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# Wedge Resection versus Thermal Ablation for Stage IA Non-Small Cell Lung Cancer (≤ 3cm): A Systematic Review and Meta-Analysis

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**Research Article**

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## Abstract

**Background**: The comparative effectiveness of wedge resection versus thermal ablation for stage IA non-small cell lung cancer (NSCLC) (≤ 3cm) remains unclear, as previous meta-analyses have included heterogeneous surgical comparators and mixed-stage populations. This meta-analysis aimed to compare long-term oncologic outcomes and perioperative profiles between wedge resection and thermal ablation specifically in stage IA NSCLC.

**Methods**: We systematically searched PubMed, Cochrane Library, Web of Science, CNKI, and Wanfang databases from inception to March 2026 for retrospective cohort studies comparing wedge resection with thermal ablation (radiofrequency or microwave) in stage IA NSCLC. The primary outcome was 5-year overall survival (OS), with secondary outcomes including hospital stay and costs. Pooled risk ratios (RR) with 95% confidence intervals (CI) were calculated using random-effects models, with sensitivity analyses performed to assess robustness.

**Results**: Three retrospective cohort studies were included in the quantitative synthesis. The primary meta-analysis included two studies (79 ablation patients, 72 surgery patients) restricted to stage IA tumors and pure wedge resection comparators. The pooled RR for 5-year mortality was 1.47 (95% CI: 0.96–2.24; P = 0.07), with no heterogeneity ($I^2$ = 0%). A sensitivity analysis including a third study with mixed IA/IB and 3-year OS data yielded a pooled RR of 1.63 (95% CI: 1.12–2.38; P = 0.01; $I^2$ = 0%). Consistent with these findings, a single propensity-matched study reported a significantly lower risk of progression or death for wedge resection versus ablation (HR = 2.24; 95% CI: 1.31–3.83; P = 0.003). Thermal ablation was consistently associated with shorter hospital stays (0–2 vs. 5–6 days) and substantially lower costs.

**Conclusions**: Among propensity-matched patients with stage IA NSCLC (≤3 cm), wedge resection offers a consistent survival benefit trend over thermal ablation, with zero heterogeneity across primary and sensitivity analyses. Ablation remains a reasonable alternative for medically inoperable patients, given its shorter recovery time and its markedly lower costs. These findings underscore the importance of patient selection and multidisciplinary decision-making, as well as the need for future studies to report outcomes separately by tumor size and T stage.


## 1. Introduction

Lung cancer remains the leading cause of cancer-related morbidity and mortality worldwide, with non-small cell lung cancer (NSCLC) accounting for approximately 85% of all cases[1]. The widespread implementation of low-dose computed tomography (LDCT) screening has substantially increased the detection of early-stage disease, resulting in a growing population of patients diagnosed with potentially curable stage IA NSCLC (tumors ≤ 3 cm)[2].

For medically operable patients with stage IA NSCLC, wedge resection has been increasingly utilized as a parenchyma-sparing surgical option, particularly for peripheral small tumors, offering comparable outcomes to more extensive resections in carefully selected individuals[3, 4]. Compared with lobectomy or segmentectomy, wedge resection represents the least extensive surgical resection, making it the most clinically relevant comparator when evaluating the oncologic efficacy of thermal ablation—a non-surgical, tissue-sparing modality.

Despite surgical progress, a considerable subset of patients are deemed inoperable due to advanced age, compromised cardiopulmonary function, or significant comorbidities. For this population, effective and less invasive alternatives are urgently needed. Image-guided thermal ablation—encompassing radiofrequency ablation (RFA) and microwave ablation (MWA)—has emerged as a viable option. By inducing tumor necrosis via extreme temperatures, these techniques offer reduced procedural trauma, faster recovery, repeatability, and greater preservation of pulmonary reserve[5]. Accumulating evidence indicates that ablation can yield favorable local control and meaningful long-term survival in patients unfit for surgery[6].

Numerous retrospective studies and prior meta-analyses have compared surgical resection with thermal ablation for stage I NSCLC, yet conclusions remain inconsistent. While several reports suggest a survival advantage with surgery[7], others demonstrate comparable outcomes in strictly defined subgroups, such as patients with tumors ≤ 2 cm or elderly cohorts[8, 9]. However, most of these analyses have included heterogeneous surgical comparators (lobectomy, segmentectomy, and wedge resection) and have not consistently restricted comparisons to the most clinically analogous groups.

