Original Article

Percutaneous microwave ablation for lung tumors: a retrospective case-control study of conventional CT and C-arm CT guidance

Kepu Du[1#], Yiming Liu[2#^], Kunpeng Wu[2^], Zhanguo Sun[2], Xinwei Han[2^], Dechao Jiao[2^]

[1]Department of Imaging Medicine, The First Affiliated Hospital of Zhengzhou University, Zhengzhou, China; [2]Department of Interventional Radiology, The First Affiliated Hospital of Zhengzhou University, Zhengzhou, China

Contributions: (I) Conception and design: K Du, Y Liu; (II) Administrative support: X Han, D Jiao; (III) Provision of study materials or patients: K Du, D Jiao; (IV) Collection and assembly of data: K Du, Y Liu, K Wu, Z Sun, D Jiao; (V) Data analysis and interpretation: K Du, Y Liu; (VI) Manuscript writing: All authors; (VII) Final approval of manuscript: All authors.

[#]These authors contributed equally to this work and should be considered as co-first authors.

Correspondence to: Dechao Jiao, PhD. Department of Interventional Radiology, The First Affiliated Hospital of Zhengzhou University, 1 Jianshe East Road, Zhengzhou 450052, China. Email: jiaodechao007@126.com.

Background: Although conventional computed tomography (cCT) is the mainstream guidance equipment for lung microwave ablation (MWA), C-arm CT can provide 3-dimensional (3D) CT-like images reconstructed from 2-dimensional (2D) digital subtraction angiography (DSA) information within 8 seconds, highlighting its utility as a new guidance tool. This retrospective case-control study was performed to evaluate the clinical performance of percutaneous MWA for lung tumors using cCT and C-arm CT guidance.

Methods: From April 2015 to April 2020, 101 consecutive patients with solitary lung tumors who underwent percutaneous MWA at our single center (Zhengzhou, China) were divided into 2 groups: the cCT group (n=56), with unarmed puncture, and the C-arm CT group (n=45), with iGuide navigation-assisted puncture. The primary endpoints were technical success, technical efficacy, puncture scoring (PS), and complete ablation (CA) rate. The secondary endpoints were complications, median progression-free survival (mPFS), and median overall survival (mOS).

Results: The technical success rates were 100% in both the C-arm CT group and cCT group. The technical efficacies were 93.3% and 91.1% in the C-arm CT group and cCT group, respectively, with no statistical difference (P=0.67). The PS (2.9 *vs.* 2.5, P=0.02), total procedure time (TPT; 39.3 *vs.* 50.0 min, P<0.001), puncture time (PT; 12.6 *vs.* 15.7 min, P=0.001), and irradiation effective dose (ED; 15.2 *vs.* 20.9 mSV, P<0.001) showed significances between patients in the C-arm CT and those in the cCT group. The ablation time (AT; 9.1 *vs.* 9.6 min, P=0.36), CA rate (93.3% *vs.* 92.9%, P=0.93), local tumor progression (LTP) rate (11.1% *vs.* 8.9%, P=0.98), complications, mPFS (9.5 *vs.* 10.1 months, P=0.52), and mOS (37.9 *vs.* 38.8 months, P=0.67) showed no statistically significant difference between the 2 groups.

Conclusions: C-arm CT guidance is as feasible and effective as cCT for lung tumor MWA, which can increase PS and decrease TPT.

Keywords: Microwave ablation (MWA); lung tumor; C-arm CT; computed tomography (CT); guidance tool

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^ ORCID: Dechao Jiao, 0000-0002-5055-4672; Yiming Liu, 0000-0001-5898-9913; Kunpeng Wu, 0000-0001-6408-8927; Xinwei Han, 0000-0003-4460-8619.

Introduction

Non-small cell lung cancer (NSCLC) accounts for 85% of all new lung cancer cases, and nearly 1/3 of cases have reached the locally advanced stage when diagnosed (1,2). The standard treatments are concurrent radiotherapy and chemotherapy, yet the long-term results are still unsatisfactory (3). The oligometastatic state refers to an intermediate status between the locally advanced and widely metastatic phases, with ≤5 metastatic/recurrent lesions and the primary tumor in a controlled state (4). From the perspective of treatment, along with systemic therapies, the focus for oligometastasis is local treatment, such as surgical resection, stereotactic radiotherapy (SRT), percutaneous ablation, and so on (5,6). Approximately 20–54% of patients with different cancers will have lung metastasis (LM) during their natural course (7), and LM with a high burden responds poorly to chemotherapy. Considering the importance of local control of NSCLC and LM, clinical experts have tried many minimally invasive therapies to strengthen local treatment, such as thermal ablation (8), cryoablation (9), and ^{125}I brachytherapy (10). Microwave ablation (MWA) is the latest representative technology of thermal ablation, which refers to the use of biological effects produced by heat to directly coagulate the lung tumor and surrounding parenchyma. Recent clinical studies (11,12) have confirmed that MWA alone or combined with systemic therapy can decrease tumor recurrence and metastasis and significantly prolong progression-free survival (PFS) and overall survival (OS).

