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Percutaneous Microwave Ablation versus Laparoscopic Partial Nephrectomy for cT1a Renal Cell Carcinoma: A Propensity-matched Cohort Study of 1955 Patients

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Background: Percutaneous microwave ablation (MWA) and laparoscopic partial nephrectomy (LPN) are two modalities indicated for early-stage renal cell carcinoma (RCC) with low extent of invasion.

Purpose: To compare the long-term results of percutaneous MWA and LPN in the treatment of cT1a RCC.

Materials and Methods: This retrospective study included 1955 patients with cT1a RCC treated with percutaneous MWA or LPN between April 2006 and November 2017. Propensity score matching was used. Oncologic outcomes were analyzed by using the Fine-and-Gray competing risk models.

Results: A total of 185 patients underwent percutaneous MWA (mean age, 63.2 years ± 15.2 [standard deviation]) and 1770 underwent LPN (mean age, 50.9 years ± 13.2). During the follow-up (median, 40.6 months), after propensity score matching, no difference was observed between local tumor progression (3.2% vs 0.5%, P = .10), cancer-specific survival (2.2% vs 3.8%, P = .24), and distant metastases (4.3% vs 4.3%, P = .76). Patients who underwent percutaneous MWA had worse overall survival (hazard ratio, 2.4; 95% confidence interval: 1.0, 5.7; P = .049 vs LPN) and disease-free survival (82.9% vs 91.4%, P = .003). Percutaneous MWA led to smaller drop in estimated glomerular filtration rate at discharge (6.2% vs 16.4%, $P < .001$), smaller estimated blood loss (4.5 mL ± 1.3 vs 54.2 mL ± 69.2), lower cost ($3150 ± 2970 vs $6045 ± 1860 U.S. dollars), shorter operative time (0.5 minute ± 0.1 vs 1.8 minutes ± 0.6), and shorter postoperative hospitalization time (5.1 days ± 2.6 vs 6.9 days ± 2.8) (all $P < .001$ vs LPN). There were fewer cases of fever in the percutaneous MWA group (16.2% vs 73.0%, $P < .001$).

Conclusion: There were no significant differences regarding oncologic outcomes and complications between percutaneous microwave ablation and laparoscopic partial nephrectomy for patients with cT1a renal cell carcinoma. Percutaneous microwave ablation led to smaller renal function change and lower blood loss. For patients who cannot be subjected to the risks of more invasive laparoscopic partial nephrectomy, percutaneous microwave ablation could be an alternative less invasive treatment option.

Online supplemental material is available for this article.

Renal cell carcinoma (RCC) is a heterogeneous group of kidney cancers mostly of proximal tubule origin (1) and represents more than 90% of all kidney cancers (2). The global yearly incidence of RCC is estimated at six per 100 000 men and three per 100 000 women (3). Patients with T1a RCC are considered to have a good prognosis, with a frequency of distant metastasis of 0.7%–7.2% (4).

Current treatment guidelines recommend partial nephrectomy as the preferred treatment for patients with clinical T1a (ie, cT1a) RCC and who are good surgical candidates (5). Thermal ablation is an appropriate option for elderly patients with comorbidities who are unfit for surgery, mainly because of the benefit of renal preservation and minimal invasion (6–8). Indeed, several studies have concluded that the oncologic control was similar between partial nephrectomy and cryoablation or radiofrequency ablation (RFA) (9–13). Microwave ablation (MWA) is one of the most recent and exciting advances among thermal ablation techniques and has been widely used for the treatment of hepatocellular carcinoma (14). Compared with the passive heating of RFA, the potential benefits of MWA include a larger ablation zone and higher intratumoral temperatures achieved through active heating (15). Therefore, MWA offers optimistic outcomes for small RCC (16–18). Previous studies by our group concluded that the oncologic outcomes with percutaneous MWA were comparable to those with radial nephrectomy (19,20). A study comparing open or laparoscopic MWA with open partial nephrectomy showed that the two modalities achieved similar results (21).

Percutaneous MWA and laparoscopic partial nephrectomy (LPN) are two modalities indicated for early-stage

Abbreviations

CSS = cancer-specific survival, DFS = disease-free survival, eGFR = estimated glomerular filtration rate, LPN = laparoscopic partial nephrectomy, LTP = local tumor progression, MWA = microwave ablation, OS = overall survival, RCC = renal cell carcinoma, RFA = radiofrequency ablation.

Summary

The complication rates and oncologic outcomes for patients with cT1a renal cell carcinoma treated with percutaneous microwave ablation were similar to those of patients treated with laparoscopic partial nephrectomy; however, percutaneous microwave ablation led to smaller renal function change and blood loss.

Key Points

- There were no differences regarding local tumor progression (3.2% vs 0.5%, $P = .10$), cancer-specific survival (2.2% vs 3.8%, $P = .24$), and metastases (4.3% vs 4.3%, $P = .76$) between percutaneous microwave ablation (MWA) and laparoscopic partial nephrectomy (LPN) in the treatment of cT1a renal cell carcinoma.
- There were no differences regarding major complications (2.2% vs 4.9%, $P = .17$) between percutaneous MWA and LPN in the treatment of cT1a renal cell carcinomas.
- Percutaneous MWA led to smaller renal function change (estimated glomerular filtration rate, 6.2% vs 16.4%, $P < .001$) and less blood loss (4.5 mL $\pm$ 1.3 vs 54.2 mL $\pm$ 69.2, $P < .001$).

RCC with less extent of invasion. Nevertheless, data about the direct comparison of percutaneous MWA and LPN are lacking regarding the treatment of T1a RCC. On the basis of the results of our previous study (19,20), we sought to determine differences in oncologic outcomes for percutaneous MWA versus LPN in treatment of cT1a RCC. The aim of the present study was to present our 12-year experience and to evaluate the long-term results of percutaneous MWA and LPN for treating cT1a RCCs.

