

Conversion to Thoracotomy After Neoadjuvant Immune Checkpoint Inhibitor Therapy for Resectable Non-Small Cell Lung Cancer: A Systematic Review and Meta-Analysis of Predictors, Technical Complexity, and Perioperative Outcomes

Stevano Mengko^{1*}, Pedro Sutrisno², Elia Afry Parlindungan Hutapea³

Samuel Moeda Naval Hospital, Indonesia¹

UPTD Puskesmas Batu, Indonesia²

DR. J. P. Wanane Hospital, Indonesia³

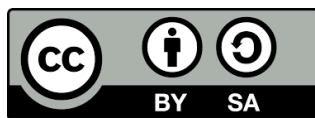
Email: stevano.mengko@gmail.com^{1*}, iamsutrisno@gmail.com², hutapeaelia@gmail.com³

Keywords:

Non-Small Cell Lung Cancer;
Neoadjuvant Immunotherapy;
Immune Checkpoint Inhibitor;
Conversion to Thoracotomy;
Meta-Analysis

ABSTRACT

Neoadjuvant chemoimmunotherapy has become an established treatment option for selected patients with resectable non-small cell lung cancer (NSCLC), although treatment-associated hilar fibrosis may increase surgical complexity. Conversion from minimally invasive surgery to open thoracotomy is an important indicator of technical difficulty; however, it has generally been reported as a secondary outcome and has not been comprehensively synthesized as a primary endpoint. This systematic review and meta-analysis aimed to estimate the incidence of conversion to thoracotomy following neoadjuvant immune checkpoint inhibitor (ICI)-based therapy and identify factors contributing to variability across studies. PubMed, Embase, Scopus, Web of Science, and the Cochrane Central Register of Controlled Trials (CENTRAL) were searched from database inception through September 19, 2026. Two independent reviewers screened studies, extracted data, and assessed methodological quality, resolving disagreements through discussion. Full-text articles were reviewed to determine eligibility. Studies were included if they enrolled adults with resectable NSCLC who received neoadjuvant ICI-based therapy, underwent an attempted minimally invasive pulmonary resection, and reported sufficient data to determine conversion events and the corresponding denominator. Conversion proportions were pooled using the Freeman–Tukey double-arcsine transformation and a DerSimonian–Laird random-effects model. The certainty of evidence was assessed using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) approach. Twenty studies comprising 1,221 attempted minimally invasive resections reported 164 conversions to thoracotomy. The pooled conversion rate was 12.2% (95% confidence interval [CI]: 9.0%–15.8%), with moderate between-study heterogeneity ($I^2 = 51.7\%$) and a 95% prediction interval of 3.2%–24.9%. Surgical approach was associated with significant variation in conversion rates, which were 1.9% in robotic-assisted thoracic surgery (RATS) series, 12.4% in video-assisted thoracoscopic surgery (VATS) series, and 14.6% in series involving mixed surgical approaches ($p = 0.006$). Overall, approximately one in eight attempted minimally invasive pulmonary resections following neoadjuvant ICI-based therapy required conversion to open thoracotomy. Surgical approach was associated with differences in



This is an open access article under the [CC BY-SA](https://creativecommons.org/licenses/by-sa/4.0/) license.

Copyright © 2026 by Author. Published by
Riviera Publishing

conversion rates across studies, whereas geographic location and cohort size were not identified as significant sources of variation.

INTRODUCTION

Lung cancer accounted for an estimated 1.8 million deaths worldwide in 2022 and remains the leading cause of cancer-related mortality (Bray et al., 2024). For patients diagnosed with resectable non-small cell lung cancer (NSCLC), treatment strategies have undergone substantial changes in recent years, particularly following the introduction of neoadjuvant immune checkpoint inhibitor (ICI)-based therapy. The CheckMate 816 trial demonstrated that three cycles of neoadjuvant nivolumab combined with platinum-based chemotherapy increased the pathological complete response (pCR) rate approximately tenfold and improved event-free survival, with subsequent follow-up demonstrating an overall survival benefit (PM et al., 2022; PM et al., 2025). Similarly, the KEYNOTE-671, AEGEAN, CheckMate 77T, and NADIM II trials reported favorable outcomes with perioperative or neoadjuvant immunotherapy-based treatment strategies (Wakelee et al., 2023; (Provencio et al., 2023). Consequently, neoadjuvant ICI-based therapy has become an established treatment option for eligible patients with resectable NSCLC, while pathological assessment of resected specimens has emerged as an important early indicator of treatment response (JV et al., 2023). Despite these advances in systemic treatment, the surgical implications of neoadjuvant immunotherapy remain incompletely understood.

The surgical management of resectable NSCLC has also evolved toward minimally invasive techniques. Randomized evidence from the Danish trial and the VIOLET trial demonstrated that video-assisted thoracoscopic surgery (VATS) lobectomy was associated with reduced postoperative pain and shorter hospital stays compared with open thoracotomy, without compromising oncological outcomes (Cascone et al., 2024; WD et al., 2020). Enhanced recovery guidelines further support the use of minimally invasive surgical approaches when anatomically and technically feasible (Tajè et al., 2026). However, conversion from a planned minimally invasive procedure to open thoracotomy may alter postoperative recovery, increase analgesic requirements, and affect patient expectations regarding surgical outcomes. Therefore, understanding the likelihood and determinants of conversion is particularly important when counseling patients undergoing pulmonary resection after neoadjuvant ICI-based therapy.

Early surgical reports following neoadjuvant nivolumab suggested that the benefits of minimally invasive surgery might be challenged by treatment-related anatomical changes. Bott and colleagues reported that, among 13 patients in the CheckMate 159 cohort who underwent attempted minimally invasive resection, seven required conversion to thoracotomy. The authors described dense, vascularized adhesions and extensive hilar lymph node fibrosis that obscured normal tissue planes and complicated surgical dissection. (Yang et al., 2024; Wang, 2025; Lim et al., 2022) This conversion rate of approximately 54% raised concerns regarding the technical feasibility of minimally invasive pulmonary resection following neoadjuvant immunotherapy. The proposed mechanism involves treatment-associated inflammatory and fibrotic changes within the hilar and mediastinal structures, potentially making dissection more challenging even in patients who achieve a pathological

complete response. These observations suggest that favorable oncological responses do not necessarily correspond to reduced surgical complexity.

Conversion to thoracotomy represents an important surgical outcome that warrants independent evaluation. It is an objectively documented intraoperative event and serves as a potential indicator of technical difficulty. In surgical settings outside neoadjuvant immunotherapy, conversion from minimally invasive pulmonary resection to open thoracotomy has been associated with prolonged hospitalization and increased postoperative complications compared with procedures completed thoracoscopically. Common reasons for conversion include intraoperative bleeding, dense adhesions, and extensive hilar or mediastinal lymph node involvement. (Pohlman et al., 2026) Nevertheless, the frequency of conversion following neoadjuvant ICI-based therapy remains uncertain, and the factors contributing to substantial differences in conversion rates across surgical series have not been adequately characterized.