To date, no meta-analysis has specifically compared wedge resection with thermal ablation in a homogeneous stage IA (≤ 3 cm) population, while excluding more extensive resections that introduce confounding by indication. Given that wedge resection and thermal ablation share similar parenchyma-sparing goals but differ fundamentally in mechanism and oncologic radicality, a head-to-head comparison in this specific subgroup is critical for informing clinical decision-making. Therefore, the primary aim of this work is to systematically synthesize available evidence comparing the efficacy and safety of wedge resection versus thermal ablation for stage IA NSCLC (≤ 3 cm), providing evidence-based guidance for multidisciplinary treatment selection, particularly for patients who are marginal surgical candidates.

# 2. Methods

*2.1 Study Design and Registration*

This study was conducted and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [10]. This study has not been registered in PROSPERO.

*2.2 Search Strategy*

We systematically searched PubMed, Cochrane Library, Web of Science, CNKI, and Wanfang databases from their inception to March 2026. The search used a combination of MeSH terms and free-text words.

**English Search Strategy (exemplified by PubMed):**

((("Lung Neoplasms/surgery"[Mesh] OR "Lung Neoplasms/therapy"[Mesh]))

AND (("Catheter Ablation"[Mesh]) OR ablation[Title/Abstract] OR "thermal ablation"[Title/Abstract]))

AND ((surgery[Title/Abstract] OR resection[Title/Abstract] OR wedge[Title/Abstract] OR sublobar[Title/Abstract]))

AND ((survival[Title/Abstract] OR recurrence[Title/Abstract] OR prognosis[Title/Abstract] OR outcomes[Title/Abstract] OR mortality[Title/Abstract]))

**Initial Search Results**: The initial search yielded 403 records from PubMed. The search of Chinese databases (CNKI and Wanfang) identified no additional studies beyond those retrieved from the English databases. After removing duplicates using Zotero, 232 records remained for further screening.

*2.3 Inclusion and Exclusion Criteria*

2.3.1 Inclusion Criteria

- **Participants**: Patients with pathologically confirmed primary non-small cell lung cancer (NSCLC), stage IA (T1N0M0, tumor size ≤3 cm). No restriction on tumor location was applied. No restrictions on age, sex, or race.
- **Interventions**: Image-guided ablation (IGA), including radiofrequency ablation (RFA), microwave ablation (MWA).
- **Comparators**: Surgical resection, restricted to wedge resection (segmental resection and lobectomy were excluded to minimize clinical heterogeneity).

- **Outcomes**: Primary outcomes included overall survival (OS), cancer-specific survival (CSS), or disease-free survival (DFS). Secondary outcomes included local recurrence rate, distant metastasis rate, complication rate, and length of hospital stay.
- **Study designs**: Randomized controlled trials (RCTs) or cohort studies (both prospective and retrospective).

2.3.2 Exclusion Criteria

- Patients with other malignancies, distant metastasis, or lymph node metastasis.
- Studies involving combined therapies (e.g., ablation combined with radiotherapy or chemotherapy).
- Duplicate publications, case reports, reviews, meta-analyses, conference abstracts, animal studies.
- Studies with insufficient or non-extractable data.

*2.4 Study Selection and Data Extraction*

A standardized data extraction form was used to collect the following information:

- **Study Characteristics**: First author, publication year, country, study design.
- **Patient Characteristics**: Sample size, age, sex, tumor size, tumor location, pathological type, clinical stage.
- **Intervention and Comparison Details**: Ablation modality (RFA/MWA/cryoablation), surgical procedure (wedge resection; lobectomy and segmentectomy were not included).
- **Outcomes**: For dichotomous outcomes, the number of events and total patients in each arm were extracted to calculate risk ratios (RR). Hazard ratios, when reported, were recorded but not used in the primary analysis.
- **Follow-up**: Median follow-up duration.

*2.5 Quality Assessment*

The Newcastle-Ottawa Scale (NOS) was used to assess the quality of cohort studies (Wells GA, Shea B, O'Connell D, *et al*. The Newcastle-Ottawa Scale (NOS) for assessing the quality of nonrandomized studies in meta-analyses. Available from: https://www.ohri.ca/programs/clinical_epidemiology/oxford.asp). The NOS has a maximum score of 9, and studies with a score of ≥7 were considered high quality.

*2.6 Statistical Analysis*

Meta-analyses were performed using RevMan software (version5.4, The Cochrane Collaboration, Copenhagen, Denmark).

