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Percutaneous thermal ablation of primary and secondary lung tumors: Comparison between microwave and radiofrequency ablation

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Radiofrequency ablation, RFA;
Microwave ablation, MWA

Abstract
Purpose: The purpose of this study was to retrospectively compare microwave (MWA) and radiofrequency (RFA) ablation in the percutaneous treatment of primary and secondary lung tumors.
Material and methods: A total of 115 patients with a total of 160 lung tumors (primary, $n = 41$; secondary, $n = 119$) were retrospectively included. There were 56 men and 59 women with a mean age of 67.8 ± 12.7 (SD) years (range: 42—89 years) who underwent either MWA (61 patients; 79 tumors) or RFA (54 patients; 81 tumors). The primary study endpoints were local recurrence during follow-up and the incidence of complications during and following thermal ablation. The MWA and RFA groups were compared in terms of treatment efficacy and complication rates.
Results: Demographics were similar in the two groups. Mean tumor diameter was smaller in RFA group (13.1 ± 5.1 [SD] mm; range: 4—27 mm) than in MWA group (17.1 ± 8.3 [SD] mm; range: 5—36 mm) ($P < 0.001$). Ablation volumes at one month were 24.1 ± 21.7 (SD) cm^3 (range: 2—97.8 cm^3) in RFA group and 30.2 ± 35.9 (SD) cm^3 (range: 1.9—243.8 cm^3) in MWA group ($P = 0.195$). During a mean overall follow-up duration of 488 ± 407 (SD) days (range: 30—1508 days), 9/160 tumors (5.6%) developed local recurrence: six (6/79; 7.6%) in the RFA group and three (3/81; 3.7%) in the MWA group ($P = 0.32$). Pneumothoraces were more frequent in the RFA group (32/79; 40.5%) than in the MWA group (20/81; 24.7%) ($P = 0.049$). The mean length of hospital stay was 4.5 ± 3.7 (SD) days (range: 1—25 days) in the RFA group and 4.7 ± 4.6 (SD) days (range: 2—25 days) in the MWA group ($P = 0.76$).

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Conclusions: MWA favorably compares with RFA and can be considered as an effective and safe thermal ablation technique for lung tumors, especially in situations where RFA has limited efficacy.

Introduction

Lung cancer is the most common malignancy in the world [1]. It is also the leading cause of cancer-related mortality in both men and women, causing approximately 1.6 million deaths each year [1]. However, about 20% of patients with Stage I non-small cell lung cancer: (NSCLC) are not candidate to surgery due to comorbidities [2—4]. Moreover, the lung is the second most frequent site of secondary extra-thoracic malignant tumors, often markers of poor prognosis [5]. Many studies have shown the potential efficacy of metastasectomy in selected patients [6—8].

Several studies have shown the benefits of less invasive techniques than surgery, such as stereotactic body radiation therapy [9] and percutaneous thermal ablation. Radiation therapy is an effective option for patients who are unable to tolerate lung surgery because of impaired cardiorespiratory function, but it has some limitations such as the occurrence of radiation pneumonitis [10—12].

Several studies have proven the efficacy of percutaneous thermal ablation as a second line of treatment for Stage I NSCLC and lung metastases [13,14]. Moreover, thermal ablation can be repeated during follow-up in the event of recurrence, which is less the case with surgery and stereotactic radiotherapy [15]. RFA is the oldest and most frequently used technique: it was first used for the treatment of pulmonary lesions since 2000 [16]. RFA consists in applying a sinusoidal current (420 to 500 kHz) to the tumor with straight or deployable electrodes, in order to obtain cell necrosis via temperatures above 70 °C [17,18]. Since air has low electrical conductivity and high heat insulation, it induces the protection of the adjacent lung parenchyma but decreases the possibility of healthy resection margins [19,20]. Moreover, the proximity of > 3 mm vessels causes a sudden reduction in temperature, also known as the ''heat sink effect'' [21]. These two parameters lead to an increase in the theoretical risk of non-healthy margins [22,23].

On the opposite, MWA uses an ellipsoidal microwave field around the needle, between 915 and 2450 MHz [24,25]. The oscillation of the electromagnetic field causes a rapid flip movement of water molecules, causing the tissues to be warmed [24,25]. MWA is not subject to low lung electrical conductivity, enabling larger ablation zones [19,26] Moreover, this technique is less affected by the heat sink effect as it coagulates the small surrounding vessels, which do not stop the heat conductivity of the tissue [19,25,26]. To our knowledge, only a few studies have compared the long-term efficacy of these two techniques [27—31].

The purpose of this study was to retrospectively compare MWA and RFA in the percutaneous treatment of primary and secondary lung tumors.

Materials and methods

Population

This retrospective study received institutional review board approval and informed consent was obtained from all patients. We analyzed the files of patients who underwent pulmonary thermal ablation in our institution between March 2013 and February 2018. The inclusion criteria were as follows:

- Patients with primary or secondary lung tumor;
- Patients considered inoperable due to clinical, functional or biological data, with an estimated life expectancy greater than six months, for whom the decision of curative thermal ablation treatment was made in a multidisciplinary meeting.

In the event of tumor recurrence, patients treated with RFA or MWA and meeting these criteria were also included. The exclusion criteria were as follows:

- simultaneous extra-thoracic or thoracic lesions inaccessible with thermal ablation at the time of treatment;
- contraindication for general anesthesia;
- severe coagulopathy or no stop of anti-platelet therapy prior to treatment.

