Technology in Cancer Research & Treatment
Volume 21: 1-8

DOI: 10.1177/15330338221094429
journals.sagepub.com/home/tct
SAGE

Factors Associated with Pulmonary Function Changes in Patients Undergoing Microwave Ablation for Pulmonary Ground-Glass Nodules

Weida Wu, MD[1], Jianyang Peng, BD[1], Hongbin Gao, MD[1], Yuanzhen Lin, MD[1], Qunying Lin, BD[2], and Zhicheng Weng, MD[1]

Abstract

Purpose: Microwave ablation has become an alternative treatment for pulmonary ground-glass nodules (GGN) and is widely accepted by clinicians. However, its effect on lung function remains unknown. Therefore, this retrospective study aimed to explore pulmonary function changes and associated risk factors in patients undergoing computed tomography (CT)-guided microwave ablation (MWA) for treating pulmonary GGN. **Materials and Methods:** Thirty-five patients diagnosed with pulmonary GGN on thin-layer chest CT and enhanced CT were examined. Patients unable or unwilling to undergo thoracoscopic surgery underwent CT-guided simultaneous percutaneous core needle biopsy and MWA. Pulmonary function tests (PFT) were performed before ablation and 3 days and 6 months post-ablation. Forced expiratory volume in one second (FEV1), FEV1%, forced vital capacity (FVC), maximal voluntary ventilation (MVV), and peak expiratory flow (PEF) values pre- and post-MWA were analysed. Linear regression analysis was used to examine the correlation between ablation volume and changes in PFT findings 3 days post-ablation. Associations between patient characteristics, rates of postoperative complications, and PFT findings were analysed. **Results:** Forty-eight lesions were completely ablated and examined intraoperatively. There were significant differences in pre- and post-operative PFT findings on day 3 but not at 6 months. The mean ablation volume after 3 days of 11.4 ± 6.3 cm^3 was positively correlated with changes in FEV1, MVV, and PEF values. Patients' age (mean, 59.4 ± 13.0 years) positively correlated with changes in PEF values. The rates of change in FVC and MVV values were significantly higher with multiple pulmonary nodules than with isolated pulmonary nodule. PFT findings were similar between patients who experienced or did not experience complications (eg, pneumothorax and pleural effusion). **Conclusions:** Pulmonary function could be impaired shortly after MWA. PFT findings may correlate with age, ablation volume, and number of ablated lesions. In most patients, pulmonary function returned to the preoperative state after 6 months.

Keywords

pulmonary ground-glass nodule, microwave ablation, pulmonary function, ablation volume, lung cancer

Abbreviations

FEV1, forced expiratory volume in one second; FVC, forced vital capacity; MVV, maximal voluntary ventilation; PEF, peak expiratory flow; CT, computed tomography; GGN, ground-glass nodule; PFT, pulmonary function test; SMPLC, synchronous multiple primary lung cancer; MWA, microwave ablation; SMGNs, multiple ground-glass nodules; COPD, chronic obstructive pulmonary disease; SD, standard deviation

[1] Department of Interventional and Vascular surgery, the Affiliated Hospital of Putian University, Putian 351100, China
[2] Department of Respiratory and Critical Care Medicine, the Affiliated Hospital of Putian University, Putian 351100, China

Corresponding Authors:
Qunying Lin, Department of Respiratory and Critical Care Medicine, the Affiliated Hospital of Putian University,No.999 Dongzhen East Road, Licheng District, Putian351100, Fujian Province,People's Republic of China.
Email:linqyin@126.com

Zhicheng Weng, Department of Interventional and Vascular surgery, the Affiliated Hospital of Putian University,No.999 Dongzhen East Road, Licheng District, Putian351100, Fujian Province,People's Republic of China.
Email: wengdoctor@163.com

Introduction

Annually, lung cancer accounts for approximately 2.1 million new cases and 18.4% of cancer-related deaths worldwide.[1] Globally, the 5-year survival rate of lung cancer patients is estimated at 19%; at the time of diagnosis, most patients have advanced disease.[2] The practice of screening programmes involving thin-layer chest computed tomography (CT) has increased the rate of asymptomatic pulmonary ground-glass nodule (GGN) diagnosis; early diagnosis and treatment of GGN are paramount for good outcomes, as these nodules are associated with increased risk of progression to lung cancer. The optimal management strategy for pulmonary GGN remains unclear, although thoracoscopic surgery remains the preferred treatment;[3] however, this approach requires the use of general anaesthesia and patients meeting relatively high cardiopulmonary function thresholds. Therefore, non-invasive pulmonary function tests (PFT) are often performed to evaluate patients' eligibility for surgery and to formulate an approach that helps reduce the risk of cardiopulmonary complications.[4] In cases where PFT findings are poor and cannot be improved through drug therapy or pulmonary function exercise, surgery may be ineffective. Patients with multiple GGNs, especially those diagnosed with synchronous multiple primary lung cancer (SMPLC), may have significant lung function impairment if all the suspected malignant lesions are resected simultaneously. Consequently, the risk of perioperative cardiopulmonary complications such as respiratory failure may significantly increase.[5] The present international consensus is that local resection can achieve radical cure;[6-7] however, some evidence suggests that non-surgical treatments for pulmonary GGN, including stereotactic body radiotherapy and thermal ablation, among others, are both safe and effective.[3,8-10] Further studies are required to confirm that thermal ablation can help some patients who cannot tolerate thoracoscopic resection or pneumonectomy owing to poor pulmonary function or SMPLC. No previous study has evaluated the effects of PFT for treating pulmonary GGN after microwave ablation (MWA). This retrospective study of 35 patients with pulmonary GGN undergoing MWA in the past 5 years aimed to provide preliminary evidence for the clinical evaluation of pulmonary function changes after ablation.

