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RESEARCH

# Long term survival with thoracoscopic versus open lobectomy: propensity matched comparative analysis using SEER-Medicare database



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## Abstract

**Objective** To compare long term survival after minimally invasive lobectomy and thoracotomy lobectomy.

**Design** Propensity matched analysis.

**Setting** Surveillance, Epidemiology and End Results (SEER)-Medicare database.

**Participants** All patients with lung cancer from 2007 to 2009 undergoing lobectomy.

**Main outcome measure** Influence of less invasive thoracoscopic surgery on overall survival, disease-free survival, and cancer specific survival.

**Results** From 2007 to 2009, 6008 patients undergoing lobectomy were identified (n=4715 (78%) thoracotomy). The median age of the entire cohort was 74 (interquartile range 70-78) years. The median length of follow-up for entire group was 40 months. In a matched analysis of 1195 patients in each treatment category, no statistical differences in three year overall survival, disease-free survival, or cancer specific survival were found between the groups (overall survival: 70.6% *v* 68.1%, P=0.55; disease-free survival: 86.2% *v* 85.4%, P=0.46; cancer specific survival: 92% *v* 89.5%, P=0.05).

**Conclusion** This propensity matched analysis showed that patients undergoing thoracoscopic lobectomy had similar overall, cancer specific, and disease-free survival compared with patients undergoing thoracotomy lobectomy. Thoracoscopic techniques do not seem to compromise these measures of outcome after lobectomy.

## Introduction

Lung cancer is the leading cause of death from cancer, and surgery is widely accepted as offering the best prospect of cure in patients with cancer amenable to resection.[1-3] As a result, operation with intent to cure is the established standard of care when the cancer is contained within one hemithorax and is within surgically removable anatomical limits, usually a pulmonary lobe. There is an impetus to increase resection rates,[4 5] with the best approach to lobectomy currently debated. Thoracoscopic lobectomy has been performed for more than 20 years, but its adoption has been slow and cautious despite the reported advantages of fewer complications and faster functional recovery compared with thoracotomy.[6-14] The oncologic efficacy of thoracoscopic lobectomy is challenged and is unfavorably compared to lobectomy through a thoracotomy.

Evidence is now accumulating to suggest that the less invasive thoracoscopic operation can be done safely and that the anticipated reduction in morbidity can be realized. However, reluctance to widespread adoption of thoracoscopic techniques exists; the opposing view is that thoracoscopic techniques compromise the oncologic quality of the operation. Resolution of that debate may require evidence from randomized trials in sufficient numbers and with long enough follow-up. Randomized controlled trials are virtually non-existent in lung cancer surgery, but large, comprehensive, and well kept databases exist.[4 5 15 16] The Surveillance, Epidemiology and End Results (SEER) program collects data on patients from 17 cancer registries in distinct geographic areas of the United States.[17] The program links these detailed data with Medicare data to create a large longitudinal cohort. We undertook an analysis of these data to gauge how great a difference might exist between thoracoscopic and thoracotomy approaches to lobectomy, what can be known from analysis of these available high quality observational data, and what are the remaining research questions that would have to be answered by a randomized trial.

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# Methods

## Data source

The SEER dataset includes patients' demographic, cancer diagnosis, and treatment related information, as well as cause of death. A program of the National Cancer Institute, SEER collects data from population based cancer registries covering approximately 28% of the US population. SEER maintains an internal quality control and improvement process to constantly refine, measure, and improve the quality and uniformity of data.[17 18] The SEER-Medicare dataset consists of registry data linked to Medicare hospital, outpatient, physician, home health, and hospice claims. Medicare insures approximately 97% of people older than 65 in the United States, allowing approximately 93% of that population in the SEER registry to be linked to the Medicare enrolment file.[18] The current release contains patients diagnosed as having cancer through 2009 linked to Medicare claims through 2010, with enrolment and survival data through 2011.[16]

## Study cohort

Medicare patients over 65 years of age who underwent a lobectomy in the time period from one month before to six months after diagnosis of a first primary non-small cell lung cancer from 2007 to 2009 were eligible for inclusion in this study. We chose these years because the code for thoracoscopic lobectomy (ICD-9-CM code 32.41) became available in 2007. We excluded patients with previous diagnoses of primary cancer. To ensure completeness of data, we included only patients who were continuously enrolled in Medicare Part A and Part B and not enrolled in a health maintenance organization from diagnosis until death or two year follow-up (fig 1⇓). We considered patients who changed enrolment status after that time to be censored at their dropout date. Follow-up time ranged from two to five years; median follow-up time for the cohort was 3.3 (range 2.6-4.1) years and was determined using the censoring distribution.[19]