Existing systematic reviews and meta-analyses have primarily examined the overall feasibility, pathological response, and postoperative morbidity associated with pulmonary resection following neoadjuvant chemoimmunotherapy, generally considering conversion to thoracotomy as a secondary outcome.(Spicer, 2024; Aburaki et al., 2024) A recent meta-analysis comparing robotic-assisted thoracic surgery (RATS) and VATS in this population also included conversion among several surgical endpoints (Li et al., 2025). Additionally, narrative reviews have described the technical challenges associated with treatment-related fibrosis and inflammatory changes but have provided limited quantitative synthesis of conversion rates (Pan et al., 2025). Consequently, a focused synthesis that evaluates conversion to thoracotomy as the primary outcome, consistently defines the denominator as the number of attempted minimally invasive resections, and investigates potential sources of between-study heterogeneity remains necessary.

Several methodological challenges complicate the interpretation and comparison of conversion rates across studies. First, inconsistencies in denominator definitions may introduce selection bias. Studies in which most patients undergo planned open thoracotomy may report lower conversion rates than studies adopting a more extensive minimally invasive surgical strategy, even when the latter involve greater technical complexity. Therefore, conversion rates should be calculated using the number of patients in whom minimally invasive resection was attempted rather than the total number of surgical procedures performed. Second, the criteria used to define conversion are frequently inconsistent or inadequately reported. For example, planned enlargement of a utility incision and emergency conversion following pulmonary artery injury may be classified within the same outcome category despite their different clinical implications. Third, the surgical platform may influence conversion rates. Although VATS and RATS are both minimally invasive approaches, they differ in instrument articulation, visualization, ergonomics, and technical capabilities during dissection of fibrotic hilar structures. However, randomized comparisons of these approaches specifically in patients undergoing surgery after neoadjuvant ICI-based therapy remain unavailable, limiting definitive conclusions regarding their comparative effectiveness.

The novelty of this systematic review and meta-analysis lies in its specific focus on conversion to thoracotomy as the primary outcome rather than a secondary component of

broader surgical feasibility assessments. Unlike previous syntheses that evaluated multiple perioperative and oncological outcomes, this review applied a consistent denominator based on attempted minimally invasive resections to improve comparability across studies and reduce potential misinterpretation arising from differences in surgical selection practices. Furthermore, four prespecified moderators—surgical platform, study design, geographic region, and cohort size—were examined to identify potential sources of heterogeneity in conversion rates. The review also incorporated available within-cohort comparisons of RATS and VATS to explore platform-related differences while partially accounting for institutional and patient-level variability. This approach was intended to provide a more clinically relevant assessment of conversion risk and its potential determinants.

Accurate estimates of conversion risk have important implications for surgical decision-making, preoperative counseling, and perioperative resource allocation. Patients undergoing pulmonary resection following neoadjuvant chemoimmunotherapy should receive realistic information regarding the possibility of conversion to open thoracotomy and its potential consequences for postoperative recovery. Furthermore, reliable conversion estimates may inform operating room scheduling, anesthetic planning, postoperative pain management, and institutional decisions regarding surgical technology and training. Identifying whether conversion rates vary according to surgical platform, geographic region, or other study characteristics may also help clarify opportunities for improving surgical planning and patient outcomes. However, any observed associations must be interpreted cautiously because differences in patient selection, surgical expertise, and institutional practices may contribute to variation between studies.

Accordingly, this systematic review and meta-analysis aimed to estimate the pooled incidence of conversion to thoracotomy among patients with resectable NSCLC undergoing attempted minimally invasive pulmonary resection following neoadjuvant ICI-based therapy. It also sought to evaluate the influence of four prespecified moderators—surgical platform, study design, geographic region, and cohort size—on conversion rates and to examine available within-cohort comparisons between robotic-assisted and video-assisted thoracoscopic approaches. By synthesizing the available evidence, this review aimed to provide clinically applicable estimates to support preoperative risk assessment, informed surgical consent, and perioperative decision-making.

METHOD

Reporting and protocol

This systematic review was conducted in accordance with the PRISMA 2020 reporting guidelines (Aburaki et al., 2024). The review protocol was developed before the literature search and was provided alongside the manuscript as a registration form and methodological document. Although the review was not registered in PROSPERO, the accompanying protocol documented the prespecified methodology and review procedures.

Eligibility criteria

Studies were eligible when they enrolled adults with clinical stage I to III non-small cell lung cancer, gave neoadjuvant or perioperative therapy that included an immune checkpoint inhibitor in every participant, planned an anatomical pulmonary resection by a

video-assisted or robotic approach, and reported both the number of patients converted to thoracotomy and the number in whom the minimally invasive approach was intended or initiated. Prospective and retrospective cohorts and the surgical reports of clinical trials all qualified.

Four situations disqualified a report. Cohorts in which only some participants received a checkpoint inhibitor were excluded, because the exposure of interest would then be diluted by chemotherapy or targeted therapy. Series of salvage resection after definitive chemoradiotherapy, and series restricted to initially unresectable disease, were excluded because the operative field there reflects a different treatment history. Reports that gave a conversion percentage without a recoverable denominator were excluded. Where two reports described overlapping patients, the larger and more complete one was retained and the other recorded as a duplicate or overlapping cohort.

Outcomes

The primary outcome was conversion to thoracotomy, expressed as a proportion of the patients in whom a minimally invasive resection was intended. Secondary outcomes were the risk of conversion by operative platform, operative time, blood loss, complete resection, length of stay, postoperative complications, ninety-day mortality and pathological response. Secondary outcomes were summarised as reported rather than pooled, because most reports give them for the whole operated cohort and do not separate converted from completed operations.

Information sources and search

Five databases were searched from inception to 19 September 2026: PubMed/MEDLINE, Embase, Scopus, Web of Science and Cochrane CENTRAL. Each string was written in that database's own syntax and combined four concept blocks: the disease, immune checkpoint inhibition, the neoadjuvant or perioperative timing, and the operation, the last carrying both the minimally invasive platform terms and the conversion and thoracotomy terms. Because a report may describe conversion without naming a platform, or name a platform without using the word conversion, the fourth concept was run three ways and the union taken. No date, language or publication status limit was applied. The full strings, with the yield of each database, appear in the search strategy document that accompanies this report. The reference lists of the included reports and of prior syntheses on the same question were screened for reports the database strategies had missed, and none was found.