We initially retrieved 152 patients who had a consultation for lung thermal ablation in our institution between March 2013 and February 2018. Among them, 37 were

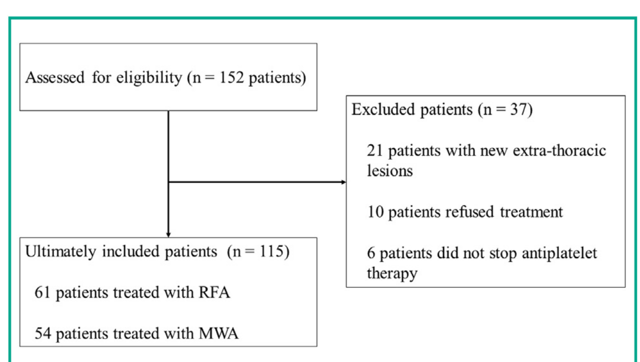

Figure 1. Study flowchart.

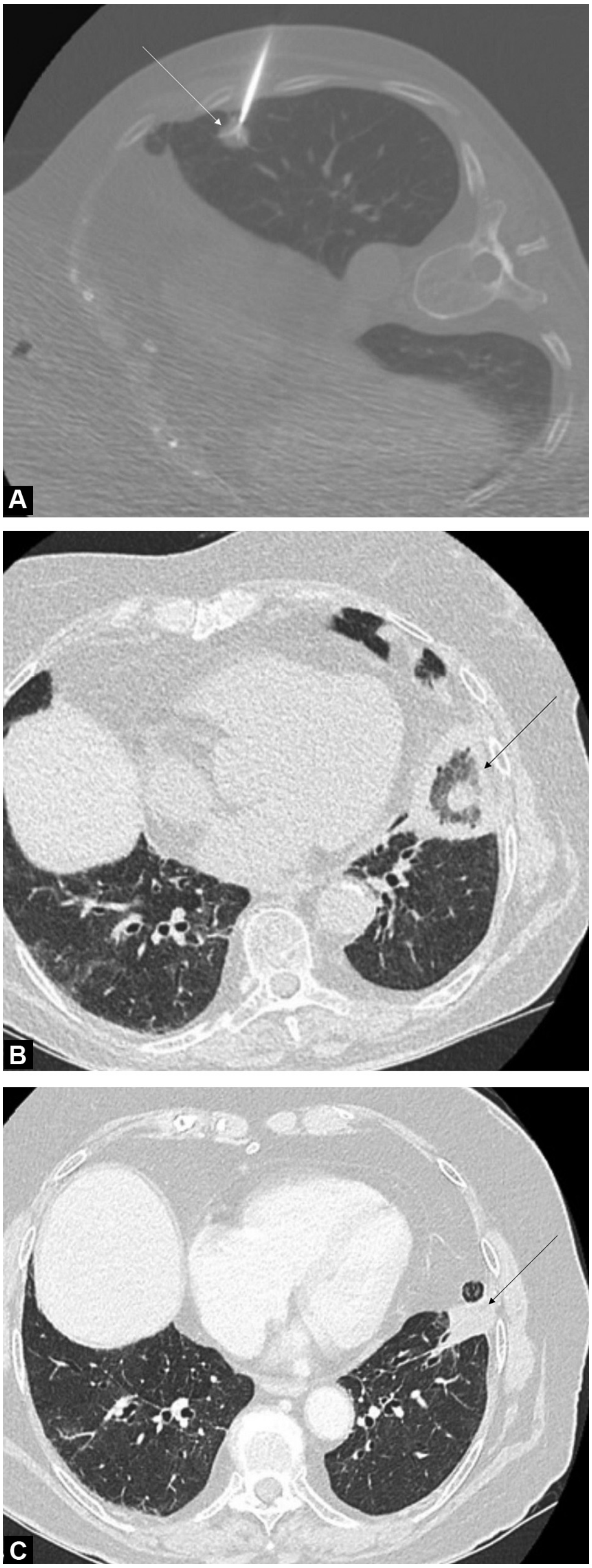

Figure 2. Seventy-seven-year-old woman with single lung metastasis from colorectal carcinoma of the left lower lobe that was treated by radiofrequency ablation (RFA). A. CT image in the axial plane obtained during RFA shows a deployable electrode inserted into a subpleural lung metastasis with an axial diameter of 15 mm (arrow). B. CT image in the axial plane obtained one month after RFA shows a ''target-like'' appearance with ground-glass opacification induced by RFA (arrow). C. CT image in the axial plane obtained 12 months after RFA shows size reduction of the lesion with residual scarring (arrow).

excluded: 21 had new extra-thoracic lesions on the chest CT scan performed before the consultation, 10 refused the treatment and 6 did not stop their anti-platelet therapy. Fig. 1 shows the flow chart of patients who were considered for this study. Our study population included 115 patients. There were 56 men and 59 women with a mean age of 67.8 ± 12.7 (standard deviation [SD]) years (range: 42—89 years).

Intervention and follow-up

All patients had a consultation with a radiologist before treatment, to ensure the feasibility of thermal ablation and check for absence of any contraindications. They had an anesthetic consultation and had blood tests to check that there were no coagulation abnormalities.