Materials and Methods

Study Design and Patients

This was a retrospective study. The electronic clinical records system of the Chinese PLA General Hospital was consulted to retrieve data in all consecutive patients who underwent percutaneous MWA or LPN for cT1a RCC between April 2006 and November 2017. Only those with histologic confirmation of RCC diagnosis and an RCC of 4 cm or smaller were included. Patients with vascular invasion or extrarenal spread confirmed at MRI or CT were excluded. This study was approved by the institutional review board of Chinese PLA General Hospital. All patients provided written informed consent for treatment, and the need for informed consent for data for publication was waived by the committee because no individual information would be demonstrated. The committee authorized the chart review.

Imaging

Unenhanced US and contrast material–enhanced US were performed in all patients by using an Acuson Sequoia 512 scanner (Siemens, Erlangen, Germany), a 3.5–5.0-MHz curved-array multifrequency transducer, and the US contrast agent Sonovue (Bracco, Milan, Italy). All patients also underwent CT or MRI. MRI was the first imaging option, but CT was performed when MRI was not possible (eg, in patients with obesity, allergy to contrast material, claustrophobia, metal implants, or foreign bodies). CT and MRI parameters are presented in Appendix E1 (online). US-guided biopsy was performed before percutaneous MWA by using an automatic biopsy gun with an 18-gauge cutting needle (Bard MaxCore Disposable Core Biopsy Instrument, Tempe, Ariz). Two or three separate punctures were performed.

Treatments

The treatment decision was made in consensus and determined by a team of six radiologists (P.L., X.Y., J.Y., Z.C., Z.H., and F.L.) and one urologist (X.Z.), all with more than 5 years of experience in the treatment of RCC. The Charlson comorbidity index was calculated prior to treatment (22). LPN was performed as previously described (23). Percutaneous MWA was performed with US guidance, as previously described (17,19,20). For further details on the treatment methods, please see Appendix E1 (online).

Follow-up and Outcomes

Surgical data were collected and included estimated glomerular filtration rate (eGFR) at discharge, postoperative hospitalization time, surgical time, and estimated blood loss. The follow-up included routine outpatient physical examination, renal function assessment (creatinine and eGFR levels), and contrast-enhanced US or CT/MRI at 1 month and 3 months after treatment and then at 6-month intervals. Local tumor progression (LTP) was defined as a new lesion found within or abutting the ablation zone or the resection bed during follow-up (24). Complications within 30 days after therapy were recorded based on the classification of the Society of Interventional Radiology (25) and the Clavien-Dindo system (26). A major complication was defined as an event that led to substantial morbidity and disability (eg, resulted in the unexpected loss of an organ) and that increased the level of care, resulted in hospital admission, or substantially lengthened hospital stay (ie, Society of Interventional Radiology class C–E or Clavien-Dindo grade III–V complications). Metastases, cancer-specific survival (CSS), overall survival (OS), and disease-free survival (DFS) were evaluated from the date of treatment.

Statistical Analysis

To control for baseline imbalances between groups, the two groups were matched by using propensity score matching. The propensity to undergo percutaneous MWA versus LPN was estimated by using a logistic regression model based on age, sex, tumor diameter, tumor histologic features, and lesion segment. The matching algorithm was 1:1 genetic matching with no replacement, which automatically finds a balance to determine the optimal weight for each covariable within the matching algorithm. Genetic matching maximizes the balance of observed covariables between two groups and is a generalization of the propensity score and Mahalanobis distance matching (27).

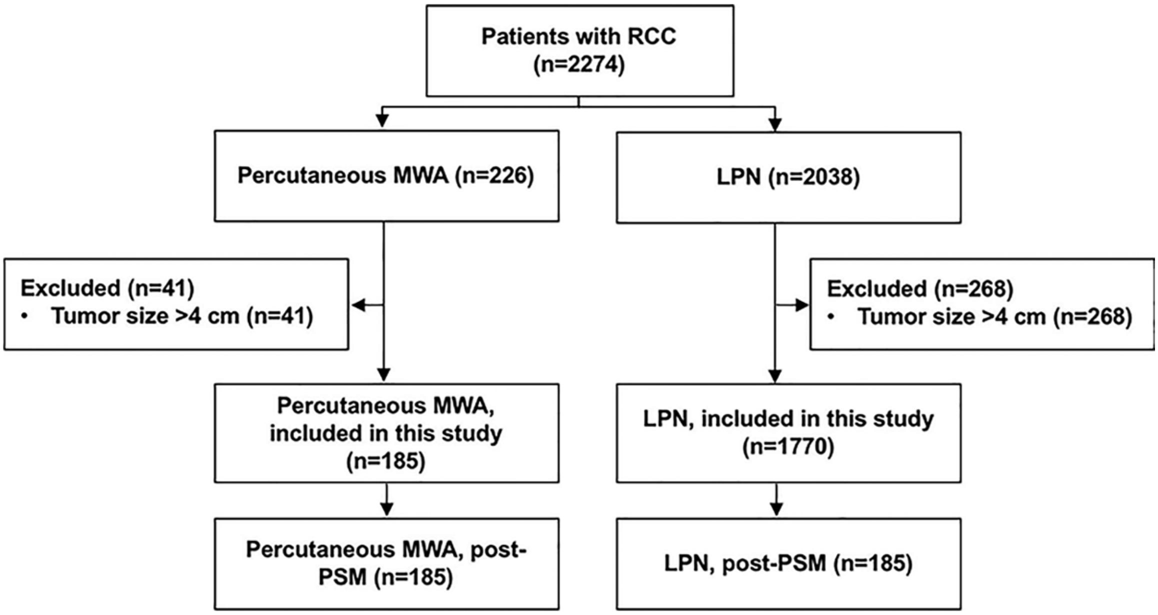

Figure 1: Patient flowchart. LPN = laparoscopic partial nephrectomy, MWA = microwave ablation, PSM = propensity score matching, RCC = renal cell carcinoma.

