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Systematic Review

Financial burden of complications in lung resection surgery: scoping review

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Abstract

Background: Lung resection surgery is a common procedure in the treatment of lung cancer. It has been associated with a high cost burden, with complications considered a substantial contributor to associated expenses. This review sought to understand and describe the financial burden associated with complications of lung resection surgery.

Methods: Key databases (Ovid MEDLINE and Embase, Cochrane CENTRAL) were searched up to 14 October 2024. Studies reporting on costs of at least one complication of lung resection surgery, including lobectomy, wedge resection, segmentectomy, sleeve resection, pneumonectomy, or a combination of these, were included. Following identification of eligible articles, all relevant data were extracted. Quality assessment tools, including the Scottish Intercollegiate Guidelines Network Checklists for Economic Evaluations and Cohort Studies and the Risk Of Bias In Non-randomized Studies—of Interventions tool, were used to confirm articles for inclusion.

Results: In all, 31 articles were identified for inclusion: 2 prospective and 29 retrospective studies. All lung-specific complications and all but one non-pulmonary complication were associated with increased hospitalization costs. Hospital expenses also increased with increasing numbers and grades of complications.

Conclusion: Substantial variation in the definitions of costs and complications across studies has rendered a comparison of findings between studies challenging. Greater uniformity in definitions and classifications of costs and complications in future studies will facilitate further characterization of the cost burden of specific complications.

Introduction

Lung cancer is the second most commonly diagnosed cancer globally[1,2] and remains the leading cause of cancer-related deaths in 93 countries[2]. In the USA, over 238 000 patients are diagnosed with lung cancer annually[3]. Surgical resection is widely regarded as the most effective treatment for lung cancer[2], especially for cancers detected at early stages, which are more amenable to curative surgery[4]. Recent advances in lung cancer screening protocols and guidelines[4], particularly the implementation of low-dose computed tomography imaging for screening high-risk individuals[1], have facilitated the early detection of the disease and contributed to a rise in the number of lung resections performed annually[2,4]. In the USA alone, over 56 000 such surgeries are performed each year, with 71% of these being lobectomies[3]. Lobectomy remains the most common surgical approach; however, other resection types, particularly wedge resections and, to a lesser extent, segmentectomies, are also common, and a smaller number of sleeve resections and pneumonectomies continue to be used in selected patients[3].

Lung resection surgery is a costly procedure[1], contributing to an annual national expenditure in the USA exceeding US $1.9 billion[5]. Given the substantial financial burden, reducing costs related to lung resection surgery has become a key priority and an ongoing area of research[5,6]. Various hospital-related lung resection surgery expenses have been examined in the literature with a view to finding ways to reduce them, including index admission costs, postsurgery emergency department visits, readmissions, and complications of surgery[4]. The literature suggests that, of these, the largest cost burden is due to complications of lung surgery[6,7].

To date, no published reviews have addressed the financial burden of all types of lung resection surgeries. A 2023 review[8] investigated the costs of thoracic surgery complications, including lobectomies; however, its scope was substantially different from that of the present article, with a greater focus on extrapulmonary procedures such as oesophagectomies and gastrectomies. Therefore, the aim of the present scoping review was to bridge this gap by understanding and quantifying the financial burden associated with complications specific to lung resection surgeries,

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including lobectomy, wedge resection, segmentectomy, sleeve resection, and pneumonectomy.

The primary objective of this review was to analyse and describe the costs associated with the type, number, and severity of complications arising from lung resection surgery. A secondary objective was to understand the association between these complications and key outcomes such as mortality, length of hospital stay, returns to theatre, admissions to the intensive care unit (ICU), and hospital readmissions.

Methods

Protocol, registration, and funding

This review has not been registered and a review protocol has not been published prior to completing the review. No sponsorship or funding was obtained.

Search strategy

A comprehensive search was conducted for relevant articles using the Ovid MEDLINE and Embase databases, as well as the Cochrane Central Register of Controlled Trials (CENTRAL) database. To ensure thorough coverage, the references of articles deemed eligible for inclusion in the review were examined. An extensive search of the grey literature was also undertaken, including Google, Google Scholar, websites of cancer and lung disease research organizations (American Lung Association[9], Lung Foundation Australia[10], Cancer Research UK[11], and The Institute of Cancer Research[12]), and clinical trials registries (ClinicalTrials.gov, International Standard Randomized Controlled Trial Number Registry, EU Clinical Trials Register, the Australian New Zealand Clinical Trials Registry, Brazilian Clinical Trials Registry, Chinese Clinical Trial Registry, Clinical Trials Registry—India, and the Pan African Clinical Trial Registry).

The search strategies used for the MEDLINE, Embase, and CENTRAL databases are available in the *supplementary methods*. The grey literature was searched using the following search terms: 'lung surgery', 'lung resection', 'lung', 'cost', 'expenditure', and 'complication'.

An initial search of all data sources was completed on 10 May 2024, and a further data search of the aforementioned databases and grey literature was completed on 14 October 2024. The review was conducted according to the PRISMA-ScR guidelines for scoping reviews[13]. The PRISMA checklist is available in the *supplementary methods*.

Inclusion and exclusion criteria

All published randomized controlled trials, cross-sectional studies, cohort studies, case reports, case series, posters, and grey literature reporting on the costs associated with complications of lung resection surgery were included. Exclusion criteria encompassed protocols for planned studies, abstracts, editorial articles, dissertations, and reviews, as well as studies where the full text or an English version was unavailable for access.

Studies were included if they contained information pertaining to patients undergoing lobectomy, wedge resection, segmentectomy, sleeve resection, pneumonectomy, or a combination of these interventions. Studies investigating other types of surgery were considered if they included specific data on the costs of complications related to lung resection surgery. Conversely, studies focused primarily on patients undergoing other surgical procedures, such as oesophagectomy, were excluded. Studies centred on lung resection surgery with a limited number of patients undergoing lung volume reduction surgery for chronic obstructive pulmonary disease were included in the analysis. However, studies with a greater focus on lung volume reduction surgery were excluded.

Outcomes

The primary outcome of interest was the hospital costs associated with complications arising from lung resection surgery. Studies that did not provide this information were excluded.

From the included studies, additional data on the following secondary outcomes were extracted: perioperative inpatient mortality or postoperative mortality up to a period of 10 years after the initial surgery; length of hospital stay; rate of return to theatre; length of stay in the ICU; rate and duration of unplanned ICU admissions; rate and duration of hospital readmissions after discharge; postoperative pain outcomes; quality-of-life outcomes; and requirement for allied health services in managing complications.

Study selection

The database searches were conducted by a single author (S.D.) and consequently exported into Covidence® (Veritas Health Innovation, Melbourne, VIC, Australia), a systematic review screening tool, which was used to manage citations throughout the screening process. The Covidence software automatically removed duplicate records. Three reviewers (S.D., F.C., and L.W.) then independently screened the titles and abstracts of all identified papers, classifying each as 'include', 'exclude', or 'unclear'. Articles classified as 'unclear' were reviewed by a fourth reviewer (P.L.-D.). 'Unclear' articles were then classified as 'include' or 'exclude'. Following the title and abstract screening, a pilot test was performed on a random sample of 50 articles. A κ statistic was calculated to assess the level of agreement between primary reviewers, ensuring strong inter-rater reliability.