Although conventional computed tomography (cCT) is the mainstream guidance equipment for lung MWA, C-arm CT can provide 3-dimensional (3D) CT-like images reconstructed from 2-dimensional (2D) digital subtraction angiography (DSA) information within 8 seconds, indicating that it can be used as a new guidance tool. Although the density of lung tumors varies widely (the density of pulmonary metastatic tumors mainly depends on their composition), they can be identified easily on a normal lung background [lung CT value: −600 to −700 Hounsfield units (HU)]. Moreover, upscale flat C-arm CT has its own virtual navigation software [iGuide software from Siemens (Erlangen, Germany) was used in this study], which can help inexperienced doctors to improve puncture success (13,14). Few studies have focused on the difference between C-arm CT and cCT guidance, so this retrospective study compared their impact on puncture performance and clinical results. We present this article in accordance with the STROBE reporting checklist (available at https://qims.amegroups.com/article/view/10.21037/qims-22-985/rc).

Methods

Patients

This was a retrospective, case-control study. From April 2015 to April 2020, 395 patients with pulmonary nodules underwent percutaneous MWA under C-arm CT or cCT guidance at our hospital (data sources from Departments of Medical Imaging and Interventional Radiology). Of these, 294 cases were due to the exclusion criteria (n=226), incomplete data (n=64), or benign tumors (n=4). The remaining 101 cases were divided into 2 groups: (I) the cCT group (n=56) with an unarmed puncture and (II) the C-arm CT group (n=45) with iGuide navigation-assisted puncture. The inclusion exclusion criteria were as follows: (I) age 18–75 years old; (II) single NSCLC local progression after the first-line treatments, or single LM; (III) lung tumor diameter ≤5 cm; (IV) lung tumors located at the middle and peripheral lung; (V) pulmonary function classification 1 or 2; (VI) Eastern Cooperative Oncology Group (ECOG) score ≤2. The exclusion criteria were as follows: (I) tumors number ≥2; (II) insufficient cardiovascular, hepatic, and renal function to accept both local and systemic treatments; (III) platelet count $<60\times10^9$/L and prothrombin time >21 seconds; (IV) life expectancy ≤6 months; (V) incomplete data. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by Ethics Committee of The First Affiliated Hospital of Zhengzhou University and the requirement for individual consent for this retrospective analysis was waived. The workflow is presented in *Figure 1*.

Procedure

All patients underwent chest-enhanced CT 1 week before the operation. All patients received intravenous combined with local anesthesia. Diloxin (5–10 mg) and dexmedetomidine (0.5 µg/kg) were injected intravenously 30 min before MWA, and the infusion speed was adjusted according to the physical pain of the patient. Lidocaine (5–10 mL, 5%) was used as the local anesthesia drug.

C-arm CT-guided MWA

All punctures were performed by the same interventional

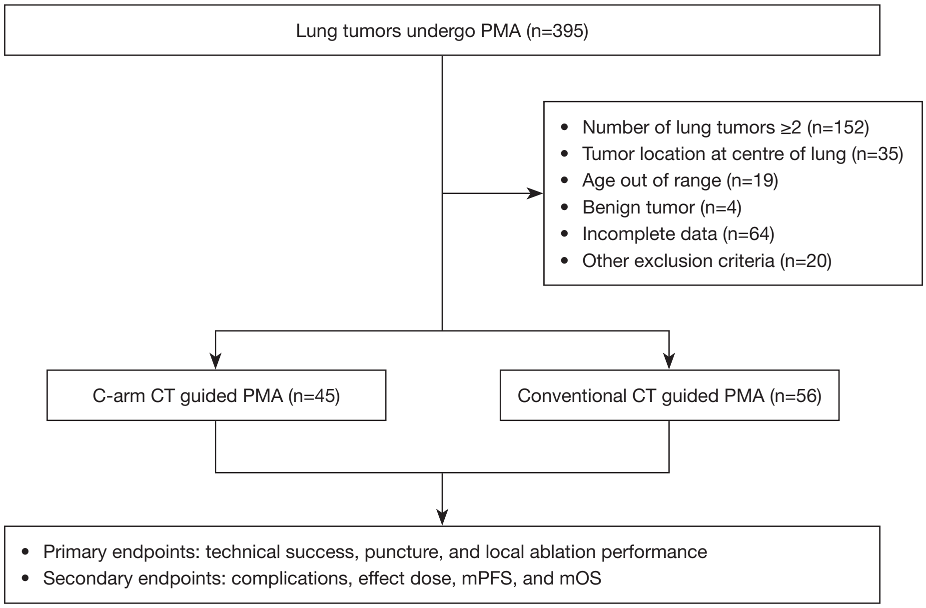

Figure 1 The workflow diagram of the study. PMA, percutaneous microwave ablation; CT, computed tomography; mPFS, median progression-free survival; mOS, median overall survival.