- **Effect Measures**: For dichotomous outcomes (e.g., 5-year overall survival, local recurrence, and complications), pooled risk ratios (RR) with 95% CIs were calculated. For continuous outcomes (e.g., length of hospital stay), pooled mean differences (MDs) with 95% CIs were calculated.
- **Heterogeneity Assessment**: Statistical heterogeneity was assessed using the Q test and the $I^2$ statistic, with $I^2 > 50\%$ considered substantial heterogeneity. Given the clinical and methodological variations across the included studies, we pre-specified the use of a random-effects model (DerSimonian-Laird) for all pooled analyses to provide a conservative estimate.
- **Subgroup Analyses**: Subgroup analyses were planned based on ablation modality (radiofrequency vs. microwave) where data permitted. Due to the limited number of included studies, formal subgroup analyses were not performed.
- **Sensitivity Analysis**: Sensitivity analyses were performed by sequentially omitting individual studies to assess the robustness of the pooled results.
- **Publication Bias**: For outcomes with at least 10 included studies, publication bias was assessed qualitatively using funnel plots and quantitatively using Egger's test[11]. Asymmetry in the funnel plot or a $P<0.05$*P*$<0.05$ on Egger's test

suggested potential publication bias.

*2.7 Quality of Evidence*

The Grading of Recommendations, Assessment, Development, and Evaluation (GRADE) system was used to rate the quality of evidence for each outcome[12]. The quality of evidence was graded as high, moderate, low, or very low.

*2.8 Data Availability Statement*

All data analyzed in this study are derived from previously published research articles, which are cited in the references. No new data were created or deposited in public repositories.

*2.9 Institutional Review Board Statement*

Not applicable. This study is a systematic review and meta-analysis of previously published literature and did not involve direct human or animal subjects.

*2.10 Informed Consent Statement*

Not applicable. This study did not involve direct interaction with human subjects.

*2.11 Generative AI Disclosure*

No generative artificial intelligence tools were used in the study design, data collection, analysis, interpretation, or writing of this manuscript.

# 3. Results

*3.1. Study Selection*

After database search and screening, three retrospective cohort studies were included in the quantitative synthesis. The primary meta-analysis included two studies[13,14] comprising 79 ablation and 72 surgery patients, with an additional study[15] (56 ablation, 28 surgery) included only in the sensitivity analysis. The study selection process is presented in Figure 1.

*3.2. Study Characteristics*

The baseline characteristics of the included studies are summarized in Table 1. A total of three retrospective cohort studies were included in the quantitative synthesis. The primary meta-analysis included two studies [13,14], comprising 79 patients in the ablation group and 72 patients in the surgery group, all restricted to stage IA tumors with 5-year overall survival data. An additional study by Alexander *et al*. [15], comprising 56 ablation and 28 surgery patients with mixed IA/IB disease, was included exclusively in the sensitivity analysis, which evaluated 3-year overall survival rather than 5-year data.

*3.3. Quality Assessment*

The methodological quality of the three included studies was assessed using the Newcastle-Ottawa Scale (NOS) for cohort studies. Two independent reviewers evaluated each study across three domains: selection of participants, comparability of cohorts, and ascertainment of outcomes. All three studies scored 7 or higher (range: 7–9), indicating high methodological quality. Specifically, all studies clearly defined the exposed and non-exposed cohorts and adequately ascertained the outcomes of interest. Both Hu *et al*. [13] and Alexander *et al*. [15] performed propensity-score matching or multivariable regression to control for baseline confounders, thereby achieving full scores in the comparability domain.

Ambrogi *et al*. [14] did not use formal matching but restricted the analysis to stage IA patients, which partially mitigated confounding. The summary of quality assessment is shown in Table 1.

*3.4. 5-year Overall Survival (OS-5y)*

3.4.1. Primary Analysis (Ambrogi + Hu)

Two studies provided binary data for 5-year overall survival restricted to stage IA tumors and pure wedge resection comparators: Ambrogi *et al*. (6 deaths among 16 surgery patients vs. 11 deaths among 23 ablation patients) and Hu *et al*. (16 deaths among 56 surgery patients vs. 25 deaths among 56 ablation patients).The pooled risk ratio (RR) was 1.47 (95% CI: 0.96–2.24; P = 0.07), with no evidence of heterogeneity ($I^2$ = 0%, P = 0.66) (Figure 2a). Although the difference did not reach statistical significance at the conventional threshold (P = 0.07), the direction of effect consistently favored surgery over ablation. Notably, the absence of statistical heterogeneity ($I^2$ = 0%) supports the robustness of this observed clinical signal. Formal publication bias assessment (funnel plot or Egger's test) was not performed due to the limited number of studies in the primary analysis (n=2).