Materials and Methods

From June 2016 to June 2021, a retrospective cohort study was conducted at our department, using de-identified patient details. Thirty-five patients were selectively diagnosed with pulmonary GGN on thin-layer chest CT and enhanced CT (Table 1). The patients were informed in detail about the risks and benefits associated with MWA before they signed a written informed consent form, which included consent for the risk of ablation procedure and regular pulmonary function tests. The study was approved by the ethics committee of the Affiliated Hospital of Putian University of Medicine institutional review board (approval number, 202039; location, the Affiliated Hospital of Putian University; date, 07 September 2020). The reporting of this study conforms to the STROBE guidelines.[11]

Table 1. Thirty-five cases of pulmonary GGN in patients and nodule characteristics.

Characteristics[U.]	Number
Total GGNs ablated	48
Age range（Median ± SD）[years]	32～81（59.4 ± 13.0）
Sex Male/Female	19/16
Location	
Left lung/Right lung	13/22
Center/Periphery	20/28
Maximum diameter range（Median ± SD）[mm]	6.0～25.0(10.9 ± 4.1)
Isolated/Multiple pulmonary nodules	23/12
GGN type Pure/Part-solid	29/19
Number of ablated lesion ：1/2/3	25/7/3
Comorbidity	
COPD	10
Diabetes	11
Cardiovascular diseases	9
Renal insufficiency	8
Smoking history: yes/no	18/17
Pathology	
Invasive adenocarcinoma	4
Minimally invasive adenocarcinoma	8
Adenocarcinoma in situ	13
Atypical adenomatous hyperplasia	8
Others	2
Ablation volume（Median ± SD）[cm^3]	11.4 ± 6.3

Patients were included in this study if they met the following criteria: 1) their GGNs measurement was ≥ 6 mm in diameter; 2) imaging findings were consistent with malignancies, such as vacuole or burr signs, pleural depression, and vascular clusters; 3) malignant transformation of the GGN, including an increase in diameter ≥ 2 mm or in the number of solid components were assessed during the standard follow-up; 4) imaging findings were consistent with multiple ground-glass nodules (SMGNs) and suggestive of SMPLC and unlikely to be completely resected; 5) history of simultaneously-performed pulmonary lobectomy with lymph node dissection for SMGNs and target lesions suggestive of invasive adenocarcinoma, which increase the risk of complications on reoperation of the residual lesion; 6) severe pleural adhesions; 7) PFT findings suggestive of increased risks of poor outcomes after pulmonary lobectomy (FEV1 ≤1 L) or segmentectomy (FEV1 ≤0.6 L).[10] Furthermore, since the lung biopsy cannot help to determine the characteristics of the entire tumour, all patients underwent additional evaluations by a multidisciplinary team including specialists from the departments of thoracic surgery, respiratory medicine, interventional medicine, and anaesthesiology, before ablation therapy. Patients unable or unwilling to undergo surgical treatment were included in this study after the risks and benefits of the procedure were thoroughly explained to them.

Patients were excluded owing to the following reasons: presented with regional or distant lymph node metastasis as revealed on enhanced CT or positron emission tomography/CT; advanced

emphysema and bullae making pneumothorax inevitable; poor cardiopulmonary function and inability to care for themselves; irreversible coagulopathy and severe bleeding tendency; altered level of consciousness or a mental disorder resulting in failure to cooperate with treatment; extensive pneumothorax requiring closed thoracic drainage; or extensive bleeding or effusion in the pleural cavity requiring puncture drainage.

Ablation Protocol

Surgical route was determined according to the location of the pulmonary GGN to obtain the best puncture route. A layer thickness of 2.5 mm was routinely used during CT scanning. For a pulmonary nodule treated using MWA (Vison Medical USA Inc.), the routes of puncture for employing the disposable semi-automatic biopsy device (specification: 18 G × 16 cm, GALLINI S.R.L, Italy) and water-cooled MWA probe (diameter: 11 G/14-19 G, length: 10 cm/15 cm) were determined after performing CT. The site of puncture was marked and disinfected, a towel was spread, and local anaesthesia was administered. A coaxial locating needle (specification: 17 G × 11 cm) and ablation probe were advanced to the predetermined position. The ablation probe was connected with a 250-mL syringe containing normal saline and with a generator through a peristaltic pump and cooling circulating water pipe. First, one or two strips of pathological tissue were obtained. Subsequently, the generator was started (ablation power: 40-70 W, ablation time: 4-8 min). During the procedure, CT was performed to confirm that the ablation range included the GGN (Figure 1, panels 1-3). In patients with SMGNs, initially, only the largest GGN or the one with the most straightforward placement was approached using the above methods; subsequently, the remaining nodules were ablated simultaneously in a single pulmonary lobe through MWA. After the procedure, CT was again performed to confirm the ablation range and observe any complications. If the target lesion had been missed, additional ablation was performed. Finally, thin-layer chest CT and PFT findings were reviewed on postoperative day 3 and at 6 months. Ablation volume was measured on day 3 using image-assisted diagnostic software V4.0 (Beijing Medical AI Technology LTD, CHINA).