radiologists (DJ and XH), who had 15- and 9-year of image-guided MWA experience, respectively. All C-arm CT images were obtained using flat-panel detector DSA (Artis Zeego, 30×40 cm flat detector, Siemens, Germany) while the patients held their breath for 8 seconds (parameters: X-ray dose: 0.36 µGy/frame; C-arm rotation: 200°; field of view: 480 mm). All data were transferred to Syngo X Workplace (Siemens, Germany) for volume reconstruction, and the C-arm CT images were displayed with sagittal, axial, coronal, and volume reconstruction images. The puncture path was planned for the use of iGuide virtual navigation (Siemens, Germany). The C-arm was adjusted to the bull's eye view (*Figure 2*), and the skin entry and lung tumor were positioned using a cross and a circle and lined up with each other. The navigation path was integrated into the real-time C-arm fluoroscopy image. Then, after local anesthesia with 2% lidocaine (5–10 mL) was administered, the microwave applicator (2.0×165 mm) with a 1.6 cm active tip (frequency: 2,450 MHz; Medical Instrument Co., Ltd., Nanjing, China) was advanced into the lesion under C-arm fluoroscopy. Subsequently, another C-arm CT scan was performed to confirm the satisfactory position of the microwave applicator. Ablation parameters [generator power: 40–60 W; ablation time (AT): 4–8 min] for a single ablation cycle were chosen according to the manufacturer's recommendations. Finally, a C-arm CT scan was performed again to confirm the technical efficacy (the post MWA ground glass opacity should cover an area at least 5 mm larger than the primary tumor on the C-arm CT images, *Figure 2*).

CT-guided MWA

All procedures were performed by the same interventional radiologists (DJ and XH). The body position was determined according to the location of the tumor with the aim of puncture facilitation. A 64-row CT (Brilliance Big Bore, Siemens, Germany) scan was carried out to localize the tumor in the axial CT image with a thickness of 3 mm (parameter: voltage 120 kV, current 90 mA). The puncture route was mapped to avoid pulmonary bullae, severe emphysema, crossing interlobar fissures, and so on. Under the repeated cCT scan, the microwave applicator was gradually inserted into the tumor until an active tip puncture was performed throughout the whole tumor (step-by-step strategy) according to the operator's experience. The ablation parameters were the same as those described in the C-arm CT group. For tumors larger than 3 cm, 2 puncture needles could be used simultaneously, or repeated adjustment of the puncture may have been needed using a single microwave applicator. The post-ablation image standards were the same as those