Study selection and data extraction

The first and second author screened every record independently, first on title and abstract and then at full paper level against the criteria above, and resolved disagreement by discussion. Both reviewers read every included report in full. Four reports sought for retrieval could not be obtained and are recorded as not retrieved in the flow. Extraction and risk-of-bias appraisal were likewise performed independently in duplicate and reconciled the same way. For each included study the following were extracted: identity and identifiers, country and number of centres, design, enrolment window, neoadjuvant regimen, operative platform, clinical stage, number resected, number in whom a minimally invasive approach was intended, number converted, stated reasons for conversion, and the perioperative outcomes listed above. Five conversion counts or denominators were not printed as integers. Four were

recomputed from a stated percentage against a stated denominator, keeping only the integer pair that reproduces every percentage the report prints. The fifth was reconstructed from the report's own arithmetic, where the number of completed minimally invasive operations and the total thoracotomy rate together fix the intended denominator. All five are labelled in the extraction workbook and named in the revision log, and each was checked against any other figure the report gives. A study whose denominator could not be pinned down this way was excluded rather than estimated.

Risk of bias and certainty

The primary outcome is a proportion within a single group, so the Joanna Briggs Institute critical appraisal checklist for studies reporting prevalence data was used rather than RoB 2 or ROBINS-I.^{21,22} No participant in these reports was allocated to conversion, and conversion is not an intervention contrast, so a randomised or non-randomised intervention tool would assess a process that does not exist. The three cohorts contributing to the platform comparison were appraised separately with ROBINS-I.²³ Certainty was rated with GRADE, starting at low for a body of non-randomised evidence.²⁴

Synthesis

Proportions were transformed with the Freeman-Tukey double-arcsine transform, pooled with a DerSimonian-Laird random-effects model, and back-transformed at the harmonic mean of the study denominators.²⁵ Heterogeneity was quantified with I squared and with Cochran's Q, and a 95 per cent prediction interval was computed.²⁶ Four moderators were specified before the analysis: operative platform, study design, geographical region, and the size of the minimally invasive denominator. Differences between strata were tested with Q between groups. Robustness was checked by refitting the model twenty times, omitting one study each time, and by Baujat plot.²⁷ Small-study effects were examined with a contour-enhanced funnel plot and Egger's regression, which was interpretable because twenty studies contributed.²⁸ The comparison of robotic with video-assisted surgery used log risk ratios from the three cohorts reporting both arms, with a continuity correction of 0.5 where an arm had no events, pooled by the same random-effects model. Analyses ran in Python with numpy and scipy; an equivalent metafor script accompanies this report, and the extraction workbook recomputes the primary synthesis from live spreadsheet formulas as an independent check.

RESULTS AND DISCUSSION

Study selection

The five databases returned 906 records: 186 from PubMed/MEDLINE, 243 from Embase, 221 from Scopus, 174 from Web of Science and 82 from Cochrane CENTRAL. Removing 258 duplicates left 648 records for screening, of which 531 were clearly irrelevant on title and abstract. Of these, 117 reports were sought and 4 could not be retrieved, leaving 113 assessed at full paper level. Ninety-three were excluded, most often because the neoadjuvant therapy included no checkpoint inhibitor (21 reports), because a thoracotomy was planned from the outset and no minimally invasive cohort existed (15), or because the population was not resectable non-small cell lung cancer (14). Six reports described patients already counted in a larger series from the same group. Two of those bear directly on this synthesis. The English cohort reported by Brunelli and colleagues is nested within their

European cohort. (Chu et al., 2025) The five-centre series of Kneuertz and colleagues shares centres, investigators and enrolment window with the six-centre series reported by Srivatsa and colleagues. (Shah et al., 2025) In each pair the larger report was retained. Twenty studies entered the review, and all twenty contributed to the meta-analysis. Table 1 and Figure 1 give the flow.

Table 1. PRISMA 2020 flow of study identification, screening and selection.

Stage	Detail	n
Identification	Records identified from databases	906
	PubMed/MEDLINE	186
	Embase	243
	Scopus	221
	Web of Science	174
	Cochrane CENTRAL	82
Screening	Duplicate records removed before screening	258
	Records screened on title and abstract	648
	Records excluded as clearly irrelevant	531
	Reports sought for retrieval	117
	Reports not retrieved, full text unavailable	4
	Reports assessed for eligibility at full paper level	113
Eligibility	Reports excluded with reasons	93
	No neoadjuvant immune checkpoint inhibitor therapy	21
	Open thoracotomy planned upfront, or no minimally invasive surgical cohort	15
	Population not resectable non-small cell lung cancer	14
	Conversion to thoracotomy not reported or not extractable	13
	Mixed neoadjuvant regimens without separable checkpoint inhibitor data	9
	No perioperative, technical complexity or predictor data	8
	Review, protocol, conference abstract, editorial or other non-primary report	7
	Duplicate or overlapping cohort	6
	Studies included in the systematic review	20
Included	Studies included in the meta-analysis	20

Five databases were searched from inception to 19 September 2026 and the yield of each is shown before deduplication. The first and second author screened, extracted and appraised independently and resolved disagreement by discussion; every included report was read at full paper level. The same flow is shown as a diagram in Figure 1.

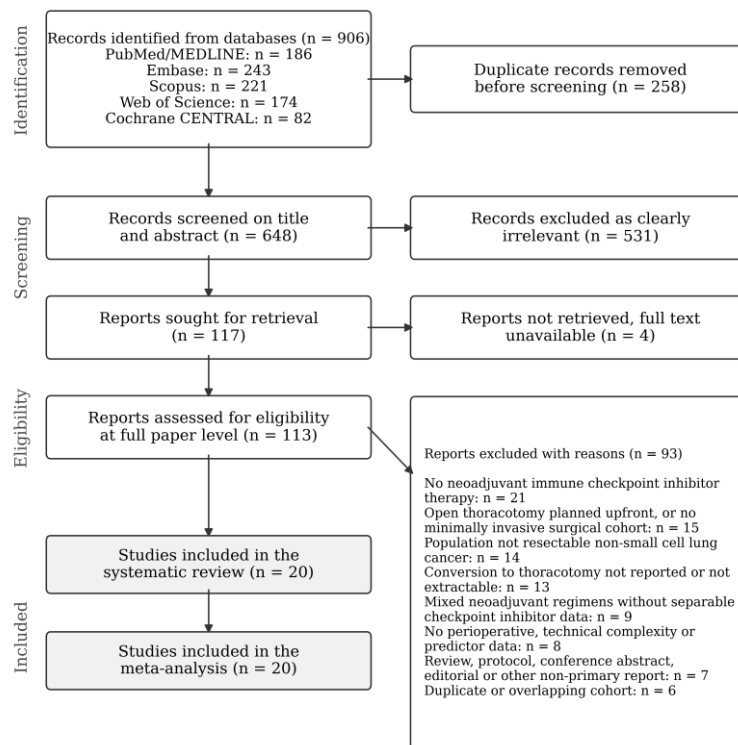


Figure 1. PRISMA 2020 flow of study identification, screening and selection
Five databases were searched from inception to 19 September 2026. The same counts appear as Table 1.