Evaluation Indexes and Postoperative Follow-up

Technical success was defined as post-ablation GGN at least 0.5 cm larger than the tumour sites.[8] "Delayed" pneumothorax was pneumothorax found on chest CT performed 3 days postoperatively (Figure 2). Recurrence was defined according to criteria presented in previous literature including GGN found at the edges of fibrosis lesions.[12] PFT findings included forced vital capacity (FVC), forced expiratory volume in one second (FEV1), FEV1%, maximal voluntary ventilation (MVV), and peak expiratory flow (PEF). Ablation volume (cm^3) was measured and recorded on postoperative day 3. Pulmonary function change rates were estimated as follows: preoperative pulmonary function value – postoperative pulmonary function value/preoperative pulmonary function value (%).

Statistical Analysis

All analyses were performed using IBM SPSS Statistics (version 17 Stata Corp, College Station, USA). Variables are expressed as the mean ± standard deviation (SD). Differences between pre- and post-MWA PFT findings were evaluated using the paired t-test. Correlations between patient characteristics, including ablation volume, and PFT change rates were analysed using the Mann–Whitney U test and Spearman's rank correlation analysis. Statistical significance was set at P-values < 0.05.

Results

A total of 48 lesions underwent simultaneous percutaneous core needle biopsy and MWA in 35 patients with pulmonary GGNs, including 3 patients with 3 nodules in a single pulmonary lobe and 7 patients with 2 nodules in a single pulmonary lobe; the remaining cases presented with a single pulmonary nodule. The technical success rate was 100%. Complications included pneumothorax, pleural effusion, haemoptysis, pulmonary haemorrhage, and cavity formation. The incidence of pneumothorax, including 6 cases of delayed pneumothorax, was 42.9% (15/35); gradual absorption occurred in all cases. The incidence of pleural effusion was 31.4% (10/35), and it was absorbed using oral anti-inflammatory drugs or haemostasis. The incidence of intrapulmonary haemorrhage was 42.9% (15/35) and that of haemoptysis with blood loss ≤ 10 mL was 8.6% (3/35); bleeding was controlled through thermal ablation and administration of haemostatic drugs. Intrapulmonary haemorrhage was absorbed, as observed on chest CT performed on postoperative day 3. The incidence of cavity formation was 8.6% (3/35), as observed on chest CT performed 1 month postoperatively; the formed pulmonary cavity was completely absorbed within 6 months. No case of air embolism, needle implantation metastasis, or bronchopleural fistula was observed. Biopsy findings are presented in Table 1. As all patients had undergone MWAs, GGN pathological characteristics observed at the time of the procedure were considered final. Four patients with invasive adenocarcinoma underwent further genetic testing.

The mean follow-up period was 21.7 ± 14.3 (range, 3-48) months. Follow-up chest CT revealed clear ablation boundaries on postoperative day 3; no case of local residual recurrence was observed. However, the ablated lesions gradually formed residual fibrous band scarring that was observed at the 6-month assessment (Figure 1, panels 4-6). Differences between pre- and post-MWA PFT findings are presented in Table 2. FVC, FEV1, MVV, and PEF values were lower on postoperative day 3 than at baseline; however, the decline of FEV1% was relatively small; differences pre- and post-MWA were all significant ($P < 0.05$). The result suggests that the pulmonary function might be impaired shortly after MWA. PFT findings 6 months postoperatively were similar to those observed preoperatively.

