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Survival after thermal ablation versus wedge resection for stage I non-small cell lung cancer < 1 cm and 1 to 2 cm: evidence from the US SEER database

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Abstract

Background This study compared the survival outcomes after thermal ablation versus wedge resection in patients with stage I non-small cell lung cancer (NSCLC) ≤ 2 cm.

Methods Data from the United States (US) National Cancer Institute Surveillance Epidemiology and End Results (SEER) database from 2004 to 2019 were retrospectively analyzed. Patients with stage I NSCLC and lesions ≤ 2 cm who received thermal ablation or wedge resection were included. Patients who received chemotherapy or radiotherapy were excluded. Propensity-score matching (PSM) was applied to balance the baseline characteristics between patients who underwent the two procedures.

Results Univariate and Cox regression analyses were performed to determine the associations between study variables, overall survival (OS), and cancer-specific survival (CSS). After PSM, 328 patients remained for analysis. Multivariable Cox regression analysis revealed, compared to wedge resection, thermal ablation was significantly associated with a greater risk of poor OS (adjusted HR [aHR]: 1.34, 95% CI: 1.09–1.63, $p=0.004$) but not CSS (aHR: 1.28, 95% CI: 0.96–1.71, $p=0.094$). In stratified analyses, no significant differences were observed with respect to OS and CSS between the two procedures regardless of histology and grade. In patients with tumor size 1 to 2 cm, compared to wedge resection, thermal ablation was significantly associated with a higher risk of poor OS (aHR: 1.35, 95% CI: 1.10–1.66, $p=0.004$). In contrast, no significant difference was found on OS and CSS between thermal ablation and wedge resection among those with tumor size < 1 cm.

Conclusions In patients with stage I NSCLC and tumor size < 1 cm, thermal ablation has similar OS and CSS with wedge resection.

Keywords Thermal ablation, Wedge resection, Non-small cell lung cancer (NSCLC), Early stage, Surveillance Epidemiology and End results (SEER)

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Background

Lung cancer, causing an estimated 1.6 million deaths globally each year, is a leading cause of cancer mortality worldwide [1]. Approximately 85% of lung cancers are non-small cell lung cancer (NSCLC), primarily adenocarcinoma and squamous cell carcinoma [2]. Lung cancer incidence increases with age, peaking between 65 and 84 years old [3]. The 5-year survival rate for NSCLC varies greatly by stage, ranging from 68% in stage IB to only 0–10% in stages IVa–IVb [4]. NSCLC often remains undiagnosed until it reaches an advanced stage [5]. Recent advancements in thin-section and low-dose computed tomography (CT) screening have made early-stage lung cancer detection more common, allowing precise assessment of lesion size and locations [6, 7].

Unnecessary removal of healthy lung tissue can markedly affect quality of life [8]. Older patients often benefit from less invasive surgeries that conserve healthy lung tissue. For certain patients, wedge resection, as compared to standard lobectomy, might preserve more lung parenchyma and thus better maintain lung function [9–12]. However, there are concerns that sublobar resection, especially wedge resection, is associated with a higher recurrence rate than lobectomy [13].

Percutaneous thermal ablation is increasingly used in early-stage NSCLC [14]. This method, involving either radiofrequency ablation (RFA) or microwave ablation, heats pathologic lung tissue to lethal temperatures, destroying the tumor and adjacent potentially malignant tissue [15]. An important advantage of thermal ablation is that surrounding tissue incurs minimal damage. A study by Zeng et al. compared stage I NSCLC treatments, finding thermal ablation and wedge resection led to similar overall survival (OS) and cancer-specific survival in patients aged over 75 years [16]. However, the study did not compare the procedures based on tumor size, leaving their effectiveness in smaller tumors uncertain.

To fill this knowledge gap, the purpose of this study was to compare the outcomes of wedge resection and thermal ablation in persons with NSCLC tumor sizes < 2 cm using data from a US national database.