Patient characteristics, tumor characteristics, and posttreatment outcomes were compared between groups before and after matching. The Wilcoxon rank sum test or t test was used for continuous variables, and the χ^2 test or Fisher exact test was used for categorical variables, as appropriate. Costs and length of follow-up were compared by using the Wilcoxon rank sum test. The risks of LTP, DFS, distant metastasis, and RCC-specific mortality were analyzed by using Fine-and-Gray competing risk models, with death from non-RCC causes considered a competing event. OS, CSS, and DFS were estimated by using the Kaplan-Meier method and were compared by using the log-rank test.

Multiple clinical variables were evaluated for their association with LTP and CSS by using a Cox proportional hazards regression model. For the matched and unmatched analyses, variables with $P < .20$ in univariable analyses were included in the multivariable models. Subgroup analyses using a Cox proportional hazards regression model were performed to assess homogeneity of the association between treatment modality and OS or DFS in clinically relevant subgroups of patients in the primary matched cohort. Effect and interaction P values were calculated. Statistical analysis was performed by using Stata 13.0 (Stata, College Station, Tex). All tests were two sided, with $P < .05$ considered to indicate a statistically significant difference.

Results

Patients

A total of 2274 consecutive patients underwent percutaneous MWA (n = 226) or LPN (n = 2038) during the study period; 1955 (86.0%) of 2038 patients met the eligibility criteria. Among the 1955 patients, 185 (9.5%) underwent percutaneous MWA and 1770 (90.5%) underwent LPN (Fig 1). After 1:1 propensity score matching, a good balance was achieved for most baseline data; however, an imbalance remained for the Charlson comorbidity index (median, 4.0 vs 1.0; $P < .001$) (Table 1). At baseline, CT was performed in 37 (20%) of the 185 patients in the percutaneous MWA group and in 54 (29.2%) of 185 patients in the LPN group, while MRI was performed in 148 (80.0%) of the 185 patients in the percutaneous MWA group and in 131 (70.8%) of the 185 patients in the LPN group (P = .053).

Intraoperative and Postoperative Outcomes

In the percutaneous MWA group, the 185 patients (with 192 tumors) received 210 treatment sessions. Among the 192 tumors, 179 were successfully treated with one percutaneous MWA session and 13 nodules were treated with two sessions. All patients in the LPN group underwent one surgery. In both the unmatched and matched analyses (Table 2), the procedure time for the LPN group was significantly longer than that for the percutaneous MWA group ($P < .001$ for both analyses). Estimated blood loss was significantly greater in the LPN group than in the percutaneous MWA group ($P < .001$); 47 patients in the LPN group needed blood transfusion with 1–12 U of red cells and/or 1–4 U of plasma volume. Transfusion was not necessary in the percutaneous MWA group.

There was no significant difference in posttreatment major complications between the percutaneous MWA and LPN groups (four [2.2%] of 185 vs 79 [4.5%] of 1770, unmatched P = .15; and four [2.2%] of 185 vs nine [4.9%] of 185, matched P = .17) (Table 2).

There were four (2.2%) major complications in 185 patients within 30 days in the percutaneous MWA group, including three (75%) Clavien-Dindo grade III complications and one (25%) grade IV complication. The complications were all directly related to the ablation procedure. Two patients developed urinary fistula necessitating discharge with an indwelling bladder

Table 1: Baseline Participant Characteristics

	Unmatched Cohort			Matched Cohort		
Parameter	MWA (n = 185)	LPN (n = 1770)	P Value	MWA (n = 185)	LPN (n = 185)	P Value
Age (y)	63.2 ± 15.2	50.9 ± 13.2	<.001	63.2 ± 15.2	60.4 ± 14.1	.07
No. of female patients	48 (26.0)	411 (23.3)	.41	48 (26.0)	47 (25.4)	.91
Charlson comorbidity index	4.0 (2.3–4.0)	1.0 (0–3.0)	.001	4.0 (2.3–4.0)	1.0 (0–3.0)	<.001
Preoperative creatinine level ≥ 0.85 mg/dL	102 (55.1)	885 (50)	.002	102 (55.1)	111 (61.6)	.21
Preoperative eGFR ≥ 120 mL/min/1.73 m^2	126 (68.1)	229 (12.9)	.003	126 (68.1)	119 (64.3)	.44
Maximal tumor size (cm)	2.3 ± 0.5	2.3 ± 0.8	.86	2.3 ± 0.5	2.3 ± 0.9	.67
Tumor side			.054			.68
Left	81 (43.8)	907 (51.2)		81 (43.8)	85 (45.9)	
Right	104 (56.2)	863 (48.8)		104 (56.2)	100 (54.1)	
Tumor location			<.001			.050
Upper segment	54 (29.2)	629 (35.5)		54 (29.2)	60 (32.4)	
Middle segment	80 (43.2)	468 (26.4)		80 (43.2)	58 (31.4)	
Lower segment	51 (27.6)	673 (38.0)		51 (27.6)	67 (36.2)	
Tumor histologic type			.56			>.99
Clear cell carcinoma	174 (94.1)	1622 (91.6)		174 (94.1)	174 (94.1)	
Papillary carcinoma	5 (2.7)	70 (4.0)		5 (2.7)	5 (2.7)	
Chromophobe cell carcinoma	6 (3.2)	57 (3.2)		6 (3.2)	6 (3.2)	
Cystic carcinoma	0	17 (1.0)		0	0	
Granular cell carcinoma	0	4 (0.2)		0	0	

Note.—Data are means ± standard deviations or medians with interquartile ranges in parentheses for continuous variables and are numbers of patients with percentages in parentheses for categorical variables. eGFR = estimated glomerular filtration rate, LPN = laparoscopic partial nephrectomy, MWA = microwave ablation. The propensity to undergo percutaneous MWA versus LPN was estimated by using a logistic regression model based on age at treatment, sex, Charlson comorbidity index, maximum tumor diameter, baseline eGFR, tumor histologic type, and side of tumor. All patients were included in the matched analysis.