3.4.2. Sensitivity Analysis (+Alexander 3-year OS)

To test the robustness of the primary findings, we performed a sensitivity analysis by additionally including Alexander *et al*. a study that comprised a mixed IA/IB population and reported only 3-year overall survival data (rather than 5-year). This deliberately less restrictive inclusion allows us to assess whether the direction and magnitude of the effect remain stable when a less homogeneous study is added to the pooled estimate.

With the inclusion of Alexander *et al*. (5 events / 28 surgery patients vs. 25 events / 56 ablation patients), the pooled RR was 1.63 (95% CI: 1.12–2.38; P = 0.01), with no heterogeneity ($I^2$ = 0%, P = 0.48) (Figure 2b). The consistency of the effect estimate across the primary and sensitivity analyses, despite the inclusion of a less homogeneous population (mixed IA/IB) and shorter follow-up (3-year OS) in the latter, reinforces the robustness of the survival benefit trend favoring wedge resection over thermal ablation.

3.4.3. Time-to-Event Data Meta-Analysis (Hazard Ratio)
Although a pooled HR meta-analysis was not feasible due to differences in covariate adjustment across studies, individual study-level HRs are reported here to provide complementary time-to-event evidence.

Hu *et al*. reported a multivariable-adjusted HR of 2.240 (95% CI: 1.311–3.829; P=0.003) for PFS and 1.432 (95% CI: 0.698–2.953; P=0.237) for OS, favoring wedge resection over microwave ablation after adjustment for age, sex, tumor size, clinical stage, pulmonary function, distance from the pericardium, and neoplasms adjacent to the atrium or ventricle.

Alexander *et al*. adjusting only for age, reported a 3.3-fold increased risk of death for RF ablation versus limited resection (HR=3.3; 95% CI: 1.3–8.6).

Although these HRs were derived from different adjustment models and could not be pooled, their direction and magnitude are consistent with the primary RR-based findings. Notably, the multivariable-adjusted PFS HR of 2.24 reported by Hu et al. aligns closely with this signal, further supporting the survival benefit trend favoring wedge resection over thermal ablation.

*3.5. Other Outcomes*

3.5.1. Hospital Stay

Due to the heterogeneous reporting formats across studies (median with range vs. mean with standard deviation), a pooled meta-analysis for hospital stay was not performed. Instead, the results are described narratively.

All three studies consistently reported significantly shorter postoperative hospital stays in the thermal ablation group compared with the surgical group. Hu *et al*. [13] reported a median hospital stay of 2 days (range, 1–5 days) for microwave ablation versus 6 days (range, 5–21 days) for wedge resection (P < 0.001). Ambrogi *et al*. [14] similarly reported a median stay of 2 days (range, 1–4 days) for radiofrequency ablation versus 6 days (range, 4–22 days) for wedge resection (P < 0.001). Alexander *et al*. [15] reported a median stay of 0 days (same-day discharge) for radiofrequency ablation versus 5 days for limited surgical resection (P < 0.0001).

3.5.2. Cost

Alexander *et al*. [15] evaluated costs from the Medicare payer perspective and found that the median cost per month lived was significantly lower for radiofrequency ablation compared with limited surgical resection ($620.74, IQR: $166.71–$1,301.93 vs. $1,195.92, IQR: $993.24–$1,957.28; P = 0.0002). The initial procedural costs were also substantially lower for ablation: Medicare Part A reimbursement ranged from $3,165.03 to $3,384.91 (with Part B fees of $219.88–$358.74), whereas surgical resection reimbursement ranged from $17,077.62 to $44,550 (with Part B fees of $867.06–$1,642.00).