Methods

Study design and data source

Data from the US National Cancer Institute (NCI) Surveillance Epidemiology and End Results (SEER) database from 2004 to 2019 were retrospectively reviewed. The SEER project was begun in 1973 in the US as a population-based registry of cancer and involves about one-tenth of the US population. The patient sample of this study was selected from de-identified patients in 17 SEER registries (SEER*Stat Database: Incidence – SEER Research Plus Data, 17 Registries, Nov 2021 Sub (2000–2019)). The data include no personal identifiers,

and were submitted to the NCI electronically, and thus allowing the data to be used in relevant medical research [17, 18]. Because this study analyzed secondary data from the publicly accessible database, no patients were involved directly. The study was approved by the local Ethics Committee and Institutional Review Board to use de-identified data, including patient clinicopathological features, tumor histology, tumor size, timing, and type of first-course treatment, and outcomes.

Patient selection criteria

The inclusion criteria were: (1) patients with NSCLC identified using tumor histology ICD-O-3 codes 8010, 8012, 8013, 8020, 8046, 8050–8052, 8070–8078, 8140, 8141, 8143, 8147, 8250–8255, 8260, 8310, 8430, 8480, 8481, 8490, 8560, and 8570–8575; (2) the first cancer of life; (3) tumor size ≤ 2 cm; and (4) underwent thermal ablation or wedge resection. In the SEER database, thermal ablation includes laser ablation, cautery, and fulguration. Exclusion criteria were: (1) missing OS or CCS information; (2) patients survived < 1 month after the procedure was performed; (3) unknown T, N, or M stage, or T0 and Tis stage; (4) with M1 stage disease; (5) lymph node-positive; and (6) patients received chemotherapy or radiotherapy. Eligible patients were divided into a thermal ablation group and a wedge resection group.

Study variables and endpoints

The study endpoints were OS and CSS. Demographic data included age at diagnosis, sex, race/ethnicity (white, black, or other), year of diagnosis (2004–2009 and 2010–2019), and marital status. The tumor-related characteristics included tumor side (left or right), site (upper lobe, middle lobe, lower lobe, unspecified), tumor size (< 1 cm or 1 to 2 cm), tumor histology (squamous cell carcinoma, adenocarcinoma, or other), and tumor grade (I/II, III/IV, or unknown).

Statistical analysis

Categorical data were presented as number (n) and percentage (%), and compared with the chi-squared test or Fisher's exact test, as appropriate. Continuous data without a normal distribution were presented as the median and interquartile range (IQR), and compared with the Wilcoxon rank sum test. Propensity score matching (PSM) was performed using 1:1 nearest neighbor matching to obtain matched pairs between the thermal ablation and wedge resection groups. Variables having a value of $p < 0.001$ between the comparison groups were used in PSM. Cox proportional hazard regression analyses were conducted to estimate the hazard ratio (HR) and 95% confidence interval (CI) of the associations between study variables, OS, and CSS. Variables with a value of $p < 0.05$ in the univariate analysis were entered into the

multivariate analyses. Kaplan–Meier survival curves were plotted according to the treatment modality. All analyses were 2-sided, and a value of $p < 0.05$ was regarded as statistically significant. Data management and statistical analyses were performed using SAS version 9.4 software (SAS Institute, Inc.).

Results

The flow diagram of the patient selection process is depicted in Fig. 1. Overall, there were 6,414,571 patients in the SEER database from 2004 to 2019. Of this population, 781,181 were diagnosed with a malignant lesion

of the bronchus and lung. Further examination of the data retrieved 7,556 patients with NSCLC and a tumor size ≤ 2 cm, received thermal ablation or wedge resection as the primary treatment. After excluding patients with missing survival data, survival < 1 month, T0/Tis or unknown T, N, or M stage, metastatic disease, lymph node-positive disease, or had received chemotherapy or radiotherapy, 5,260 patients were identified and included in the analysis. Of the patients, 3.2% received thermal ablation. After 1:1 PSM, there remained 328 patients in the analytic sample (Fig. 1).