Table 2: Comparison of Intraoperative and Postoperative Outcomes between the Percutaneous MWA and LPN Groups

	Unmatched Cohort			Matched Cohort		
Parameter	MWA (n = 185)	LPN (n = 1770)	P Value	MWA (n = 185)	LPN (n = 185)	P Value
Postoperative hospitalization time (d)	5.1 ± 2.6	6.9 ± 3.0	<.001	5.1 ± 2.6	6.9 ± 2.8	<.001
Procedure time (h)	0.5 ± 0.1	1.9 ± 0.7	<.001	0.5 ± 0.1	1.8 ± 0.6	<.001
Estimated blood loss (mL)	4.5 ± 1.3	63.1 ± 83.4	<.001	4.5 ± 1.3	54.2 ± 69.2	<.001
Percentage decrease in eGFR at discharge	6.2	17.0	<.001	6.2	16.4	<.001
Cost (U.S. dollars)	3150 ± 2970	6475 ± 3660	<.001	3150 ± 2970	6045 ± 1860	<.001
Major complication	4 (2.2)	79 (4.5)	0.15	4 (2.2)	9 (4.9)	0.17
Fever > 38°C	30 (16.2)	1250 (70.6)	<.001	30 (16.2)	135 (73.0)	<.001

Note.—Data are means ± standard deviations or medians with interquartile ranges in parentheses for continuous variables and are numbers of patients with percentages in parentheses for categorical variables. eGFR = estimated glomerular filtration rate, LPN = laparoscopic partial nephrectomy, MWA = microwave ablation. The propensity to undergo percutaneous MWA versus LPN was estimated by using a logistic regression model based on age at treatment, sex, Charlson comorbidity index, maximum tumor diameter, baseline eGFR, tumor histologic type, and side of tumor. All patients were included in the matched analysis.

catheter. One patient with liver cirrhosis developed hepatic encephalopathy with liver dysfunction, which was treated with intravenous drugs. One patient developed colon perforation, which was treated with surgery.

There were 79 (4.5%) major complications in 1770 patients within 30 days in the LPN group, with 67 (84.8%) Clavien-Dindo grade III complications and 12 (15.2%) grade IV complications. The major complications after LPN included postoperative bleeding, urinary fistula, acute renal failure, urinary tract infection, and pancreatitis. Urinary fistula was treated with an indwelling bladder catheter; the other complications were treated with intravenous drugs and blood transfusion.

Fever was the most common adverse event in both groups. In the unmatched and matched analyses, the percutaneous MWA group had a lower frequency of fever after treatment compared with the LPN group (unmatched: 30 [16.2%] of 185 vs 1250 [70.6%] of 1770, $P < .001$; matched: 30 [16.2%] of 185 vs 135 [73.0%] of 185, $P < .001$) and shorter postoperative hospitalization time than the LPN group (unmatched: 5.1 days ± 2.6 vs 6.9 days ± 3.0, $P < .001$; matched: 5.1 days ± 2.6 vs 6.9 days

Table 3: Oncologic Outcomes and Recurrence

	Unmatched Cohort				Matched Cohort			
Outcome	MWA (*n* = 185)	LPN (*n* = 1770)	Hazard Ratio*	*P* Value	MWA (*n* = 185)	LPN (*n* = 185)	Hazard Ratio*	*P* Value
Local tumor progression	6 (3.2)	17 (1.0)	1.0 (0.4, 2.5)	.92	6 (3.2)	1 (0.5)	6.0 (0.7, 50.2)	.10
Distant metastasis†	8 (4.3)	39 (2.2)	0.9 (0.4, 2.0)	.81	8 (4.3)	8 (4.3)	0.8 (0.3, 2.5)	.76
Disease-free survival	155 (82.9)	1674 (94.6)	5.1 (3.3, 8.0)	<.001	155 (82.9)	169 (91.4)	3.1 (1.5, 6.6)	.003
Death from any cause	19 (10.3)	46 (2.6)	3.8 (2.2, 6.5)	<.001	19 (10.3)	7 (3.8)	2.4 (1.0, 5.7)	.049
Death from RCC†	4 (2.2)	40 (2.3)	0.8 (0.3, 2.3)	.68	4 (2.2)	7 (3.8)	0.5 (0.1, 1.6)	.24

Note.—Unless otherwise specified, data are numbers of patients, with percentages in parentheses. Fine-and-Gray models were used for local tumor progress, distant metastasis, and renal cell carcinoma (RCC) death, with death from any other causes considered as a competing event. Cox proportional hazards models were used for death from any cause. Hazard ratios greater than 1 indicate a higher risk of an event or outcome with percutaneous microwave ablation (MWA). LPN = laparoscopic partial nephrectomy.

* Data in parentheses are 95% confidence intervals.

† Distant metastasis or death from RCC were proved in all patients at biopsy or surgical pathologic examination.

± 2.8, *P* < .001). As for the decrease in eGFR from baseline to discharge, both in unmatched and matched analysis, the percutaneous MWA group showed a smaller variation in eGFR than the LPN group (6.2% vs 16.4%, *P* < .001 in the unmatched and matched analysis). LPN was about twice as expensive as percutaneous MWA (unmatched analysis: $3150 ± 2970 vs $6465 ± 3660 U.S. dollars, *P* < .001; matched analysis: $3150 ± 2970 vs $6045 ± 1860, *P* < .001).