Characteristics of the included studies

The twenty studies enrolled patients between 2015 and 2026 and reported 1567 resections, of which 1221 began with a minimally invasive approach. Seven came from East Asia, five from North America and eight from Europe or Turkey. Fifteen were observational cohorts, four of them multicentre. (Bendixen et al., 2016) The other five were the surgical reports of clinical trials.^{12,35–38} Eleven series reported a mixture of platforms. Two used a robotic platform exclusively.^{39,40} Seven used video-assisted surgery exclusively.^{41–45} Regimens were a platinum doublet with a programmed cell death protein 1 or ligand 1 inhibitor in eighteen studies. Nivolumab was given alone in the earliest series. One series used pembrolizumab with or without chemotherapy. Clinical stage was II to IIIB in most cohorts. Table 2 sets out the detail.

Risk of bias

Of the twenty studies, 9 were judged at low risk of bias and 11 at moderate risk. None was judged at high risk. The recurring problems were small denominators, an undefined conversion threshold, and five reports in which the numerator, the denominator or both had to be reconstructed rather than read. One study analysed a propensity-matched subset rather than its consecutive video-assisted cohort, so its proportion is conditional on the matching model. Table 3 gives the domain judgements and the extraction workbook records the written basis for each one. None was excluded on that basis. Among the three cohorts contributing to the platform comparison, two were at serious risk of bias and one at moderate risk under ROBINS-I.

Conversion to thoracotomy

Conversion occurred in 164 of 1221 patients. The pooled proportion was 12.2 per cent (95 per cent confidence interval 9.0 to 15.8). Heterogeneity was moderate: I squared was 51.7 per cent, Q was 39.37 on 19 degrees of freedom ($p = 0.004$), and tau squared was 0.0048. The 95 per cent prediction interval ran from 3.2 to 24.9 per cent, which is the range a new series should expect rather than the confidence interval around the mean. Three series reported no conversion at all. The earliest reported 54 per cent. Figure 2 shows the forest plot.

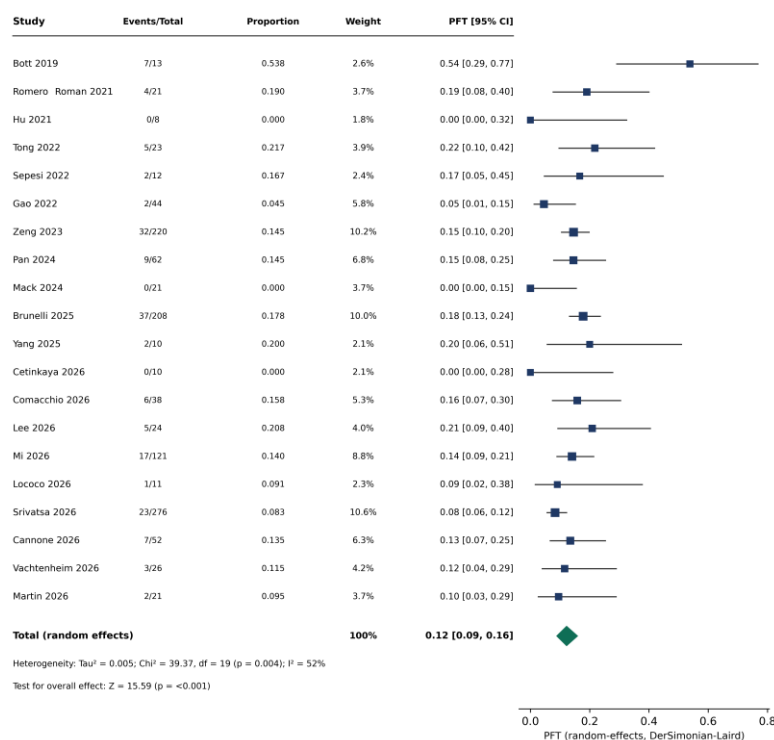


Figure 2. Forest plot of conversion to thoracotomy among intended minimally invasive resections

Proportions are on the Freeman-Tukey double-arcsine scale, pooled by a DerSimonian-Laird random-effects model and back-transformed at the harmonic mean denominator. Squares are scaled by weight; the diamond is the pooled estimate.

What explains the variation

Operative platform was the only moderator that mattered, and it mattered a great deal. Series using a robotic platform exclusively pooled at 1.9 per cent (0.7 to 7.8), video-assisted series at 12.4 per cent (8.2 to 17.2) and mixed series at 14.6 per cent (10.2 to 19.5), with a test for subgroup differences of $p = 0.006$. Within the robotic and the video-assisted strata heterogeneity fell to zero. That is what a real moderator looks like.

Trial surgical cohorts converted at 22.2 per cent against 10.8 per cent in observational practice, a difference that did not reach conventional significance ($p = 0.062$). The five trials are also the five earliest reports in the set, so calendar time and design are confounded here and neither can be credited on its own. Region made no difference: 12.1 per cent in East Asia, 16.4 per cent in North America and 11.6 per cent in Europe and Turkey ($p = 0.86$). Neither did cohort size, at 12.4 per cent in the fourteen series with fewer than fifty minimally invasive

patients against 12.1 per cent in the six larger ones ($p = 0.93$). Table 4 and Figure 3 give the stratified estimates.