## Outcomes

We defined overall survival as time from surgery until death from any cause, with patients censored at the end of the study (December 31, 2011) or the end of their enrolment. SEER provides information about disease specific cause of death, allowing us to determine cancer specific survival; in this case, patients are additionally censored at the time of a non-disease related death. Recurrent disease is not identified directly in the SEER-Medicare database. We determined treated recurrences with methods validated by Lund et al, by identifying patients receiving chemotherapy more than six months post-surgery.[20] Disease free survival in our case is the time until treated recurrence is identified or cancer specific death. We assessed additional in-hospital outcomes as previously described.[6]

## Variables

We categorized patients by disease, site, demographic, and surgery specific variables provided in the SEER registry, including stage (Derived AJCC Stage Group, 6th ed), histology (adenocarcinoma, adenosquamous, squamous, bronchioloalveolar carcinoma, other), side, site (lower, middle, upper lobe), tumor size (mm) and number of nodes examined, age on surgery date, year of procedure, sex, race (black, white, other), marital status at diagnosis, metropolitan area (rural, urban), and zip code per capita income (quarters). We defined extent of lymph node dissection as fewer than 12 versus 12 or more lymph nodes by using the European Society of Thoracic Surgeons' guidelines and previous SEER analyses, which advise the removal of three hilar lymph nodes and three nodes from at least three mediastinal lymph node stations.[21-24] Additionally, we identified patients with a diagnosis of diabetes, hypertension, congestive heart failure, coronary artery disease, peripheral vascular disease, or chronic pulmonary disease during the index hospital admission and/or six months previously by using Elixhauser's published measures.[25]

## Statistical analysis

In observational studies, in which participants are not randomized to treatment groups, propensity score matching can be used to reduce selection bias by creating cohorts of patients who are similarly likely to receive a treatment on the basis of measured baseline characteristics. In this study, we created the probability for receiving a thoracoscopic procedure, or propensity score, by using logistic regression based on potential confounding variables, including age, sex, race, stage, site, histology, tumor size, diagnosis of diabetes, hypertension, congestive heart failure, coronary artery disease, peripheral vascular disease, hypertension, hospital volume, and metropolitan location. We did not create propensity scores for the 2.3% of patients missing key covariates. We then created a balanced cohort by using a one to one nearest neighbor matching algorithm that pairs patients who have the closest propensity score, within a defined limit.[26] Only patients who are matched are included. We used the logit of the propensity score for matching, with a caliper of 0.2 times its standard deviation as recommended by Austin.[27 28] We used the absolute difference and post-match C statistic to assess balance.[29]

We compared samples' characteristics, in-hospital mortality, and complications in the raw sample by using *t* tests, $\chi^2$ squared tests, and Wilcoxon rank sum tests as appropriate. In the matched cohort, we used paired *t* tests, McNemar's tests, and the Wilcoxon signed rank tests. We used Kaplan-Meier life tables, independent and paired sample log rank tests, and Cox proportional hazards models to examine survival rates between the two treatment groups in the full sample and matched cohort. Hospital level clustering and the propensity matched study design were accounted for with marginal model analysis using the id statement of the SAS PHREG procedure and sandwich covariance matrix estimation.[30] All analyses were carried out using SAS 9.3.

# Results

## Patients

From 2007 to 2009, we identified 6008 patients with non-small cell lung cancer undergoing lobectomies, 4715 (78%) of which were performed by thoracotomy (table 1⇓). Table 1⇓ lists patients' demographics, comorbidities, and tumor characteristics. Patients undergoing thoracoscopic lobectomy were older, were more likely to be female, had higher median incomes, and were more likely to have surgery in a metropolitan centre (91.9% *v* 82.3%, P<0.001). These patients also had a lower prevalence of coronary artery disease (28.1% *v* 31.3%, P=0.03), congestive heart failure (2.9% *v* 4.8%, P=0.003), and chronic pulmonary disease (50.6% *v* 60.6%, P<0.001) compared with those undergoing open lobectomy (table 1⇓). Histologic characteristics of the tumors were similar between the two groups; most patients had adenocarcinoma or subtypes of adenocarcinoma (table 1⇓). However, some distinctions between the two groups were apparent. Patients who underwent thoracotomy lobectomy had higher rates of pathologic stage II and III tumors resected (24.3%

*v* 29.9%, P=0.002). These patients also had larger tumors resected than did those who underwent thoracoscopic lobectomy. Patients undergoing thoracotomy lobectomy also had higher rates of squamous cell carcinoma resected (35.2% *v* 28.4%, P<0.001).

The matched cohort consisted of 1195 patients in each treatment category, and balance was achieved on the basis of available variables (C=0.538). Patients who underwent thoracoscopic lobectomy had more lymph nodes harvested than did those who underwent thoracotomy lobectomy in the full (mean 20.1 *v* 17.7, P=0.005) and matched (mean 19.9 *v* 17.6, P=0.03) cohorts. Furthermore, a significantly greater proportion of patients had at least 12 nodes resected (37.1% *v* 29.1%, P<0.001) (table 2⇓).