Recurrence and Survival

The median follow-up was 42.0 months (range, 23.5–69.3 months) in the percutaneous MWA group and 40.6 months (range, 25.1–63.4 months) in the LPN group (*P* = .06). For follow-up evaluation, 26 (14.1%) of 185 patients underwent CT, 138 (74.6%) underwent MRI, and 21 (11.4%) underwent contrast-enhanced US in the percutaneous MWA group; 35 (18.9%) of 185 patients underwent CT, 140 (75.7%) underwent MRI, and 10 (5.4%) underwent contrast-enhanced US in the LPN group (matched cohort, *P* = .07). LTP, distant metastasis, and death from RCC were not significantly different between the two groups, both before and after matching (Table 3; Fig 2, *A*). Compared with the LPN group, patients in the percutaneous MWA group displayed worse DFS and OS both before and after matching (Table 3; Fig 2, *B, C*).

In the unmatched cohort, 19 (10.3%) of the 185 patients in the percutaneous MWA group and 46 of the 1770 patients in the LPN group (2.6%) died (hazard ratio, 3.8; 95% confidence interval: 2.2, 6.5; *P* < .001). In the percutaneous MWA group, the cause of death was RCC progression in four patients, other cancer progression in six patients, heart failure in five patients, cerebral hemorrhage in three patients, and upper gastrointestinal hemorrhage in one patient. In the LPN group, the cause of death was RCC progression in 40 patients, other cancer progression in two patients, myocardial infarction in three patients, and severe pancreatitis in one patient. In the matched cohort, seven (3.8%) of the 185 patients in the LPN group died, all from RCC progression. Percutaneous MWA was associated with worse OS among the whole matched cohort (hazard ratio, 2.4; 95% confidence interval = 1.0, 5.7; *P* = .042; Fig 2, *C*).

Risk Factors Associated with Patient Outcome

After propensity score matching, histologic type and major complication during treatment were independent prognostic factors of CSS; however, the treatment modality was not significant (hazard ratio, 0.8; 95% confidence interval: 0.5, 1.2; *P* = .26) (Table 4). No factor, including treatment modality, was discovered to be independently associated with LTP (Table 5). Major complications were independently associated with DFS, while age and preoperative serum creatinine level were independently associated with OS (Tables E1–E6 [online]).

Subgroup Analyses by Important Covariables

Among patients 60 years of age or older, regardless of subgroup, percutaneous MWA treatment conferred a higher risk of disease progression and all-cause mortality (Figs 3, 4; Figs E1–E4 [online]; Tables E7–E12 [online]). Among patients less than 60 years of age, the risk of disease progression with percutaneous MWA was greatly reduced (Figs 3, 4; Figs E1–E4 [online]; Tables E7–E12 [online]). The associations of treatment modality with other outcomes are displayed in Figures E1–E4 (online) and Tables E7–E12 (online).

Discussion

Percutaneous microwave ablation (MWA) led to a smaller decrease in estimated glomerular filtration rate at discharge (6.2% vs 16.4%, *P* < .001), less estimated blood loss (4.5 mL ± 1.3 vs 54.2 mL ± 69.2), lower cost ($3150 ± 2970 vs $6045 ± 1860 U.S. dollars), shorter procedure time (0.5 min ± 0.1 vs 1.8 min ± 0.6), and shorter postoperative hospitalization time (5.1 days ± 2.6 vs 6.9 days ± 2.8) (*P* < .001 for all vs laparoscopic partial nephrectomy [LPN]). There were fewer cases of fever in the percutaneous MWA group (16.2% vs 73.0%, *P* < .001). During follow-up (median, 40.6 months), after propensity score matching, no significant difference was observed between local tumor progression (3.2% vs 0.5%, *P* = .10), cancer-specific survival (2.2% vs 3.8%, *P* = .24), and distant metastasis (4.3% vs 4.3%, *P* = .76). Patients who underwent percutaneous MWA had worse overall survival (hazard ratio = 2.4; 95% confidence interval: 1.0, 5.7; *P* = .049) and