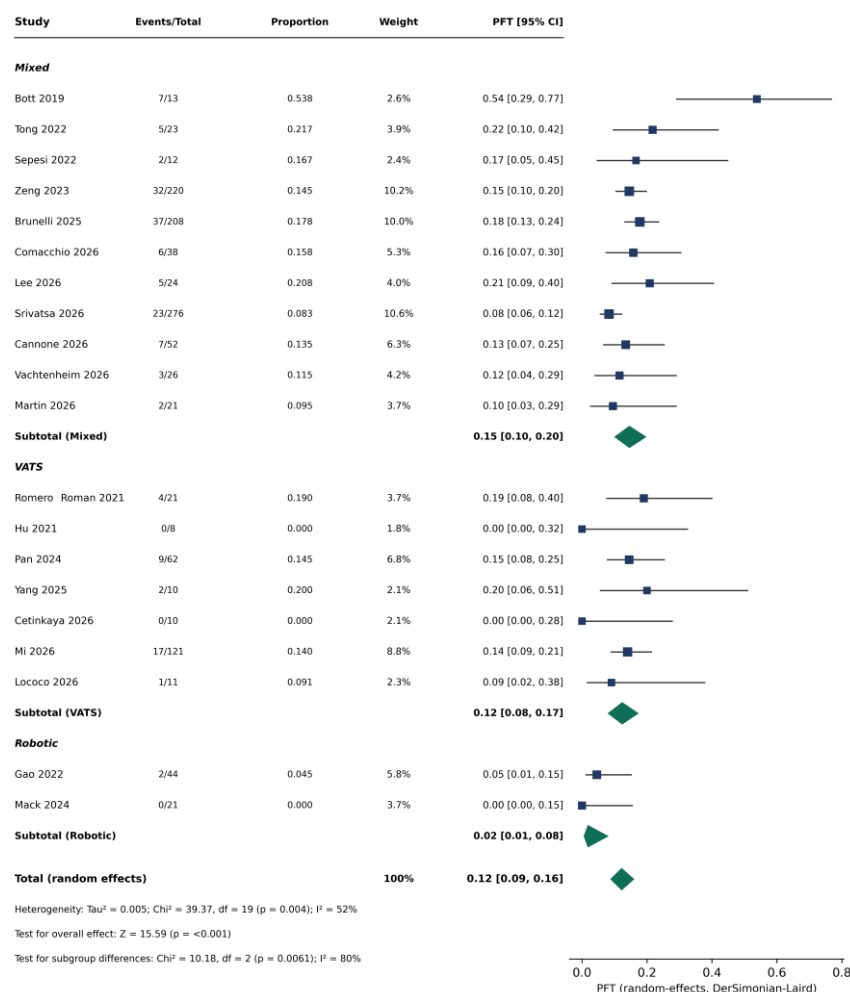


Figure 3. Conversion to thoracotomy by operative platform, with subtotals and a test for subgroup differences.

Strata are the studies that used a robotic platform exclusively, a video-assisted platform exclusively, and those that used both.

Robotic against video-assisted surgery within the same cohorts

Three cohorts reported both platforms with recoverable counts. Conversion occurred in 25 of 395 robotic operations and 35 of 125 video-assisted operations. The pooled risk ratio was 0.24 (95 per cent confidence interval 0.14 to 0.39) with I^2 of 0 per cent, so the three cohorts agreed closely. The direction was the same in each of them, and the largest reported that the difference persisted after inverse probability weighting. Figure 4 shows the comparison. The estimate is not randomised evidence: platform was chosen by the operating surgeon, robotic adoption rose across each enrolment window, and the smallest cohort contributed ten robotic patients.

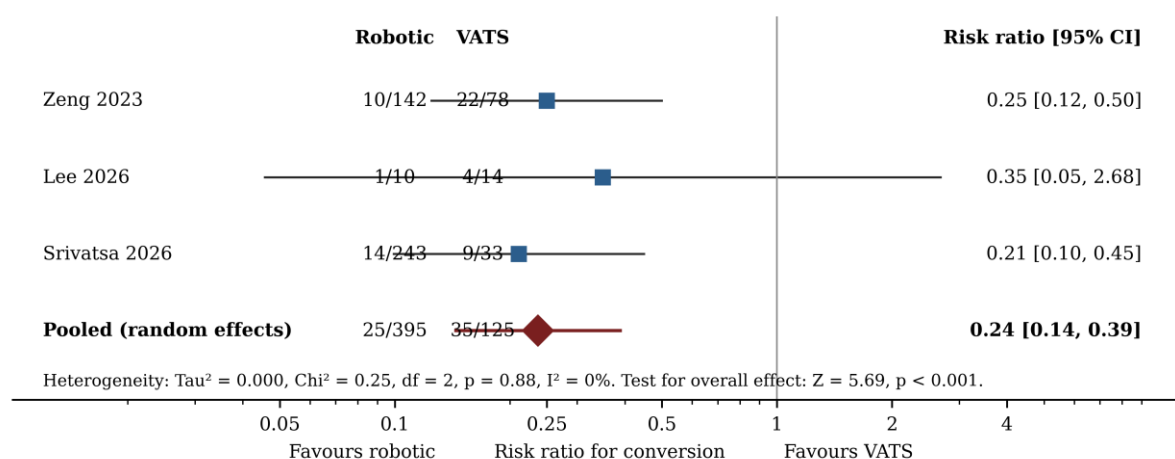


Figure 4. Risk of conversion with a robotic compared with a video-assisted approach, in the three cohorts reporting both arms

Risk ratios below one favour the robotic approach. A continuity correction of 0.5 was applied where an arm had no events. These are non-randomised comparisons within institutions, not randomised contrasts.

Sensitivity, influence and small-study effects

Omitting each study in turn moved the pooled estimate between 11.5 per cent, when Bott 2019 was omitted, and 13.0 per cent, when Srivatsa 2026 was omitted. No single study drove the result. The estimate held. The Baujat plot placed the earliest series furthest from the origin, which is consistent with its small denominator and its position at the extreme of the distribution. Egger's regression gave an intercept of 0.298 with $p = 0.640$, so there was no detectable small-study effect, and the contour-enhanced funnel plot was symmetrical about the pooled estimate. Figures 5 and 6 show the funnel and Baujat plots.

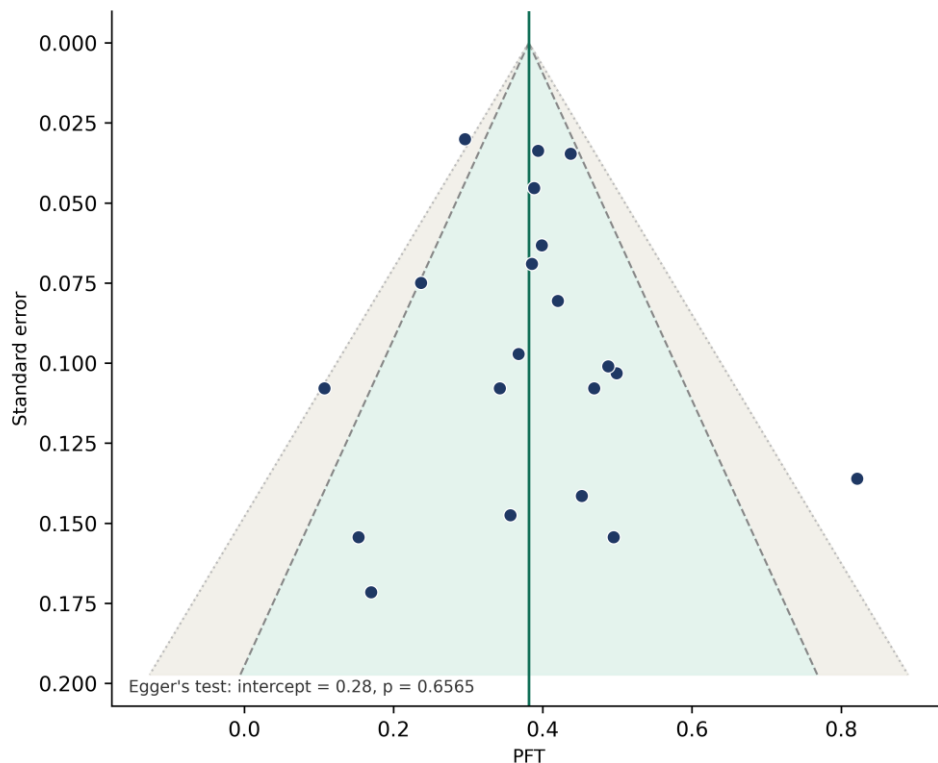


Figure 5. Contour-enhanced funnel plot of the primary synthesis.