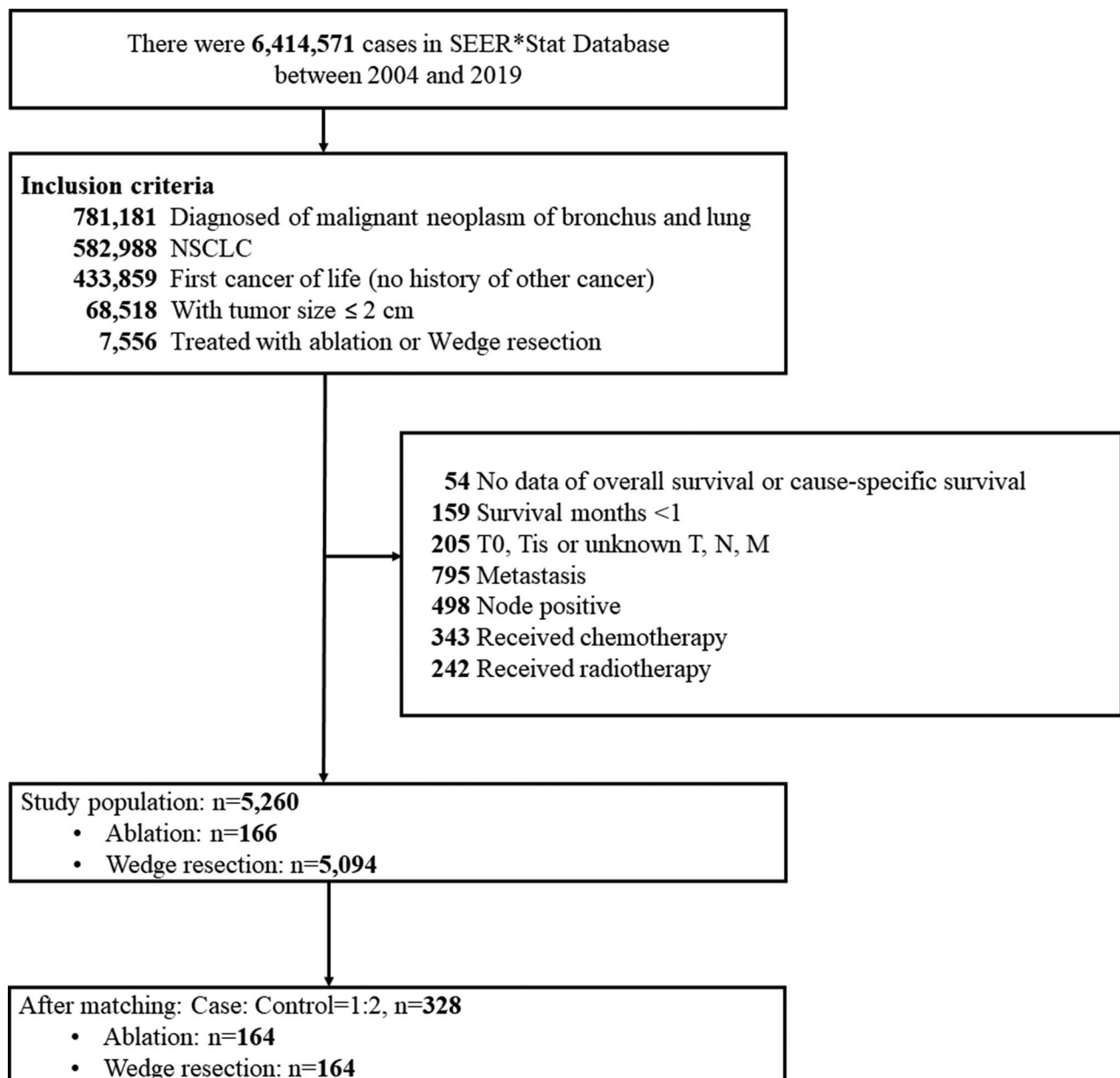


Fig. 1 Flow Diagram of study selection process

Characteristics of patients who received thermal ablation and wedge resection

Patient baseline characteristics are summarized in Table 1. The median age of all patients was 70 years,

and more than half of the patients were females (58.6%). The majority of patients were White (86.9%), diagnosed during the period from 2010 to 2019 (65.7%), and were married (55.8%). More than half of the patients had an

