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# BMJ Open Mortality and failure-to-rescue major complication trends after lung cancer surgery between 2005 and 2020: a nationwide population-based study

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## ABSTRACT

**Objectives** To estimate the evolution of quality indicators (30-day mortality and failure-to-rescue) inpatients who underwent lung cancer surgery in France over the past 15 years and to study the potential influencing factors.

**Design** Retrospective cohort study using data from the French hospital database (PMSI).

**Setting** Nationwide population-based study.

**Participants** All patients who underwent pulmonary resection for lung cancer in France (2005–2020) were included (N=1 57 566). Characteristics of patients (age, gender, comorbidities), surgery (surgical approach, type of resection, extent of resection) and hospital (type of hospital, hospital volume for pulmonary resections) were retrieved.

**Primary and secondary outcome measures** We studied two outcome indicators: 30-day mortality and failure-to-rescue. We used regression-based techniques (including interrupted time-series) to assess the effects of patient and hospital characteristics on 30-day mortality and failure-to-rescue (number of deaths among patients with at least one major postoperative complication within the 30 days after surgery), adjusting for case mix.

**Results** The 30-day mortality rate increased from 3.8% in 2005 to 4.9% in 2010 and then decreased to 2.9% in 2020. The failure-to-rescue rate decreased from 12.2% in 2005 to 7.1% in 2020. The pneumonectomy rate decreased significantly over time (18.1% in 2005 to 4.8% in 2020) and had the greatest contribution on the reduction of mortality between two periods (2005–2010/2015–2020). The use of video-assisted thoracoscopic surgery or robot-assisted surgery had a great influence on the reduction of mortality (16% of the observed difference in mortality) between the two periods, as did hospital volume.

**Conclusions** The change in surgical practices, particularly the reduction in pneumonectomies, could be one of the main reasons for reduction in postoperative mortality and failure-to-rescue in France since 2011. Hospital volume is another important factor in reducing postoperative mortality. Our study should encourage the use of technological or organisational innovation, such as changes in surgical practice and cancer surgery authorisations, to improve quality of care.

## STRENGTHS AND LIMITATIONS OF THIS STUDY

- ⇒ Our national administrative database, PMSI, is an important tool for assessing quality of care as it collects the characteristics of patients from all hospitals (public and private) in France, with a national recruitment over 15 years.
- ⇒ Data pertaining to pulmonary resection for lung cancer are reliable enough to count such patients: large size of our sample (157 566 patients operated on for lung cancer in France from 2005 to 2020).
- ⇒ Characteristics of patients (age, gender, comorbidities), surgery (surgical approach, type of resection, extent of resection) and hospital (type of hospital, hospital volume for pulmonary resections) were retrieved.
- ⇒ The tumour, node, metastases stage cannot be retrieved in the PMSI, nor can Eastern Cooperative Oncology Group (ECOG) or previous treatment status.
- ⇒ No details were available concerning the accommodation facilities of the centre (number of beds in the surgical department and intensive care unit, number of days spent in intensive care, number of nurses and medical practitioners) and the organisation (tumour board meeting, application of recommendations, qualification of surgeons and years of experience and surgery performed by residents).

## INTRODUCTION

Lung cancer remains to be one of the deadliest cancers today despite the therapeutic progress made in the recent years.<sup>1 2</sup> Over the past 15 years, surgical practice has progressed with the development of video-assisted thoracoscopic surgery (VATS) and then robot-assisted surgery.<sup>2</sup> The frequencies of various types of lung resection have also changed in recent years as a result of diagnoses being made earlier in the course of the disease. Patients are more often referred to the surgeon with smaller, more peripheral tumours. Various studies have confirmed the interest of segmentectomy for peripheral tumours with a diameter of <2 cm.<sup>3</sup>

In 2009, a French national strategy for quality improvement in cancer management (Cancer Plan), which included a number of new measures, was implemented in an attempt to improve cancer care.<sup>4</sup> These measures concerned cancer research, screening and the medical and surgical management of patients with lung cancer. To obtain authorisation to perform lung cancer surgery, surgical teams have to perform at least 30 lung resections per year,<sup>4</sup> which has resulted in fewer hospitals performing these surgeries.