## Morbidity and mortality

Postoperative complications occurred in 629/1293 (48.7%) of patients in the thoracoscopic group and 2564/4715 (54.4%) of patients in the thoracotomy group (584/1195 (48.9%) *v* 642/1195 (53.7%) in the matched cohort). Comparisons of outcomes in the full and matched cohorts showed that thoracoscopic lobectomy patients had decreased rates of postoperative arrhythmias, pneumonia, atelectasis, need for mechanical ventilation, and sepsis (table 2⇓). Patients undergoing thoracoscopic lobectomy had a shorter length of stay compared with those undergoing thoracotomy lobectomy (5 *v* 7 days, P<0.001) and lower in-hospital mortality rates (25/1195 (2.1%) *v* 43/1195 (3.6%), P=0.03).

## Overall, cancer specific, and disease-free survival

The median follow-up for the entire group was 40 months (36 months for thoracoscopic lobectomy and 42 months for thoracotomy lobectomy). In the matched cohort, follow-up was 36 months for both groups. In our unmatched analysis, overall survival, cancer specific survival, and disease-free survival were longer in patients undergoing thoracoscopic lobectomy than in those undergoing thoracotomy lobectomy for the entire cohort (three year overall survival 71.2% *v* 63.8%, P<0.001; three year cancer specific survival 92.1% *v* 84.7%, P<0.001; three year disease-free survival 86.5% *v* 77.6%, P<0.001) (fig 2⇓). However, in our propensity matched cohort, we found no statistically significant difference in overall survival, cancer specific survival, or disease-free survival for the matched groups (three year overall survival 70.6% *v* 68.1%, P=0.55; three year cancer specific survival 92% *v* 89.5%, P=0.05; three year disease-free survival 86.2% *v* 85.4%, P=0.46) (fig 2⇓).

We used Cox proportional hazards models accounting for clustering to compare the two treatment groups. In the full cohort, we found significantly lower hazard ratios for overall (hazard ratio 0.74, 95% confidence interval 0.66 to 0.83), cancer specific (0.47, 0.37 to 0.60), and disease-free survival (0.58, 0.49 to 0.69) (fig 3⇓). In our matched cohort, we also found lower hazard ratios for all three outcomes; however, only the difference in cancer specific survival was statistically significant (hazard ratio for overall survival 0.90, 0.78 to 1.04; cancer specific survival 0.74, 0.56 to 0.97; disease-free survival 0.86, 0.69 to 1.07).

# Discussion

Our propensity matched based analysis of long term overall, cancer specific, and disease-free survival after lobectomy suggests that patients undergoing thoracoscopic lobectomy have a similar survival to those undergoing lobectomy by thoracotomy. Thoracoscopic lobectomy does not seem to compromise the measured survival outcomes after lobectomy for lung cancer.

## Implications of findins

Our results support and substantially advance the previous analysis of several institutional case series and an examination of the Danish lung cancer registry.[11 31 32] In these studies, thoracoscopic lobectomy was found to be non-inferior to open lobectomy with respect to overall survival. However, the concerns about this new technology remained as the studies had fewer patients and may have been underpowered to detect a difference. Recent studies have also questioned the completeness of the lymph node dissection by a minimally invasive approach, which was not evident in our analysis.[33]

Whenever thoracotomy is put up as the gold standard against which procedural differences for thoracoscopic resection are compared, we should remember that the practice of lung resection for lung cancer is not based on randomized evidence. No large randomized studies have been done in any directly comparable patient group that show resection to be superior to non-resection.[2 3] Before modern imaging, five year survival was between 25% and 30% and improved to about 50% with exclusion of patients who were "staged" as incurable.[34 35] Despite the lack of large randomized trials, surgical resection remains the current standard for the treatment of early stage lung cancer. Given the possible inherent biases of both a minority of surgeons and probably most patients toward less invasive surgeries, making a randomized comparison between the two methods is difficult, but such a trial (VIOLET: video assisted thoracoscopic lobectomy versus conventional open lobectomy for lung cancer) is due to open in the UK.[36] In the absence of evidence from such a trial, we did a population based analysis using the SEER-Medicare database to compare long term survival in patients undergoing thoracoscopic versus thoracotomy lobectomy.

The conventional criticism of our analysis might be that patients undergoing thoracotomy for lobectomy have larger tumors, more central tumors, and more advanced stage of disease than those undergoing thoracoscopic procedures, so their survival is expected to be worse. However, we used propensity scores to create comparable cohorts; in our propensity matched analysis, no significant difference was apparent in overall, cancer specific, or disease-free survival between the two groups. The small benefit seen in cancer specific survival in favor of thoracoscopic lobectomy in our Cox proportional hazards model can be attributed to the lower mortality early after thoracoscopic surgery.