Shaded regions mark pseudo 95 and 99 per cent confidence contours around the pooled estimate. Egger's regression was interpretable because twenty studies contributed.

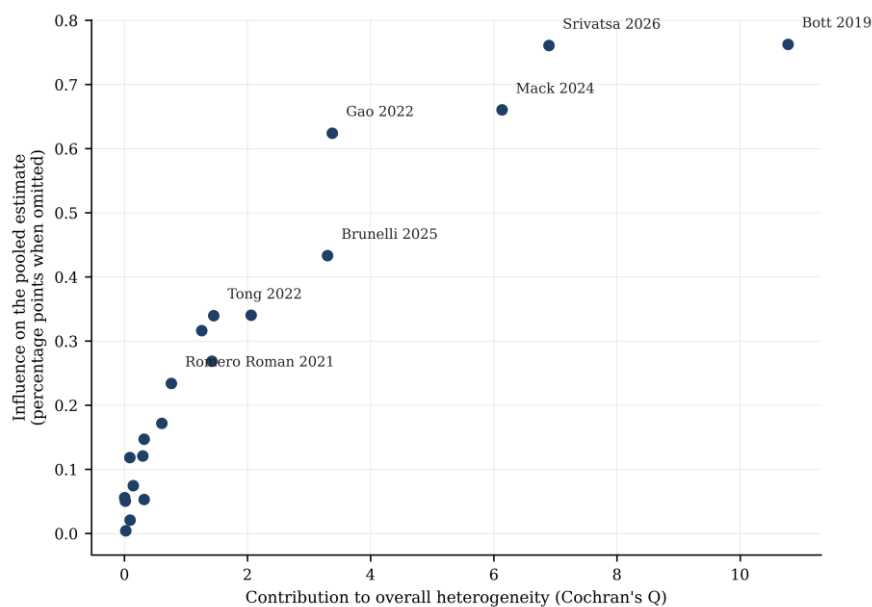


Figure 6. Baujat plot of each study's contribution to heterogeneity and its influence on the pooled estimate

The horizontal axis is each study's contribution to Cochran's Q; the vertical axis is how far the pooled estimate moves, in percentage points, when that study is omitted. Only studies material on one axis or the other are labelled; the largest displacement is under one percentage point.

Perioperative and short-term oncological outcomes

These outcomes were reported inconsistently and almost always for the whole operated cohort rather than for the minimally invasive denominator, so they are summarised rather than pooled. Complete resection was reported in fifteen studies and reached at least 90 per cent in every one of them, including the three largest cohorts. Ninety-day mortality was stated in twelve studies and was zero in eight of them; the highest was 5.4 per cent in the Czech nationwide cohort, where none of the deaths was attributed to the operation. The shortest median stay, two days, was in a robotic series. The longest, seven days, was in a uniportal sleeve resection series. Operative time was longer than the institutional benchmark wherever a comparison was made. Pathological complete response, where stated, ran from 15 to 59 per cent. Three reports named the intraoperative findings behind their conversions, and all three named the same two: dense hilar or mediastinal fibrosis, and bleeding during dissection of an obliterated plane. Table 6 sets out the reported values.

Principal findings

Across twenty studies and 1221 patients in whom a minimally invasive resection was intended after neoadjuvant checkpoint inhibitor based therapy, 12.2 per cent were converted to thoracotomy. That is roughly one operation in eight. The confidence interval is narrow, running from 9.0 to 15.8 per cent, but the prediction interval is not: a new series should expect anything between 3.2 and 24.9 per cent. The gap between those two intervals is the finding that matters for a surgeon planning a list, and it is why a single pooled number, quoted without its spread, would mislead.

Most of the spread is explained by which platform the unit uses. Robotic series pooled at 1.9 per cent and video-assisted series at 12.4 per cent, and within each stratum the studies agreed with one another. The comparison that carries the most weight is not that between-study contrast but the within-cohort one: where the same institution offered both platforms to a similar group of patients, conversion was about four times less likely with the robot, with a risk ratio of 0.24 and no heterogeneity between the three cohorts. The direction never reversed. Two analyses of the same question outside the immunotherapy setting point the same way, and one of them was designed around conversion itself.

What may explain the platform difference

A plausible mechanism is mechanical rather than oncological. Checkpoint blockade leaves fibrosis and nodal calcification where the treatment worked, and the tissue plane between a pulmonary artery branch and an adherent node is exactly where a rigid thoracoscopic instrument is least capable. Wristed instruments, stable three-dimensional magnification and a surgeon-controlled camera make a slow dissection in that plane feasible where a video-assisted approach would demand either a rapid conversion or an unsafe pull. The instrument is the constraint. The same cohorts that converted less often with the robot also harvested more nodes and more nodal stations, which fits a mechanical rather than a selection explanation. Bronchoplasty and angioplasty were performed only robotically in the largest comparative series.

Selection remains the competing explanation and cannot be dismissed. Platform was chosen by the operating surgeon, robotic programmes matured over the same years in which chemoimmunotherapy was adopted, and a unit that has a robot may also have higher volume and a more experienced team. Randomised comparisons of the two platforms in unselected

lung cancer have shown shorter stays and better node yield with the robot without reporting a conversion advantage of this magnitude. A large registry analysis found a similar but smaller gap. None of those studies enrolled patients treated with neoadjuvant immunotherapy, so the question of whether the fibrotic hilum amplifies the platform difference is open.

The trial and cohort contrast

Conversion was about twice as common in the surgical reports of clinical trials as in routine practice, 22.2 against 10.8 per cent, though with five trials the difference does not reach conventional significance ($p = 0.06$). Design is not the likely cause. The five trial cohorts are also the five earliest reports here, they used single-agent or early combination regimens, and they were performed when no surgeon had operated on more than a handful of such patients. Bott and colleagues converted seven of thirteen in 2019; by 2026 the large multicentre series were reporting rates between 8 and 18 per cent. Whether that represents a learning curve, better case selection, wider robotic use, or a reluctance to start minimally invasively in the hardest cases cannot be separated with these data. The last of those possibilities deserves attention, because a unit that begins its difficult cases open reports a low conversion rate while offering fewer patients a keyhole operation. The proportion of resections attempted minimally invasively ranged from 44 to 100 per cent across these series, so that ascertainment concern is real.

The trial literature supports the ascertainment reading. In the surgical report of CheckMate 816 the great majority of resections were performed through a thoracotomy from the outset, and the randomised NEOSTAR comparison likewise recorded thoracotomy as the default approach. A protocol that permits any approach, in an era when surgeons are uncertain what they will find, produces a self-selected minimally invasive denominator of the most favourable cases and a conversion rate calculated on a small and unrepresentative group. That is the opposite of the bias one might assume. It means the trial figure of 22.2 per cent is probably an underestimate of what an unselected minimally invasive attempt would have cost in those years, not an overestimate.