Table 1 Baseline characteristics of patients with stage I NSCLC ≤ 2 cm

Characteristics	Before PSM			<i>p</i>	After 1:1 PSM			<i>p</i>
	Total (<i>N</i> = 5,260)	Ablation (<i>n</i> = 166)	Wedge resection (<i>n</i> = 5,094)		Total (<i>n</i> = 328)	Ablation (<i>n</i> = 164)	Wedge resection (<i>n</i> = 164)	
Demography								
Age, years				< 0.001				1.000
< 60	70 (63–76)	73 (67–81)	70 (63–76)	< 0.001	30 (9.1)	15 (9.1)	15 (9.1)	
60–64	810 (15.4)	15 (9.0)	795 (15.6)		33 (10.1)	16 (9.8)	17 (10.4)	
65–69	686 (13.0)	16 (9.6)	670 (13.2)		47 (14.3)	24 (14.6)	23 (14.0)	
70–74	1035 (19.7)	24 (14.5)	1011 (19.8)		72 (22.0)	36 (22.0)	36 (22.0)	
75–79	1101 (20.9)	36 (21.7)	1065 (20.9)		52 (15.9)	26 (15.9)	26 (15.9)	
≥ 80	906 (17.2)	26 (15.7)	880 (17.3)		94 (28.7)	47 (28.7)	47 (28.7)	
Sex				0.713				0.654
Male	2177 (41.4)	71 (42.8)	2106 (41.3)		136 (41.5)	70 (42.7)	66 (40.2)	
Female	3083 (58.6)	95 (57.2)	2988 (58.7)		192 (58.5)	94 (57.3)	98 (59.8)	
Race				0.719				0.824
White	4555 (86.9)	142 (86.1)	4413 (87.0)		284 (86.9)	140 (85.9)	144 (87.8)	
Black	397 (7.6)	15 (9.1)	382 (7.5)		27 (8.3)	15 (9.2)	12 (7.3)	
Other	288 (5.5)	8 (4.8)	280 (5.5)		16 (4.9)	8 (4.9)	8 (4.9)	
Unknown	20	1	19		1	1	0	
Year of diagnosis				< 0.001				0.912
2004 to 2009	1804 (34.3)	87 (52.4)	1717 (33.7)		169 (51.5)	85 (51.8)	84 (51.2)	
2010 to 2019	3456 (65.7)	79 (47.6)	3377 (66.3)		159 (48.5)	79 (48.2)	80 (48.8)	
Marital status				0.020				0.273
Single	593 (11.8)	21 (13.0)	572 (11.7)		34 (10.7)	21 (13.2)	13 (8.2)	
Married	2814 (55.8)	73 (45.3)	2741 (56.1)		154 (48.6)	72 (45.3)	82 (51.9)	
Separated/divorced/widowed	1637 (32.5)	67 (41.6)	1570 (32.2)		129 (40.7)	66 (41.5)	63 (39.9)	
Unknown	216	5	211		11	5	6	
Tumor-related								
Histology				< 0.001				1.000
Squamous cell carcinoma	1284 (24.4)	44 (26.5)	1240 (24.3)		88 (26.8)	44 (26.8)	44 (26.8)	
Adenocarcinoma	3692 (70.2)	89 (53.6)	3603 (70.7)		178 (54.3)	89 (54.3)	89 (54.3)	
Other	284 (5.4)	33 (19.9)	251 (4.9)		62 (18.9)	31 (18.9)	31 (18.9)	
Grade				< 0.001				0.989
I / II	3345 (63.6)	43 (25.9)	3302 (64.8)		86 (26.2)	43 (26.2)	43 (26.2)	
III / IV	1352 (25.7)	29 (17.5)	1323 (26.0)		59 (18.0)	29 (17.7)	30 (18.3)	
Unspecified	563 (10.7)	94 (56.6)	469 (9.2)		183 (55.8)	92 (56.1)	91 (55.5)	
Tumor size, cm				0.005				0.659
< 1	776 (14.8)	12 (7.2)	764 (15.0)		22 (6.7)	12 (7.3)	10 (6.1)	
1 to 2	4484 (85.2)	154 (92.8)	4330 (85.0)		306 (93.3)	152 (92.7)	154 (93.9)	
Tumor side				0.143				0.058
Right	2972 (56.5)	103 (62.0)	2869 (56.3)		185 (56.4)	101 (61.6)	84 (51.2)	
Left	2288 (43.5)	63 (38.0)	2225 (43.7)		143 (43.6)	63 (38.4)	80 (48.8)	
Tumor Site				0.341				0.511
Upper lobe	3363 (64.8)	97 (59.9)	3266 (64.9)		202 (62.9)	96 (60.0)	106 (65.8)	
Lower lobe	1618 (31.2)	59 (36.4)	1559 (31.0)		109 (34.0)	58 (36.3)	51 (31.7)	
Middle lobe	210 (4.0)	6 (3.7)	204 (4.1)		10 (3.1)	6 (3.8)	4 (2.5)	
Unspecified	69	4	65		7	4	3	

Categorical data are presented as number (%), and continuous data are presented as median and interquartile range (IQR). Significant results are shown in bold PSM, propensity-score matching; NSCLC, non-small cell lung cancer

adenocarcinoma (70.2%), a grade I/II (63.6%) tumor, a tumor size of 1 to 2 cm (85.2%), and the tumor located in an upper lobe (64.8%).