# 4. Discussion

*4.1. Main findings*

This meta-analysis demonstrates a consistent survival benefit trend favoring wedge resection over thermal ablation in stage IA NSCLC. The pooled RR for 5-year mortality was 1.47 (95% CI: 0.96–2.24; P = 0.07), with no heterogeneity ($I^2$ = 0%). Although the result did not reach statistical significance at the conventional threshold, the zero heterogeneity and consistent effect direction across all analyses suggest a genuine clinical signal rather than a chance finding—particularly given the limited sample size and event counts. This interpretation is further supported by PFS data from Hu *et al*., which showed a significantly higher risk of progression or death for ablation versus wedge resection (HR = 2.24; 95% CI: 1.31–3.83; P = 0.003) after multivariable adjustment. Beyond oncologic outcomes, ablation was consistently associated with shorter hospital stays (0–2 vs. 5–6 days) and substantially lower costs, underscoring its value as a resource-sparing alternative for patients who are not surgical candidates. Taken together, the convergence of OS, PFS, and perioperative evidence supports wedge resection as the preferred oncologic option for operable patients, while acknowledging ablation as a reasonable alternative in appropriately selected, inoperable patients.

***4.2. The Impact of Stage Heterogeneity: IA versus IB***

A critical observation from the primary studies—particularly Ambrogi *et al*. [14]—underscores the importance of separating IA from IB tumors in comparative effectiveness research. In that study, the survival advantage of surgery over ablation was statistically significant in the overall stage I population (5-year OS: 52% vs. 35%; P = 0.044), which included both IA and IB tumors. However, when the analysis was restricted to stage IA tumors only, the difference was no longer statistically significant (62% vs. 52%; P = 0.499). This discrepancy suggests that the apparent survival benefit of surgery in the mixed-stage population is largely driven by IB tumors—which, by virtue of their larger size (≥3 cm), are inherently less amenable to complete ablation and more suitable for surgical resection.

This finding has two important implications. First, pooling IA and IB tumors in meta-analyses may exaggerate the treatment effect of surgery in the IA subgroup, contributing to the high heterogeneity observed in prior studies that did not stratify by T stage. Second, it highlights the need for future studies to report outcomes separately by tumor size and T stage, particularly to clarify whether thermal ablation may be more comparable to wedge resection in tumors ≤1 cm or ≤2 cm, as suggested by Yim *et al*. [8] Until such data are available, treatment decisions for stage IA NSCLC should be made with caution, recognizing that the available evidence for this specific subgroup remains limited.

***4.3. Clinical Implications: Hospital Stay and Cost***

The shorter hospital stays and lower costs associated with thermal ablation have direct clinical and health-economic implications. In the three included studies, ablation was consistently associated with shorter median hospital stays than wedge resection, ranging from 0 to 2 days for ablation versus 5 to 6 days for surgery[13–15]. Alexander *et al*. reported that all ablation patients were discharged on the same day (median 0 days), whereas surgical patients remained hospitalized for a median of 5 days.

The cost differential is substantial. Alexander *et al*. analyzing from the Medicare payer perspective, found that the median cost per month lived was nearly twice as high for surgery as for ablation ($1,195.92 vs. $620.74; P = 0.0002), and initial procedural costs for ablation were approximately one-fifth to one-tenth of those for surgical resection[15].

These perioperative advantages are particularly relevant in healthcare systems where resources are constrained. In high-volume thoracic surgery centers, reduced hospital stay translates directly into improved bed turnover and shorter waiting times for elective procedures. The lower procedural cost also has implications for healthcare payers and patients alike, especially in settings where out-of-pocket expenses remain a concern. While the cost data are derived from the U.S. Medicare system, the relative advantage of a less invasive, outpatient-amenable procedure is likely to hold across different healthcare systems. This suggests that, for appropriately selected patients who are not surgical candidates or who prefer less invasive management, thermal ablation represents a cost-effective alternative to surgery.

### *4.4.* ***Limitations***

Several limitations of this meta-analysis should be acknowledged. First, the number of studies included in the quantitative synthesis is modest, with only two studies contributing to the primary analysis and one additional study included in the sensitivity analysis. This reflects our strict inclusion criteria—requiring stage IA tumors, pure wedge resection as the surgical comparator, and 5-year overall survival data—rather than a lack of available literature. While this restrictive approach yielded zero heterogeneity ($I^2 = 0\%$) across all pooled analyses, supporting the clinical homogeneity of the included studies, it also limits the generalizability of our findings to broader or more heterogeneous populations.

Second, all included studies were retrospective cohort designs, which are inherently susceptible to selection bias and residual confounding. Although Hu *et al*. and Alexander *et al*. employed propensity-score matching or multivariable regression to mitigate baseline imbalances, unmeasured confounders—particularly cardiopulmonary reserve, frailty indices, performance status, and the specific reasons for surgical ineligibility—could not be fully accounted for [13,15]. Ambrogi *et al*. did not use formal matching but restricted their analysis to stage IA patients, which partially addressed confounding by tumor size but did not eliminate other sources of bias [14].

