how CA and MA are being used currently, the efficacy of each procedure, and relevant predictors of local and metastatic recurrence.

Materials and methods

Data collection

The MEDLINE, CINAHL, and PUBMED databases were searched in October 2012 to review reports of the treatment of small renal masses using CA or MA. Search terms included "CA", "MA", "small renal masses", and "renal cell carcinoma", as well as all possible permutations of these terms. Small renal masses were defined as solid renal tumors that enhance on computed tomography and magnetic resonance imaging and are suspected of being RCCs. Inclusion criteria were prospective and retrospective studies in which the patient population contained sporadic primary renal tumors managed by open, laparoscopic, or percutaneous CA or MA. Studies that contained patients with Von Hippel-Lindau syndrome or other hereditary cancer syndromes were excluded. In studies with overlapping patient populations, the most recent series or the series with the largest population was selected to avoid double counting of patients. In total, 51 studies met the inclusion criteria and were analyzed as shown in Table 1 (14–64).

Statistical analysis

The retrieved articles were separated into three groups: CA, MA, and the combination of both modalities. Studies that did not differentiate their findings according to ablation type ("combination group") were excluded from the analysis. Data were collected and compiled by one coder but were also reviewed by the primary author to check for consistency and completion. Results were cross-referenced with review articles to check for accuracy and comprehensiveness. Statistical analysis was performed using Statistical Package for Social Sciences (IBM SPSS Statistics version 20.0, IBM Corp., Armonk, New York, USA). Primary effectiveness was defined as the proportion of tumors without residual enhancement after one treatment session. Cancer-specific survival is the probability of surviving

Table 1. Studies analyzed in the cryoablation and microwave ablation groups

Cryoablation			
Tanagho et al. (14)	2012	Bourne et al. (36)	2009
Duffey et al. (15)	2012	Malcolm et al. (37)	2009
Goyal et al. (16)	2012	Tsakiris, et al. (38)	2009
Schmit et al. (17)	2012	Badger et al. (39)	2009
Spreafico et al. (18)	2011	Derweesh et al. (40)	2008
Atwell et al. (19)	2011	Hinshaw et al.(41)	2008
Haber et al. (20)	2011	Georgiades et al. (42)	2008
Tsivian et al. (21)	2011	Hui et al. (43)	2008
Rodriguez et al. (22)	2011	Badwan et al. (44)	2008
Klatte et al. (23)	2011	Lin et al. (45)	2008
Strom et al. (24)	2011	Bandi et al. (46)	2008
Vricella et al. (25)	2011	Caviezel et al. (47)	2008
Chalasani et al. (26)	2010	Wright et al. (48)	2007
Beemster et al. (27)	2010	Bandi et al. (49)	2007
Mues et al. (28)	2010	Malcom et al. (50)	2007
Tsivian et al. (29)	2010	Littrup et al. (51)	2007
Weisbrod et al. (30)	2010	O'Malley et al. (52)	2007
Ko et al. (31)	2010	Gore et al. (53)	2005
Malcolm et al. (32)	2010	Bachmann et al. (54)	2005
Park et al. (33)	2010	Moon et al. (55)	2004
Ham et al. (34)	2010	Colón and Fuchs (56)	2004
Rodriguez et al. (35)	2000	Khorsandi et al. (57)	2003
Microwave ablation			
Yu et al. (58)	2012	Bai et al. (62)	2010
Guan et al. (59)	2012	Guan et al. (63)	2010
Muto et al. (60)	2011	Carrafiello et al. (64)	2010
Castle et al. (61)	2011		

Table 2. Patients, tumor characteristics, and outcome according to ablation modality