In contrast to previous reports suggesting that patients undergoing thoracoscopic lobectomy had inferior nodal harvesting, we found that patients undergoing thoracoscopic lobectomy had more lymph nodes resected than did those undergoing open surgery. The reason for this is not certain, but it could be that thoracoscopic surgeons are generally more experienced in thoracic surgery and work in larger and more specialist practice, leading to more thorough nodal dissection. Previous reports have shown that less than half of all of lobectomies performed in the United States are done by general thoracic surgeons specialized in pulmonary resection, resulting in many resections having incomplete mediastinal staging.[37 38] Our results should be interpreted with this in mind; SEER-Medicare samples represent the generalizable spectrum of cases in the United States performed by general and cardiothoracic surgeons alike.

From a technological perspective, thoracoscopic lobectomy and other minimally invasive surgical procedures represent a paradigm shift in surgery. By decreasing the physiologic insult from surgery, minimally invasive surgery expands the pool of operable patients to those previously considered potentially inoperable due to age and comorbidities. It also removes the surgeon from direct manipulation of patients' tissues. Those who have adopted and practice newer less invasive technologies argue that they allow for greater precision in the surgical manipulation of tissue.[6] Adoption of minimally invasive surgery is not uniform, at least in the United States where rates of minimally invasive surgery vary widely by region.[39]

Our analysis shows a trend toward improved survival with a thoracoscopic lobectomy.. The trend may be due to the early mortality benefit seen with thoracoscopic lobectomy or selection biases (unknown confounders) that cannot be controlled for in our propensity matching. A randomized controlled trial would be ideal to answer these and other unresolved questions regarding thoracoscopic lobectomy. However, it is unclear whether such a large scale trial can be completed with the inherent biases of both patients and surgeons in favor of new technology. VIOLET, a multicenter randomized controlled trial with an internal pilot study, as proposed from the Royal Brompton and Harefield NHS Foundation Trust, may be able to answer some of the critical questions along with its primary objective of comparing functional outcomes after thoracoscopic and open lobectomy.[36] That such a trial has not been performed to date in thoracic oncology is disappointing, as other surgical disciplines such as colorectal surgery have focused on conducting large randomized controlled trials comparing laparoscopic with open surgery for colorectal carcinoma.[40 41] Inherent biases from large volume centers that favor one or other technique, such that equipoise would be lost in a randomized controlled trial, or marketing pressure to offer minimally invasive surgery as has been suggested in the case of robotic surgery are possible explanations.[42] We believe that various solutions such as randomized controlled trials using clustering of surgical techniques on a large scale can help to advance evaluation of new technology in surgery.

## Limitations of study

We recognize that our analysis has several limitations. Firstly, and most importantly, this is not a randomized controlled trial and inherent selection biases exist that can be adjusted for but never completed eliminated. We attempted to account for apparent biases in our propensity matching. However, we cannot account for differences between the two groups that are not known, such as the experience of surgeons and institutions. Lobectomy procedures are also not standardized, and both thoracotomy and thoracoscopic techniques have variations that are not captured in SEER-Medicare. SEER-Medicare also, as noted, does not capture clinical staging data. Therefore, we were unable to evaluate pathologic upstaging data. SEER-Medicare also does not provide disease recurrence data. Our analysis identified only treated recurrences, which may be less than the number of total recurrences, so our estimate of disease-free survival may be overestimated. Also, the overall quality of postoperative care and surveillance cannot be extrapolated from SEER-Medicare data. Even if thoracoscopic techniques were found to be superior in a randomized controlled trial, implementation of techniques would not be instantaneous. Surgeons would have to be trained and experience gained at centers currently not using thoracoscopic techniques. Broadly implementing and increasing access to new technologies in surgery and healthcare in general in a safe and efficient manner is not trivial and is a broader policy matter.

## Conclusion

Our population based analysis of SEER-Medicare data with its inherent limitations suggests that patients undergoing thoracoscopic lobectomy have similar long term survival outcomes compared with patients undergoing thoracotomy lobectomy. Further investigation in the form of a randomized controlled trial, its variations, or continuous large scale registry analyses is warranted for evaluation of this technology. Survival rates are the measure of success of cancer surgery, and on the current evidence these do not seem to be compromised by sparing patients the additional morbidity of thoracotomy.

Contributors: SP, NKA, and AS were responsible for the study concept and design. SP and AJI acquired the data. SP, AS, AJI, and TT analyzed and interpreted the data. SP and AJI drafted the manuscript. SP, AS, NKA, and TT critically revised the manuscript for important intellectual content. AJI and AS were responsible for the statistical analysis. SP and AS supervised the study. SP, AS, and AJI are the guarantors.

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Competing interest: All authors have completed the ICMJE uniform disclosure form at www.icmje.org/coi_disclosure.pdf (available on request from the corresponding author) and declare: AS received funding from the US FDA for establishing the MDEpiNet Science and Infrastructure Centre; no financial relationships with any organizations that might have an interest in the submitted work in the previous three years; no other relationships or activities that could appear to have influenced the submitted work.