Third, the Alexander *et al*. study, included only in the sensitivity analysis, comprised a mixed IA/IB population and reported 3-year rather than 5-year overall survival data, representing a less homogeneous comparator. Its inclusion in the sensitivity analysis was deliberate—to test whether adding a less homogeneous study would alter the direction or magnitude of the primary findings. The fact that the sensitivity analysis yielded consistent results (RR = 1.63, $I^2 = 0\%$) supports the robustness of our conclusions, but the differences in follow-up duration and stage composition should be borne in mind when interpreting this result.

Fourth, the type of thermal ablation (radiofrequency vs. microwave) and surgical approach (open vs. video-assisted thoracoscopic surgery) varied across studies. Microwave ablation, used in Hu *et al*., may offer advantages over radiofrequency ablation in terms of ablation zone size and convection profile, but the small number of studies precluded formal subgroup analysis by ablation modality. Similarly, we could not assess whether surgical approach influenced outcomes due to insufficient data.

Fifth, formal publication bias assessment using funnel plots or Egger's test was not performed due to the limited number of studies in the primary analysis (n = 2). Such tests have low statistical power when fewer than 10 studies are available, and their results would be unreliable. Finally, the cost data from Alexander *et al*. were derived from the U.S. Medicare system and may not directly translate to other healthcare settings with different reimbursement structures and cost drivers. Despite these limitations, the consistency of the effect estimates across primary and sensitivity analyses, combined with the zero heterogeneity, suggests that the findings are robust within the defined scope of this meta-analysis.

### *4.5.* ***Future Directions***

The findings of this meta-analysis highlight several priorities for future research.

First, prospective randomized controlled trials comparing wedge resection with thermal ablation in medically operable patients with stage IA NSCLC are urgently needed. Although such trials face significant recruitment challenges—patients are often unwilling to be randomized between surgery and a less invasive alternative—they remain the gold standard for establishing comparative effectiveness. Until such trials are available, well-designed prospective cohort studies with rigorous propensity-score matching and standardized outcome reporting would provide valuable complementary evidence.

Second, future studies should systematically report outcomes stratified by tumor size, particularly distinguishing between tumors ≤1 cm, 1–2 cm, and 2–3 cm. The available evidence from Yim *et al*. suggests that the survival disadvantage of ablation may be minimal or absent in the smallest tumors (≤1 cm), whereas it becomes more apparent in tumors 1–2 cm [8]. If this observation is confirmed in future studies, it could inform more nuanced treatment recommendations, with ablation being considered a more acceptable option for the smallest lesions.

Third, the integration of advanced imaging biomarkers and deep learning models may help refine patient selection for ablation. Xu *et al*. demonstrated that a Vision Transformer model based on preoperative CT images could effectively stratify patients by prognosis after ablation, suggesting that imaging-based risk prediction may identify those most likely to benefit from less invasive therapy[16]. Future research should validate and extend such approaches, potentially incorporating genomic and clinical data to build more robust predictive models.

Fourth, the potential for thermal ablation to be safely and effectively performed in secondary or community hospitals deserves further investigation. Currently, most ablation data originate from tertiary referral centers with specialized interventional radiology services. If ablation can be safely delivered in less specialized settings, it could help decentralize early-stage lung cancer care, reduce patient travel burden, and alleviate the pressure on major thoracic surgery centers. This is particularly relevant in countries with large populations and unevenly distributed healthcare resources, where access to surgical expertise remains a significant barrier to timely treatment.

Finally, future studies should incorporate patient-reported outcomes and quality-of-life metrics. While survival and recurrence remain the primary endpoints in oncologic research, treatment burden, recovery time, and impact on daily functioning are equally important to patients—particularly older or frail individuals who may prioritize these factors over marginal survival gains. Shared decision-making, informed by both clinical evidence and patient preferences, should guide treatment selection for stage IA NSCLC.