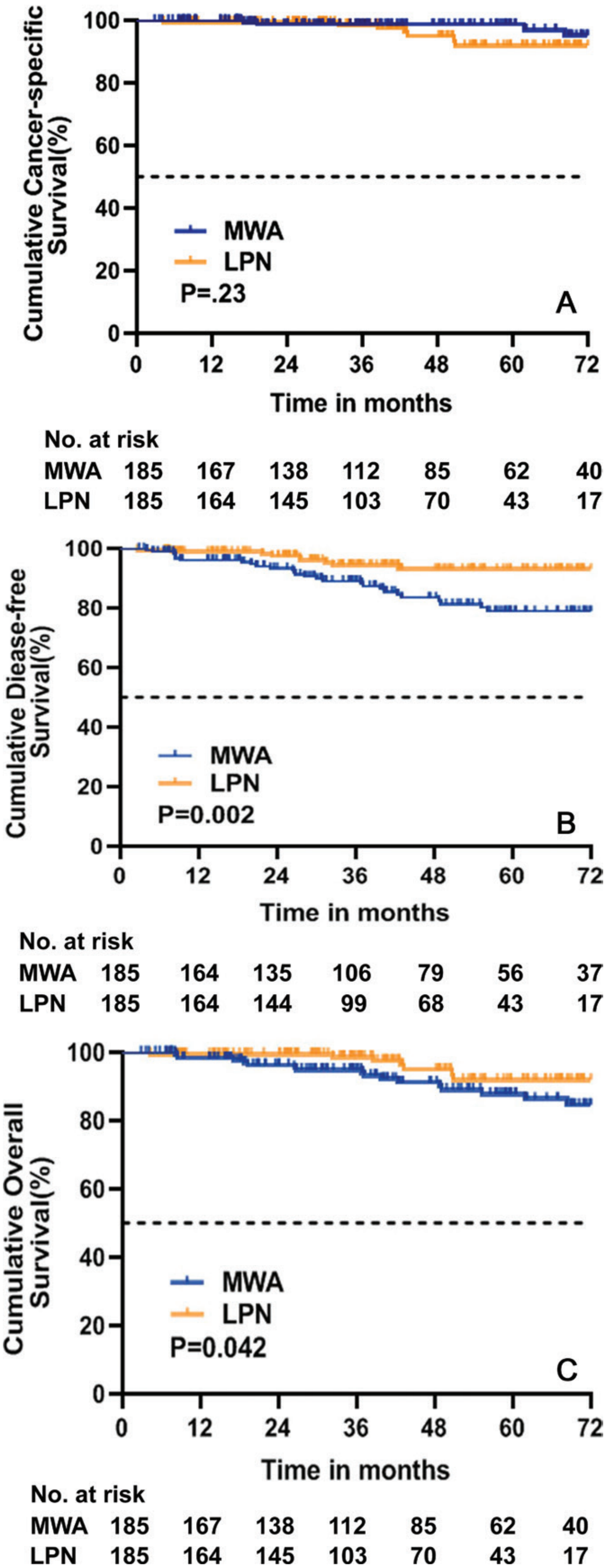

Figure 2: Graphs show Kaplan-Meier survival estimates for survival between propensity score–matched patients who underwent percutaneous microwave ablation (MWA) or laparoscopic partial nephrectomy (LPN). *A*, Graph shows cumulative cancer-specific survival (CSS). There was no significant difference in cumulative CSS between the percutaneous MWA and LPN groups ($P = .23$, log-rank test). *B*, Graph shows cumulative disease-free survival (DFS). The DFS of the LPN group was better than that of the percutaneous MWA group ($P = .002$, log-rank test). *C*, Graph shows cumulative overall survival (OS). The 1-, 3-, and 5-year OS rates, respectively, were 98.3%, 94.0%, and 86.3% in the percutaneous MWA group and 98.6%, 97.6%, and 91.9% in the LPN group. The OS in the LPN group was better than that in the percutaneous MWA group ($P = .042$, log-rank test). Dashed line = 50% survival.

disease-free survival (82.9% vs 91.4%, $P = .003$) than those who underwent LPN.

Clinical practice guidelines recommend partial nephrectomy for stage T1 RCC, with the goal of preserving healthy renal parenchyma without compromising cancer control (10–13). Percutaneous ablation—in particular, cryoablation and RFA—has been increasingly used as an alternative nephron-sparing option and has been supported by several high-quality prospective studies (10–13). MWA is another heat-based ablation modality with several physical advantages regarding heat delivery (15). During the past decade, new MWA devices with internally cooled systems and higher thermal efficiencies have been developed, offering better potential advantages over older systems (28). Outcomes in patients with RCC treated with MWA were reported to be optimistic by a number of studies (16,17,19,20,29–33). Nevertheless, the possible oncologic equivalence of MWA as a treatment option to partial nephrectomy for the management of T1a RCC is still, to our knowledge, unknown.

To our knowledge, only three preliminary reports (19–21) have compared surgery and MWA in patients with RCC, including percutaneous MWA versus radical nephrectomy and laparoscopic or open ablation versus partial nephrectomy, and failed to find evidence of differences regarding survival outcomes between the two modalities. In our study, both the oncologic and functional outcomes were compared between percutaneous MWA and LPN for cT1a tumors in a large group of patients. To best control for selection and informational biases, the two groups were matched on the basis of key variables known to influence the outcomes. Our study revealed that percutaneous MWA was inferior to LPN regarding OS and DFS but did not find evidence of a difference in regard to CSS ($P = .23$); these results may be related to a poorer health condition with a higher Charlson comorbidity index in the percutaneous MWA group. Indeed, the Charlson comorbidity index at baseline was different between the two groups, even after propensity score matching. This could explain, at least in part, the worse OS and DFS observed with percutaneous MWA, while the analyses did not find evidence of differences regarding CSS, LTP, and metastasis, which are pure oncologic outcomes. With regard to renal functional outcomes, eGFR preservation was better with percutaneous MWA ($P < .001$ vs LPN). Furthermore, the percutaneous MWA group showed smaller blood loss, shorter procedure time, and shorter hospitalization time than the LPN group. The percutaneous MWA group had a lower rate of major complications than the LPN

Table 4: Univariable and Multivariable Analyses of Prognostic Factors for Cancer-specific Survival in the Matched Cohort

	Univariable Analysis		Multivariable Analysis	
Parameter*	Hazard Ratio	*P* Value	Hazard Ratio	*P* Value
Sex (male vs female)	0.9 (0.7, 1.2)	.53	…	…
Age (y)	1.0 (1.0, 1.0)	.053	1.0 (1.0, 1.0)	.64
Charlson comorbidity index	1.0 (0.9, 1.0)	.045	1.0 (0.9,1.0)	.38
Histologic type (renal cell carcinoma vs others)	1.8 (1.1, 2.8)	.011	1.9 (1.2,3.0)	.007
Tumor diameter (cm)	1.0 (0.9, 1.2)	.79	…	…
Preoperative serum creatinine level (≥0.85 vs <0.85 mg/dL)	0.9 (0.8,1.2)	.55	…	…
Preoperative eGFR (≥120 vs <120 mL/min/1.73 m^2)	1.0 (0.8, 1.3)	.86	…	…
Decrease in eGFR by discharge (≥10% vs <10%)	1.1 (0.9, 1.4)	.38	…	…
Procedure time (h)	1.1 (1.0, 1.3)	.12	0.9 (0.7,1.1)	.26
Estimated blood loss (mL)	1.0 (1.0, 1.0)	.61	…	…
Side of tumor (left vs right kidney)	1.0 (0.8, 1.2)	.78	…	…
Lesion segment				
Middle vs upper segment	0.8 (0.6, 1.0)	.051	0.8 (0.6, 1.0)	.055
Lower vs upper segment	1.0 (0.8, 1.3)	.93	…	…
Complication (yes vs no)	0.6 (0.3, 1.1)	.084	0.5 (0.3, 1.0)	.04
Treatment modality (MWA vs LPN)	0.8 (0.6, 1.0)	.023	0.8 (0.5,1.2)	.26

Note.—Data in parentheses are 95% confidence intervals. The Cox proportional hazards regression model was used for the univariable and multivariable analysis. Variables with $P < .20$ in univariable analyses were included in the multivariable model. Hazard ratios greater than 1 indicate a higher risk of an event or outcome with percutaneous microwave ablation (MWA). eGFR = estimated glomerular filtration rate, LPN = laparoscopic partial nephrectomy.