The interventions were performed under general anesthesia, with the ongoing presence of an anesthesiologist during the procedure. For both RFA and MWA, the intervention was performed under CT fluoroscopy (BrightSpeed™, General Electric Healthcare) by one of three interventional radiologists with 7-, 10- and 15-years of experience in percutaneous thermal ablation. A biopsy was performed during treatment when the tumor histology was not known. A thermocouple was used to control the temperature if there was a risk of damaging a nearby organ.

To choose between the two techniques, we considered the following principles: RFA was favored since we had more experience with this technique. In the event of a tumor > 25 mm, or when the tumor was near a vessel greater than 3 mm in diameter, MWA was selected. MWA was preferred when there were multiple lesions to treat (at least two lesions in the same lung).

For RFA treatment, a generator (RF 3000™, Boston Scientific) and a 14 G needle electrode with a co-axial system (LeVeen CoAccess™, Boston Scientific) were used (Fig. 2). If necessary, the RFA needle was repositioned to complete the ablation, depending on the volume of the target lesion. Dispersion electrodes were placed on the patients' thighs. The treatment wattage and duration used were based on the manufacturer's chart (range: 25—180 W). For MWA treatment a microwave generator and a 16-G probe (AMICA MWA System™; Hospital Service) were used (Fig. 3). From experience, we mainly treated with 40 W power (range: 20—80 W).

At the end of the thermal ablation therapy, a plain chest CT examination was performed to search for complications such as pneumothorax, intra-alveolar hemorrhage or bronchial fistulization (Fig. 4). In case of pneumothorax, we proceeded as follows: when the pneumothorax was minimal and well tolerated, the patient had no drain placement. In other situations, a drain (Skater™ 8F, Argon Medical) was positioned within the pneumothorax. To avoid another puncture site, whenever it was possible and safe, the drain was inserted via the electrode entry point,

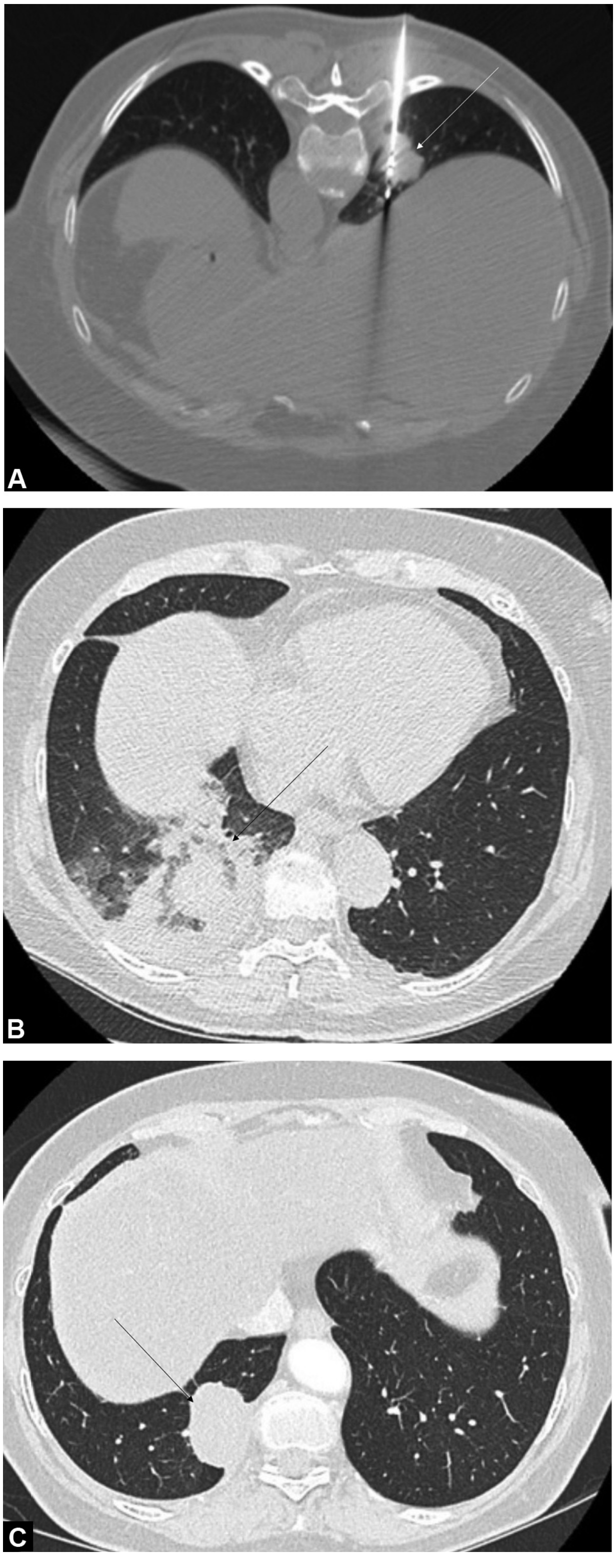

Figure 3. Seventy-year-old man with single lung metastasis from colorectal carcinoma in the right lower lobe that was treated by microwave ablation (MWA). A. CT image in the axial plane obtained during MWA shows MWA needle inserted into a subpleural, 31-mm large, pulmonary metastasis in the right lower lobe (arrow). B. CT image in the axial plane obtained one month after MWA shows a ''target-like'' appearance with ground-glass opacification induced by MWA (arrow). C. CT image in the axial plane obtained 12 months after MWA shows residual scarring with an axial diameter of 38 mm (arrow).

running to the apical and anterior section of the largest area of the pneumothorax. The patient was then hospitalized in our institution and underwent chest X-ray six hours later. The patient was discharged after good clinical tolerance was obtained and normalization of chest X-ray findings.