As compared to patients who received wedge resection, those who received thermal ablation were older (median 73 vs. 70 years), had lower proportion who were diagnosed during the period from 2010 to 2019 (47.6% vs. 66.3%, $p < 0.001$), had a lower proportion who were married (45.3% vs. 56.1%, $p = 0.020$), a lower percentage of adenocarcinoma (53.6% vs. 70.7%, $p < 0.001$), and a lower percentage of tumor size < 1 cm (7.2% vs. 15.0%, $p = 0.005$). However, patients who received thermal ablation had a higher proportion of tumors with an unspecified grade (56.6% vs. 9.2%, $p < 0.001$). After PSM, differences in baseline characteristics between the two groups were gone (Table 1).

Association between thermal ablation vs. wedge resection, OS, and CSS after PSM

As shown in Fig. 2, patients who received thermal ablation had a poorer OS and CSS than those who received wedge resection (both log-rank $p < 0.001$).

Results of the univariate and multivariable Cox regression analysis of OS and CSS after PSM are shown in Table 2. After adjusting for relevant confounders, compared to wedge resection, thermal ablation was significantly associated with a greater risk of poor OS (adjusted HR [aHR]: 1.34, 95% CI: 1.09–1.63, $p = 0.004$) but not CSS (aHR: 1.28, 95% CI: 0.96–1.71, $p = 0.094$) (Table 2).

Stratified association between thermal ablation versus wedge resection, OS, and CSS

Results of multivariable Cox regression analyses of OS and CSS stratified by histology, tumor grade, and tumor size are summarized in Table 3. After adjustments, CSS

was not significantly different between thermal ablation and wedge resection among all subgroups. In addition, OS was not significantly different between thermal ablation and wedge resection when stratified by histology or grade. Among patients with a tumor size < 1 cm, there were also no significant differences in OS between the two procedures; however, among patients with a tumor size 1 to 2 cm, thermal ablation was associated with a significantly higher risk of poor OS (aHR: 1.35, 95% CI: 1.10–1.66, $p = 0.004$) (Table 3).

Discussion

This study investigated whether thermal ablation had an equivalent prognostic impact compared to wedge resection in patients with < 2 cm stage I NSCLC. The analyses revealed that patients who received thermal ablation had a higher risk of poor OS than wedge resection. However, according to the stratified analysis, OS and OSS between thermal ablation and wedge resection appear similar in any histology or grade. Finally, when stratified by tumor size, among patients with tumor size < 1 cm, no difference was found in OS and CSS between the two procedures. However, in patients with tumor size 1 to 2 cm, thermal ablation appears to have a higher risk of poor OS.

When NSCLC is diagnosed at an early stage during chest CT screening, sublobar resection is used as an alternative surgical strategy [19]. Segmentectomy shows better survival than wedge resection for tumors < 2 cm, with no difference for ≤ 1 cm tumors [20]. Sublobar resection matches lobectomy in survival and improves pulmonary function in peripheral stage IA NSCLC ≤ 2 cm [21]. Another study documented that for patients with NSCLC and peripheral tumors ≤ 2 cm, it is contentious whether segmentectomy or wedge resection is preferable [22]. Suzuki et al. find no significant difference in