Ethical approval: The study was approved by the Weill Cornell Medical College institutional review board (protocol No 1308014193).

Declaration of transparency: The lead authors (study guarantors) affirm that this manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained.

Data sharing: Technical appendix and statistical code available from the corresponding author at pas2022@med.cornell.edu; dataset available from SEER-Medicare at http://appliedresearch.cancer.gov/seermedicare/.

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**What is already known on this topic**

Thoracoscopic lobectomy is associated with fewer postoperative complications than thoracotomy lobectomy, but whether the long term outcomes are compromised is unclear

**What this study adds**

Patients undergoing thoracoscopic lobectomy had similar overall, cancer specific, and disease-free survival compared with those undergoing open thoracotomy lobectomy

Minimally invasive techniques do not seem to compromise the long term outcomes after lobectomy in this largest study to date representing modern practice in the United State

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# Tables

**Table 1| Patients' baseline characteristics for thoracoscopic and thoracotomy lobectomy in SEER-Medicare population from 2007 to 2009. Values are numbers (percentages) unless stated otherwise**

| | Full sample | | | Propensity matched cohort | | |
|---|---|---|---|---|---|---|
| Variables | Thoracoscopy (n=1293) | Thoracotomy (n=4715) | Absolute difference | Thoracoscopy (n=1195) | Thoracotomy (n=1195) | Absolute difference |
| Mean (SD) age, years* | 74.9 (5.8) | 74.2 (5.7) | 0.7 | 74.8 (5.8) | 74.9 (5.9) | 0.1 |
| Median (interquartile range) age, years | 75 (70-79) | 74 (69-78) | 1 | 75 (70-79) | 74 (70-79) | 1 |
| Age group: | | | | | | |
| 65-69 years | 281 (21.7) | 1189 (25.2) | 3.5 | 261 (21.8) | 272 (22.8) | 1 |
| 70-74 years | 355 (27.5) | 1436 (30.5) | 3 | 334 (27.9) | 330 (27.6) | 0.3 |
| 75-79 years | 363 (28.1) | 1180 (25.0) | 3.1 | 334 (27.9) | 320 (26.8) | 1.1 |
| ≥80 years | 294 (22.7) | 910 (19.3) | 3.4 | 266 (22.3) | 273 (22.8) | 0.5 |
| Female sex* | 725 (56.1) | 2396 (50.8) | 5.3 | 664 (55.6) | 676 (56.6) | 1 |
| Race*: | (n=1292) | (n=4708) | | | | |
| White | 1161 (89.9) | 4174 (88.7) | 1.2 | 1074 (89.9) | 1076 (90.0) | 0.1 |
| Black | 67 (5.2) | 265 (5.6) | 0.4 | 62 (5.2) | 55 (4.6) | 0.6 |
| Other | 64 (5.0) | 269 (5.7) | 0.7 | 59 (4.9) | 64 (5.4) | 0.5 |
| Married | 746/1245 (59.9) | 2746/4587 (59.9) | 0 | 683/1149 (59.4) | 699/1172 (59.6) | 0.2 |
| Comorbidities: | | | | | | |
| Diabetes* | 266 (20.6) | 1027 (21.8) | 1.2 | 243 (20.3) | 252 (21.1) | 0.8 |
| Hypertension* | 854 (66.0) | 3179 (67.4) | 1.4 | 796 (66.6) | 800 (66.9) | 0.3 |
| Coronary artery disease* | 363 (28.1) | 1475 (31.3) | 3.2 | 343 (28.7) | 339 (28.4) | 0.3 |
| Congestive heart failure* | 38 (2.9) | 228 (4.8) | 1.9 | 37 (3.1) | 35 (2.9) | 0.2 |
| Chronic pulmonary disease* | 654 (50.6) | 2857 (60.6) | 10 | 621 (52.0) | 620 (51.9) | 0.1 |
| Peripheral vascular disease | 214 (16.6) | 786 (16.7) | 0.1 | 198 (16.6) | 194 (16.2) | 0.4 |
| Metropolitan statistical area* | 1188 (91.9) | 3880 (82.3) | 9.6 | 1094 (91.5) | 1083 (90.6) | 0.9 |
| 2000 census tract median income*: | | | | | | |
| 1st quarter | 237 (18.3) | 1267 (26.9) | 8.6 | 225 (18.8) | 206 (17.2) | 1.6 |
| 2nd quarter | 274 (21.2) | 1251 (26.5) | 5.3 | 270 (22.6) | 271 (22.7) | 0.1 |
| 3rd quarter | 344 (26.6) | 1171 (24.8) | 1.8 | 321 (26.9) | 328 (27.4) | 0.5 |
| 4th quarter | 438 (33.9) | 1026 (21.8) | 12.1 | 379 (31.7) | 390 (32.6) | 0.9 |
| Year of treatment*: | | | | | | |
| 2007 | 107 (8.3) | 1690 (35.8) | 27 | 106 (8.9) | 109 (9.1) | 0.2 |
| 2008 | 508 (39.3) | 1472 (31.2) | 8.1 | 474 (39.7) | 456 (38.2) | 1.5 |
| 2009 | 608 (47.0) | 1400 (29.7) | 17.3 | 553 (46.3) | 563 (47.1) | 0.8 |
| 2010 | 70 (5.4) | 153 (3.2) | 2.2 | 62 (5.2) | 67 (5.6) | 0.4 |
| Stage*: | (n=1276) | (n=4653) | | | | |
| Stage 0 or occult | 4 (0.3]) | 19 (0.4) | 1.2 | 1 (0.1) | 1 (0.1) | 0 |
| Stage I | 928 (72.7) | 3104 (66.7) | 6 | 865 (72.4) | 850 (71.1) | 1.3 |
| Stage II | 142 (11.1) | 655 (14.1) | 2.9 | 140 (11.7) | 161 (13.5) | 1.8 |
| Stage III | 169 (13.2) | 734 (15.8) | 2.5 | 159 (13.3) | 149 (12.5) | 0.8 |
| Stage IV | 33 (2.6) | 141 (3.0) | 0.4 | 30 (2.5) | 34 (2.8) | 0.3 |
| Histology*: | | | | | | |
| Adenocarcinoma | 630 (48.7) | 2159 (45.8) | 2.9 | 573 (47.9) | 565 (47.3) | 0.6 |
| Adenosquamous | 42 (3.2) | 166 (3.5) | 0.3 | 42 (3.5) | 34 (2.8) | 0.7 |
| Bronchioloalveolar carcinoma | 235 (18.2) | 669 (14.2) | 4 | 210 (17.6) | 209 (17.5) | 0.1 |