Variable	Cryoablation	n (%)	Microwave ablation	n (%)	*P*
Number of series	44	-	7	-	-
Number of patients	2989	-	164	-	-
Number of lesions	3786	2989 (100)	164	164 (100)	-
Age (years)	66.95±4.82	2885 (96.52)	58.81±14.38	164 (100)	0.15
Tumor size (cm)	2.58±0.38	2793 (93.44)	3.13±0.81	164 (100)	0.04
Duration of follow-up (months)	30.22±14.04	2989 (100)	17.86±7.93	164 (100)	0.07
Primary effectiveness (%)	93.75±17.02	2625 (87.82)	91.28±13.22	164 (100)	0.41
Cancer-specific survival (%)	98.27±1.13	1008 (33.72)	96.80±0.00	106 (64.3)	0.48
Local tumor progression (%)	4.08±1.56	1887 (63.13)	2.54±1.62	154 (93.90)	0.46
Progression to metastatic disease (%)	0.80±0.81	1544 (51.65)	0.00±0.00)	164 (100)	0.12

Unless otherwise specified, data are given as mean±standard deviation.

cancer in the absence of other causes of death. Local tumor progression is defined as any detectable local disease at follow up, either alone or in conjunction with generalized recurrence. Progression to metastatic disease is defined as the occurrence of cancer in a nonrenal location within the duration of follow-up.

Baseline patient, tumor, and outcome variables were compared using a two-sided t test, with a 95% threshold for significance ($P < 0.05$). Univariate regression was performed using a straight line regression equation (Y=a+bX), with local recurrence and metastatic recurrence used as the dependent Y variable, and sample size, mean patient age, mean tumor size, mean duration of follow-up, and mean duration of ablation were used as independent X variables. A 95% threshold for significance ($P < 0.05$) was utilized. Multivariate regression was performed using local recurrence: metastatic recurrence was used as the dependent Y variable, and sample size, mean patient age, mean tumor size, mean duration of follow up, and mean duration of ablation were used as independent X variables. All variables were entered in the model in a single step, and univariate, multivariate and combined models were calculated with *P* values. A 95% threshold for significance ($P < 0.05$) was utilized. The proportion of complications that were described, proportion of lesions biopsied, and biopsy pathology results between the CA and MA groups were compared using chi-square test for the comparison of two proportions with a 95% threshold for significance ($P < 0.05$).

Table 3. *P* values from univariate and multivariate regression analyses of factors postulated to influence local and metastatic tumor progression in patients treated with cryoablation

	Local tumor progression		Metastatic progression	
	Univariate analysis	Multivariate analysis	Univariate analysis	Multivariate analysis
Sample size	0.219	0.699	0.243	0.085
Patient age (years)	0.339	0.687	0.848	0.090
Tumor size (cm)	0.968	0.579	0.422	0.578
Duration of follow-up (months)	0.009	0.063	0.003	0.071
Duration of ablation (min)	0.549	0.923	0.531	0.082
Combined		0.337		0.132

Results

Fifty-one studies, comprising 3950 kidney lesions, were analyzed (Table 2). No significant differences in mean patient age ($P = 0.150$) were found. The mean tumor size was significantly larger in the MA group than in the CA group (2.58 vs. 3.13 cm, respectively; $P = 0.040$). The mean duration of follow-up trended toward being shorter for MA than for CA, but the difference was not statistically significant (30.22 vs. 17.86 months, respectively; $P = 0.070$). There was no difference in primary effectiveness (93.75% vs. 91.27%, $P = 0.400$), cancer-specific survival (98.27% vs. 96.8%, $P = 0.470$), local tumor progression (4.07% vs. 2.53%, $P = 0.460$), or progression to metastatic disease (0.8% vs. 0%, $P = 0.120$).

Univariate and multivariate regression analyses were performed to determine whether a series of variables are predictive of local tumor progression or metastatic progression as shown in Table 3. The duration of follow-up was significantly predictive of metastatic progression in the univariate model ($P = 0.003$), and of local tumor progression in the univariate model ($P = 0.009$). Sample size, mean patient age, mean tumor size, and duration of ablation were not statistically significant in the univariate or multivariate analysis. Sample size, mean tumor size, mean duration of follow-up, and mean duration of ablation were not statistically significant in predicting overall, major, or minor complications in the univariate and multivariate analyses (Table 4). Patient age was predictive of overall complications in the multivariate analysis ($P = 0.020$). Univariate and multivariate analyses were attempted for the MA data, but the sample size