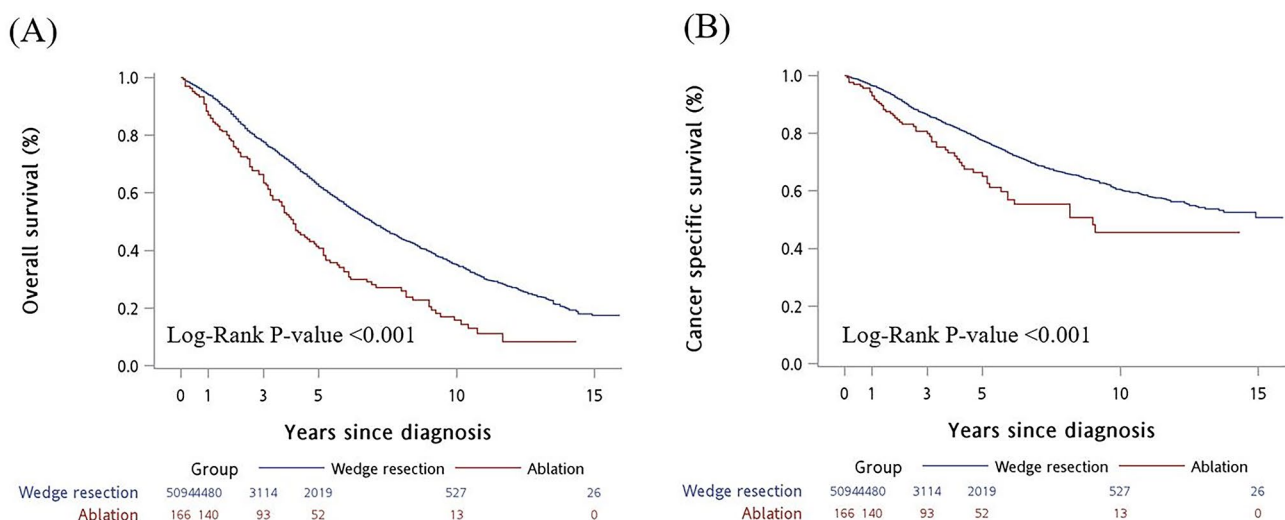


Fig. 2 Kaplan–Meier survival curves were plotted according to treatment modality. **(A)** Overall survival. **(B)** Cancer specific survival

Table 2 Cox regression analysis of OS and CSS of patients with stage I NSCLC ≤ 2 cm, after PSM

Study variables	OS			CSS		
	HR (95% CI)	p	aHR (95% CI)	HR (95% CI)	p	aHR (95% CI)
Ablation vs. wedge resection	1.82 (1.51–2.20)	< 0.001	1.34 (1.09–1.63)	1.63 (1.24–2.15)	< 0.001	1.28 (0.96–1.71)
Age, years (vs. < 60)						
60–64	1.52 (1.28–1.80)	< 0.001	1.44 (1.21–1.72)	1.51 (1.20–1.90)	< 0.001	1.49 (1.18–1.88)
65–69	1.51 (1.29–1.77)	< 0.001	1.46 (1.24–1.72)	1.46 (1.18–1.80)	< 0.001	1.47 (1.18–1.82)
70–74	1.98 (1.70–2.30)	< 0.001	1.85 (1.58–2.17)	1.63 (1.33–2.01)	< 0.001	1.64 (1.32–2.03)
75–79	2.59 (2.23–3.02)	< 0.001	2.34 (1.99–2.74)	2.09 (1.69–2.58)	< 0.001	1.99 (1.60–2.47)
≥ 80	3.23 (2.77–3.76)	< 0.001	2.89 (2.46–3.40)	2.44 (1.97–3.02)	< 0.001	2.27 (1.81–2.84)
Sex (vs. female)						
Male	1.41 (1.30–1.52)	< 0.001	1.44 (1.32–1.57)	1.32 (1.18–1.47)	< 0.001	1.36 (1.20–1.53)
Race (vs. White)						
Black	0.89 (0.76–1.04)	0.130	0.94 (0.80–1.10)	1.13 (0.93–1.38)	0.221	1.19 (0.97–1.46)
Other	0.58 (0.46–0.71)	< 0.001	0.63 (0.51–0.79)	0.64 (0.47–0.86)	0.003	0.72 (0.53–0.97)
Year of diagnosis (vs. 2004 to 2009)						
2010 to 2019	0.76 (0.69–0.82)	< 0.001	0.83 (0.76–0.90)	0.69 (0.61–0.78)	< 0.001	0.76 (0.67–0.85)
Marital status (vs. single)						
Married	1.03 (0.90–1.18)	0.666	0.86 (0.75–0.99)	0.92 (0.76–1.10)	0.363	0.81 (0.67–0.98)
Separated/divorced/widowed	1.30 (1.13–1.50)	< 0.001	1.01 (0.87–1.17)	1.21 (1.00–1.47)	0.051	1.03 (0.84–1.25)
Histology (vs. squamous cell carcinoma)						
Adenocarcinoma	0.61 (0.56–0.67)	< 0.001	0.76 (0.69–0.83)	0.77 (0.67–0.88)	< 0.001	0.96 (0.83–1.10)
Others	1.13 (0.97–1.32)	0.112	1.06 (0.90–1.24)	1.58 (1.29–1.95)	< 0.001	1.42 (1.15–1.77)
Grade (vs. I / II)						
III / IV	1.50 (1.37–1.63)	< 0.001	1.28 (1.17–1.41)	1.59 (1.41–1.80)	< 0.001	1.37 (1.20–1.56)
Unspecified	1.18 (1.03–1.35)	0.017	1.13 (0.98–1.30)	1.17 (0.97–1.42)	0.109	1.04 (0.85–1.28)
Tumor size, cm (vs. < 1)						
1 to 2	1.44 (1.27–1.64)	< 0.001	1.21 (1.07–1.38)	1.48 (1.24–1.77)	< 0.001	1.23 (1.03–1.48)
Tumor side (vs. right)						
Left	1.06 (0.98–1.15)	0.153		1.03 (0.92–1.15)	0.633	
Tumor Site (vs. upper lobe)						
Lower lobe	0.98 (0.90–1.07)	0.719		1.07 (0.94–1.21)	0.299	
Middle lobe	0.98 (0.80–1.19)	0.817		1.18 (0.91–1.53)	0.207	