**Table 1 (continued)**

| Variables | Full sample | | | Propensity matched cohort | | |
|---|---|---|---|---|---|---|
| | Thoracoscopy (n=1293) | Thoracotomy (n=4715) | Absolute difference | Thoracoscopy (n=1195) | Thoracotomy (n=1195) | Absolute difference |
| Squamous | 367 (28.4) | 1658 (35.2) | 6.8 | 353 (29.5) | 366 (30.6) | 1.1 |
| Other | 19 (1.5) | 63 (1.3) | 0.2 | 17 (1.4) | 21 (1.8) | 0.4 |
| Site*: | | | | | | |
| Lower lobe | 486 (37.6) | 1592 (33.8) | 3.8 | 448 (37.5) | 439 (36.7) | 0.8 |
| Middle lobe | 75 (5.8) | 229 (4.9) | 0.9 | 65 (5.4) | 72 (6.0) | 0.6 |
| Upper lobe | 714 (55.2) | 2781 (59.0) | 3.8 | 666 (55.7) | 664 (55.6) | 0.1 |
| Other or not otherwise specified | 18 (1.4) | 113 (2.4) | 1 | 16 (1.3) | 20 (1.7) | 0.4 |
| Mean (SD) tumor size, mm*: | 30.0 (17.1) | 34.9 (21.7) | 4.6 | 30.7 (17.3) | 30.9 (17.9) | 0.6 |
| Tumor size: | (n=1280) | (n=4651) | | | | |
| 0-20 mm | 425 (33.2) | 1254 (27.0) | 6.2 | 368 (30.8) | 383 (32.1) | 1.3 |
| 21-30 mm | 383 (29.9) | 1256 (27.0) | 2.9 | 365 (30.5) | 346 (29.0) | 1.4 |
| 31-40 mm | 234 (18.3) | 880 (18.9) | 0.6 | 227 (19.0) | 229 (19.2) | 0.2 |
| 41-50 mm | 110 (8.6) | 510 (11.0) | 2.4 | 109 (9.1) | 106 (8.9) | 0.2 |
| ≥51 mm | 128 (10.0) | 751 (16.1) | 6.1 | 126 (10.5) | 131 (11.0) | 0.5 |
| Hospital volume*: | | | | | | |
| 1st quarter | 172 (13.3) | 1311 (27.8) | 14.5 | 163 (13.6) | 160 (13.4) | 0.2 |
| 2nd quarter | 296 (22.9) | 1187 (25.2) | 2.3 | 291 (24.4) | 298 (24.9) | 0.5 |
| 3rd quarter | 323 (25.0) | 1104 (23.4) | 1.6 | 309 (25.9) | 291 (24.4) | 1.5 |
| 4th quarter | 502 (38.8) | 1113 (23.6) | 5.2 | 432 (36.2) | 446 (37.3) | 1.1 |

*Used in propensity score matching.