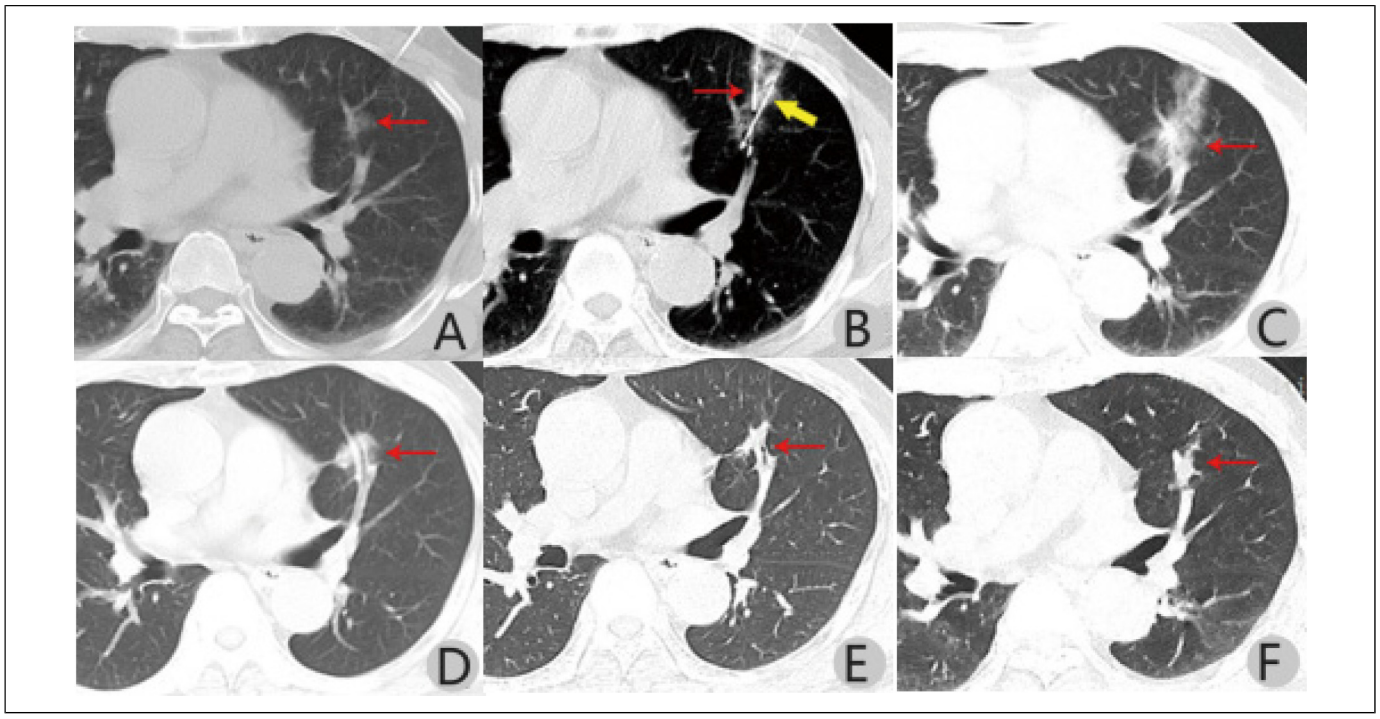

Figure 1. Chest computed tomography (CT) of a 72-year-old man obtained during simultaneous percutaneous core needle biopsy and microwave ablation (MWA) and at the postoperative follow-up. (A) Thin-layer chest CT showing the location of the target lesion (arrow). (B) Microwave antenna (thick yellow arrow) and biopsy needle (thin red arrow) puncture the lesion. (C) Ablated lesion immediately after biopsy followed by MWA (arrow). (D) Range of ablation lesion reduced (arrow) after 1 month. (E) Ablated lesion presents as a fibre cord (arrow) at the 6-month follow-up. (F) Lesion approximately the same as 1 year after ablation (arrow).

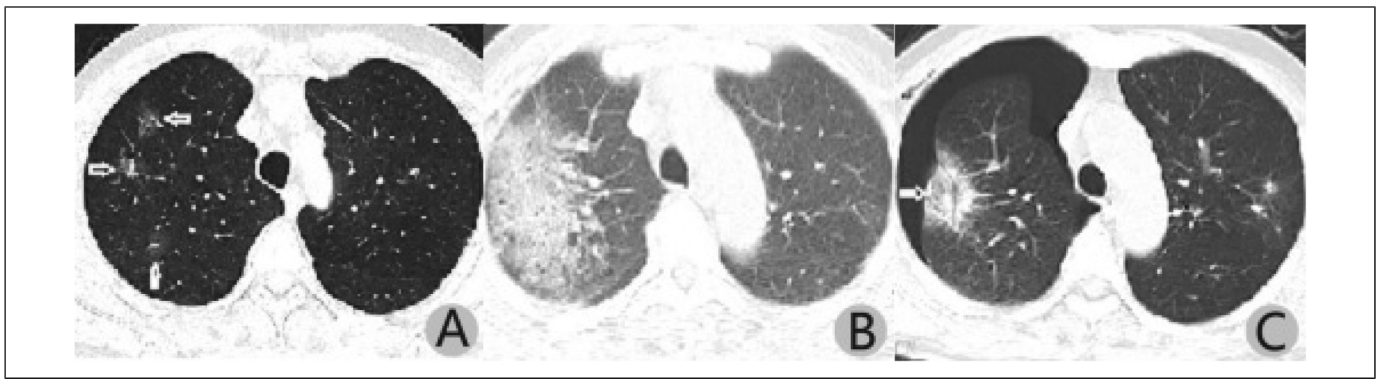

Figure 2. Chest computed tomography (CT) of a 61-year-old man presenting with delayed pneumothorax and intrapulmonary haemorrhage. (A) Thin-layer chest CT consistent with synchronous multiple primary lung cancer (arrow). (B) Ablated lesion immediately showing massive intrapulmonary haemorrhage. (C) Delayed pneumothorax 3 days after ablation. Boundaries of the ablated lesion were clear after intrapulmonary haemorrhage was absorbed (arrow).