* For categorical variables with the categories in the parentheses, the former was compared with the latter (the reference) in calculating hazard ratios and 95% confidence intervals.

Table 5: Univariable and Multivariable Analyses of Prognostic Factors for Local Tumor Progression in the Matched Cohort

	Univariable Analysis		Multivariable Analysis	
Variable*	Hazard Ratio	*P* Value	Hazard Ratio	*P* Value
Sex (male vs female)	2.1 (0.2, 17.2)	.51	…	…
Age (y)	1.0 (0.9, 1.0)	.27	…	…
Charlson comorbidity index	1.0 (0.7, 1.5)	.82	…	…
Tumor diameter (≥2.5 vs <2.5 cm)	2.4 (0.5, 10.7)	.26	…	…
Preoperative serum creatinine level (≥0.85 vs <0.85 mg/dL)	4.3 (0.5, 35.4)	.18	4.9 (0.6, 40.6)	.15
Preoperative eGFR (≥120 vs <120 mL/min/1.73 m^2)	0.5 (0.1, 2.1)	.31	…	…
Decrease in eGFR by discharge (≥10% vs <10%)	0.4 (0.1, 1.9)	.24	…	…
Procedure time (hours)	0.3 (0.1, 1.8)	.20	0.9 (0.0, 23.1)	.93
Estimated blood loss (mL)	1.0 (0.9, 1.0)	.24	…	…
Side of tumor (left vs right kidney)	0.4 (0.1, 2.1)	.28	…	…
Lesion segment				
Middle vs upper segment	0.8 (0.1, 5.7)	.81	…	…
Lower vs upper segment	1.5 (0.2, 8.7)	.68	…	…
Treatment modality (MWA vs LPN)	4.8 (0.6, 40.3)	.14	4.5 (0.0, 589.2)	.55

Note.—Data in parentheses are 95% confidence intervals. The Cox proportional hazards regression model was used for the univariable and multivariable analysis. Variables with $P < .20$ in univariable analyses were included in the multivariable model. Hazard ratios greater than 1 indicate a higher risk of an event or outcome with percutaneous microwave ablation (MWA). eGFR = estimated glomerular filtration rate, LPN = laparoscopic partial nephrectomy.

* For categorical variables with the categories in the parentheses, the former was compared with the latter (the reference) in calculating hazard ratios and 95% confidence intervals.

group (2.2% vs 4.9%), but the difference was not statistically significant after matching ($P = .17$). Given that there was no significant difference in CSS between the two groups, it could be suggested that the higher complication rate following LPN should be considered as an indication for percutaneous MWA in selected patients (ie, those with comorbidities or a need to preserve as much kidney function as possible). The multivariable analyses and subgroup analyses in patients aged 60 years or older both showed that treatment modality was not associated with CSS and LTP. Therefore, for older patients (≥60 years),

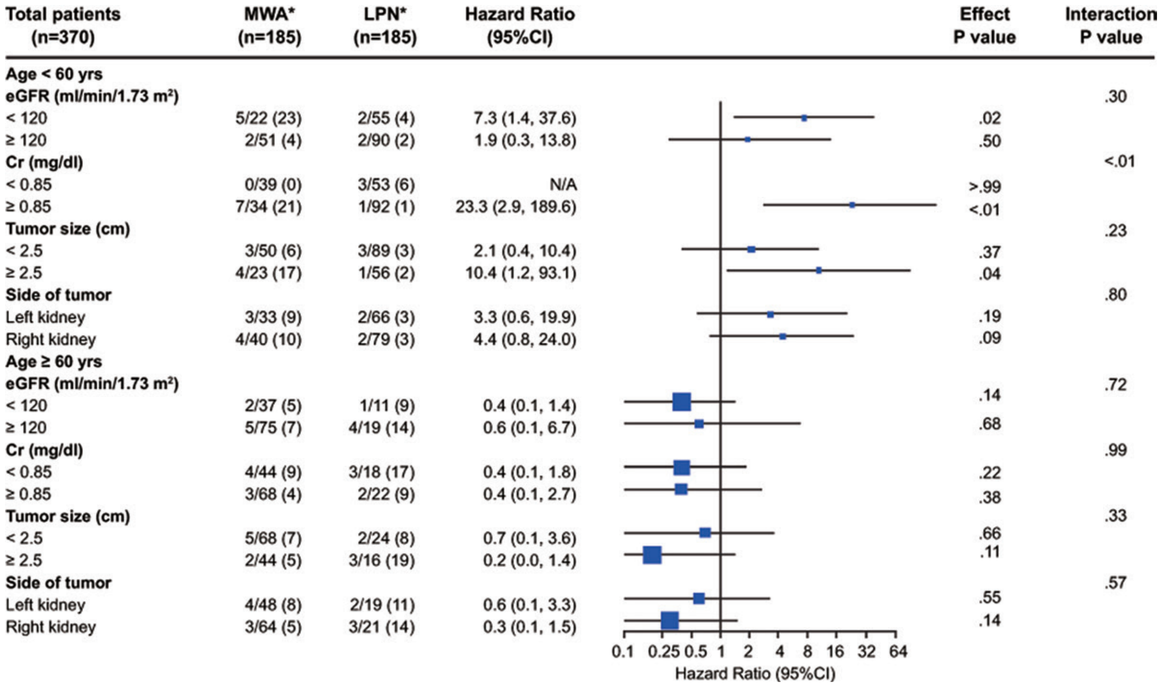

Figure 3: Forest plot for subgroup analyses (estimated glomerular filtration rate [eGFR], creatinine [Cr] level, tumor size, side of tumor) of overall survival according to patient age. * Data are no. of deaths/no. of patients at risk, with percentages in parentheses. CI = confidence interval, LPN = laparoscopic partial nephrectomy, MWA = microwave ablation.