Significant results are shown in bold

NSCLC, non-small cell lung cancer; aHR, adjusted HR; CI, confidence interval; CSS, cancer-specific survival; HR, hazard ratio; OS, overall survival; PSM, propensity-score matching

Table 3 Stratified Cox regression analysis of OS and CSS in patients with stage I NSCLC ≤ 2 cm, after PSM

	Total	Thermal ablation vs. wedge resection					
		OS			CSS		
		Death	aHR (95% CI)	<i>p</i>	Event	aHR (95% CI)	<i>p</i>
Histology^a							
Adenocarcinoma	1236	696	1.34 (0.93–1.92)	0.117	302	1.47 (0.84–2.58)	0.176
Squamous cell carcinoma	3520	1470	1.25 (0.93–1.68)	0.134	782	0.89 (0.55–1.43)	0.623
Grade^b							
I / II	3181	1355	0.99 (0.66–1.49)	0.960	677	0.86 (0.46–1.61)	0.636
III / IV	1311	780	1.21 (0.80–1.83)	0.358	413	1.36 (0.79–2.33)	0.270
Tumor size, cm^c							
< 1	733	266	1.63 (0.64–4.17)	0.310	133	2.06 (0.59–7.12)	0.256
1 to 2	4298	2116	1.35 (1.10–1.66)	0.004	1076	1.29 (0.96–1.74)	0.090

NSCLC, non-small cell lung cancer; aHR, adjusted HR; CI, confidence interval; CSS, cancer-specific survival; HR, hazard ratio; OS, overall survival; PSM, propensity score matching

^a Adjusted for age in category, sex, race, year, marital status, grade, and tumor size

^b Adjusted for age in category, sex, race, year, marital status, histology, and tumor size

^c Adjusted for age in category, sex, race, year, marital status, histology, and grade

postoperative complications between segmentectomy and lobectomy, except for more air leakage in segmentectomy [23].

Although sublobar resections were developed to limit the functional impairments associated with lobectomy in early NSCLC, approximately 20% of patients are still ineligible for surgical procedures due to relatively severe comorbidities [24]. For instance, many individuals are ineligible for surgery because of advanced age or the presence of comorbidities such as pulmonary insufficiency or atherosclerosis [24]. An important advantage of thermal ablation over surgical resection is that it can destroy lung tumors by locally heating the lung parenchyma, while avoiding damage to surrounding normal lung tissue [25, 26]. Nevertheless, whether thermal ablation has equivalent long-term survival outcomes to wedge resection in early NSCLC is unclear and needs substantive evidence.