Articles classified as 'include' then progressed to full-text screening. EndNote™ (Clarivate, Philadelphia, PA, USA) software was used at this stage to locate full-text articles and manage records. Two reviewers (S.D. and F.C.) independently completed the full-text screening. During this process, reasons for excluding were documented carefully; any discrepancies between the two reviewers were resolved by discussion and, where required, consultation with a third reviewer (L.W.). At the conclusion of the full-text screening, articles for final inclusion in the review were determined.

Data extraction

One author (S.D.) extracted data from all included studies and created a data extraction table, which was further reviewed by a second author (L.W.). From each study, all available data pertaining to the following outcomes was extracted: methodology and study characteristics (study design, aims, inclusion and exclusion criteria, sample size, dates of data collection, institution, country, sources of sponsorship); population demographics (age, sex, ethnicity, socioeconomic status, public or private health facility, private health insurance status, operative indication, treatment with neoadjuvant chemotherapy or radiotherapy, preoperative screening, health status, functional status, physical status and respiratory function); type of surgery (lobectomy, wedge resection, segmentectomy, sleeve resection, pneumonectomy, a combination of the above, or other); surgical approach (open, video-assisted, robotic, hybrid, or other); definitions of costs and complications within the study; incidence and costs of complications; and data related to perioperative or postoperative mortality, length of hospital stay, rate of return to theatre, rate and

duration of admission to the ICU, rate and duration of unplanned readmissions to hospital following discharge, postoperative pain outcomes, quality-of-life outcomes, and requirement for allied health services in managing complications.

Quality assessment

Quality assessment was independently completed by two authors (S.D. and L.W.) using the Risk Of Bias In Non-randomized Studies—of Interventions (ROBINS-I) tool[14] and the Scottish Intercollegiate Guidelines Network (SIGN) checklists for economic evaluations and for cohort studies (checklists 6 and 3, respectively)[15]. Only studies assessed as being of high or acceptable quality were retained for analysis to ensure that the conclusions drawn from the findings of this study are informed by evidence of acceptable quality.

Data analysis and synthesis

Data analysis was conducted using Microsoft Excel® (Microsoft Corporation, Redmond, WA, USA). Where published, costs associated with complications were identified in the studies. When these costs were not provided, they were computed by calculating the difference in costs between the groups of patients who did and did not experience the complication.

To ensure comparability between studies, all costs were converted into a single currency and inflation-adjusted to their January 2024 equivalent. First, expenses reported in other currencies were converted to US dollars using average annual currency exchange rates as reported by the Federal Reserve Bank of St. Louis[16,17]. For studies spanning a number of years, the average of the annual exchange rates for each year of cost data collection was used for conversion. Once all costs were expressed as US dollars, average annual adjustment rates reported by the United States Bureau of Labor Statistics Consumer Price Index Inflation Calculator[18] were used to further adjust costs to account for inflation, with all costs adjusted to their January 2024 equivalent. Where studies had specified a currency year for which adjusted costs were reported, where required, the annual conversion rates for the specified year served as the base exchange rate, along with adjustments for inflation. Where articles had already converted reported costs to an alternative currency, the year of conversion was used as the base currency year for further adjusting costs to their January 2024 US dollar equivalent. Where no currency year was specified, average annual conversion rates across all years for which the study had collected cost data were used for both currency conversion and inflation adjustment. Finally, all costs were converted from January 2024 US dollars to January 2024 euros (€), using the January 2024 monthly exchange rate as reported by the Federal Reserve Bank of St. Louis[17].

Summary tables of cost data by type, number, and grade of complications across all studies were then constructed. Data from any study that specified a singular cost value attributed to types, numbers, or grades of complications were recorded within the respective table. For studies that provided ranges of costs rather than specific values, these were recorded separately, but were not tabulated with specific costs to facilitate comparison of specific figures where reported. These findings were also summarized graphically as appropriate.

Results

Study selection

After removing duplicates, the literature search retrieved a total of 5138 records. *Figure 1* shows the process used for identifying, screening, and selecting eligible articles. Following this process, 31 studies were retained for analysis (*Table S1*). The selected studies contained information regarding the costs of at least one complication of lung resection surgery. This information was presented either as specified cost increases attributable to the complications or as overall costs for patients with and without these complications. The included studies reported data on at least one type of lung resection surgery, including lobectomy, wedge resection, segmentectomy, sleeve resection, pneumonectomy, or lung resection surgery in general.

Studies focusing on other types of resection surgeries were excluded unless cost data were reported in relation to the complications of lung resection surgery specifically, as in the study of Pan *et al.*[19]. Similarly, studies focusing on or including a substantial proportion of lung volume reduction surgery procedures were excluded; however, one study[20] in which lung volume reduction surgery accounted for < 0.5% of the procedures performed was included because lung resection surgery was its primary focus. No studies that had initially met the inclusion criteria were excluded.

Study characteristics

The 31 articles included in the analysis comprised 10 cohort studies, 18 cross-sectional studies, 1 hybrid study consisting of cross-sectional and cohort study components, 1 case series, and 1 randomized controlled trial. Twenty-nine studies were completed retrospectively, and two were prospective. Most studies were completed in the USA (18)[19–36], with the remainder conducted in China (5)[37–41], the UK (4)[7,42–44], Austria (1)[45], Japan (1)[46], France (1)[47], and Spain (1)[48]. Most studies used data from nationwide and other large multihospital databases[19,20,24,25,28,30–32,35,36] or hospital-level data obtained from multihospital databases[22,26,27,33,41,47]. The remaining studies obtained hospital-level data directly from health services. Overall, the studies contained data collected over a period spanning from 1994[34] to 2021[39,40].

The inclusion criteria of individual studies were broad and frequently included lung cancer having been the indication for surgery, the requirement for patients to be aged ≥ 18 years, specific surgical approaches (such as video-assisted, robotic, or open), and specific resection types. With the exception of one study[19] that did not specify which types of lung resection surgery were included , all studies reported a substantial proportion of patients undergoing lobectomies. The specific resection types included in each study are reported in *Table S1*. Most studies[7,19,22,24,25,28–32,35–37,39,42,44,47,48] included procedures involving at least two combinations of open, video-assisted, and robotic approaches. One study[34] exclusively included patients undergoing open resections , whereas another[26] focused solely on patients receiving robotic surgery. Eight studies[27,33,38,40,41,43,45,46] focused exclusively on patients undergoing video-assisted surgery. A small number of studies did not specify any surgical approach. Exclusion criteria varied substantially between studies and frequently included factors such as missing data, patients' medical history and relevant co-morbidities, advanced stages of lung cancer, specific resection types, requirement for a converted surgical approach, source of patient admission, and discharge disposition. The sample sizes of patients undergoing lung resection surgery in the individual studies ranged from 11[40] to 123 044[19].