In theory, in order to claim that there has been medical progress, any technological or organisational innovation should be accompanied by a demonstration of improved quality of care. Over the past 15 years, have the changes in surgical practice and the advent of new technologies led to an improvement in the quality of care? It seemed important to answer this question for patients having to undergo lung cancer surgery. To our knowledge, this work has not been carried out in France to date.

The years 2009–2014 can be considered as an important transition period. This period corresponds to the implementation of the ‘Cancer Plan’ authorisations in France.<sup>4</sup> In this period, there was also an increase in the use of the minimally-invasive approach among surgeons performing lung resections for cancer.

The number of lung resections performed per year per hospital, known as hospital volume, is an indicator that influences postoperative mortality,<sup>5,6</sup> which is one of the quality indicators of lung cancer surgery, as recently demonstrated by Fernandez *et al.*<sup>7</sup>

We used two quality indicators, 30-day mortality and failure-to-rescue, which have been the subject of several publications aiming to assess quality of care.<sup>7,8</sup>

A national administrative database is an important tool for assessing the quality of care, and provides data relative to all patients and all care centres nationwide. In particular, the French national administrative database for hospital care (PMSI) provides a huge amount of epidemiological information concerning hospitalised French patients.<sup>9–11</sup>

The main objective of this work was thus to estimate the evolution of quality indicators (30-day mortality and failure-to-rescue) from 2005 to 2020 in patients who underwent lung cancer surgery using this national medico-administrative database. The second objective was to study the different factors that may have influenced the evolution of these quality indicators over time.

## METHODS

### Data source and study population

For this retrospective cohort study, all data for patients who underwent pulmonary resection for lung cancer in France were collected from January 2005 to December 2020 from the national administrative database. This database, called PMSI for ‘*Programme de Médicalisation des Systèmes d’Information*’, was inspired by the US Medicare system. The reliability and validity of PMSI data have

already been assessed.<sup>9–11</sup> Routinely collected medical information includes the principal diagnosis, secondary diagnoses and procedures performed. Diagnoses identified during the hospital stay are coded according to the International Classification of Diseases, tenth revision (ICD-10).<sup>12,13</sup> All patients undergoing lung cancer surgery in France were included. We thus selected patients for whom a diagnosis of primary lung cancer was coded as the principal discharge diagnosis (all codes C34), associated with a procedure of lung cancer surgery (thoracotomy, VATS or robot-assisted surgery) during the same hospital stay. As we only included patients who had undergone surgery, no patients with stage IV disease were included. Procedures are coded according to the CCAM (*Classification Commune des Actes Médicaux*).<sup>14</sup> For all patients, lung cancer was proven by pathology analyses according to the 2004 WHO Classification of Lung Cancer.<sup>12</sup> Surgery-related variables included the surgical approach (thoracotomy, VATS or robot-assisted surgery), the type of resection (limited resection, lobectomy, bilobectomy and pneumonectomy), bronchoplasty and the extent of the pulmonary resection (to the chest wall, the left atrium, the carina, the diaphragm, and the superior vena cava).

### Ethical approval

Patient consent was not required, and patient-identifying information was not used in the research as this national retrospective study was based on pseudonymised data. In fact, the French national administrative hospital database does not contain any patient-identifying data. The patient’s identity is pseudonymised, making it possible to link data from the same patient without knowing his or her identity. Ethics approval for use of this database was obtained from the French National Commission for Data protection (*Commission Nationale de l’Informatique et des Libertés*: No 1576793), and this study adhered to the tenets of the Declaration of Helsinki.

### Patient and public involvement

Patients were not involved in the research as this national retrospective study was based on pseudonymised data.

### Patient characteristics

Baseline demographics included age and gender. From the national administrative database, we included the following comorbidities: pulmonary disease (chronic bronchitis, emphysema), heart disease (coronary artery disease, cardiac arrhythmia, congestive heart failure, valvular heart disease, pulmonary artery hypertension, pulmonary embolism), peripheral vascular disease, liver disease, cerebrovascular events, neurological diseases (hemiplegia or paraplegia), renal disease, haematological disease (leukaemia, lymphoma), metabolic disease (including obesity), anaemia, other therapies (preoperative chemotherapy including neoadjuvant therapies, steroids) and infectious disease. We also calculated a

modified Charlson Comorbidity Index (CCI) as a marker of comorbidity.<sup>15</sup>

### Hospital characteristics

In France, hospitals that perform thoracic procedures are classified as either non-academic public, academic public, private non-profit or private for profit. The explanatory variables of interest were hospital volume for pulmonary resections for lung cancer. For each hospital, the number of times each type of pulmonary resection was performed was calculated in the period from 1 January 2005 to 31 December 2020. Hospital volume was defined as the median number of procedures performed per year. For the analysis, hospital volume was represented as a continuous variable that was transformed into a logarithm.