Comparison with existing evidence

Earlier syntheses of surgery after neoadjuvant chemoimmunotherapy reported conversion among a list of feasibility endpoints and did not model it. A recent meta-analysis comparing robotic with video-assisted resection in this population reported a conversion advantage for the robot consistent with the risk ratio found here.¹⁸ The contribution of the present review is the denominator. By requiring the number of patients in whom a minimally invasive approach was intended, rather than the number who completed one, it avoids the inversion in which the most conservative unit appears to have the best results. Two reports were excluded for precisely that reason. One was a national database analysis that could not separate intent from completion. The other compared neoadjuvant with adjuvant therapy and weighted its conversion rates rather than counting them. Two further reports were excluded because their populations were mixed. One was a robotic series in which only 65 per cent received immunotherapy. The other was a salvage series after definitive therapy. Those exclusions cost information, and they are the price of a denominator that means the same thing in every row.

Work on predicting difficulty before the incision is beginning to appear. A multifactorial model of surgical complexity after chemoimmunotherapy and an analysis of

preoperative predictors both identified nodal burden, central tumour location and radiological response as candidate markers. The earliest series here made the same observation informally: five of eight node-positive patients attempted thoracoscopically were converted, against one of four with stage I disease, and a major pathological response did not predict conversion either way. A prospective study that recorded intent, platform, nodal status and radiological response, and then measured conversion, would settle in one dataset what this review can only assemble.

Clinical implications

Three things follow for practice. A patient consented for a minimally invasive resection after chemoimmunotherapy should be told that roughly one in eight such operations becomes a thoracotomy, and that the figure is higher where nodal disease is present. Units that perform this surgery through a video-assisted approach should know that the robotic literature reports lower conversion in comparable patients, which is a consideration for case allocation where both are available rather than a reason to defer surgery where they are not. Conversion did not appear to cost oncological quality: complete resection stayed above 90 per cent everywhere, and one multicentre analysis found that converted operations achieved the same perioperative outcomes as planned thoracotomies. That last point deserves emphasis, because the purpose of measuring conversion is to plan for it. It is not to avoid it at the cost of an unsafe dissection. Conversion outside this setting is associated with longer stay and more complications than a completed thoracoscopic operation, so it is not a free event.

Limitations

Four reports sought for retrieval could not be obtained in full text, so a small amount of eligible evidence may sit outside this synthesis. Grey literature was not searched separately, and conference abstracts without a full report were excluded by design, which is the conventional trade between completeness and the ability to read a method. Egger's regression was reassuring and the funnel plot was symmetrical, but neither addresses a report that was never retrieved.

The included evidence is observational. Nineteen of twenty studies were non-randomised, the twentieth was a randomised trial whose randomisation concerned the systemic regimen rather than the operative platform. No participant anywhere was allocated to conversion. Certainty is very low for both the pooled proportion and the platform comparison: the proportion is downgraded from its observational starting point for the undefined conversion threshold and the reconstructed counts, and the platform comparison for risk of bias and imprecision. Few reports defined what counted as a conversion, which leaves a threshold effect that no statistical method can repair. No transform fixes a definition. Five studies contributed a numerator or a denominator that was reconstructed rather than read as an integer. Four of those reconstructions are exact, in the sense that one integer pair alone reproduces every percentage the report prints. The fifth is uncertain by a single event. The leave-one-out analysis shows that none of the five is influential, but they are not on the same footing as the rest. Secondary outcomes were reported inconsistently across the twenty reports, which constrains what can be said about them far more than it constrains the primary estimate.

Finally, the moderator analyses are observational comparisons between groups of studies, not randomised contrasts, and four of them were tested on twenty studies. The

platform result survives that concern better than the others because the same direction appears within cohorts as well as between them, and because a mechanism is available. The design result does not, since design and calendar year are perfectly confounded in this set. Perioperative and oncological outcomes were reported for whole operated cohorts rather than for the minimally invasive denominator in all but two reports. The question of what conversion costs a patient, as opposed to how often it happens, therefore remains unanswered here.

CONCLUSION

Following neoadjuvant immune checkpoint inhibitor (ICI)-based therapy for resectable non-small cell lung cancer (NSCLC), approximately 12.2% of attempted minimally invasive pulmonary resections required conversion to open thoracotomy, with a 95% prediction interval of 3.2%–24.9%, indicating substantial variability in conversion rates across surgical settings. Surgical platform emerged as an important source of between-study heterogeneity. In three cohorts comparing robotic-assisted thoracic surgery (RATS) and video-assisted thoracoscopic surgery (VATS) among comparable patient populations, RATS was associated with approximately one-quarter of the conversion risk observed with VATS. Geographic region and cohort size were not identified as significant moderators of conversion rates. However, these findings were derived from nonrandomized studies, and the overall certainty of evidence was rated as very low. Therefore, the results, particularly the comparison between surgical platforms, should be interpreted cautiously because surgeon-directed selection of operative approaches may have introduced confounding and selection bias. Nevertheless, the findings may inform preoperative patient counseling, surgical risk assessment, and operating room scheduling. Future prospective comparative studies should systematically document the intended surgical approach, platform selection, treatment-associated hilar fibrosis, reasons for conversion, and perioperative outcomes to determine whether robotic instrumentation improves the feasibility of completing minimally invasive pulmonary resections following neoadjuvant ICI-based therapy.

FUNDING

The authors declare that no financial support or external funding was received for the research, authorship, and/or publication of this article.

CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial, financial, or personal relationships that could be construed as a potential conflict of interest.

AUTHOR CONTRIBUTIONS

Stevano Mengko, Pedro Sutrisno and Elia Afry Parlindungan Hutapea contributed to the conceptualization, theoretical development, literature synthesis, and analytical interpretation of the study. Both authors participated in drafting, reviewing, and revising the manuscript, approved the final version for publication, and agreed to be accountable for the integrity and accuracy of the work.

GENERATIVE AI STATEMENT

The authors declare that generative artificial intelligence (AI) tools were used solely to assist in improving the clarity, language, and grammatical structure of the manuscript. Generative AI was not used to generate the conceptual arguments, theoretical analysis, analytical findings, or scholarly conclusions presented in this study. All AI-assisted content was critically reviewed and verified by the authors, who retain full responsibility for the accuracy, originality, integrity, and final content of the manuscript.