Patient demographics and other characteristics

Demographic data extracted included age, sex, ethnicity, socioeconomic status, nature of the health service (public or

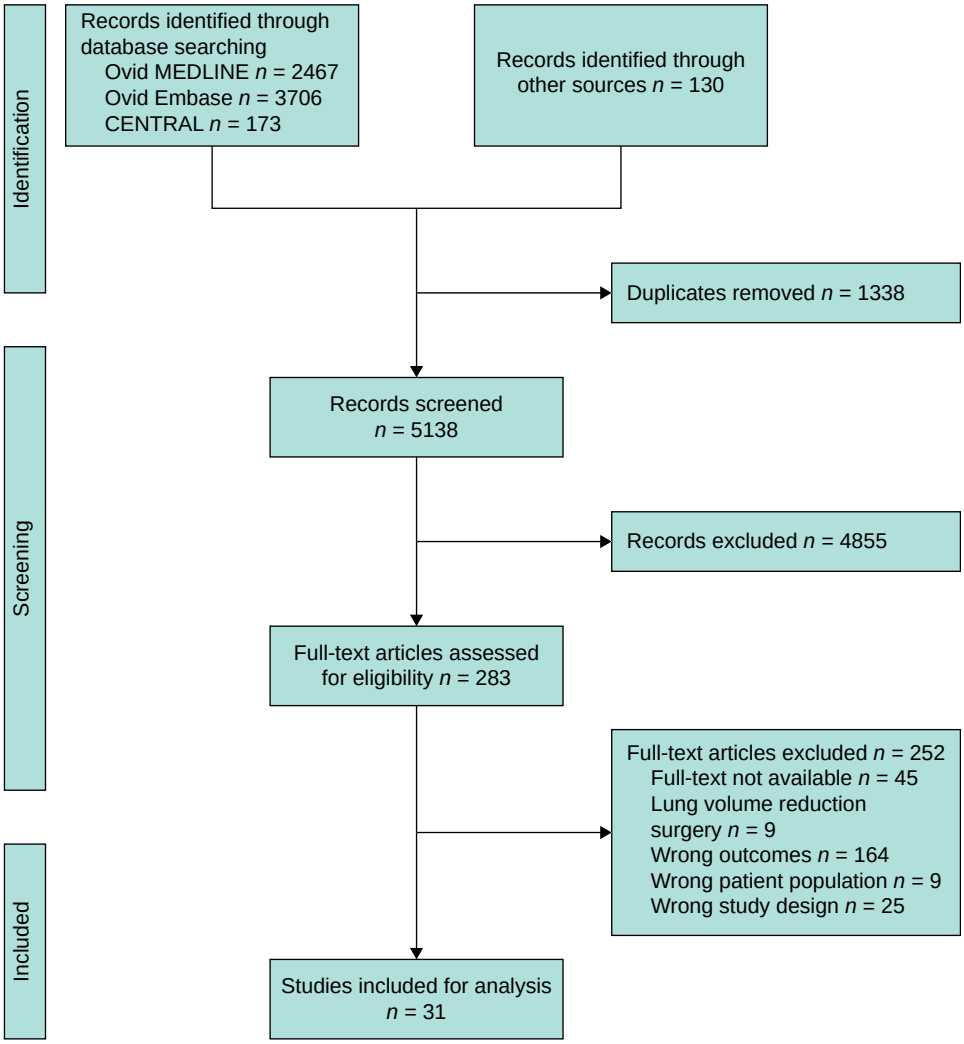

Fig. 1 PRISMA flow diagram

private), private insurance status, operative indication, use of neoadjuvant chemotherapy or radiotherapy, any information regarding preoperative screening, respiratory function, and patients' overall health, functional, or physical status. Not all studies indicated a mean or median age; for those that did, the values varied from 55.5 years[39] to 71 years[19]. All studies included both sexes; however, in some studies[34,40,48], one sex was represented substantially more than the other. Seven studies[20,22,25,27,28,31,33] provided information regarding patient ethnicity, with the majority classified as White or Caucasian and lower levels of representation from Black or African American, Asian, Hispanic, Native American, and other ethnicities. Almost no studies provided numerical data regarding patients' socioeconomic or private health insurance status. The operative indication across most studies was lung cancer, with some studies specifically including only patients with non-small cell lung cancer. Six studies[7,21,26,27,33,39] reported a proportion of patients receiving neoadjuvant chemotherapy at rates varying from 2.9%[26] to 22.7%[21]. Two studies[27,33] reported a small percentage of patients receiving neoadjuvant radiotherapy (3.4 and 6.1%, respectively). An additional five studies[23,29,38,45,46] reported that a proportion of patients received some form of neoadjuvant treatment but did not offer further details. Information regarding preoperative screening, respiratory function, and overall health and functional status varied widely across studies. Hence, these have not been summarized here.

Definitions and classification systems

The definitions and classification systems used to identify complications varied significantly among the 31 studies included in the analysis. Classification systems used included the Clavien–Dindo classification system[46], the Thoracic Morbidity and Mortality classification system, which incorporates the Clavien–Dindo system[7,38,42], and the International Classification of Diseases (9th or 10th revisions)[19,20,24,30,31,35,36]. *Table S1* summarizes the specific definitions of complications each study used.

The definitions of hospitalization costs also varied significantly across studies (*Table S1*). Some studies[22,34,38] focused solely on direct costs , whereas others[23,26,29,44] included both direct and indirect costs. Of the studies[7,22,23,42,43] that specified the inclusion of fixed or variable costs, all included both fixed and variable costs but many did not provide this information. Studies also varied, markedly in the methods used to calculate costs. Furthermore, some studies only provided cost information for the initial admission, whereas others[22,25,28,44] additionally reported costs for readmissions or an extended period of 90 days after the initial lung resection surgery.