Table 4. *P* values for univariate and multivariate regression analyses of factors postulated to influence overall, major, and minor complications in patients treated with cryoablation

	Overall complications		Major complications		Minor complications	
	Univariate analysis	Multivariate analysis	Univariate analysis	Multiavariate analysis	Univariate analysis	Multiavariate analysis
Sample size	0.335	0.102	0.713	0.817	0.444	0.685
Patient age (years)	0.135	0.020	0.919	0.403	0.094	0.980
Tumor size (cm)	0.362	0.899	0.937	0.933	0.164	0.555
Duration of follow-up (months)	0.281	0.538	0.915	0.618	0.544	0.992
Duration of ablation (min)	0.086	0.484	0.176	0.203	0.390	0.439
Combined		0.940		0.433		0.916

was too small for the analysis to be performed. Specific complications can be found in Tables 5 and 6. The MA group had significantly more reported complications than the CA group (61.11% vs. 28%, respectively; $P = 0.007$). The most common complications in the MA group were fever and flank pain; in the CA group, fever and transfusion were the most common complications.

Within the CA group, 35.73% were biopsied and proven to be RCCs, compared with 86.50% in the MA group ($P < 0.0001$). Clear cell and angiomyolipoma pathologies were documented more frequently in the MA group ($P < 0.0001$ and $P = 0.033$, respectively), and papillary, chromophobe, and oncocytoma pathologies were documented more frequently in the CA group ($P < 0.0001$, $P < 0.0001$, and $P = 0.0004$, respectively). The relative proportions of documented pathologies are shown in Table 7.

CA was usually performed at a similar frequency in laparoscopic (49.17%) and percutaneous approaches (49.79%) (Table 8). Open access was used more often with MA than with CA (12.20% vs. 1.04%, respectively; $P < 0.0001$), and percutaneous access was used more frequently with CA than with MA (88.64% *vs*. 37.20%, respectively; $P = 0.002$). These statistics were available for 3356 (88.6%) of the CA lesions and 164 (100%) of the MA lesions.

Table 5. Spectrum of complications in cryoablation

Complication	n	Complication	n
Fever	17	Delayed urosepsis	1
Transfusion	5	Pulmonary embolism	1
Heart failure	4	Loss of kidney	1
Perinephric hemorrhage	4	Internal jugular vein thrombosis	1
Retroperitoneal hematoma	4	Small bowel injury	1
Capsular fracture	4	Deep venous thrombosis	1
Gross hematuria	3	Pneumothorax	2
Cryoablated tissue fracture	3	Intercostal artery injury	1
Renal hematoma	2	Renal fracture	1
Splenic hematoma	2	Stroke	1
Atelectasis	2	Hydronephrosis	1
Pneumonia	2	Postoperative ileus	1
Urine leak	2	Myocardial infarction	1
Pulmonary edema	1	Hemothorax	1
Ureteric-pelvic junction obstruction	1	Obstructed solitary kidney	1
Herpetic esophagitis	1	Perirenal fluid collection	1
Superficial wound abscess	1	Atrial fibrillation	1
Worsening hypertension	1		
Total	77		
Fraction reported (%)[a]	28		

[a]Fraction reported reflects the proportion of complications described in detail, within the raw number of reported complications.

Discussion

As clinical outcomes data of small renal mass esablation using microwave and cryoablative methods begin to accumulate, the question as to which is preferable arises. The purpose of the current study was to compare differences in outcome between the aforementioned techniques. With a lack of literature directly comparing the efficacy of CA versus MA, we had to indirectly compare the two in many retrospective and prospective studies. There was no significant difference between primary effectiveness and cancer-specific survival between the CA and MA groups. Additionally, no difference was found in local tumor progression or metastatic progression.