**Table 2| In-hospital outcomes comparison for thoracoscopic versus thoracotomy lobectomy**

| | Full sample | | | Propensity matched cohort | | |
|---|---|---|---|---|---|---|
| In-hospital outcomes | Thoracoscopy (n=1293) | Thoracotomy (n=4715) | P value | Thoracoscopy (n=1195) | Thoracotomy (n=1195) | P value |
| Mean (SD) nodes examined | 20.1 (27.8) | 17.7 (27) | 0.0053 | 19.9 (27.5) | 17.6 (26) | 0.0327 |
| Median (interquartile range) nodes examined | 10 (5-18) | 8 (5-15) | <0.0001 | 10 (5-18) | 9 (5-15) | 0.0004 |
| ≥12 nodes examined, No (%) | 429/1157 (37.1) | 1151/4263 (27.0) | <0.0001 | 398/1072 (37.1) | 317/1090 (29.1) | <0.0001 |
| Mean (SD) length of stay | 6.5 (6) | 9.0 (7.4) | <0.0001 | 6.6 (6) | 8.7 (6.6) | <0.0001 |
| Median (interquartile range) length of stay | 5 (3-7) | 7 (5-10) | <0.0001 | 5 (3-8) | 7 (5-10) | <0.0001 |
| In-hospital mortality, No (%) | 25 (1.9) | 155 (3.3) | 0.0114 | 25 (2.1) | 43 (3.6) | 0.0290 |
| Complications, No (%): | | | | | | |
| Arrhythmia | 247 (19.1) | 1056 (22.4) | 0.0109 | 229 (19.2) | 265 (22.2) | 0.0690 |
| Pneumonia | 76 (5.9) | 402 (8.5) | 0.0018 | 74 (6.2) | 100 (8.4) | 0.0423 |
| Atelectasis | 133 (10.3) | 735 (15.6) | <0.0001 | 125 (10.5) | 176 (14.7) | 0.0013 |
| Ventilation | 33 (2.6) | 213 (4.5) | 0.0016 | 32 (2.7) | 48 (4.0) | 0.07 |
| Sepsis | 18 (1.4) | 109 (2.3) | 0.0417 | 16 (1.3) | 32 (2.7) | 0.0209 |

No significant differences were seen in postoperative stroke, myocardial infarction, puncture, pneumothorax, pulmonary edema, empyema, renal failure, accidental puncture, or bleeding.

# Figures

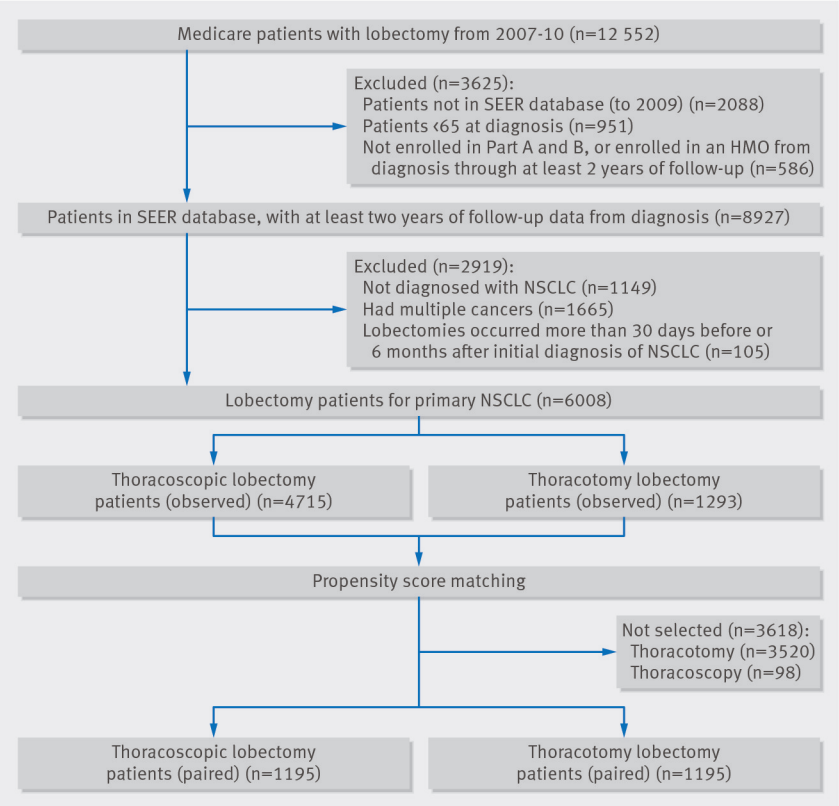


**Fig 1** Patient selection flow chart. HMO=health maintenance organization; NSCLC=non-small cell lung cancer; SEER=Surveillance, Epidemiology and End Results