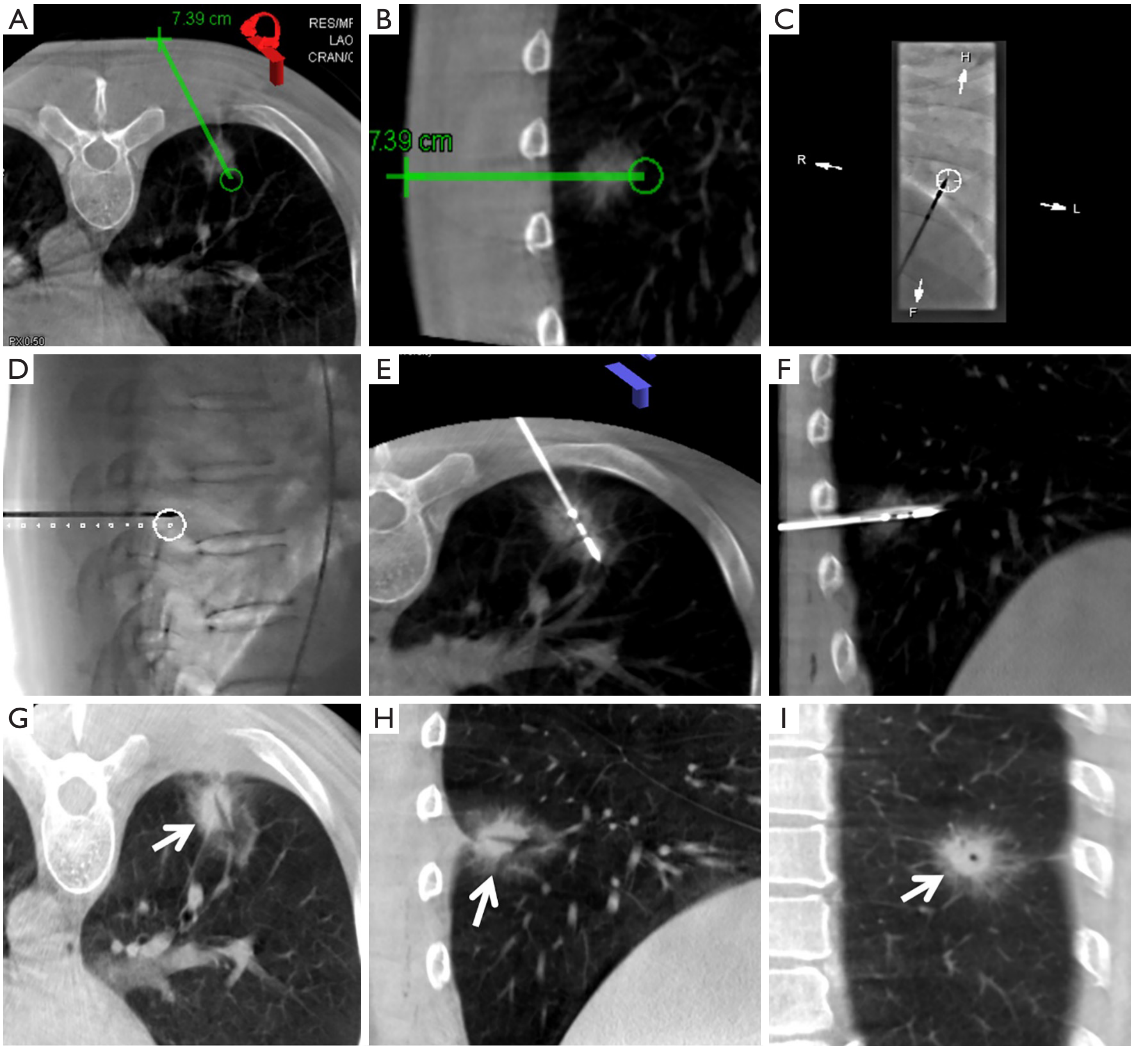

Figure 2 The process of C-arm CT-guided MWA for NSCLC. The puncture path (green line) was designed on transverse (A) and sagittal (B) C-arm CT images, which was designed on iGuide system (Artis Zeego, Germany), and the circle and fork represent target and skin puncture point, respectively. The virtual navigation line was displayed on the fluoroscopy, (C) is "Bull's eye view" and (D) is the needle "progression view". The microwave applicator was punctured with tumor on transverse (E) and sagittal (F) C-arm CT. Transverse (G), sagittal (H) and coronal (I) C-arm CT images showing that the tumor had been completely ablated (arrows). R, right; H, head; L, left; F, foot; CT, computed tomography; MWA, microwave ablation; NSCLC, non-small cell lung cancer.

in the C-arm CT group.

Definition

The primary endpoints were technical success, technical efficacy, puncture scoring (PS) and complete ablation (CA) rate. The secondary endpoints were complications, median PFS (mPFS) and median OS (mOS). Technical success was defined as the successful completion of puncture and ablation procedures. Technical efficacy was defined as the tumor being covered by ground glass opacity on post-ablation immediate C-arm CT and cCT on multiple planes. PS for lung tumors according to treatment plan was assessed using a score of 1–4: (I) score 1: unsuccessful applicator puncture; (II) score 2: successful puncture requiring more than 5 applicator punctures; (III) score 3: successful puncture requiring 3–4 applicator punctures; (IV) score 4: successful puncture requiring 1–2 applicator punctures. Total procedure time (TPT) = puncture time (PT) + AT + other preparation time (includes pre-procedure image acquisition and processing time). PFS was defined as the duration from MWA to the date of disease progression or death. OS was defined as the duration between the initial MWA and the most recent follow-up or death from any cause. Complications were defined according to the Common Terminology Criteria for Adverse Events version 5.0 {Grade 1 (mild) to Grade 5 [death related to adverse events (AEs)]} (15). The higher the score, the more serious the AEs. Grade 3–5 and 1–2 AEs were defined as major and minor complications, respectively. The dose area product (DAP) and dose length product (DLP) were collected in the irradiation monitoring system. The effective dose (ED; mSv) was calculated according to the dose conversion formula described by the International Commission on Radiological Protection (ICRP). The conversion constant (κ_{DAP} and κ_{DLP}) adopted the same value as the C-arm CT and CT systems in previous studies (16,17). ED = κ_{DAP} × DAP or ED = κ_{DLP} × DLP; κ_{DAP} =0.17 mSv/Gy·cm^2; κ_{DLP} =0.015 mSv/mGy·cm.

Follow-up protocol

Lung contrast-enhanced CT was performed every month for the first 3 months after MWA and then every 3 months thereafter. All cases were able to accept the follow-up system treatments (such as chemotherapy, targeted therapy, and immune therapy). All follow-up data were analyzed by both interventional radiologists (DJ and XH). The survival status of all cases was also analyzed.