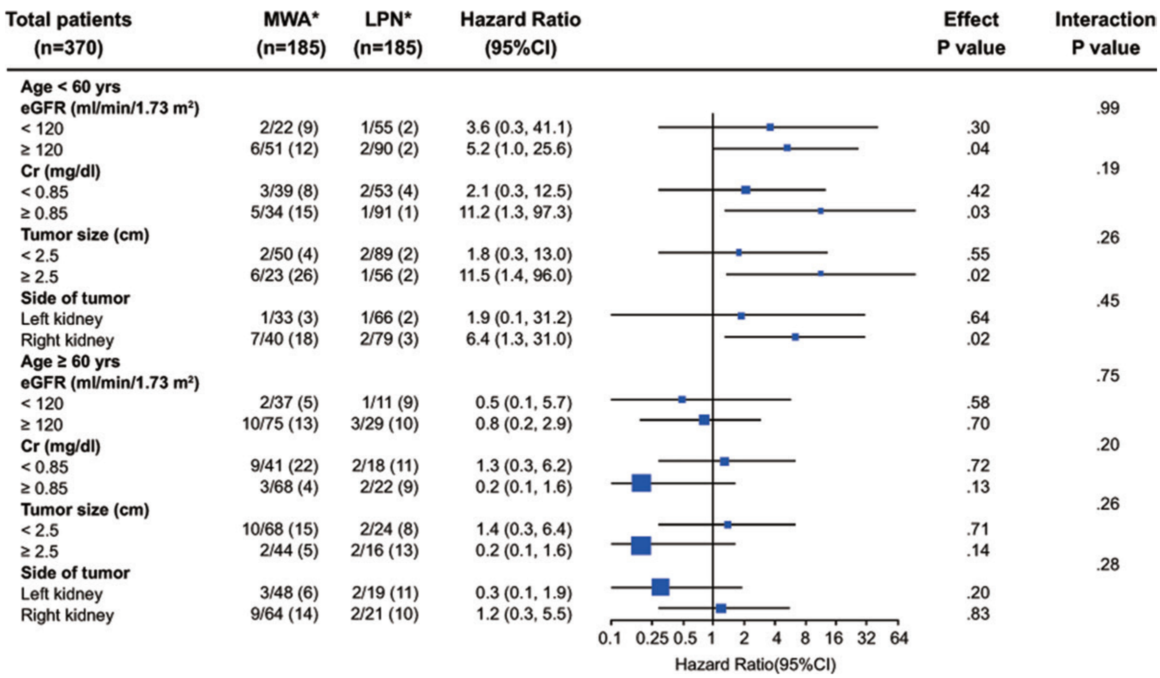

Figure 4: Forest plot for subgroup analyses (estimated glomerular filtration rate [eGFR], creatinine [Cr] level, tumor size, tumor location) of disease-free survival according to patient age. * Data are no. of deaths/no. of patients at risk, with percentages in parentheses. CI = confidence interval, LPN = laparoscopic partial nephrectomy, MWA = microwave ablation.

percutaneous MWA could be a more suitable treatment for cT1a RCC, with less invasiveness and lower risk of mortality.

Guo et al (7) failed to find evidence of differences in oncologic outcomes among partial nephrectomy, cryoablation, and RFA in 1424 patients with cT1a RCC, with 3-year LTP-free survival rates of 98%, 98%, and 98%, respectively. However, metastasis-free survival was significantly better after partial nephrectomy (P = .005) and cryoablation (P = .021) compared with RFA. According to a meta-analysis on the management of RCC by Pierorazio et al (34), cancer-specific survival after radical nephrectomy, partial nephrectomy, RFA, and cryoablation ranged from 95% to 100% and did not differ significantly among treatments. LTP-free survival ranged from 97% to 100% for partial nephrectomy and ablation, and differences were not significant after multiple sessions of ablation. Klapperich et al (16) reported on 96 patients who underwent MWA for T1a RCC and found that 3-year LTP-free survival, CSS, and OS were 88%, 100%, and 91%, respectively. Compared with those studies, our study had the largest sample size and found no evidence of differences in CSS and LTP for T1a RCC after percutaneous MWA and LPN, although two sessions of treatment were required for 13 lesions.

Our study did have limitations worthy of discussion. First, although we controlled for several patient and tumor characteristics in the matching process, an observational study cannot escape selection bias. The patients in the percutaneous MWA group were frailer and had higher Charlson comorbidity. Therefore, a competing risk analysis was used to minimize this impact on the oncologic outcomes. Second, we could not acquire accurate numbers of exophytic, central, or endophytic tumors, which may influence the evaluation for an exact LTP. Third, our long-term results mainly represent outcomes for US-guided percutaneous MWA and LPN, and these might not be a true reflection of the current practice for MWA and partial nephrectomy.

In conclusion, percutaneous microwave ablation could be a minimally invasive alternative to partial nephrectomy for the treatment of T1a renal cell carcinoma, especially for medically fragile patients with indications for nephron-sparing surgery, who cannot be subjected to the risks of a more invasive procedure.

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