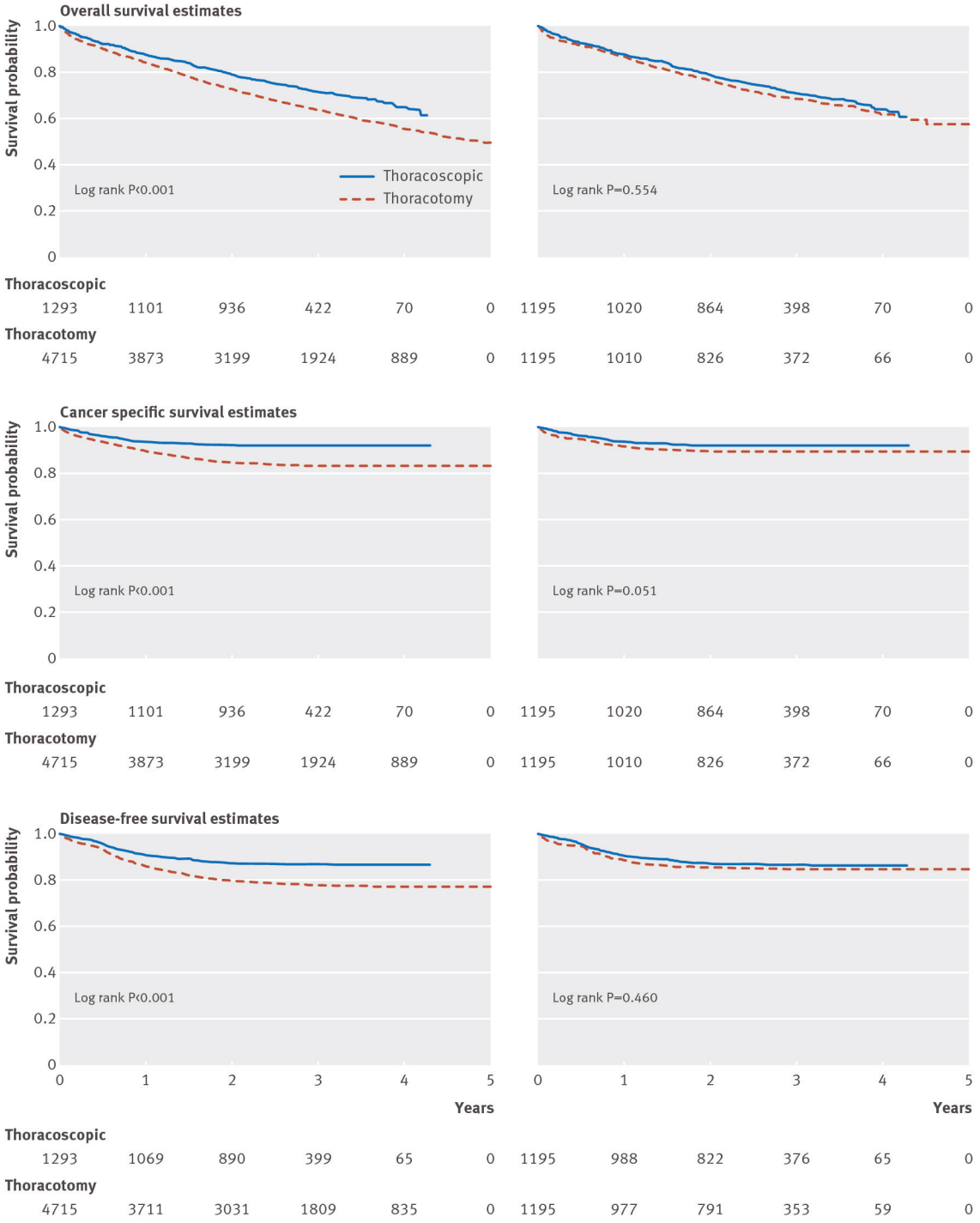


**Fig 2** Kaplan-Meier survival plots (time until death with number of participants at risk) for thoracoscopic and thoracotomy lobectomy in unmatched (left side) and matched (right side) samples

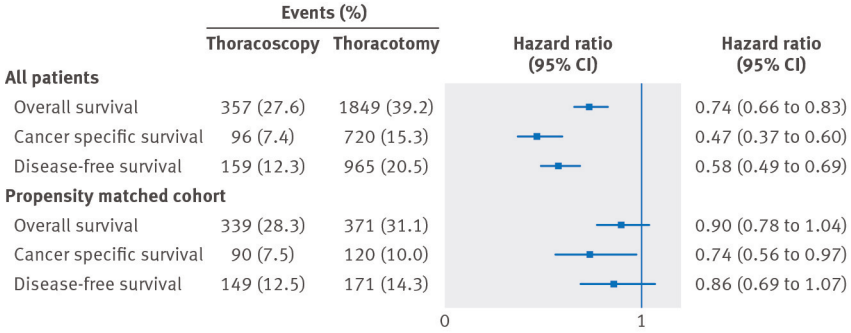


**Fig 3** Cox proportional hazards models for all cause mortality, disease specific mortality, and disease recurrence in matched and unmatched samples