Statistical analyses

All statistical analyses were performed using SPSS 21.0 software (IBM Corp., Armonk, NY, USA). Continuous variables were expressed as the mean ± standard deviation or the median. Pearson's χ^2 test, continuity-adjusted chi-square test, Fisher's exact test, or *t*-tests were performed to compare patient characteristics, complications, CA and local tumor progression (LTP) rates between the 2 groups, whereas mPFS and mOS were calculated using the Kaplan-Meier method (log-rank test). A statistically significant difference was considered when P<0.05.

Results

General data

A total of 101 cases were ultimately included in this retrospective study. Among them, 70 patients were considered as lung metastases based on their previous malignant tumor history and new image evidence of lung lesions. The remaining 31 patients underwent CT-guided biopsy before ablation to obtain malignant evidence. The maximum tumor diameter was 0.9–5.0 cm, and the mean diameters in the C-arm CT and cCT groups were 3.1±1.0 and 3.1±0.8 cm, respectively (P=0.99). Sex, age, tumor origin, tumor stage, tumor location, the distance between the pleura and lesion, pulmonary function, smoking abuse, primary treatment, ECOG score, and follow-up treatments are listed in *Table 1*, and those characteristics showed no significant differences between the 2 groups (all P>0.05).

Primary endpoint

Technical success rates were 100% in both the C-arm CT group and the cCT group. Technical efficacies were 93.3% and 91.1% in the C-arm CT group and cCT group, respectively, with no statistical difference (P=0.67). PSs of 4, 3, 2, and 1 were 10, 22, 12, and 1 in the C-arm CT group and 5, 19, 27, and 5 in the cCT group, respectively, which showed a statistically significant difference (P=0.02). The mean TPT and PT were 39.3 (range, 26.1–54.5) and 12.6 (range, 4.5–23.5) min in the C-arm CT group and 50.0 min (range, 29.3–78.0 min, P<0.001) and 15.7 min (range, 8.2–26.5 min, P=0.001) in the cCT group, respectively, and both parameters showed statistically significant differences. The 2-month CA and LTP rates were 93.3% and 11.1% in the C-arm CT group and 92.9% and 8.9% in the cCT group, respectively, which showed no statistically significant difference (P=0.93 and 0.72, respectively). Detailed information is listed in *Table 2*.

Secondary endpoint

The mean ED was 15.2 mSv (range, 4.8–31.4 mSv) in the C-arm CT group and 20.9 mSv (range, 8.7–59.0 mSv) in the cCT group, which showed a significant difference between the 2 groups (P<0.001). Major complications included pleural effusion requiring drainage (Grade 3) in 8 cases, severe pulmonary hemorrhage (Grade 3) in 3 cases, bronchopleural fistula (Grade 4) in 2 cases, pneumothorax requiring drainage (Grade 3) in 1 case, and severe pneumonia (Grade 3) in 1 case. The comparison of complications also showed no statistically significant difference, and the detailed P values are shown in *Table 3*.

During the median follow-up of 24.6 months (range,

Table 1 Patient characteristics in 2 groups

Parameter	C-arm CT group (n=45)	cCT group (n=56)	P value
Sex (male/female)	30/15	36/20	0.84†
Mean age (years)	59.0±11.6	59.4±9.8	0.87‡
BMI (kg/m^2)	26.9±4.6	26.2±4.1	0.77‡
Tumor origin			0.99†
NSCLC	14	19	
LM of colorectal cancer	10	12	
LM of renal cancer	7	9	
LM of esophageal cancer	7	8	
LM of other organs	7	8	
Tumor stage (I/II/III/IV)	3/4/7/31	4/6/9/37	0.76§
Max. tumor diameter (cm)	3.1±1.0	3.1±0.8	0.99‡
Tumor location (left/right)	25/20	25/31	0.32†
Distance between pleura and lesion (cm)	2.6±1.4	2.6±1.4	0.78‡
Pulmonary function classification (1/2)	42/3	52/4	0.93§
Smoking history (yes/no)	16/29	19/37	0.52†
Primary treatment (S/C/R/other)	26/34/15/16	30/38/19/13	0.83†
ECOG score (0/1/2)	26/15/4	32/19/5	0.96§
Follow-up treatment after PMA (C/T/I)	37/22/15	46/18/11	0.37†

Data are presented as mean ± standard deviation or number (frequency). †, Pearson's χ^2 test; ‡, independent *t*-tests; §, Fisher's exact test. CT, computed tomography; cCT, conventional computed tomography; BMI, body mass index; NSCLC, non-small cell lung cancer; LM, lung metastasis; S, surgery; C, chemotherapy; R, radiotherapy; ECOG, Eastern Cooperative Oncology Group; PMA, percutaneous microwave ablation; T, targeted therapy; I, immunotherapy.