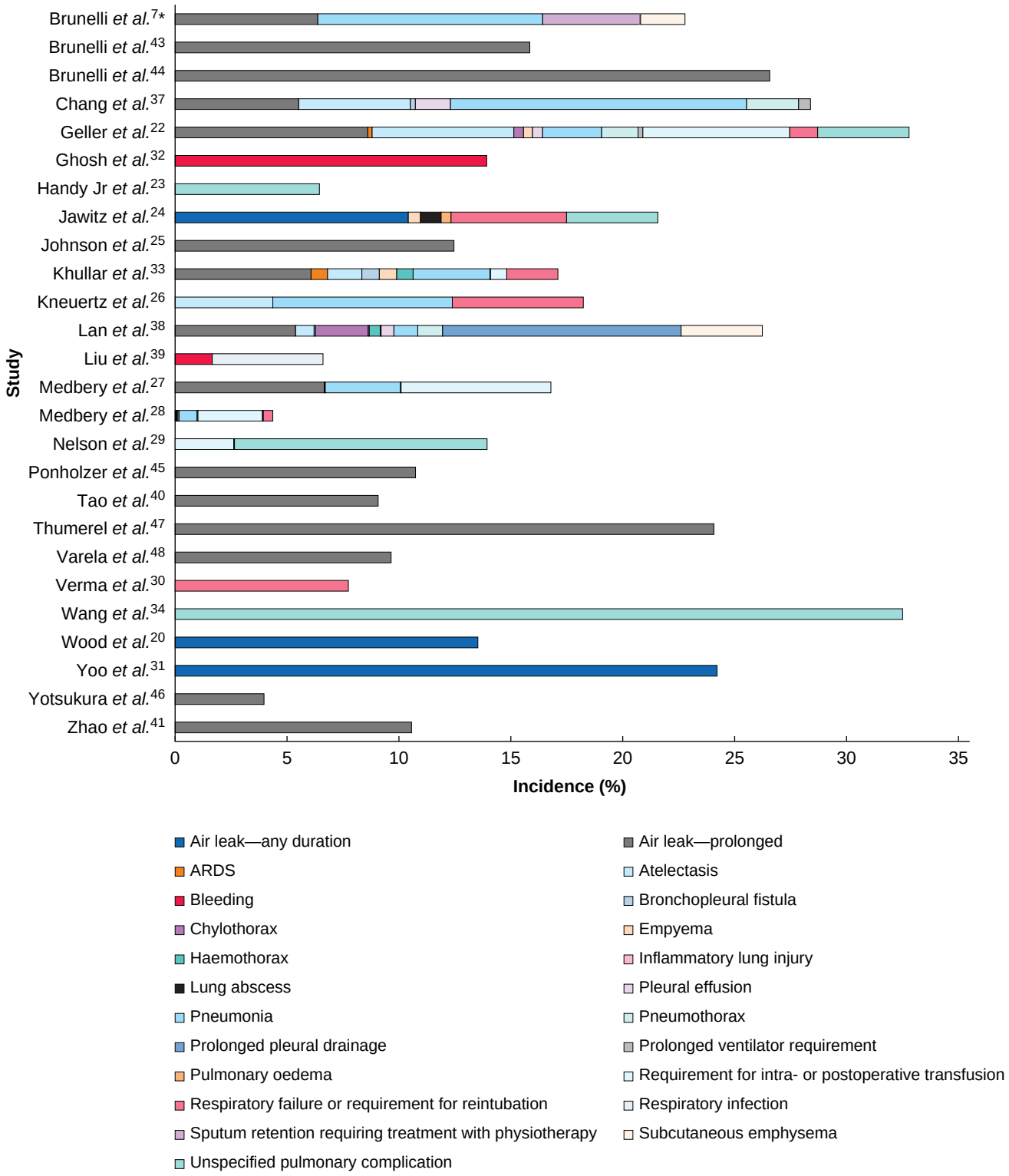

Fig. 2 Incidence of lung-specific complications

Categories have been standardized to facilitate comparison between studies. In addition, because most studies did not report numbers of patients who experienced more than one complication, this is not reflected in the overall incidence rates depicted here. *Minor complications study. ARDS, acute respiratory distress syndrome.

Incidence of complications

Most studies reported on at least one lung-specific complication. *Figure 2* illustrates the incidence of these complications within each study, expressed as a percentage of the overall study cohort. The incidence of complications was highly variable between studies. Some studies[31,44] focused on single complications, reporting relatively high incidence rates for each, whereas others reported lower incidence rates across a number of complications.

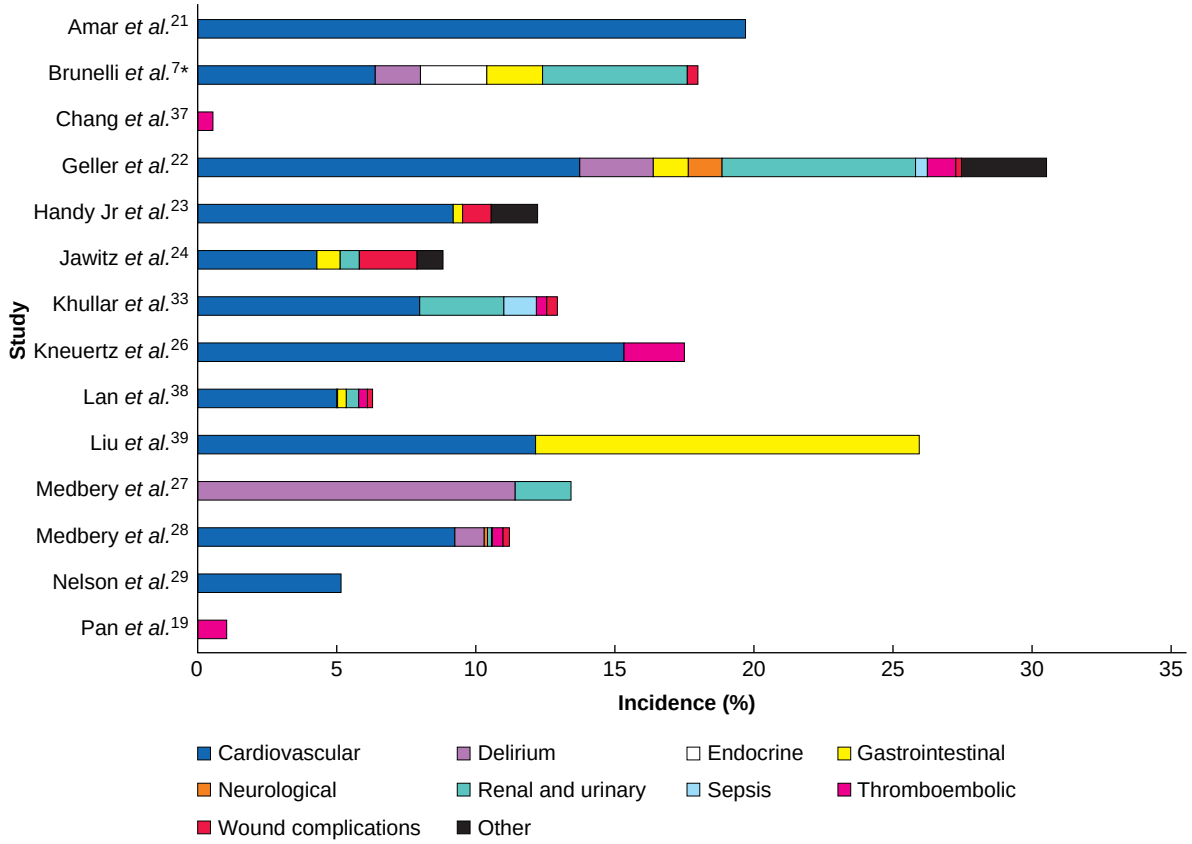

Fig. 3 Incidence of non-pulmonary complications

Categories have been standardized to facilitate comparison between studies. In addition, because most studies have not reported numbers of patients who experienced more than one complication, this is not reflected in the overall incidence rates shown here. *Minor complications study.

Figure 3 provides an overview of the incidence of non-pulmonary complications of lung resection surgery, which were investigated in less than half of the included studies. Of the non-pulmonary complications, cardiovascular complications were the most frequently reported. Most reported cardiovascular complications involved cardiac arrhythmias, including atrial, ventricular, or unspecified arrhythmias[7,21–23,26,28,33,38,39]. Other non-pulmonary complications included gastrointestinal complications (gastrointestinal bleeding, ileus, delayed gastric emptying, and abdominal distension), renal complications (acute kidney injury and electrolyte imbalances), urinary complications (urinary retention and urinary tract infection), neurological complications (recurrent laryngeal nerve injury), vascular complications (venous thromboembolism (pulmonary embolus or deep vein thrombosis), and central neurological events or cerebrovascular accidents), delirium, wound infection or other wound-related complications, sepsis, shock of unspecified cause, and a need for tracheostomy for unspecified reasons.