The results of the univariate and multivariate linear regressions were largely nonsignificant. The duration of follow-up was a predictor of local and metastatic tumor progression in patients undergoing CA. This is expected because tumor recurrence generally increases with time. Patient age was also a predictor of the overall complication rate in the multivariate analysis. The same analysis was attempted for the MA data, but the sample size was too small for the analysis to be completed. However, MA had a higher fraction of reported complications than CA. The cause may be the severity of complications, the lack of standardized criteria for reporting complications, or the

Table 6. Spectrum of complications in microwave ablation

Complication	n
Fever of unknown origin	2
Flank pain	2
Genitofemoral neuralgia	1
Hematuria	1
Kidney atrophy	1
Perinephric hematoma	1
Pleuritic chest pain	1
Skin burn	1
Urine leak and abscess formation	1
Total	11
Fraction reported (%)[a]	61.11

[a]Fraction reported reflects the proportion of complications described in detail, within the raw number of reported complications.

Table 7. Distribution of small renal mass pathology

Small renal mass subtypes	Cryoablation n (%)	Microwave ablation n (%)	*P*
Proportion biopsied	37.53%	85.97%	< 0.0001
Clear cell	496 (34.90)	119 (84.40)	< 0.0001
Papillary	496 (34.90)	7 (4.96)	< 0.0001
Chromophobe	195 (13.72)	2 (1.42)	< 0.0001
Oncocytoma	195 (13.72)	4 (2.84)	0.0004
Angiomyolipoma	39 (2.74)	9 (6.38)	0.0328
Total	1421 (100.00)	141 (100.00)	

Table 8. Types of access used for cryoablation and microwave ablation

Types of access	Cryoablation n (%)	Microwave ablation n (%)	*P*
Laparoscopic access	1650 (49.17)	83 (50.61)	0.7793
Open access	35 (1.04)	20 (12.20)	< 0.0001
Percutaneous access	1671 (49.79)	61 (37.20)	0.0021
Number of masses	3356 (88.64)	164 (100.00)	-

experimental nature of MA. Publication of more data regarding the use of MA for small renal masses will enable identification of predictors of primary effectiveness, cancer-specific survival, and local and metastatic tumor progression. The Society of Interventional Radiology (SIR) clinical practice guidelines provide a classification scheme for complications (65); however, much of the literature does not follow this classification. In addition, many of the complications may fit into multiple categories, depending on the severity of the complication and the clinical picture. Very few reports state how specific complications were classified, but instead describe the rates of complications within major or minor categories. Because the guidelines offer broad categories of complications, there may be significant interobserver differences for determining where a particular complication fits, particularly with complications that have much variability in severity, such as pain. Therefore, we could not organize complications according to SIR guidelines but instead relied on the classification used for a particular study.

With the advent of molecular classification of renal tumors, new inroads have been made in understanding how histological and molecular subtypes of RCCs affect prognosis (66, 67). Clear-cell histology appears to be independently associated with worse outcomes in patients who undergo surgery for RCC, even after controlling for factors known to influence prognosis (66). However, this has yet to be established for percutaneous ablative techniques. In our study, most lesions treated with MA were of the clear-cell subtype (84.40%), whereas in the CA group, these comprised a much smaller proportion of lesions (34.90%). Interestingly, although the MA group had a higher proportion of a subtype that is known to negatively affect outcomes in the surgical treatment of RCCs, primary effectiveness, cancer-specific survival, and local and metastatic recurrence were not significantly different between the CA and MA groups. There may be several reasons for this. This statistic may reflect a lack of negative prognostic value for the clear-cell subtype in ablative techniques, or MA had sufficient efficacy to overcome this negative prognostic factor. A third possibility is that due to the lack of follow up in the MA group, the statistics are favorably skewed in favor of MA, as cancer-specific survival and local or metastatic recurrence may increase with time, as shown in our linear regression analysis—albeit this relationship applied to CA and may not necessarily carry over to MA. To discriminate among these possibilities, further studies should focus on whether RCC subtype affects prognosis and the relationship of follow-up duration (and other variables) in predicting outcome in MA.

Finally, our data showed that, in the CA group, laparoscopic access was used with similar frequency to percutaneous access (49.17% vs. 49.79%, respectively), whereas laparoscopic access was favored over percutaneous access in the MA group (50.61% vs. 37.20%, respectively). Recent studies have shown that percutaneous access for CA has the benefit of shorter durations of hospital stay with no significant difference in residual and recurrent disease, overall survival, cancer-specific survival, and

recurrence-free survival (16). If percutaneous access is increasingly utilized, this may result in considerable savings for hospitals in terms of hospital resources as well as financially. This relationship has not been shown in MA (59), and so more studies are required.