9.2–45.4 months), among 29 cases with tumor progression in the C-arm CT group, 16 cases had extrapulmonary metastasis, 8 cases died, 3 cases had local recurrence and multiple metastases, and 2 cases had local recurrence. Among 35 cases with tumor progression in the cCT group, 18 cases had extrapulmonary metastasis, 12 cases died, 3 had local recurrence, and 2 cases had local recurrence and multiple metastases. The 1- and 2-year PFS rates were 73.3% and 51.1% in the C-arm CT group and 78.6% and 57.1% in the cCT group, respectively. The mPFS was 9.5 months [95% confidence interval (CI): 7.9–11.1] in the C-arm CT group and 10.1 months (95% CI: 9.3–10.9) in the cCT group, which showed no statistically significant difference (P=0.52, *Figure 3A*).

The 1-, 2-, and 3-year OS rates were 100%, 92.0%, and 51.6% in the C-arm CT group and 98.1%, 95.3%, and 60.0% in the cCT group, respectively. The mOS was 37.9 months (95% CI: 31.1–44.7) in the C-arm CT group and 38.8 months (95% CI: 35.3–42.3) in the cCT group, which showed no statistically significant difference (P=0.67, *Figure 3B*).

Discussion

An ideal guidance tool should fulfill the 3 key requirements: tumor visualization, applicator localization, and ablation evaluation. Currently, CT is the most widely used guidance tool for lung puncture intervention with the advantages of convenience, fast scanning, and high-density resolution. Although intermittent CT fluoroscopy can provide real-time guidance to detect pneumothorax or discover microwave applicator displacement during ablation, it is not as fast and convenient as C-arm fluoroscopy. Moreover, puncture success depends mostly on the operator's

Table 2 Outcomes of lung tumors treated with MWA under C-arm CT or cCT guidance

Parameter	C-arm CT group (n=45)	cCT group (n=56)	P value
Technical success	100% (45/45)	100% (56/56)	>0.99
Technical efficacy	93.3% (42/45)	91.1% (51/56)	0.67†
Total procedure time (min)	39.3±7.0	50.0±8.9	<0.001‡
Ablation power (W)	40.7±4.2	40.8±3.0	0.87‡
Puncture time (min)	12.6±4.3	15.7±4.9	0.001‡
Scan times	6.2±2.4	10.8±3.2	0.00‡
Probe per patient	1.1±0.3	1.1±0.4	0.23‡
Treatment cycle	1.45±0.74	1.45±0.5	0.95‡
Ablation time (min)	9.1±2.8	9.6±2.4	0.36‡
Puncture scoring (4/3/2/1)	10/22/12/1	5/19/27/5	0.02§
Effective dose (mSv)	15.2±5.8	20.9±8.7	<0.001‡
Hospital stays (days)	7.5±4.1	7.1±4.8	0.63‡
2-month CA rate	42/45	52/56	0.93†
LTP rate	5/45	5/56	0.98¶
mPFS (months)	9.5	10.1	0.52#
Survival status (alive/death)	37/8	44/12	0.65†
mOS (months)	37.9	38.8	0.67#

Data are presented as mean ± standard deviation, median, or number. †, Pearson's χ^2 test; ‡, independent *t*-test; §, Fisher's exact test; ¶, continuity-adjusted chi-square test; #, Kaplan-Meier method (log-rank test). MWA, microwave ablation; CT, computed tomography; cCT, conventional computed tomography; CA, complete ablation; LTP, local tumor progression; mPFS, median progression-free survival; mOS, median overall survival.

Table 3 Complications between 2 groups

Parameter	CTCAE grade	C-arm CT group (n=45)	cCT group (n=56)	P value
Major complications				
Bronchopleural fistula	4	1	1	0.89†
Severe pulmonary hemorrhage	3	1	2	0.69†
Pneumothorax requiring drainage	3	0	1	0.37†
Pleural effusion requiring drainage	3	4	4	0.75†
Severe pneumonia	3	1	0	0.20†
Minor complications				
Pleural effusion	1–2	8	13	0.50‡
Pneumothorax	1–2	4	10	0.19†
Pneumonia	1–2	3	4	0.72†
Post ablation syndrome	1–2	13	16	0.97‡
Chest pain requiring drug analgesia	1–2	14	17	0.94‡

Data are presented as number (frequency). †, Fisher's exact test; ‡, Pearson's χ^2 test. CTCAE, Common Terminology Criteria for Adverse Events; CT, computed tomography; cCT, conventional computed tomography.