REFERENCES

- Aburaki, R., Fujiwara, Y., Chida, K., Horita, N., & Nagasaka, M. (2024). Surgical and safety outcomes in patients with non-small cell lung cancer receiving neoadjuvant chemoimmunotherapy versus chemotherapy alone: A systematic review and meta-analysis. *Cancer Treatment Reviews*, 131, 102833. <https://doi.org/10.1016/j.ctrv.2024.102833>
- Bendixen, M., OD, J., Kronborg, C., Andersen, C., & PB, L. (2016). Postoperative pain and quality of life after lobectomy via video-assisted thoracoscopic surgery or anterolateral thoracotomy for early stage lung cancer: a randomised controlled trial. *Lancet Oncol*, 17(6), 836–844. [https://doi.org/10.1016/S1470-2045\(16\)00173-X](https://doi.org/10.1016/S1470-2045(16)00173-X)
- Bray, F., Laversanne, M., Sung, H., Ferlay, J., RL, S., & Soerjomataram I. (2024). Global cancer statistics 2022: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries. *CA Cancer J Clin*, 74(3), 229–263. <https://doi.org/10.3322/caac.21834>
- Cascone, T., MM, A., JD, S., He, J., Lu, S., & Sepesi B. (2024). Perioperative Nivolumab in Resectable Lung Cancer. *N Engl J Med*, 390(19), 1756–1769. <https://doi.org/10.1056/NEJMoa2311926>
- Chu, N.-Q., Tan, K. S., Dycoco, J., Adusumilli, P. S., Bains, M. S., & Bott, M. J. (2025). Determinants of successful minimally invasive surgery for resectable non-small cell lung cancer after neoadjuvant therapy. *The Journal of Thoracic and Cardiovascular Surgery*, 169(3), 753-762.e6. <https://doi.org/10.1016/j.jtcvs.2024.08.012>
- JV, H., Harpole, D., Mitsudomi, T., JM, T., Galffy, G., & Hochmair M. (2023). Perioperative Durvalumab for Resectable Non-Small-Cell Lung Cancer. *N Engl J Med*, 389(18), 1672–1684. <https://doi.org/10.1056/NEJMoa2304875>
- Li, H.-J., Ding, J.-Y., Nie, Q., Hong, H.-Z., Qiu, Z.-B., & Fu, R. (2025). Advantages of robotic-assisted thoracic surgery after neoadjuvant therapy in NSCLC: A propensity score-matched analysis. *European Journal of Surgical Oncology*, 51(8), 110022. <https://doi.org/10.1016/j.ejso.2025.110022>
- Lim, E., RA, H., HE, M., TJ, B., Dunning, J., & Shackcloth M. (2022). Impact of video-assisted thoracoscopic lobectomy versus open lobectomy for lung cancer on recovery assessed using self-reported physical function: VIOLET RCT. *Health Technol Assess*, 26(48), 1–162. <https://doi.org/10.3310/THBQ1793>
- Pan, H., Chen, H., Kong, W., Ge, Z., Zhang, J., & Tian, Y. (2025). Minimally invasive surgery could be attempted with preoperatively predictable difficulty for non-small cell lung cancer after neoadjuvant immunochemotherapy: A large multicenter study. *Surgery*, 184, 109458. <https://doi.org/10.1016/j.surg.2025.109458>
- PM, F., JD, S., Provencio, M., Mitsudomi, T., MM, A., & Wang C. (2025). Overall Survival with Neoadjuvant Nivolumab plus Chemotherapy in Lung Cancer. *N Engl J Med*, 393(8), 741–752. <https://doi.org/10.1056/NEJMoa2502931>

- PM, F., Spicer, J., Lu, S., Provencio, M., Mitsudomi, T., & Awad MM. (2022). Neoadjuvant Nivolumab plus Chemotherapy in Resectable Lung Cancer. *N Engl J Med*, 386(21), 1973–1985. <https://doi.org/10.1056/NEJMoa2202170>
- Pohlman, A., Marten, A. D., Coughlin, J. M., Lubawski, J., Raad, W., & Abdelsattar, Z. M. (2026). Impact of Neoadjuvant Therapy, Tumor Size, and Surgical Approach on Conversion to Open Thoracotomy During Lobectomy. *The Annals of Thoracic Surgery*, 122(4), 948–956. <https://doi.org/10.1016/j.athoracsur.2026.03.046>
- Provencio, M., Nadal, E., JL, G.-L., Martínez-Martí, A., Bernabé, R., & Bosch-Barrera J. (2023). Perioperative Nivolumab and Chemotherapy in Stage III Non-Small-Cell Lung Cancer. *N Engl J Med*, 389(6), 504–513. <https://doi.org/10.1056/NEJMoa2215530>
- Shah, S. K., Khan, A. A., Basu, S., & Seder, C. W. (2025). Minimally Invasive Pneumonectomy vs Open Pneumonectomy: Outcomes and Predictors of Conversion. *The Annals of Thoracic Surgery*, 119(3), 634–642. <https://doi.org/10.1016/j.athoracsur.2024.07.027>
- Spicer, J. D. (2024). Neoadjuvant pembrolizumab plus chemotherapy followed by adjuvant pembrolizumab compared with neoadjuvant chemotherapy alone in patients with early-stage non-small-cell lung cancer (KEYNOTE-671): a randomised, double-blind, placebo-controlled, phase 3 trial. *The Lancet*, 404(10459), 1240–1252. [https://doi.org/10.1016/S0140-6736\(24\)01756-2](https://doi.org/10.1016/S0140-6736(24)01756-2)
- Tajè, R., Gallina, F. T., & Spicer, J. D. (2026). Stage II Non-Small Cell Lung Cancer: Upfront Surgery or Neoadjuvant Chemoimmunotherapy. *The Annals of Thoracic Surgery*. <https://doi.org/10.1016/j.athoracsur.2026.05.037>
- Wakelee, H., Liberman, M., Kato, T., Tsuboi, M., SH, L., & Gao S. (2023). Perioperative Pembrolizumab for Early-Stage Non-Small-Cell Lung Cancer. *N Engl J Med*, 389(6), 491–503. <https://doi.org/10.1056/NEJMoa2302983>
- Wang, M. (2025). Conversion surgery for initially unresectable stage III non-small cell lung cancer after induction treatment of immunochemotherapy: A multicenter study. *Clinical Lung Cancer*, 26, e131-e140.e1. <https://doi.org/10.1016/j.clc.2024.11.005>
- WD, T., Dacic, S., Wistuba, I., Sholl, L., Adusumilli, P., & Bubendorf L. (2020). IASLC Multidisciplinary Recommendations for Pathologic Assessment of Lung Cancer Resection Specimens After Neoadjuvant Therapy. *J Thorac Oncol*, 15(5), 709–740. <https://doi.org/10.1016/j.jtho.2020.01.005>
- Yang, Z., Wang, S., Yang, H., Jiang, Y., & Zhu, L. (2024). Treatment patterns and clinical outcomes of patients with resectable non-small cell lung cancer receiving neoadjuvant immunochemotherapy: A large-scale, multicenter, real-world study (NeoR-World). *The Journal of Thoracic and Cardiovascular Surgery*, 168(4), 1245-1258.e17. <https://doi.org/10.1016/j.jtcvs.2024.02.006>