Using the SEER data from 2004 to 2019, our analytic results indicate that thermal ablation may be the best option for individuals with stage I NSCLC with a tumor size of 1 cm, since it is less invasive and led to no significantly different OS and CSS compared to wedge resection. As mentioned above, Zeng et al., querying the same database but with a shorter follow-up than our study, assessed the prognostic impact of thermal ablation versus wedge resection for stage I NSCLC with mixed tumor sizes [16]. It should be noted that no analysis was performed according to different tumor sizes in their report. Moreover, the result of their study was likely biased due to the lack of exclusion of chemotherapy and radiotherapy, thus limited interpretations.

The use of thermal ablation as an alternate therapy for patients who are not surgical candidates has increased because only one-third of stage I NSCLC patients are eligible for curative surgical resection [27]. It was previously believed that patients who received thermal

ablation alone have a greater risk of local tumor recurrence because of insufficient ablation margins [28]. Inconsistent with our findings, a meta-analysis compared the relative safety and efficacy of thermal ablation and sublobar resection for treating stage I NSCLC and indicated that ablation was associated with shorter survival compared to surgery [29]. With regard to safety, it has been reported that thermal ablation for NSCLC, via percutaneous or bronchoscopic methods, can lead to complications such as pneumothorax, pleural effusion, pneumonia, and, rarely significant hemorrhage. However, bronchoscopic approaches generally show a safer profile with fewer adverse events [30, 31]. RFA shares similar complications, but these are typically temporary and manageable with appropriate treatments [32].

Each technology for thermal ablation has a benefit or detriment [33]. A previous single-center, retrospective study by Huang et al. evaluated 10-year OS, progression-free survival (PFS), and local control rates in patients with inoperable stage IA NSCLC who underwent CT-guided RFA [34]. The results showed that CT-guided RFA performed by a thoracic surgeon is a feasible, safe, and effective procedure for inoperable high-risk early-stage NSCLC, and should be considered as an alternative to sublobar resection. A recent study by Li et al. indicated that RFA, compared to no treatment, has better survival in patients with unresected stage IA NSCLC [35]. Another study by Streitparth et al. also highlighted the feasibility and safety of RFA in early, NSCLC [32].

Strength and limitations

The study is inherently limited by its retrospective and observational nature. The SEER database lacks data on complications, cardiopulmonary function, performance status, and recurrence, precluding the incorporation of these into the analysis. In addition, SEER does not make

it possible to know the ablation energy used, locations of tumors (central or peripheral), or patients' baseline comorbidities. Furthermore, the notable low number of ablation cases across the entire population, as well as within specific subgroups analyzed, while potentially reflecting real-world scenarios, could pose a challenge to the reliability of the analytic results. Despite the above-mentioned limitations, the present analyses utilized the latest data in a national cohort, and are likely to be robust under the implementation of PSM and multiple stratified analyses.

Conclusions

For patients with stage I NSCLC and a tumor size of 1 to 2 cm, thermal ablation is associated with a higher risk of poor OS than wedge resection; however, in patients who had a tumor size <1 cm, thermal ablation, and wedge resection show no difference on OS and CSS. Future prospective studies are still warranted to confirm the prognostic role of thermal ablation in this specific patient subgroup.

Abbreviations

NSCLC	Non-small cell lung cancer
US	United States
SEER	Surveillance Epidemiology and End Results
OS	Overall survival
CSS	Cancer specific survival
CT	Computed tomography
HR	Hazard ratio

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Author contributions

Shelly Yim: Conception and design; Drafting of the manuscript; Critical revision of the manuscript; guarantor of integrity of the entire study; literature research. Wei Chan Lin: Conception and design; Drafting of the manuscript; definition of intellectual content. Jung Sen Liu: Analysis and interpretation of data; Drafting of the manuscript; literature research. Ming Hong Yen: Conception and design; Acquisition of data; Analysis and interpretation of data; Critical revision of the manuscript; statistical analysis; literature research; Administrative, technical or material support; Supervision All authors read and approved the final manuscript.

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Data availability

The data generated in the present study may be requested from the corresponding author.

Declarations

Ethics approval and consent to participate

Because this study analyzed secondary data from the publicly accessible database, no patients were involved directly. The study was approved by the local Ethics Committee and Institutional Review Board to use de-identified data, including patient clinicopathological features, tumor histology, tumor size, timing, and type of the first course treatment, and outcomes.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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