It is important to note that these results are not conclusive and must be interpreted with caution. Although primary effectiveness and cancer-specific survival were not significantly different, several factors may have influenced the results. The CA group had a smaller average tumor size, which may have increased both the primary effectiveness and cancer-specific survival. Conversely, follow-up duration was longer in the CA group, with a trend toward statistical significance, and may have influenced the rate of local and metastatic tumor progression, as well as primary effectiveness and cancer-specific survival. Without a direct comparison of the two techniques in a randomized trial and without baseline differences between groups, it is difficult to identify the factors that directly influenced the apparent efficacy of the two techniques. Another limitation of the current study was the statistical power. The literature involving MA for small renal masses was limited, and as such, the sample size may have been insufficient to evaluate small differences between the groups. This is evident in the metastatic tumor progression; the CA group had 0.80% of lesions progressing, while the MA group had no lesions progressing. Although the result was statistically nonsignificant, use of a larger population might have allowed evaluation of the difference in metastatic progression due to a larger sample size, resulting in an increased statistical power and a lower probability of type II error—failure to reject a false null hypothesis.

In conclusion, ablation of small renal masses is a viable strategy in patients who are not surgical candidates, have renal insufficiency, or have a solitary kidney. Current data suggest no difference in local tumor control or metastatic spread with MA, even with significantly larger tumors in the MA group and a higher proportion of clear cell and angiomyolipoma subtypes relative to the CA group. This suggests equivalent clinical efficacy in a population with a larger average tumor size and may represent a more appropriate method of treating larger tumors, which have a less favorable outcome with CA and RFA. MA avoids the charring-related impedance observed in RFA and has similar clinical and oncologic outcomes to CA. Additionally, the spectrum of complications are less severe in MA. As more reports on MA are published, further studies should compare the efficacy and cost-effectiveness of ablative therapies and evaluate factors associated with negative clinical outcomes.

Conflict of interest disclosure

The authors declared no conflicts of interest.