Cost data

Of the 31 studies included in the analysis, 20 reported costs in US dollars. Of these, four[37,42,43,46] had converted their cost data into US dollars from other currencies (Japanese yen[46], British pound sterling[42,43], and a non-specified, presumably Chinese currency[37]). Four studies collected and reported cost data in Chinese currencies, either renminbi[38,40,41] or yuan[39]. Three studies[45,47,48] collected and reported cost data in euros. Two studies[7,44] collected data in British pound sterling and reported the figures in euros. A number of studies[19,25,28,30,31,34,36] reported costs that had been inflation-adjusted to a specified year; this year was then considered the base year when further adjusting costs to their January 2024 equivalent. Two studies[22,29] reported costs as percentages rather than absolute figures.

Overall, all lung-specific complications substantially increased hospitalization costs (*Fig. 4*). The most expensive lung-specific complications were respiratory failure or a requirement for reintubation[28], empyema[28], and pneumonia[28]; notably, these figures were all reported in the same study, which investigated costs over a 90-day postoperative period, whereas most studies reported costs only for the index admission. The most expensive lung-specific complications reported by the other studies included intraoperative or postoperative transfusion[27], empyema[24], and prolonged air leak[35].

Prolonged air leak was the most extensively investigated complication in this review, with one-third of the included studies reporting data on its costs. Due to its prominence, these costs are summarized in *Table 1*. The reported costs and definitions of prolonged air leaks varied widely across studies. For example, Brunelli *et al.*[43] defined prolonged air leak as an air leak lasting for more than 5 days after surgery and reported an associated adjusted cost of €1800, whereas Swanson *et al.*[35] defined prolonged air leak as a pneumothorax with a length of hospital stay of more than 5 days and reported an adjusted cost of €20 188.

Compared with lung-specific complications, substantially fewer studies reporting on the costs of non-pulmonary complications were identified, with half of the non-pulmonary complications reported across all reviewed studies coming from a single study[28]. *Figure 5* summarizes the costs of these complications.

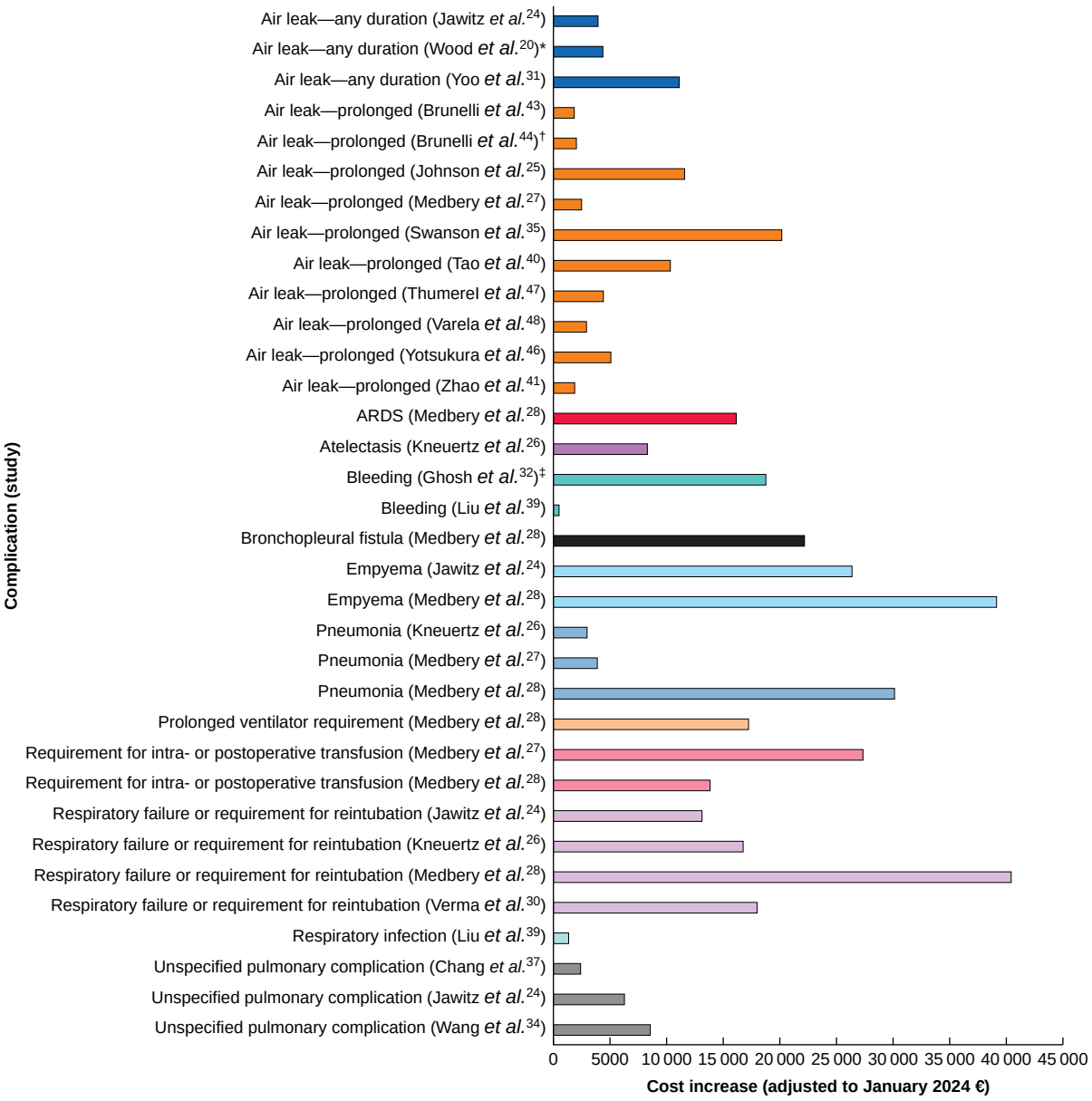

Fig. 4 Cost increase attributed to lung-specific complications

Categories have been standardized to facilitate comparison between studies. *Reported both mean and median values; mean values have been included here. †Figures include index admission costs only (readmission costs not included). ‡The figure represents the cost increase for 'significant' bleeding, defined as severe bleeding and a requirement for at least 3 units of blood products, including at least 1 unit of red blood cells. ARDS, acute respiratory distress syndrome.

Table 1 Additional costs associated with postoperative prolonged air leak

Reference	Definition of prolonged air leak	Cost increase associated with prolonged air leak* (€)
Brunelli *et al.*[43] (2018)	Air leak lasting over 5 days after surgery	1800
Brunelli *et al.*[44] (2020)†	Air leak lasting over 5 days after surgery	1988
Varela *et al.*[48] (2005)	Air leak lasting over 5 days after surgery	2921
Yotsukura *et al.*[46] (2022)	Air leak lasting over 5 days after surgery	5120
Zhao *et al.*[41] (2017)	Air leak lasting over 5 days after surgery	1872
Swanson *et al.*[35] (2014)	Pneumothorax with hospital stay over 5 days	20 188
Johnson *et al.*[25] (2023)	Postoperative air leak or pneumothorax with inpatient hospital stay over 5 days	11 622
Thumerel *et al.*[47] (2021)	Drain removal after postoperative day 5	4462
Medbery *et al.*[27] (2014)	Not specified	2486
Tao *et al.*[40] (2022)	Not specified	10 345

*All figures have been adjusted to January 2024 euros (€). †Index admission costs only.