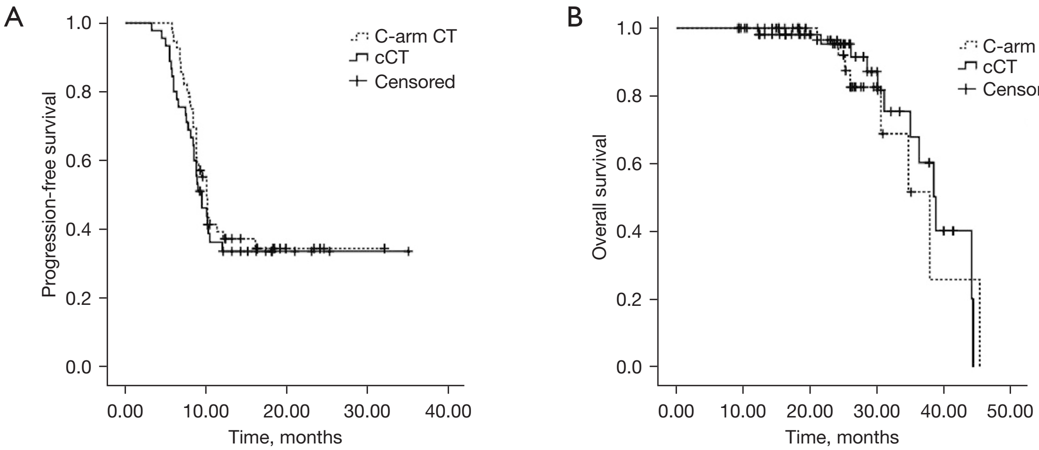

Figure 3 PFS and OS. (A) PFS showed no significance between the C-arm CT and cCT group. (B) OS showed no significance between the C-arm CT and the cCT group. CT, computed tomography; cCT, conventional computed tomography; PFS, progression-free survival; OS, overall survival.

experience (18).

The present study revealed that technical success, technical efficacy, AT, complications, CA rate, mPFS, and mOS were not significantly different between the 2 groups. This result was expected because the 2 groups only had differences in guidance tools, but the subsequent ablation and follow-up protocols were similar. Yuan *et al.* (19) compared TE, tumor response, complications, mPFS and mOS with C-arm CT and angio-CT and found that all those parameters also showed no significance. Lyu *et al.* (20) retrospectively analyzed data from patients with hepatocellular carcinoma who underwent radiofrequency ablation guided by C-arm CT (n=21) and cCT (n=26). The complication and 1-, 3-, and 6-month local responses also had no significance. Cazzato *et al.* (21) reported that 40 lung tumors were treated using both guidance tools, and multivariable regression analysis showed that the C-arm CT was faster than cCT in placing the electrode for tumors less than 10 mm (2.5 *vs.* 8.0 min). The prospective study from Abi-Jaoudeh *et al.* (22) showed that the mean number of the needle re-positions in C-arm CT was 0.3 compared with 1.9 times with cCT, whereas the skin entry ED decreased by 29% using C-arm CT compared with cCT (53.3 *vs.* 75.4 mGy). A prospective study by Braak *et al.* (23) showed that ED with CT-guided needle interventions was 15.1 mSv in the lower thorax, and that it will result in a reduction of 13–42% ED compared with cCT guidance. PS, TPT, PT, and ED showed significance in our study. A total of 71.1% successful applicator punctures were achieved within 4 adjustments (PS =3 or 4) in the C-arm CT group, and the rate was 36.9% in the cCT group. The PT decreased by 19.7% in the C-arm CT group compared with the cCT group, which may mainly be due to the application of iGuide virtual navigation. Although the ED values of various studies are quite different, which may be related to the different manufacturers and calculation methods, these studies all confirm that the ED of needle intervention in the lung by C-arm CT is lower than that of cCT navigation, which is the requirement of our clinical practice.

The most common complication after MWA is pneumothorax, with an incidence rate of 8.5–63% reported in a previous study (24,25). Self-limited pneumothorax was 8.9% in the C-arm CT group and 15.4% in the cCT group, which showed no significant difference. Pleural effusion was 17.8% in the C-arm CT group and 20% in the cCT group, which falls within the previously reported values (1–60%) (26,27). There was 1 case of bronchopleural fistula (classified as a Grade 4 complication, *Figure 4*) in each group, and both lesions were very close to the pleura. As we know, MWA has a high efficacy direct heating effect versus resistive heating through electrical currents of radiofrequency in a low conductive medium such as the lung (28). The larger ablation zone means more damage. We suggest a low-power/short-time ablation strategy (35–45 W/3–5 min) if the tumor is located within 10 mm of the pleura, and if patients feel obvious chest pain during ablation, it is recommended to stop ablation immediately and perform another C-arm CT or cCT. The ablation range reached the edge of the pleura, which can be judged as a technical success. Stratified analysis was conducted