References

1. Luciani LG, Cestari R, Tallarigo C. Incidental renal cell carcinoma-age and stage characterization and clinical implications: study of 1092 patients. Urology 2001; 57:206–207.
2. McKiernan J, Simmons R, Katz J, Russo P. Natural history of chronic renal insufficiency after partial and radical nephrectomy. Urology 2002; 59:816–820.
3. Fergany AF, Hafez KS, Novick AC. Long-term results of nephron-sparing surgery for localized renal cell carcinoma: 10-year follow-up. J Urol 2000; 163:442–445.
4. Gill IS, Colombo JR Jr, Frank I, Moinzadeh A, Kaouk J, Desai M. Laparoscopic partial nephrectomy for hilar tumors. J Urol 2005; 174:850–854.
5. Gill IS, Matin SF, Desai MM. Comparative analysis of laparoscopic versus open partial nephrectomy for renal tumors in 200 patients. J Urol 2003; 170:64–68.
6. Olweny EO, Park SK, Tan YK, Best SL, Trimmer C, Cadeddu JA. Radiofrequency ablation versus partial nephrectomy in patients with solitary clinical T1a renal cell carcinoma: comparable oncologic outcomes at a minimum of 5 years of follow-up. Eur Urol 2012; 61:1156–1161.
7. Stern JM, Svatek R, Park S, et al. Intermediate comparison of partial nephrectomy and radiofrequency ablation for clinical T1a renal tumours. BJU Int 2007; 100:287–290.
8. Sung HH, Park BK, Kim CK, Choi HY, Lee HM. Comparison of percutaneous radiofrequency ablation and open partial nephrectomy for the treatment of size and location matched renal masses. Int J Hyperthermia 2012; 28:227–234.
9. Desai MM, Aron M, Gill IS. Laparoscopic partial nephrectomy versus laparoscopic cryoablation for the small renal tumor. Urology 2005; 66:23–28.
10. Dib ER, Touma NJ, Kapoor A. Cryoablation vs radiofrequency ablation for the treatment of renal cell carcinoma: a meta-analysis of case series studies. BJU Int 2012; 110:510–516.
11. Tatli S, Acar M, Tuncali K, Morrison PR, Silverman S. Percutaneous cryoablation techniques and clinical applications. Diagn Interv Radiol 2010; 16:90–95.
12. Tatli S, Tapan U, Morrison PR, Silverman SG. Radiofrequency ablation: technique and clinical applications. Diagn Interv Radiol 2012; 18:508–516.
13. Simon CJ, Dupuy DE, Mayo-Smith WW. Microwave ablation: principles and applications. Radiographics 2005; 25:S69–83.
14. Tanagho YS, Roytman TM, Bhayani S, et al. Laparoscopic cryoablation of renal masses: single-center long-term experience. Urology 2012; 80:307–314.
15. Duffey B, Nguyen V, Lund E, Koopmeiners JS, Hulbert J, Anderson JK. Intermediate-term outcomes after renal cryoablation: results of a multi-institutional study. J Endourol 2012; 26:15–20.
16. Goyal J, Verma P, Sidana A, Georgiades CS, Rodriguez R. Single-center comparative oncologic outcomes of surgical and percutaneous cryoablation for treatment of renal tumors. J Endourol 2012; 26:1413–1419.
17. Schmit GD, Thompson RH, Kurup AN, et al. Percutaneous cryoablation of solitary sporadic renal cell carcinomas. BJU Int 2012; 110:E526–531.
18. Spreafico C, Nicolai N, Lanocita R, et al. CT-guided percutaneous cryoablation of renal masses in selected patients. Radiol Med 2011; 117:593–605.
19. Atwell TD, Carter RE, Schmit GD, et al. Complications following 573 percutaneous renal radiofrequency and cryoablation procedures. J Vasc Inerv Radiol 2012; 23:48–54.
20. Haber G-P, Lee MC, Crouzet S, Kamoi K, Gill IS. Tumour in solitary kidney: laparoscopic partial nephrectomy vs laparoscopic cryoablation. BJU Int 2011; 109:118–24.
21. Tsivian M, Caso J, Kimura M, Polascik TJ. Renal function outcomes after laparoscopic renal cryoablation. J Endourol 2011; 25:1287–1291.
22. Rodriguez R, Cizman Z, Hong K, Koliatsos A, Georgiades C. Prospective analysis of the safety and efficacy of percutaneous cryoablation for pT1NxMx biopsy-proven renal cell carcinoma. Cardiovasc Intervent Radiol 2010; 34:573–578.
23. Klatte T, Mauermann J, Heinz-Peer G, et al. Perioperative, oncologic, and functional outcomes of laparoscopic renal cryoablation and open partial nephrectomy: a matched pair analysis. J Endourol 2011; 25:991–997.
24. Strom KH, Derweesh I, Stroup SP, et al. Recurrence rates after percutaneous and laparoscopic renal cryoablation of small renal masses: does the approach make a difference? J Endourol 2011; 25:371–375.