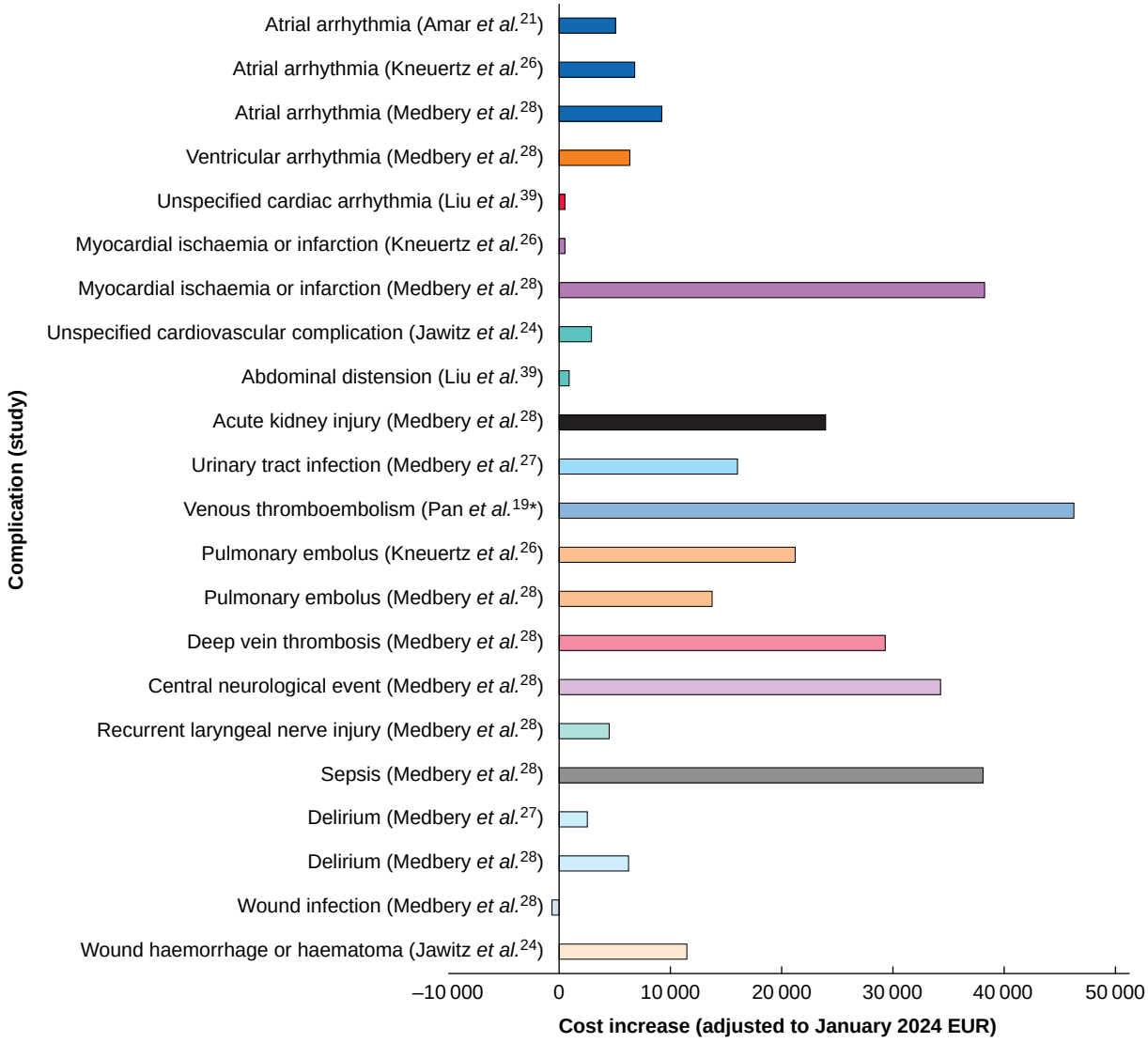

Fig. 5 Cost increase attributed to non-pulmonary complications

Categories have been standardized to facilitate comparison between studies. *Reported figures include index admission costs only. Costs related to both pulmonary embolus and deep vein thrombosis are included under venous thromboembolism.

Table 2 Summary of costs associated with increasing number of complications

No. of complications	Medbery *et al.*[28] (2021)		Brunelli *et al.*[42] (2017) (severe complications)		Khullar *et al.*[33] (2016)		Handy *et al.*[23] (2011)		Kneuertz *et al.*[26] (2019)	
	Total cost (€)	Added cost* (€)	Total cost	Added cost (€)	Total cost (€)	Added cost (€)	Total cost (€)	Added cost* (€)	Total cost (€)	Added cost (€)
0	42 350	n.a.	4200	n.a.	21 846	n.a.	25 849	0	n.a.	n.a.
1	59 120	14 204	5952	n.a.	29 793	n.a.	42 580	16 444	n.a.	6980
2	87 304	40 599	7249	n.a.	34 323	n.a.	65 226	37 511	n.a.	14 914
≥ 3	475 478	336 184	33 703	n.a.	70 990	n.a.	206 791	180 645	n.a.	48 098

Costs have been adjusted to January 2024 euros (€). *Figures based on predicted costs without complications. n.a., Not available.

All non-pulmonary complications were associated with increased hospitalization costs, with the exception of postoperative wound infection, which demonstrated costs lower by €664[28]. The non-pulmonary complication associated with the greatest cost increase was venous thromboembolism (including both pulmonary embolus and deep vein thrombosis)[19].

Several studies[23,26,28,33,42] specifically investigated the association between the number of complications and the increase in hospitalization costs. *Table 2* summarizes these findings, demonstrating an increase in both total hospital costs and additional costs associated with each additional complication up to three complications. Similarly, a few studies[7,38,42] investigated

Table 3 Summary of costs by Clavien–Dindo grade of complication

Complication grade	Lan et al.[38] (2021)		Brunelli et al. (2017) (Minor complications)[7]		Brunelli et al. (2017) (Severity of complications)[42]	
	Incidence (*n*)	Cost (€)	Incidence (*n*)	Cost (€)	Incidence (*n*)	Cost (€)
No complications	1943	8909	117	4476	272	4200
I	703	10 329	28	5997	57	5366
II			65	6410	108	5791
III	235	11 018	Excluded from study		29	7541
IV					17	17 162
V					20	20 876

Costs have been adjusted to January 2024 euros (€).

the impact of complication grade on hospital costs (*Table 3*), demonstrating increased costs with each increase in complication grade. However, these increments appeared less marked compared with the findings for the number of complications.

To identify additional factors that may be associated with cost-related findings, secondary analyses investigating any association of costs with factors such as surgical approach, geographical region of surgery, and time frames were completed. *Figure S1* shows variation in the costs of complications by surgical approach, incorporating data from all studies reporting on costs by type of complication for one specific surgical approach (open, robotic, or video-assisted surgery). *Figure S2* highlights variations in the cost of lung-specific complications by geographical region. A secondary analysis of the costs of non-pulmonary complications by geographical region was not undertaken because all but two studies reporting on these costs were conducted in the USA. Given the extensive investigation of prolonged air leak in the literature, there were sufficient data to undertake a more detailed exploration of the costs of prolonged air leak; *Fig. S3* summarizes the costs by geographical region and *Fig. S4* summarizes costs by the mean year of cost data collection. A linear regression line was applied to the findings in *Fig. S4* and demonstrated a small increase in costs over time. Owing to a lack of consistency in further demographic data reported in individual studies, further analysis investigating possible confounding factors was not possible.