## 5. Conclusions

This meta-analysis, restricted to stage IA NSCLC and wedge resection as the comparator, demonstrates that wedge resection offers a consistent survival benefit trend over thermal ablation, with the direction of effect favoring surgery across both primary and sensitivity analyses and no evidence of statistical heterogeneity in the primary analysis. Thermal ablation, however, is consistently associated with shorter hospital stays and substantially lower costs, making it a reasonable alternative for patients who are medically inoperable or who decline surgery. The divergent findings between IA and IB subgroups—as suggested by the primary studies—underscore the importance of separating tumor stages in future

comparative research and caution against pooling stage I populations indiscriminately. Treatment decisions should be individualized through multidisciplinary evaluation, weighing oncologic efficacy against patient fitness, comorbidities, and preferences. Prospective randomized trials with standardized outcome definitions and stage-stratified reporting are urgently needed to definitively compare these modalities and refine patient selection, particularly for the smallest tumors (≤1 cm) where the survival disadvantage of ablation may be less pronounced.

# Declarations

### Ethics approval and consent to participate

Approval of the research protocol by an Institutional Reviewer Board: N/A.

### Consent for publication

Not applicable

### Competing interests

The authors have no conflicts of interest to declare.


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### Authors' contributions

YZ and JZ were involved in drafting the manuscript. JZ was involved in acquisition of data. CS designed and revised the manuscript.


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### Availability of data and materials

All data for this study are publicly available and are ready for the public from database of hospital.

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## Table

Table 1. Characteristics of included studies

| Author, Year | Country | Study Design | Ablation Modality | Surgical Procedure | Sample Size (Ablation/Surgery) | Tumor Size (cm) | Follow-up (months) | NOS Score |
|---|---|---|---|---|---|---|---|---|
| Hu et al., 2021[13] | China | Retrospective cohort (PSM) | MWA | Wedge resection | 56 / 56 | 2.3 (2.0–3.0) | 47 (median) | 9 |
| Ambrogi et al., 2015[14] | Italy | Retrospective cohort | RFA | Wedge resection | 23 / 16 | 2.6 (1.2–4.3)* | 42 (ablation) / 36 (surgery) | 7 |
| Alexander et al., 2013** [15] | USA | Retrospective cohort | RFA | Wedge resection | 56 / 28 | IA/IB stage | 16.7 (median) | 7 |

*Tumor size data are reported for the entire stage I cohort (including IB), as IA-specific tumor size was not separately reported in the original study. The IA subgroup analysis was derived from the reported T1-stage survival data.
**Alexander et al. included a mixed IA/IB population and was included only in the sensitivity analysis (3-year overall survival data), not in the primary meta-analysis.