Factors associated with postoperative decline in PFT values are presented in Table 3 and Figure 3. The mean rates of change in FVC, FEV1, FEV1%, MVV, and PEF were $18.7 \pm 9.1\%$, $21.6 \pm 8.9\%$, $1.7 \pm 6.5\%$, $18.7 \pm 8.8\%$, and $18.1 \pm 8.8\%$, respectively. The mean ablation volume was 11.4 ± 6.3 cm^3 on postoperative day 3, and it positively correlated with the rates of change in FEV1, MVV, and PEF in linear regression analysis. The results suggest that the larger the ablation range, the more obvious the lung function impairment. The patients' mean age was 59.4 ± 13.0 years, and it positively correlated with the rates of PEF change. These findings suggest that a decline in PEF may be greater in older patients. There were 12 patients with multiple pulmonary nodules and 10 who underwent ablation of ≥ 2 lesions simultaneously. The change rates of predicted FVC and predicted MVV were significantly higher with multiple pulmonary nodules than with isolated pulmonary nodule ($P < 0.05$). The reason for this could be that the more the lesions were ablated, the larger the volume and the more obvious the

Table 2. The pre- and post-PFT results for all the patients.

PFT	Preoperative	After 3 days	t	*P*
FEV1 (L)	2.05 ± 0.59	1.60 ± 0.49	11.924	<0.001
FEV1%	73.31 ± 9.62	71.81 ± 8.94	2.264	0.03
FVC (L)	2.73 ± 0.67	2.22 ± 0.58	11.287	<0.001
MVV (L/min)	84.97 ± 23.24	69.2 ± 20.86	12.287	<0.001
PEF (L/s)	6.00 ± 2.10	4.97 ± 1.95	12.173	<0.001
PFT	Preoperative	After 6 months	t	*P*
FEV1 (L)	2.05 ± 0.59	2.01 ± 0.60	1.871	0.07
FEV1%	73.31 ± 9.62	73.34 ± 10.49	−0.064	0.95
FVC (L)	2.73 ± 0.67	2.71 ± 0.67	0.215	0.831
MVV (L/min)	84.97 ± 23.24	84.59 ± 24.01	0.775	0.444
PEF (L/s)	6.00 ± 2.10	5.95 ± 2.04	1.217	0.232

Paired-t test,a *P* value less than 0.05.

lung function damage. Complications, including pneumothorax and pleural effusion, may reduce the lung function generally. In the present study, there was no difference in PFT findings between patients who did and did not experience complications.

Discussion

Thoracoscopic surgery remains the main treatment for pulmonary GGNs with imaging-based evidence of malignancy. GGNs tend to be differentiated into benign and malignant, based on imaging findings, except in cases where percutaneous biopsy findings are available. In clinical practice, pulmonary GGN size and internal structural characteristics (including solid components and signs of vacuoles) and dynamic changes observed during the follow-up period are often used to predict malignancy and determine treatment.[13] However, some patients are unable or unwilling to undergo thoracoscopic surgery; therefore, an alternative approach is required for this patient group. In this study, all patients with pulmonary GGNs were treated with CT-guided MWA, performed under local anaesthesia. No signs of local recurrence or lymph node metastasis were observed during the follow-up period. All patients achieved a curative effect, which was expected, based on previous studies.[14-15]

This study aimed to examine the differences in pre- and post-MWA pulmonary function of patients with GGN. Assessments performed 3 days after ablation represent short-term effects. Intrapulmonary bleeding occurred immediately after MWA in some patients, affecting the assessment of ablation range. However, bleeding was re-absorbed in most patients 3 days postoperatively (Figure 2), helping complete the measurement of ablation volume. PFT findings 6 months postoperatively represent long-term effects. Re-evaluation schedule depends on the dynamic evolution of ablated lesions observed on follow-up chest CT.

In this study, although PFT values decreased in most patients on postoperative day 3, they failed to decrease in some patients, the reasons of which were considered to be related to the poor cooperation during the lung function tests, and for the contributing factors including patients' age, education level, and individual cognitive ability.[16] The t-test revealed that postoperative FVC, FEV1, MVV, and PEF values were lower than the baseline values. FEV1% decreased relatively slowly. Ten patients presented with chronic obstructive pulmonary disease (COPD), and the lowest FEV1% was 43.19%. No patient experienced aggravating asthma after ablation. There was no significant difference in PFT findings between the COPD and non-COPD groups. These findings suggest that MWA may have relatively little impact on patients with obstructive airway diseases such as COPD. In addition, ablation volume positively correlated with the rate of FEV1, MVV, and PEF changes. Ablation volume may be associated with a decline in PFT values. Meanwhile, patients' age may affect the rate of PEF change; specifically, older patients may be more susceptible to PEF changes than younger patients. Multiple pulmonary nodules had a greater effect on the rates of FVC and MVV changes than did isolated pulmonary nodules; this finding may be accounted for the larger ablation range present when two or three nodules are simultaneously ablated. These findings suggest that simultaneous ablation of multiple lesions for SMGNs may be performed, provided the number of lesions ablated is reduced if preoperative PFT findings are poor. In contrast, the values of FVC, FEV1, FEV1%, MVV, and PEF 6 months postoperatively were comparable with the preoperative ones. These findings suggest that pulmonary function can be restored in most patients within 6 months of the procedure, including in cases of SMGNs.