The patients underwent follow-up unenhanced CT examination one month after thermal ablation, then every three months for one year.

Data analysis

We classified the patients into two groups: RFA and MWA. For each patient, a radiology resident noted the following variables: age, sex, primary or secondary origin, site of the primary tumor, location of the lung lesion, and treatment modality. Tumor size was measured in the three planes on chest CT performed before thermal ablation. The following parameters were studied on control CT after thermal ablation: occurrence of pneumothorax (drained or not), intra-alveolar hemorrhage or bronchial fistulization (cavitation). Using the Cardiovascular and Interventional Radiological Society of Europe (CIRSE) classification [32], undrained pneumothorax and intra-alveolar hemorrhage were classified as Grade 1 complications. Drained pneumothorax and bronchopleural fistulas were classified as Grade 2 and Grade 3 complications, respectively. The radiology resident also recorded the length of the hospital stay and the duration of follow-up. The diameter of the ablation zone was measured within the three planes and then its volume was calculated (length $\times$ width $\times$ height $\times$ $\pi/6$) on CT examination performed at one month, which closely matches with gross pathologic ablation size [33]. Any recurrence by contact with thermal ablation or at a distance was noted, and the duration of disease-free survival was calculated (i. e., time between thermal ablation and the first CT examination that showed recurrence). Lastly, we created a point cloud representing ablation time in MWA at 40 W and ablation small diameter one month after treatment, to estimate the appropriate MWA duration to obtain a complete and safe ablation.

The primary study endpoints were local recurrence during follow-up and the incidence of complications during and following thermal ablation.

Statistical analysis

Statistical analysis was performed by using XLSTAT^{TM} (Addinsoft) software. Quantitative variables were expressed as means, SD, and ranges. Qualitative variables were expressed as raw numbers, proportions, and percentages. Comparisons between the groups were performed using Student *t*-test for continuous variables and chi-square tests with Yates correction for categorical variables. Correlation between axial tumor short diameter at one month after treatment and MWA duration was searched using the Pearson correlation test. *P*-values < 0.05 were considered indicative of statistical significance.