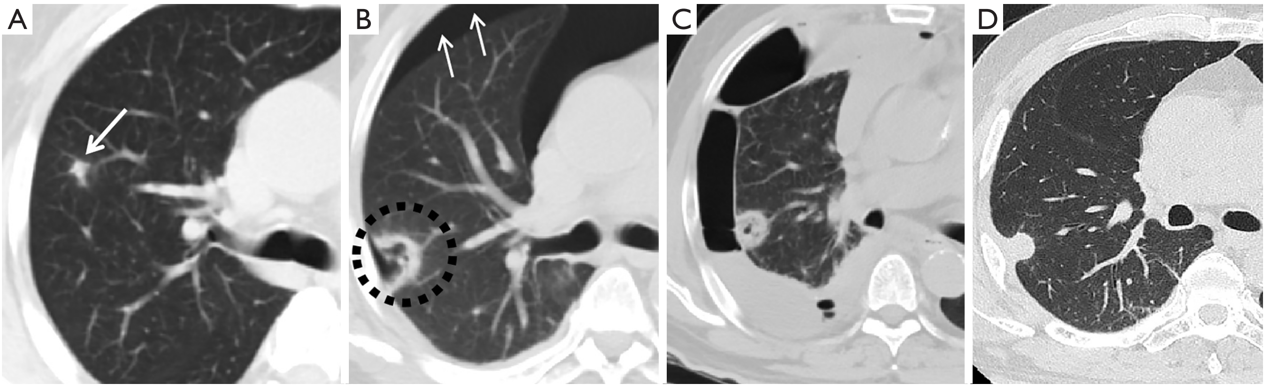

Figure 4 A 61-year-old male patient with a lung tumor from primary NSCLC experienced rare complication of bronchopleural fistula (classified as Grade 4 complication) at conventional CT group. (A) Preoperative CT showed that the size of the lesion was 0.9 cm (arrow). (B) CT conducted immediately after MWA showed that the local lung tissue was seriously damaged (black circle) and pneumothorax was formed (arrows). (C) On the 3rd day after MWA, the patient complained of increased chest pain and breath difficulty, and subsequently underwent percutaneous chest drainage. (D) 18 days after drainage, the drainage tube was removed and the local solid nodule was formed. NSCLC, non-small cell lung cancer; CT, computed tomography; MWA, microwave ablation.

Table 4 The correction of PS between technical efficacy, major complication, and 2-month CA status

Parameter	C-arm CT group (n=45)		cCT group (n=56)		P value
	PS (4–3)	PS (1–2)	PS (4–3)	PS (1–2)	
Technical efficacy	30	12	37	14	0.91‡
Major complication	4	3	5	3	0.83†
2-month CA status	31	11	39	13	0.90‡

†, Fisher's exact test; ‡, Pearson's χ^2 test. PS, puncture scoring; CA, complete ablation; CT, computed tomography; cCT, conventional computed tomography.

to analyze the major complications, TE, and 2-month CA status between the 2 sub-groups in PS (3–4) and PS (1–2) (*Table 4*). There are theoretically 2 key differences between C-arm CT and cCT in terms of complications: (I) the iGuide navigation can assist the puncture, which is especially helpful for inexperienced doctors to decrease puncture complications; (II) the C-arm CT can provide cross, sagittal, and coronal anatomical relationships directly, whereas cCT provides only cross-sectional information and post processing reconstruction is required if 3D information is needed, which will take some time. However, all these factors showed no difference, which further showed that iGuide virtual navigation can provide better assistance and reduce PT, but the limited puncture adjusting times did not increase major complications and reduce the TE. The reasons may be due to the thin MWA applicator and the rich experience of operators.

Our study demonstrated the special advantages of C-arm CT (16): (I) C-arm CT can automatically reconstruct CT-like images showing 3D information of the tumor and needle (such as multiplanar and volume reconstruction imaging) in less than 5 seconds, saving time of secondary reconstruction of cCT; (II) DynaCT has an iGuide virtual-navigation function, which can accurately locate the needle entry point and target point of skin puncture, thus reducing PT and improving puncture success; (III) DSA also has a real-time fluoroscopy function, which can correct the changes in puncture angle and depth caused by breathing at any time, especially for the lesions located in both lower lungs; and (IV) virtual-navigation can reduce the radiation dose accepted by all patients.

However, C-arm CT also has its own technical defects; for example, the soft tissue resolution is only 5–10 HU. Although it does not affect the localization of pulmonary lesions (the gas in the lung tissue is in sharp contrast with the mass) and the judgment of MWA damage range, it still faces some technical challenges in the identification of blood vessels, which need to be repeatedly compared with enhanced cCT images. In addition, patients need to hold their breath many times during the scanning period to achieve better image quality. For elderly patients, it is best to exercise respiratory coordination before commencing the surgery. This clinical study had shortcomings such as retrospective design, sample selection bias, and small sample size. Prospective, multicenter research data is needed for future research.

Conclusions

In conclusion, C-arm CT guidance is a useful and effective tool to CA for lung tumors, and iGuide virtual navigation system can help operators to increase puncture confidence.

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Footnote

Reporting Checklist: The authors have completed the STROBE reporting checklist. Available at https://qims.amegroups.com/article/view/10.21037/qims-22-985/rc

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://qims.amegroups.com/article/view/10.21037/qims-22-985/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by ethics committee of The First Affiliated Hospital of Zhengzhou University and the requirement for individual consent for this retrospective analysis was waived.

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