Previous studies have shown that patients with SMGNs account for approximately 20–30% of all patients diagnosed with pulmonary GGN.[17] When such patients undergo pulmonary lobectomy with simultaneous lymph node dissection to the target lesions, the remaining nodules may present with signs of malignancy during the follow-up, specifically, in cases of nodules placed close to the deep lung hilar region. These changes may increase the risks associated with the use of anaesthesia and may reduce postoperative lung function significantly. However, there is currently no standard approach to the treatment of residual pulmonary nodules in patients who undergo pulmonary lobectomy. In this study, three patients diagnosed with SMGNs as target lesions were treated with pulmonary lobectomy, and pathology findings revealed stage I lung adenocarcinoma. Patients with GGNs suggestive of malignant transformation underwent MWA more than 6 months later. No fatalities were observed. Patients with SMGNs are more likely to progress to SMPLC rather than to metastatic lung cancer.[16] SMPLC has a significant impact on pulmonary function owing to the large range of pneumonectomy, which may increase the risk of cardiopulmonary complications postoperatively. Consequently, surgery remains controversial, and there is a lack of clear guidelines on the preferred surgical modality. Similarly, there is a lack of clear guidelines on the management of residual nodules.[18] In this study, one patient suggested of having SMPLC underwent repeat MWAs more than 6 months

Table 3. Associations between patient characteristics and pulmonary function test findings

Characteristics	*P* value(correlation coefficienta #)				
	% Predicted FVC	% Predicted FEV1	% Predicted FEV1%	% Predicted MVV	% Predicted PEF
age #	0.781 (-0.049)	0.697 (-0.068)	0.421 (-0.140)	0.392 (0.149)	**0.019** (0.394)
Sex: Male/Female*	0.832	0.367	0.385	0.635	0.161
Left lung/Right lung*	0.091	0.578	0.18	0.987	0.408
Isolated/Multiple pulmonary nodules*	**0.045**	0.905	0.878	**0.019**	0.932
COPD: yes/no*	0.483	0.439	0.577	0.788	0.577
Ablation volume #	0.605 (0.091)	**0.005** (0.464)	0.821 (0.040)	**<0.001** (0.786)	**0.019** (0.396)
Complications					
Pneumothorax*	0.479	0.961	0.805	0.755	0.438
Pleural effusion*	0.377	0.788	0.377	0.788	0.105

Spearman's rank correlation.
*Mann-Whitney U test.
Bold text indicates statistically significant difference with a *P* value less than 0.05.
Data above were obtained pre-operatively and on post-operative day 3.