Secondary outcomes

Secondary outcomes investigated in the studies included inpatient[20,23–25,27,30,31,33,34,40,41,43,47], 30-day[23,29,40,48], 60-day[26], and 90-day[29,38,44,47] perioperative mortality; length of hospital stay[7,19–24,26–41,43–48]; rate of return to theatre[26–29,33,45]; rate of any[21,27,33] or unplanned[27,42] admission to the ICU; and duration of admission to ICU[25,39]. Other outcomes investigated were the rate[25,29,30,35,44,47,48] and duration[19] of unplanned hospital readmission after discharge, postoperative pain[39], quality-of-life outcomes[30], and a requirement for allied health involvement in managing complications[7]. Where the original study had reported observed differences in secondary outcomes attributed to complications, these have been summarized in *Table S1*. Specifically, secondary outcomes that showed statistically significant associations with complications included inpatient perioperative mortality[25,30,31], length of hospital stay[7,20,21,30,31,34,37,39,41,43–46,48], rate of return to theatre[45], rate of admission to the ICU[21], duration of ICU admission[25], rate of unplanned readmission to hospital after discharge[30], and rate of non-home discharge destination[30]. No data were reported on mortality at 1, 5, or 10 years after surgery, or whether death was related to a primary lung cancer. In addition, no studies specifically reported on the duration of postoperative ICU admissions that were unplanned.

Quality assessment

A rigorous quality assessment was undertaken, using multiple appraisal tools where appropriate. First, all studies included in the review were assessed as being either acceptable or high quality in accordance with the SIGN checklist for economic evaluations[15]. Furthermore, all cohort studies and the single hybrid study with both cohort and cross-sectional study components were assessed as being either acceptable or high quality according to the SIGN checklist for cohort studies[15]. The single randomized controlled trial was also assessed by means of the Cochrane ROBINS-I tool[14] and was deemed appropriate for inclusion. An overview of the quality assessment of each study has been provided in *Table S2*.

Discussion

Overall, this scoping review revealed that complications following lung resection surgery are common and costly, emphasizing the significant focus on lung-specific complications in the existing literature. The majority of studies included in this review reported that a substantial proportion of patients experienced at least one lung-specific complication, with computed cumulative complication incidence rates exceeding 20% across many studies. However, these cumulative figures may be artificially inflated to some degree because most studies did not report on the number of patients who experienced more than one complication.

Further investigation found that, although all lung-specific complications of lung resection surgery were associated with an increase in the total cost of hospitalization, the cost burden of these complications varied substantially, ranging from an additional cost of €474 with postoperative bleeding[39] to an additional cost of €40 448 with respiratory failure or the requirement for reintubation[28]. This substantial variation in costs may be attributed to differences in the definitions of complications, the methodologies for calculating costs, and the length of the postoperative time frames over which cost data were collected. Consequently, direct comparisons across studies to identify the primary contributors to the overall cost burden of complications are challenging. Despite these limitations, certain lung-specific complications emerged as having the highest associated adjusted costs as reported in individual studies; these included respiratory failure or requirement for reintubation, empyema, and pneumonia. These findings align with expectations, given that managing these complications necessitates invasive ventilation and ICU admissions for respiratory failure, as well as prolonged

admissions with surgical treatment of empyema. Given these findings in the literature, it is surprising that there is limited published research investigating costs associated with these complications. This review identified only four studies that evaluated the costs associated with respiratory failure and reintubation, two that explored the costs of postoperative empyema, and three that investigated the costs of pneumonia following lung resection.

In contrast, this review identified a comparatively substantial body of literature investigating the costs associated with postoperative air leaks. Ten studies specifically examined the costs of prolonged air leaks, with an additional three exploring costs related to air leaks of undefined duration. Although prolonged air leak was reported to have relatively low associated costs across most studies, with the exception of one study[35] that reported a cost increase of €20 188, this complication remains a significant topic of interest because of its relatively high incidence and its associated risk of developing further serious complications[41], including both empyema and pneumonia[25,46]. One study[46] included in the review revealed that patients with a prolonged air leak were significantly more likely than those without to develop other complications, the most common of which was empyema. The use of various lung sealants and other measures to reduce the occurrence of, and costs associated with, prolonged air leak is attracting growing attention from researchers[25], although an evaluation of the financial impact of these prophylactic measures was outside the scope of the present review.

In comparison with lung-specific complications, the literature included few studies on non-pulmonary complications and their costs. Less than half of the reviewed studies detailed the incidence of non-pulmonary complications, and only seven commented on their costs. Furthermore, a substantial amount of the non-pulmonary complication-related cost data presented in this review was sourced from a single study[28] because of the scarcity of more extensive published data. Importantly, that study[28] reported on costs over a 90-day postoperative period; this will have likely led to some of the costs reported in this review appearing inflated compared with reports from other studies on the index admission costs of non-pulmonary complications.

This scoping review is therefore limited in its ability to comment on the specific non-pulmonary complications that most significantly contribute to the cost burden associated with lung resection; further original research in this area is required. Nevertheless, the review does summarize preliminary data demonstrating that non-pulmonary complications following lung resection surgery are costly; for example, an additional index admission cost of €46 357 associated with postoperative venous thromboembolism (including both pulmonary embolus and deep vein thrombosis) was reported in one study[19], although it is presently unclear whether the rate of these thrombotic events is higher than the rate of thrombotic events in patients with lung cancer being managed without surgery, given that cancer itself is a known risk factor for thrombosis. Overall, these findings suggest that non-pulmonary complications and their costs remain a worthwhile area for further investigation.

The length of hospital stay after lung resection surgery has been investigated extensively in the literature and nearly all reviewed studies reported on this secondary outcome; 14 studies[7,20,21,30,31,34,37,39,41,43–46,48] included in this review demonstrated a statistically significant increase in the length of hospital stay associated with complications. For example, a 10.58-day increase in length of hospital stay was reported for patients experiencing a prolonged air leak[45] and a 6.6-day increase was reported with even minor complications[7]. It is therefore likely that prolonged hospital stay is a compounding factor in the increased costs of hospitalization for patients experiencing postoperative complications. However, none of the reviewed studies provided specific information regarding the sources of increased costs associated with complications. It is therefore likely that further investigations into the contributions of specific cost components associated with the increased cost of complications will be an imperative next step in identifying opportunities to reduce the financial burden of lung resection surgery complications. Furthermore, although the authors sought to collect data on various other secondary outcomes, including ICU admissions and hospital readmissions, these factors were not investigated widely in the studies included in this review and are likely to be an important area for future exploration.

In addition to the aforementioned primary analyses, a series of secondary analyses was undertaken to investigate external and possible confounding factors that may affect the observed trends in cost data. Overall, however, the findings from these analyses suggest that it is presently difficult to draw meaningful conclusions from the data, particularly in relation to the costs specific to a particular surgical approach, or costs varying by geographical region, owing to a lack of extensive data within subcategories. The exception to this was in the case of prolonged air leak, given that this has been investigated more extensively in the literature. A comparison of costs of prolonged air leak by geographical region demonstrated substantial variation, ranging from €1800 in Europe (UK)[43] to €20 188 in North America (USA)[35]. However findings varied substantially both across and within geographical regions, and it is therefore presently unclear whether there is an association between prolonged air leak costs and specific geographical locations.