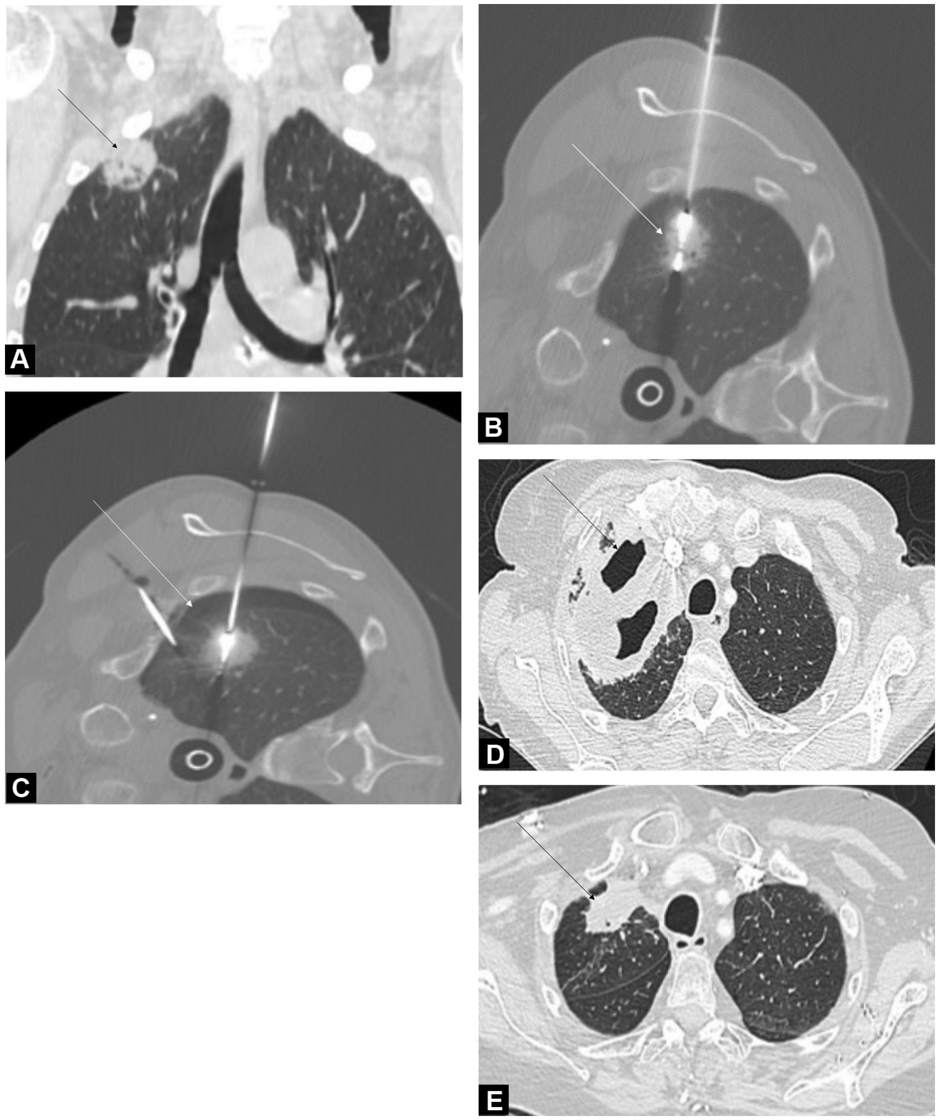

Figure 4. Sixty-two-year-old man with a primary lung tumor in the right upper lobe who developed bronchopleural fistula after microwave ablation (MWA). A. CT image in the coronal plane obtained before MWA shows a subpleural primary lung cancer, with an axial diameter of 30 mm (arrow). B. CT image in the axial plane obtained during thermal ablation shows MWA needle placed into the tumor. A trans-osseous approach was chosen to be parallel to the long axis of the lesion (arrow). C. CT image in the axial plane obtained during MWA. A pneumothorax (arrow) was created to protect the right brachial plexus during MWA. D. CT image in the axial plane obtained one month after MWA shows cavitation (arrow) attributed to a bronchopleural fistula. E. CT image in the axial plane obtained six months after MWA shows complete regression of the bronchopleural fistula and residual scarring with an axial diameter of 38 mm (arrow).

Results

Baseline characteristics and follow-up

Among the 115 patients, 61 (61/115; 53%) had RFA and 54 (54/115; 47%) had MWA. There were no significant differences between the two groups in terms of age and sex distribution (Table 1). A total of 160 tumors were treated, including 41 (41/160; 25.6%) primary lung tumors and 119 (119/160; 74.4%) lung metastases. Seventy-nine tumors (79/160; 49.4%) were treated by RFA and 81 (81/160; 50.6%) by MWA. Before treatment, the mean largest diameters of the tumors was 13.1 ± 5.1 (SD) mm (range: 4—27 mm) in the RFA group and 17.1 ± 8.3 (SD) mm (range: 5—36 mm) in the MWA group ($P < 0.001$). No differences in largest tumor diameters were found between the two groups. We performed several sessions with multiple ablations: 15 (15/79; 19%) for RFA and 17 (17/81; 21%) for MWA. The mean follow-up time in the study population was 488.4 days, with no significant differences between RFA group (505.8 ± 308 [SD] days; range: 30-1509 days) and MWA group (471 ± 299 [SD] days; range: 30—1379 days) ($P = 0.67$).

Treatment efficacy

Technical success was observed in all procedures (160/160; 100%), yielding a technical success rate of 100% (Table 2). The mean duration of thermal ablation was 15.35 ± 6.6 (SD) min (range: 2—45 min) for RFA and 7.51 ± 4.5 (SD) min

Table 1 Baseline characteristics of 115 patients with 160 lung tumors who underwent thermal ablation.

Variable	Radiofrequency ablation	Microwave ablation	*P*
Number of patients	61 (61/115; 53%)	54 (54/115; 47%)	
Sex			0.94
Male	29 (29/61; 47%)	27 (27/54; 50%)	
Female	32 (32/61; 53%)	27 (27/54; 50%)	
Age (y)	67.4 ± 14 [42–89]	68.1 ± 11.7 [45–83]	0.57
No. of tumors	79 (79/160; 49%)	81 (81/160; 51%)	
Tumor origin			0.5
Primary	18 (18/79; 23%)	23 (23/81; 28%)	
Secondary	61 (61/79; 77%)	58 (58/81; 72%)	
Colorectal	43 (43/61; 70%)	32 (32/58; 55%)	
Head & Neck	7 (7/61; 11%)	9 (9/58; 15%)	
Bladder	3 (3/61; 5%)	1 (1/58; 2%)	
Breast	2 (2/61; 3%)	1 (1/58; 2%)	
Kidney	2 (2/61; 3%)	5 (5/58; 9%)	
Pancreas	2 (2/61; 3%)	2 (2/58; 3%)	
Uterus	2 (2/61; 3%)	8 (8/58; 14%)	
Largest tumor diameter (mm)	13.1 ± 5.1 [4–27]	17.1 ± 8.3 [5–36]	< 0.001
Number of sessions with multiple ablations	15 (15/79; 19%)	17 (17/81; 21%)	0.91

Quantitative variables are expressed a mean ± SD; numbers in brackets are ranges. Qualitative variables are expressed as raw numbers, proportions; numbers in parentheses are percentages.

Table 2 Procedure parameters, recurrences and complications in 115 patients with 160 lung tumors who underwent thermal ablation.