25. Vricella GJ, Haaga JR, Adler BL, et al. Percutaneous cryoablation of renal masses: impact of patient selection and treatment parameters on outcomes. Urology 2011; 77:649–564.
26. Chalasani V, Martinez CH, Lim D, Abdelhady M, Chin JL. Surgical cryoablation as an option for small renal masses in patients who are not ideal partial nephrectomy candidates: intermediate-term outcomes. Can Urol Assoc J 2010; 4:399–402.
27. Beemster PT, Barwari K, Mamoulakis C, Wijkstra H, la Rosette de J, Laguna MP. Laparoscopic renal cryoablation using ultrathin 17-gauge cryoprobes: mid-term oncological and functional results. BJU Int 2010; 108:577–582.
28. Mues AC, Okhunov Z, Haramis G, D'Agostino H, Shingleton BW, Landman J. Comparison of percutaneous and laparoscopic renal cryoablation for small renal masses. J Endourol 2010; 24:1097–1100.
29. Tsivian M, Chen VH, Kim CY, et al. Complications of laparoscopic and percutaneous renal cryoablation in a single tertiary referral center. Eur Urol 2010; 58:142–148.
30. Weisbrod AJ, Atwell TD, Frank I, et al. Percutaneous cryoablation of masses in a solitary kidney. Am J Roentgenol 2010; 194:1620–1625.
31. Ko YH, Choi H, Kang SG, et al. Efficacy of laparoscopic renal cryoablation as an alternative treatment for small renal mass in patients with poor operability: experience from the Korean single center. J Laparoendosc Adv Surg Tech A 2010; 20:339–345.
32. Malcolm JB, Logan JE, Given RW, et al. Renal functional outcomes after cryoablation of small renal masses. J Endourol 2010; 24:479–482.
33. Park SH, Kang SH, Ko YH, et al. Cryoablation for endophytic renal cell carcinoma: intermediate-term oncologic efficacy and safety. Korean J Urol 2010; 51:518.
34. Ham BK, Kang SG, Choi H, Ko YH, Kang SH, Cheon J. The impact of renal tumor size on the efficacy of laparoscopic renal cryoablation. Korean J Urol 2010; 51:171.
35. Rodriguez R, Chan DY, Bishoff JT, et al. Renal ablative cryosurgery in selected patients with peripheral renal masses. Urology 2000; 55:25–30.
36. Bourne AE, Kramer BA, Steiner HL, Schwartz BF. Renal insufficiency is not a contraindication for cryoablation of small renal masses. J Endourol 2009; 23:1195–1198.
37. Malcolm JB, Berry TT, Williams MB, et al. Single center experience with percutaneous and laparoscopic cryoablation of small renal masses. J Endourol 2009; 23:907–911.
38. Tsakiris P, Beemster P, Wijkstra H, la Rosette de J, Laguna P. In vivo factors influencing the freezing cycle during cryoablation of small renal masses. J Endourol 2009; 23:545–549.
39. Badger WJ, de Araujo HM, Kuehn DM, Angresen KJ, Winfield HN. Laparoscopic renal tumor cryoablation: appropriate application of real-time ultrasonographic monitoring. J Endourol 2009; 23:427–430.
40. Derweesh IH, Malcolm JB, Diblasio CJ, et al. Single center comparison of laparoscopic cryoablation and CT-guided percutaneous cryoablation for renal tumors. J Endourol 2008; 22:2461–2468.
41. Hinshaw JL, Shadid AM, Nakada SY, Hedican SP, Winter TC, Lee FT. Comparison of percutaneous and laparoscopic cryoablation for the treatment of solid renal masses. Am J Roentgenol 2008; 191:1159–1168.
42. Georgiades CS, Hong K, Bizzell C, Geschwind J-F, Rodriguez R. Safety and efficacy of CT-guided percutaneous cryoablation for renal cell carcinoma. J Vasc Inerv Radiol 2008; 19:1302–1310.
43. Hui GC, Tuncali K, Tatli S, Morrison PR, Silverman SG. Comparison of percutaneous and surgical approaches to renal tumor ablation: metaanalysis of effectiveness and complication rates. J Vasc Inerv Radiol 2008; 19:1311–1320.
44. Badwan K, Maxwell K, Venkatesh R, et al. Comparison of laparoscopic and percutaneous cryoablation of renal tumors: a cost analysis. J Endourol 2008; 22:1275–1278.
45. Lin YC, Turna B, Frota R, et al. Laparoscopic partial nephrectomy versus laparoscopic cryoablation for multiple ipsilateral renal tumors. Eur Urol 2008; 53:1210–1218.