In addition to investigating the impact of geographical region, the availability of sufficient data allowed an exploration of any variation in costs of prolonged air leak over time, recognizing the inherent differences in clinical practice, political climates, and other factors with time. The findings from this analysis demonstrated a slight increasing trend in costs over time, but substantial variation in reported costs for studies completed within similar time frames renders the reliability of these findings unclear. Further research reporting on the costs of prolonged air leak will provide a greater understanding of temporal trends.

Overall, despite an extensive and systematic approach applied to searching and screening the literature, including a comprehensive search of multiple databases, national and international clinical trial registries, and the grey literature, this scoping review identified a relatively small number of relevant articles reporting on the costs of complications of lung resection surgery. This is likely to reflect the specific focus of this review on the financial burden of complications of lung resection surgery and the relative scarcity of research directly addressing this topic. Given the findings that lung resection surgery complications present a considerable additional cost to the healthcare system, this scoping review underscores the need for further research investigating both costs and ways to reduce them.

Broadly, the findings from this review contrast with those of previous literature, particularly in relation to specific complications identified as ‘high cost’. Before undertaking the present study, one published review[8] evaluating the costs of lung resection surgery complications was identified. The authors of that review provided a first review of the literature, specifically focused on patients undergoing thoracic surgery, including lobectomy, as well as other procedures such as oesophagectomy and

gastrectomy. Although both the previous[8] and present reviews identified venous thrombosis as a major contributor to the cost burden of complications, other costs highlighted in the previous review, including those associated with sepsis, cerebrovascular complications, and emphysema[8], were not identified as major contributors to cost burden in the present analysis. This observed variation is likely due to key differences in methodology, because costs reported across complications in the previous review are mean values computed from data across a number of studies. Although the present review adjusted all costs to a single currency and for inflation to facilitate comparison, the authors endeavoured to consider each reported cost individually, considering the marked variation in the nature of cost data reported across studies. As such, the authors believe the present scoping review has further complemented and clarified the current landscape with respect to understanding the financial burden of lung resection surgery.

This scoping review has certain limitations. First, the studies included in this review demonstrated substantial variation in their definitions of costs. Not all studies provided specific information regarding the nature of costs analysed, with some focusing solely on direct costs and others including indirect costs, such as hospital utility expenses (for example heating and lighting). In addition, some studies considered only index admission costs, whereas others also investigated readmissions or costs within a 90-day postoperative period. Similarly, the definitions and classifications of complications varied significantly. Some studies provided specific diagnostic criteria used to determine the presence or absence of a particular complication, whereas others did not.

Numerous studies investigated broad categories of complications such as 'postoperative pulmonary complications'; however, specific definitions regarding the types of complication considered under such categories varied between studies. Furthermore, although a small number of studies used the Clavien–Dindo and Thoracic Morbidity and Mortality classification systems to identify and describe complications, seven studies used the ninth or tenth revisions of the International Classification of Diseases, and the remaining studies did not use any formal classification system. Owing to these inherent interstudy variations, it was not possible to directly synthesize the data to obtain overall average costs attributable to each complication. As such, it is presently not possible to clearly identify the overall primary contributors to the cost burden of complications.

Future studies demonstrating greater uniformity in cost definitions and standardized time frames for collecting cost data will be beneficial in identifying which complications most significantly increase hospitalization costs, thereby providing greater information regarding worthwhile potential target areas for reducing the cost burden of complications. Furthermore, the standardized use of classification systems, along with uniform definitions and diagnostic criteria for complications, will provide a valuable future direction for studies in this area. As the body of literature focused on the cost burden of lung resection surgery complications continues to expand, with greater consistency in definitions and methodology across studies, there is likely to be greater scope to undertake a further systematic review with synthesis of results, as well as opportunities to incorporate sensitivity and subgroup analyses to increase the reliability of conclusions drawn. Future reviews focused on complications specific to different surgical approaches (open, video-assisted, or robotic) will also provide valuable insights, because the incidence and impact of complications may vary substantially with different surgical approaches. In addition, as the financial burden of lung resection surgery complications continues to grow as an area of research interest, studies investigating the long-term financial impacts of complications will provide valuable insights because, to date, no longitudinal studies have been identified in this area.

The findings from this scoping review underscore three main implications for clinical practice and possible policy changes. First, the findings suggest that a greater emphasis on prevention of complications is likely to be worthwhile. This may include preoperative care, including the optimization of preoperative assessments, such as identifying patients at higher risk of developing high-cost complications, and postoperative care, such as enhanced recovery protocols, as well as protocols for the early identification of, and interventions for, complications to minimize disease progression. These efforts are likely to be strengthened by involvement of multidisciplinary healthcare teams, such as the involvement of physiotherapy in promoting early mobilization and airway clearance techniques to reduce the occurrence of postoperative pneumonia.

Second, given that this review has shown that the complications of lung resection surgery are costly, an emphasis on further research into optimizing the prevention and management of complications identified as high cost is likely to be beneficial. In particular, the implementation of national or international cost data collection registries that will provide detailed and standardized information about the cost burden of complications will allow a greater understanding of complications associated with the highest costs, as well as any interhospital or regional variation in these, to inform clearer targets for improvement. Finally, the findings from this scoping review support the prioritization of funding for research with a focus on reducing the cost burden of complications, as well as financial incentives that reward health services for initiatives seeking to reduce complication rates.

This scoping review has demonstrated that complications following lung resection surgery contribute significantly to increased hospitalization costs. Future research with standardized definitions for both costs and complications will provide valuable insights into opportunities to reduce hospitalization costs following lung resection surgery.

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Author contributions

Suwandi Dewapura (Data curation, Formal analysis, Investigation, Methodology, Writing—original draft, Writing—review & editing), Fabien Chu (Formal analysis, Investigation, Writing—review & editing), Patryck Lloyd-Donald (Investigation, Writing—review & editing), Ella Francis (Formal analysis, Writing—review & editing), Junyang Zhao (Formal analysis, Writing—review & editing), Prabhashi Ratnayakemudiyanselage (Formal analysis, Writing—review & editing), Fawaz Prem Navaz (Formal analysis, Writing—review & editing), Chin Jin Ker (Formal analysis, Writing—review & editing), Elizabeth P. Hu (Formal analysis, Writing—review & editing), Sepideh Roshanaei (Formal analysis, Writing—review & editing), Jacques Elias (Formal analysis, Writing—review & editing), Nattaya Raykateeraroj (Formal analysis, Writing—review & editing), Ronald Ma (Formal analysis, Writing—review & editing), Stephen A. Barnett (Formal analysis, Writing—review & editing), Dong-Kyu Lee (Formal analysis, Writing—review & editing), Simon Knight (Formal analysis, Writing—review & editing), and Laurence Weinberg (Conceptualization, Data curation, Formal analysis, Supervision, Writing—original draft, Writing—review & editing)

Disclosure

The authors declare no conflict of interest.

Supplementary material

Supplementary material is available at *BJS Open* online.

Data availability

Because all data used to complete this review were sourced from published primary research, the summary data are not published in a public repository. A summary table of standardized cost data can be provided on request, if required.

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