	Radiofrequency ablation	Microwave ablation	*P*
Ablation datas			
Ablation duration (min)	15.4 ± 6.6 [2–45]	7.5 ± 4.5 [1–20]	< 0.001
Ablation volume (cm3)	24.1 ± 21.7 [2-97.8]	30.2 ± 35.9 [1.9-243.8]	0.20
Ablation short diameter (cm)	2.7 ± 0.9 [1.3-4.6)	2.8 ± 1.1 [1–7]	0.36
Technical success	79 (79/79; 100%)	81 (81/81; 100%)	1
Follow-up duration (days)	505.8 ± 308 [30–1509]	471 ± 299 [30–1379]	0.67
Recurrences	24 (24/79; 30%)	27 (27/81; 33%)	0.82
Local recurrences	6 (6/79; 7.6%)	3 (3/81; 3.7%)	0.32
Distant recurrences	18 (18/79; 22.8%)	24 (24/81; 29.6%)	0.42
Time before recurrence (days)	306.8 ± 223 [30–745]	297.4 ± 259 [37-1024)	0.89
Disease-free survival (days)	424.8 ± 371.5 [30–1471]	333.1 ± 313.2 [37–1227]	0.16
Total pneumothorax	32 (32/79; 40.5%)	20 (20/81; 24.7%)	0.049
Low abundance pneumothorax	10 (10/79; 12.7%)	7 (7/81; 8.6%)	0.57
Exsufflated pneumothorax	2 (2/79; 2.5%)	4 (4/81; 4.9%)	0.68
Drained pneumothorax	20 (20/79; 25.3%)	9 (9/81; 11.1%)	0.03
Intra-alveolar hemorrhage	6 (6/79; 7.6%)	2 (2/81; 2.5%)	0.16
Bronchopleural fistula	1 (1/79; 1.2%)	3 (3/81; 3.7%)	0.32
Grade 1 complications	18 (18/79; 22.7%)	13 (13/81; 16%)	0.28
Grade 2 complications	20 (20/79; 25.3%)	9 (9/81; 11.1%)	0.03
Grade 3 complications	1 (1/79; 1.2%)	3 (3/81; 3.7%)	0.32
Grade 4, 5 and 6 complications	0 (0/79; 0%)	0 (0/81; 0%)	> 0.99
Length of hospital stay (days)	4.5 ± 3.7 [1–25]	4.7 ± 4.6 [2–5]	0.76

Quantitative variables are expressed a mean ± SD; numbers in brackets are ranges. Qualitative variables are expressed as raw numbers, proportions; numbers in parentheses are percentages.

(range: 1–20 min) for MWA ($P < 0.001$). After treatment, the mean volume of the ablation zone was 27.2 cm^3. No differences in mean volume of ablation zone were found between MWA group (30.2 ± 35.9 [SD] cm^3; range: 2–97.8 cm^3) and RFA group (24.1 ± 21.7 [SD] cm^3; range 1.9–243.8 cm^3) ($P = 0.195$) (Fig. 5). No differences in sphericity indexes were found between tumors in the MWA groups (0.60 ± 0.13 [SD]; range: 0.33–0.88) and those in the RFA group (0.64 ± 0.15