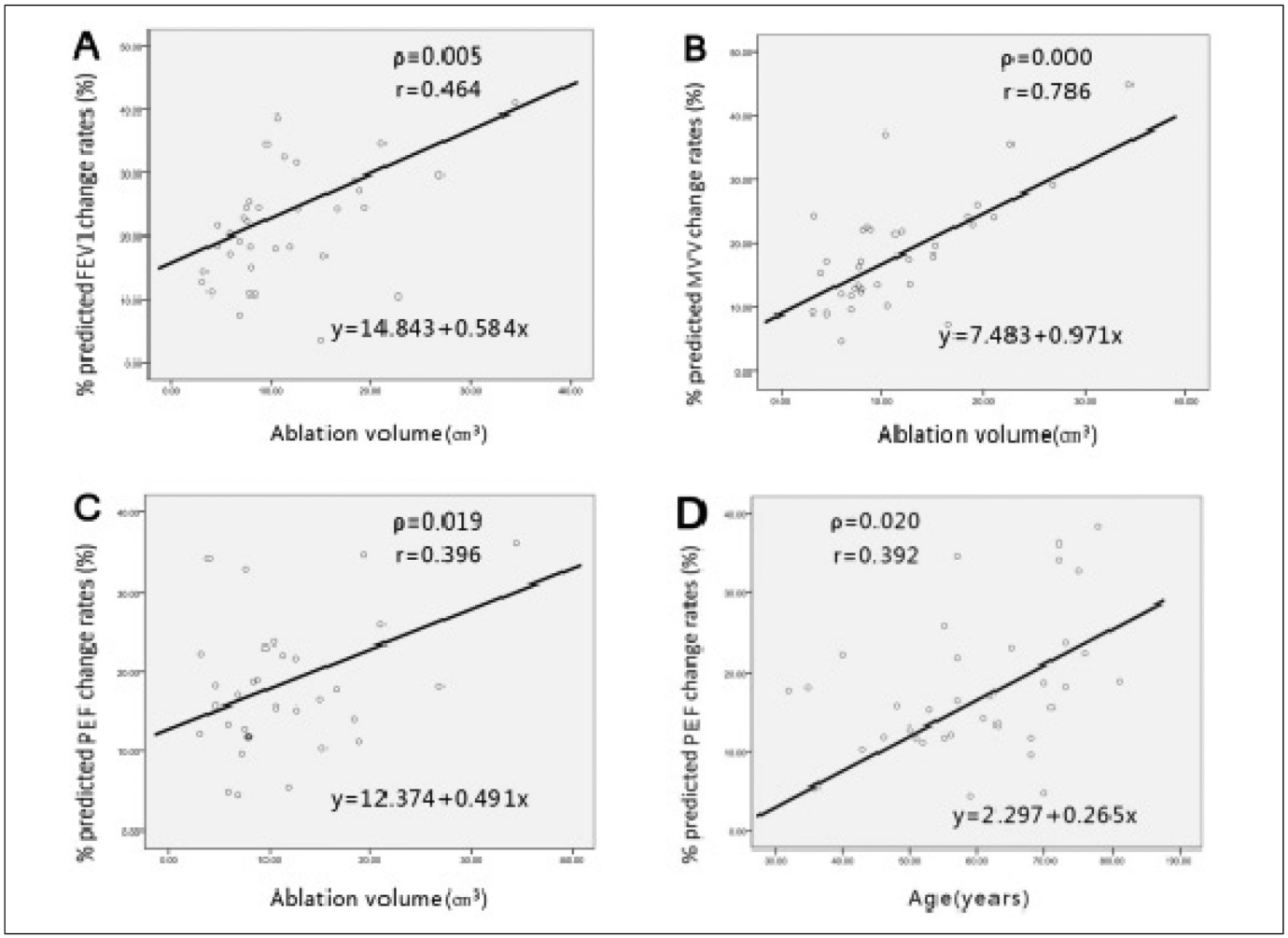

Figure 3. Circles represent patients with the change rates of PFT value. The solid lines are regression lines. r = Spearman's rank correlation coefficient. Scatter plot of ablation volume versus changes in percent predicted FEV1, MVV and PEF(A-C). Scatter plot of age versus changes in percent predicted PEF(D).

apart, remaining under close observation at the time of writing. Our experience on the treatment of SMGNs suggests that up to three GGNs present in the same lobe may be ablated during a single procedure; GGNs present in different lobes should be approached separately to ensure patient safety. Patients presenting with SMGNs and requiring treatment for more than two lesions should undergo MWA with the number of target lesions determined based on PFT findings.

Pneumothorax is the most common complication of MWA and core needle biopsy for lung cancer.[19] In this study, the incidence of pneumothorax was approximately 42.9%. Delayed pneumothorax was relatively more common, which may be owing to the thickness of the ablation probe and the timing of pleural puncture. The incidence of pleural effusion was 31.4%; however, it was absorbed in all patients during the follow-up period. Pneumothorax and pleural effusion may negatively affect PFT findings. There was no difference in PFT findings between patients with and without complications in this study, excluding those with a large amount of pneumothorax or pleural effusion required to perform pleural puncture catheterisation. Intrapulmonary haemorrhage is another common complication after MWA. Haemorrhage may cover the ablation site, making it difficult to confirm that the GGN was completely ablated. CT may be used to confirm whether GGNs have been completely ablated, provided adjustments are made to the grey scale, and the placement of GGN relative to the surrounding structures, such as the trachea or blood vessels, is known.

This study has some limitations and arguments. First, puncture pathology examination of two patients revealed a benign growth rather than lung adenocarcinoma; these patients may have been over-treated. However, benign nodules with signs of malignancy may cause damage to the normal lungs similar to that after thoracoscopic surgery, as assessed on imaging. The risks and benefits of all procedures should be adequately communicated to the patients and their families to prevent conflict. Second, four patients with biopsy findings of lung invasive adenocarcinoma underwent further genetic testing. GGN biopsy findings may not characterise the whole tumour; consequently, biopsy may fail to reveal cases where pulmonary GGNs have progressed to invasive adenocarcinoma. However, genetic testing may aid the diagnosis in such cases and such patients may be at an increased risk of tumour recurrence. However, owing to some biological characteristics of GGNs, including the slow growth,[20] local recurrence of ablated lesions or lymph node metastasis may occur only after many years.[3] In such cases, new molecular or immunological information may already be present, and these must be confirmed through re-biopsy or surgical resection to guide clinical treatment.

Third, this was a retrospective study with a small sample size and no clinical control group. Large studies are required to validate the present findings. Finally, the present follow-up period was insufficient, given the rate of GGN growth. Future studies should involve follow-up periods of 6–10 years to confirm the overall efficacy of MWA. PFT was not performed within 6 months. Follow-up through PFT should be conducted earlier to examine whether the lung function has returned to the preoperative state within 6 months.

Conclusions

Pulmonary function could be significantly impaired in the early period after CT-guided MWA for treating pulmonary GGNs; the degree of impairment might be comparable in patients with and without airway obstruction disease. The decline in FEV1, MVV, and PEF values might be associated with the ablation volume, while the decline in PEF values might also be related to patients' age. Decreased pulmonary function in patients with multiple pulmonary nodules might be more pronounced than that in patients with isolated pulmonary nodule. Most patients recovered their lung function 6 months postoperatively, thus necessitating reoperation.

Acknowledgements

We are grateful to the patients and their families for their collaboration.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The authors disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This research was sponsored by the Fujian provincial health technology project (grant no. 2020QNB049).

Ethics Statement

The study was approved by institutional review board number with 202039.