## Figures

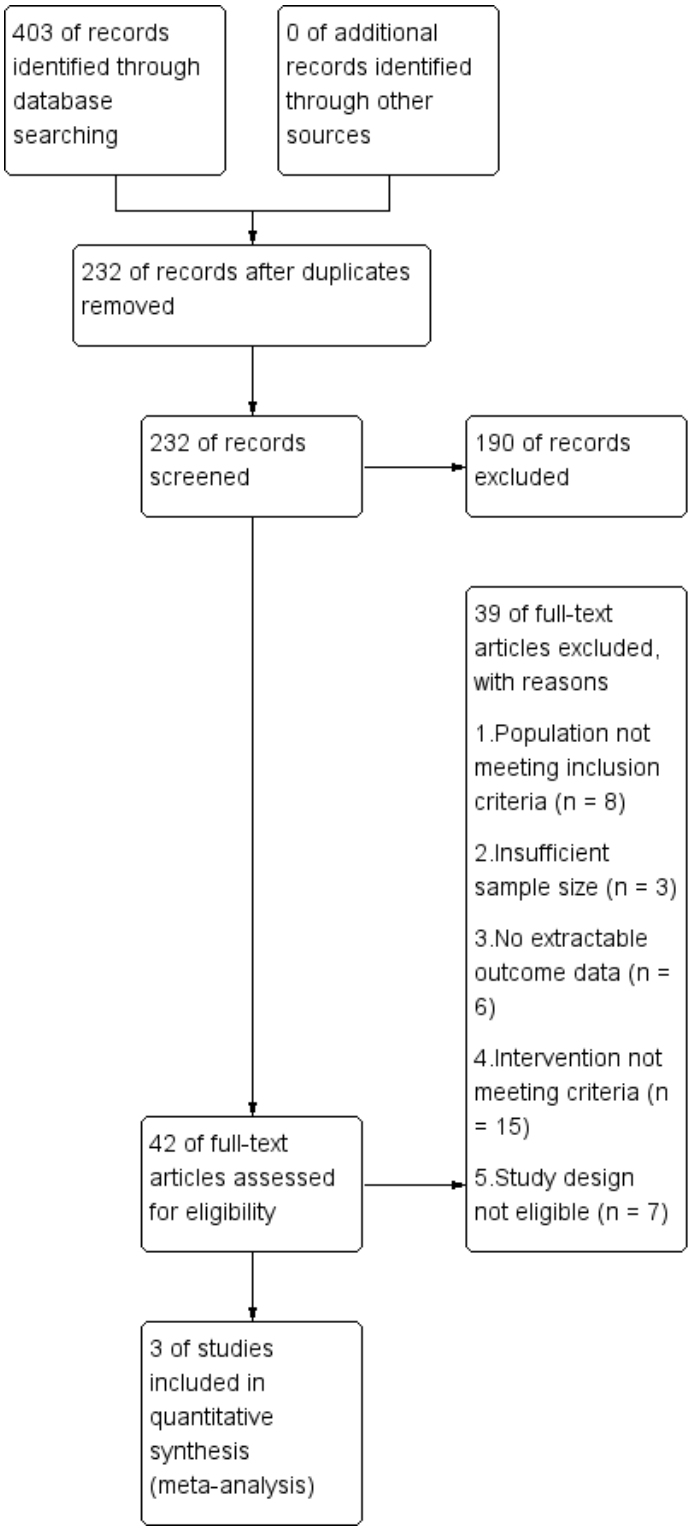



**Figure 1**

PRISMA flow diagram of study selection.

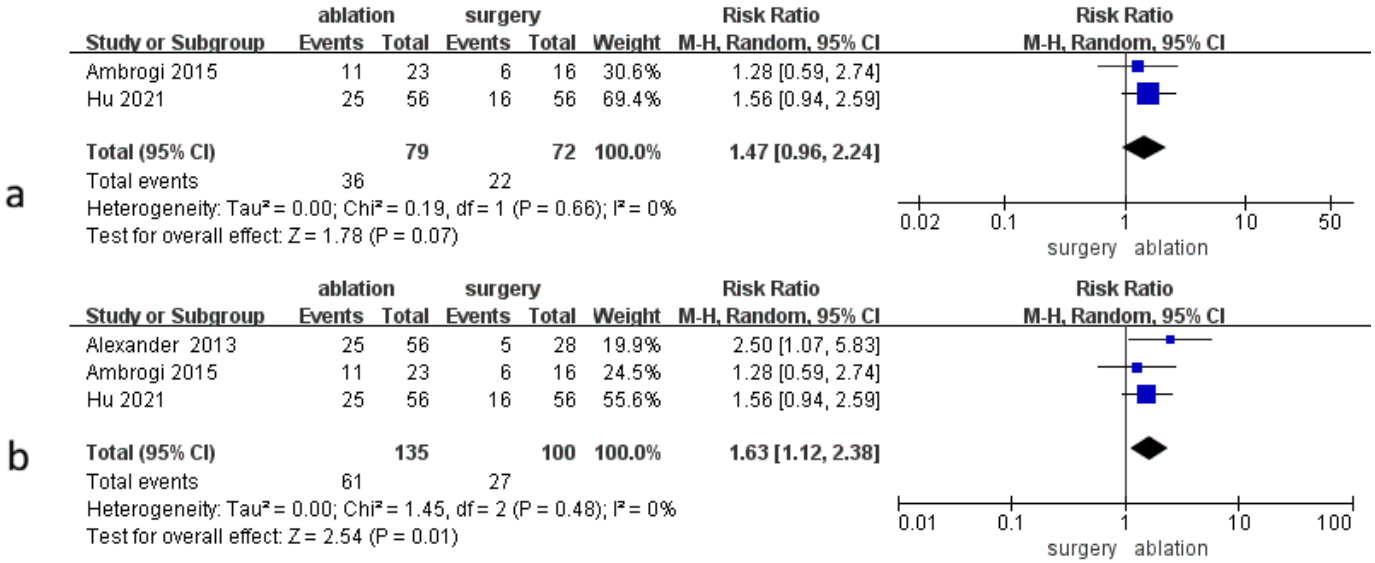



**Figure 2**

Forest plots for 5-year overall survival. (a) Primary meta-analysis restricted to stage IA tumors, comparing wedge resection with thermal ablation (Ambrogi *et al*. [14] and Hu *et al*. [13]). (b) Sensitivity analysis including Alexander *et al*. [15] (3-year overall survival data; mixed IA/IB population). Risk ratios (RR) and 95% confidence intervals (CI) were calculated using a random-effects model (DerSimonian-Laird). Heterogeneity was assessed using the $I^2$ statistic.