46. Bandi G, Hedican S, Moon T, Lee FT, Nakada SY. Comparison of postoperative pain, convalescence, and patient satisfaction after laparoscopic and percutaneous ablation of small renal masses. J Endourol 2008; 22:963–968.
47. Caviezel A, Terraz S, Schmidlin F, Becker C, Iselin C. Percutaneous cryoablation of small kidney tumours under magnetic resonance imaging guidance: medium-term follow-up. Scand J Urol Nephrol 2008; 42:412–416.
48. Wright AD, Turk TMT, Nagar MS, Phelan MW, Perry KT. Endophytic lesions: a predictor of failure in laparoscopic renal cryoablation. J Endourol 2007; 21:1493–1496.
49. Bandi G, Wen CC, Hedican SP, Moon TD, Lee FT, Nakada SY. Cryoablation of small renal masses: assessment of the outcome at one institution. BJU Int 2007; 100:798–801.
50. Malcolm JB, Gold R, Derweesh IH. Pilot experience with transhepatic percutaneous renal cryoablation. J Endourol 2007; 21:721–725.
51. Littrup PJ, Ahmed A, Aoun HD, et al. CT-guided percutaneous cryotherapy of renal masses. J Vasc Interv Radiol 2007; 18:383–392.
52. O'Malley RL, Berger AD, Kanofsky JA, Phillips CK, Stifelman M, Taneja SS. A matched-cohort comparison of laparoscopic cryoablation and laparoscopic partial nephrectomy for treating renal masses. BJU Int 2007; 99:395–398.
53. Gore JL, Kim HL, Schulam P. Initial experience with laparoscopically assisted percutaneous cryotherapy of renal tumors. J Endourol 2005; 19:480–483.
54. Bachmann A, Sulser T, Jayet C, et al. Retroperitoneoscopy-assisted cryoablation of renal tumors using multiple 1.5-mm ultrathin cryoprobes: a preliminary report. Eur Urol 2005; 47:474–479.
55. Moon TD, Lee FT, Hedican SP, Lowry P, Nakada SY. Laparoscopic cryoablation under sonographic guidance for the treatment of small renal tumors. J Endourol 2004; 18:436–440.
56. Colón I, Fuchs GJ. Early experience with laparoscopic cryoablation in patients with small renal tumors and severe comorbidities. J Endourol 2003; 17:415–423.
57. Khorsandi M, Foy RC, Chong W, Hoenig DM, Cohen JK, Rukstalis DB. Preliminary experience with cryoablation of renal lesions smaller than 4 centimeters. J Am Osteopath Assoc 2002; 102:277–281.
58. Yu J, Liang P, Yu XL, et al. US-guided percutaneous microwave ablation of renal cell carcinoma: intermediate-term results. Radiology 2012; 263:900–908.
59. Guan W, Bai J, Liu J, et al. Microwave ablation versus partial nephrectomy for small renal tumors: intermediate-term results. J Surg Oncol 2012; 106:316–321.
60. Muto G, Castelli E, Migliari R, D'Urso L, Coppola P, Collura D. Laparoscopic microwave ablation and enucleation of small renal masses: preliminary experience. Eur Urol 2011; 60:173–176.
61. Castle SM, Salas N, Leveillee RJ. Initial experience using microwave ablation therapy for renal tumor treatment: 18-month follow-up. Urology 2011; 77:792–797.
62. Bai J, Hu Z, Guan W, et al. Initial experience with retroperitoneoscopic microwave ablation of clinical T(1a) renal tumors. J Endourol 2010; 24:2017–2022.
63. Guan W, Bai J, Hu Z, Su Y, Zhuang Q, Ye Z. Retroperitoneoscopic microwave ablation of renal hamartoma: middle-term results. J Huazhong Univ Sci Technol 2010; 30:669–671.
64. Carrafiello G, Mangini M, Fontana F, et al. Single-antenna microwave ablation under contrast-enhanced ultrasound guidance for treatment of small renal cell carcinoma: preliminary experience. Cardiovasc Intervent Radiol 2009; 33:367–374.
65. Sacks D, McClenny TE, Cardella JF, Lewis CA. Society of Interventional Radiology clinical practice guidelines. J Vasc Interv Radiol 2003; 14:S199–202.
66. Teloken PE, Thompson RH, Tickoo SK, et al. Prognostic impact of histological subtype on surgically treated localized renal cell carcinoma. J Urol 2009; 182:2132–2136.
67. Schuetz AN, Yin-Goen Q, Amin MB, et al. Molecular classification of renal tumors by gene expression profiling. J Mol Diagn 2005; 7:206–218.