Informed Consent

Written informed consent was obtained from the patient(s) for their anonymized information to be published in this article.

ORCID iD

Weida Wu https://orcid.org/0000-0003-3380-8922

References

1. Páez Carpio A, Gómez FM, Isus Olivé G, et al. Image-guided percutaneous ablation for the treatment of lung malignancies: current state of the art.[J]. *Insights Imaging.* 2021;12(1):57-57.
2. Howlader N, Noone AM, Krapcho M, et al. SEER Cancer Statistics Review 1975–2016, updated December11, 2019, posted at https://seer.cancer.gov/statistics/reports.html.
3. Onishi H, Shioyama Y, Matsumoto Y, et al. Stereotactic body radiotherapy in patients with lung tumors composed of mainly ground-glass opacity.[J]. *J Radiat Res.* 2020;61(3):426-430.
4. Choi H, Mazzone P. Preoperative evaluation of the patient with lung cancer being considered for lung resection.[J]. *Curr Opin Anaesthesiol.* 2015;28(1):18-25.

5. Liu M, He W, Yang J, et al. Surgical treatment of synchronous multiple primary lung cancers: a retrospective analysis of 122 patients. *J Thorac Dis*. 2016;8(6):1197-1204. doi: 10.21037/jtd.2016.04.46
6. Kadota K, Villena-Vargas J, Yoshizawa A, et al. Prognostic significance of adenocarcinoma in situ, minimally invasive adenocarcinoma, and nonmucinous lepidic predominant invasive adenocarcinoma of the lung in patients with stage I disease. *Am J Surg Pathol*. 2014;38-(4):448-460. doi: 10.1097/PAS.0000000000000134
7. Eguchi T, Kadota K, Park BJ, et al. The new IASLC-ATS-ERS lung adenocarcinoma classification: what the surgeon should know. *Semin Thorac Cardiovasc Surg*. 2014;26(3):210-222. doi: 10.1053/j.semtcvs.2014.09.002
8. Yang X, Ye X, Lin Z, et al. Computed tomography-guided percutaneous microwave ablation for treatment of peripheral ground-glass opacity–lung adenocarcinoma: a pilot study[J]. *J Cancer Res Ther*. 2018;14(4):764-771.
9. Tsurugai Y, Kozuka T, Ishizuka N, et al. Relationship between the consolidation to maximum tumor diameter ratio and outcomes following stereotactic body radiotherapy for stage I non-small-cell lung cancer. *Lung Cancer*. 2016;92:47-52.
10. Miller JI, Grossman GD, Hatcher CR. Pulmonary function test criteria for operability and pulmonary resection.[J]. *Surg Gynecol Obstet*. 1981;153(6):893-895.
11. von Elm E, Altman DG, Egger M, et al. The strengthening the reporting of observational studies in epidemiology (STROBE) statement: guidelines for reporting observational studies. *Ann Intern Med*. 2007;147(8):573-577.
12. Araujo-Filho JA, Menezes RS, Horvat N, et al. Lung radiofrequency ablation: post-procedure imaging patterns and late follow-up. *Eur J Radiol Open*. 2020;7:100276. doi: 10.1016/j.ejro.2020.100276
13. Fu F, Zhang Y, Wen Z, et al. Distinct prognostic factors in patients with stage I non-small cell lung cancer with radiologic part-solid or solid lesions. *J Thorac Oncol*. 2019;14(12):2133-2142. doi: 10.1016/j.jtho.2019.08.002
14. Zhong L, Sun S, Shi JH, et al. Clinical analysis on 113 patients with lung cancer treated by percutaneous CT- guided microwave ablation［J］. *J Thorac Dis*. 2017;9(3):590-597.
15. Li G, Xue M, Chen W, et al. Efficacy and safety of radiofrequency ablation for lung cancers： a systematic review and meta-analysis［J］. *Eur J Radiol*. 2018;100:92-98.
16. Mehta M, Chapman KR, Heffer M, et al. Impact of pulmonary nontuberculous mycobacterial treatment on pulmonary function tests in patients with and without established obstructive lung disease. *Respirology*. 2015;20(6):987-993.
17. Detterbeck FC, Chansky K, Groome P, et al. The IASLC lung cancer staging project: methodology and validation used in the development of proposals for revision of the stage classification of NSCLC in the forthcoming (eighth) edition of the TNM classification of lung cancer. *J Thorac Oncol*. 2016;11(9):1433-1446. doi: 10.1016/j.jtho.2016.06.028[3]
18. Xu G, Fu X. One-stage video-assisted thoracic surgery for bilateral multiple pulmonary nodules[J]. *J Thorac Dis*. 2019;11(2): 535-541.
19. Lee HY, Lee IJ. Assessment of independent risk factors of developing pneumothorax during percutaneous core needle lung biopsy： focus on lesion depth［J］. *Iran J Radiol*, . 2016;13(4):e30929.
20. Chiu CF, Lin YY, Hsu WH, et al. Shorter-time dual-phase FDG PET/CT in characterizing solid or ground-glass nodules based on surgical results. *Clin Imaging*. 2012;36-(5):509-514.