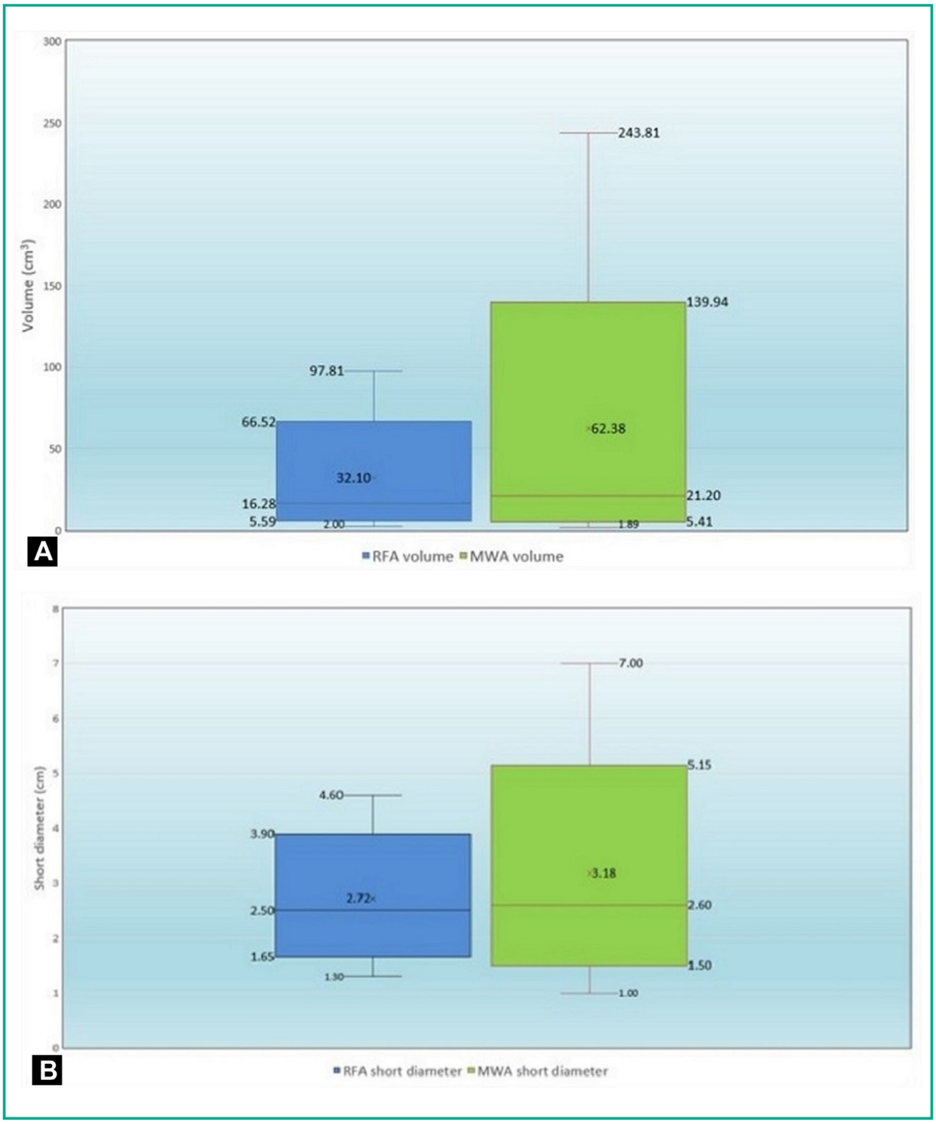

Figure 5. Box plots show ablation volumes (A) and short tumor diameters (B) one month after radiofrequency ablation (in blue) and microwave ablation (in green). The bars in the box represent (from bottom to top) the first quartile, the median and the third quartile. The lower and upper outside bars represent the minimum and the maximum values respectively. (RFA: Radiofrequency ablation; MWA: Microwave ablation).

[SD]; range: 0.34—0.94) (*P* = *0.16*). Fig. 6 shows the linear correlation between lesion long diameter and respectively RFA and MWA short and long diameters one month after thermal ablation.

Among the 160 tumors treated, we observed a total of nine local recurrences during the follow-up. No differences in local recurrence rates were observed between the RFA group (6/79; 7.6%) and the MWA group (3/81; 3.7%) (*P* = 0.32). Of these local recurrences, five were treated with RFA, two with MWA and one with cryotherapy, with good local control. The remaining recurrence presented as a diffuse disease, with no indication for local curative treatment.

In addition, patients treated with RFA had a total of 18 distant pulmonary or extra-pulmonary recurrences (18/79; 22.8%) while 24 patients treated with MWA had distant recurrence (24/81; 29.6%) (*P* = 0.42). Among them, the time before recurrence was 306.75 ± 223 (SD) days (range: 30-745 days) for RFA and 297.40 ± 259 (SD) days (range: 37—1024 days) for MWA (*P* = 0.89). No differences in disease-free survival were found between RFA group (424.8 ± 371.5 [SD] days; range: 30—1471 days) and MWA group (333.1 ± 313.2 [SD] days; range: 37—1227 days) (*P* = 0.16).

A linear relationship was found between small-diameter ablation zone at one month after MWA and the duration of the procedure at 40 W ($R^2 = 0.6157$) (Fig. 7).

Side effects and complications

No deaths were attributed to thermal ablation. No deaths occurred during the 30 days following thermal ablation. The most common complication was pneumothorax (excluding voluntary pneumothorax, induced to protect high-risk

Figure 6. Graphs show comparison between lesion long diameter and RFA (A) or MWA (B) short and long diameters: short diameters one month after ablation were consistently larger than lesion long diameter, while controlling ablation volumes. Each bar refers to a single tumor. (RFA: Radiofrequency ablation; MWA: Microwave ablation).

organs). A total of 52 pneumothoraces 52/160; 32.5%) were observed. They were more frequent in the RFA group (32/79; 40.5%) than in the MWA group (20/81; 24.7%) (P = 0.049). Of these, 29 required drainage: 20 required drainage in the RFA group (20/79; 25.3%) compared to 9 in the MWA group (9/81; 11.1%) (P = 0.03). Six RFA (6/79; 7.6%) and two MWA (2/81; 2.5%) procedures were complicated by intra-alveolar hemorrhage (P = 0.16). Four bronchopleural fistulas were observed; three in the MWA group (3/81; 3.7%) and one in the RFA group (1/79; 1.2%) (P = 0.32) (Fig. 3). There were no differences between the two groups in terms of Grade 1 and Grade 3 complications. No Grade 4, 5 or 6 complications were observed. Overall, the mean length of hospital stay was 4.57 days, with no differences between RFA (4.46 ± 3.7 [SD] days; range: 1—25 days) and MWA group (4.68 ± 4.6 [SD] days; range: 2—25 days) (P = 0.76).

Discussion

Considering our results, MWA can be considered as an effective and safe ablation technique for the treatment of primary and secondary inoperable lung tumors, as the local control rate was not statistically different between MWA and RFA. This rate is consistent with those reported in the literature. Of the few studies comparing these two pulmonary ablation techniques, none showed superiority of RFA over MWA [27—30,34]. Only Macchi et al. included 52 patients prospectively in the LUMIRA study [27]. There

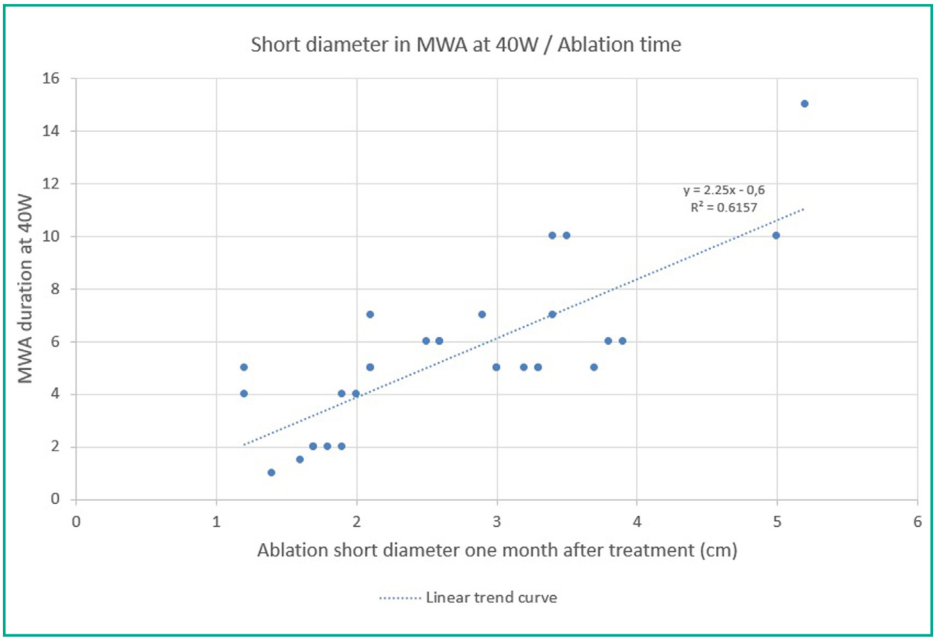

Figure 7. Graph shows linear correlation between microwave ablation time and short diameter at 40 W. (MWA: Microwave ablation).

were no statistical differences in terms of efficacy or complications between RFA and MWA [27]. In another study, Shi et al. retrospectively compared 43 patients treated with RFA and 32 treated with MWA [28]. The overall response rates were 79% and 69% respectively and the complication rates were 49% for RFA and 50% for MWA, without any significant differences between these two techniques [28].

MWA has a number of potential advantages. First, it provides a higher coagulation necrosis volume compared to RFA [25,35]. Second, MWA yields shorter ablation time by comparison with RFA. This enabled us to treat up to five lung metastases in a single session, which could be of interest for frail patients under general anesthesia with iterative treatments. Finally, the absence of limitation by the heat sink effect is an advantage for MWA, especially for tumors adjacent to blood vessels, to decrease the risk of incomplete ablation [36].

Several studies have demonstrated that RFA is an effective curative technique. However, it has some limitations [23]. De Baere et al. showed that tumors larger than 2 cm were an independent risk factor for local recurrence [13]. In these situations, RFA overlapping technique leads to a larger number of passages through the pleura, theoretically increasing the risk of complications, post-procedural pain and the duration of the procedure. For these reasons, in our opinion, MWA remains a preferred indication in this frequent situation, provided that the parameters of the procedure are controlled. A thermocouple can also be used to control the ablation volume, in order to obtain a sufficient volume to ensure healthy resection margins without damaging lung tissue. The thermocouple is therefore placed one centimeter away from the lesion, either where there is the highest risk of non-healthy margins, or else in contact with a nearby structure to avoid damaging it.

As demonstrated by our results, MWA can achieve a much larger ablation zone. However, in our study, the mean ablation volumes were similar in the two groups. These data appear reassuring since they indicate that MWA can be well controlled by appropriate monitoring and by choosing the right ablation parameters. From experience, the majority of our thermal ablations were performed at a 40 W voltage and duration between two and 10 minutes, leading to a satisfactory compromise between ablation volume control, duration, efficacy and safety of thermal ablation. A linear correlation seems to be the most accurate way to predict ablation zone diameter depending on MWA duration. Studies with larger population could help create charts for MWA in lung parenchyma similar to that made for renal tumors [37].

Another interesting finding of our study is that pneumothorax is less frequent in patients treated using MWA than in those treated using RFA. The main hypothesis is that MWA yields larger, unrestricted ablation volumes, responsible for necrosis phenomena with retraction and pleural inflammation, potentially limiting the risk of pneumothorax. The larger size of the RFA needle (14-G) compared to the MWA probe (16-G) can also partially explain this result [38]. However, this result should be interpreted with caution because of potential selection bias due to the retrospective nature of our study. Indeed, RFA was preferred in patients with emphysema, which is a risk factor for pneumothorax.

Our study had several limitations. First, the retrospective nature and the selection criteria between RFA and MWA led to selection bias, since the patients were not randomized to receive one treatment or another. In addition, our study was monocentric and the radiologists practicing this procedure had several years of experience with pulmonary or extra-pulmonary MWA. We did not collect functional data before or after the procedure. Moreover, even though this did not affect our main endpoints, our survival data were biased by the absence of some parameters such as the differentiation between primary and secondary tumors and the concomitant use of other treatments. Lastly, MWA and RFA were not performed in combination with immunomodulation treatment, which seems to be a promising therapeutic strategy [39].

In conclusion, MWA favorably compares with RFA and can be considered as an effective and safe thermal ablation technique for the treatment of lung tumors. MWA can be applied to tumors for which RFA might be not effective because of a tumor greater than 25 mm, a tumor close to a vessel greater than 3 mm in diameter or because of multiple lesions. Our results suggest that MWA may broaden the indications of pulmonary thermal ablation.

Human and animal rights

The authors declare that the work described has been carried out in accordance with the Declaration of Helsinki of the World Medical Association revised in 2013 for experiments involving humans.

Informed consent and patient details

The authors declare that this report does not contain any personal information that could lead to the identification of the patient(s).

The authors declare that they obtained a written informed consent from the patients and/or volunteers included in the article. The authors also confirm that the personal details of the patients and/or volunteers have been removed.

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Disclosure of interest

The authors declare that they have no competing interest.

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