### Outcome measurements

To assess the quality of care, we chose two outcome indicators identified at the patient level: 30-day mortality and failure-to-rescue major complications.

30-Day mortality was defined as any patient who died in hospital (including transferred patients) within the first 30 days after the operation and those who died later during the same hospitalisation.

Failure-to-rescue was defined as the number of deaths among patients with at least one major postoperative complication within the 30 days after surgery. The major complication outcome was defined as the presence of one or more of the following postoperative conditions: tracheostomy, reintubation, adult respiratory distress syndrome, bronchopleural fistula, empyema, pulmonary embolus, pneumonia, bleeding requiring reoperation, myocardial infarction, stroke, and heart failure.

We determined the rate of failure-to-rescue for each hospital by evaluating the proportion of patients with major postoperative complications who died (numerator) relative to the total number of patients with major postoperative complications (denominator). This represents the ability of a centre to manage postoperative complications and to avoid death.

### Statistical analysis

We used  $\chi^2$  tests to determine the significance of trends for patient characteristics, procedure and hospital characteristics. To estimate changes in mortality over time, we used Interrupted Time Series (ITS) analysis, which is a segmented regression analysis.<sup>16</sup>

For the longitudinal analysis, we used a model in which the outcome is a count denoting the number of times that an event occurred (eg, number of deaths or failure-to-rescue events). To estimate the effect of the approach, type of surgery, type of hospital or hospital volume on 30-day mortality and failure-to-rescue, we used different models including Poisson regression, negative binomial regression, zero-inflated Poisson regression, multilevel negative binomial regression and multilevel Poisson regression. We built a multilevel Poisson regression model and multilevel negative binomial regression model

using hospital-specific variables as random effects. The expected events included in the model for each hospital were estimated by characteristics of patients (age, sex, comorbidities and CCI). Akaike's Information Criterion (AIC) was used to compare the different models and to determine the best model.<sup>17</sup>

To understand the effects of patient characteristics, the procedure and hospital volume on mortality and failure-to-rescue over time, we examined the differences in mortality and failure-to-rescue between the period from 2005 through 2010 and the period from 2015 through 2020 using a regression-based decomposition approach developed by Blinder and Oaxaca. The choice of these two periods aimed to consider 2009–2014 as a transition period, as mentioned in the introduction, because the different measures outlined in the 'Cancer Plan' were being generalised to the surgical teams. The Blinder-Oaxaca method is a labour-economics technique that was initially developed to examine the contribution of factors responsible for wage disparities.<sup>18</sup> Because our analysis involves dichotomous outcomes (mortality, failure-to-rescue), we used a modification of this technique that was designed for use with non-linear models. In the analysis, death or failure-to-rescue was the dependent variable, with age, sex, patient factors, year of inclusion, approach, type of resection, extended resection, type of hospital, volume of hospital procedures (number of procedures per year) and volume variation labelled here as 'volume creep' of each hospital modelled as independent variables. The volume creep for each hospital was determined by the ratio of the total number of lung cancer resections from 2015 through 2020 to the total number of lung cancer resection from 2005 through 2010. When the ratio was greater than 1, the value of the variable was 1. When the ratio was 1 or <1, the value of the variable was 0. We could then determine the relative contribution of each factor to explain differences in mortality or failure-to-rescue between the two periods. Using Fairlie's method, a non-linear decomposition was performed for the contributions of the differences.<sup>18</sup>

Calculations were performed with STATA V.14 statistical software (StataCorp, College Station, Texas, USA).

### RESULTS

Between 2005 and 2020, 157 566 patients were operated on for lung cancer in France. The 30-day mortality rate increased from 3.8% in 2005 to 4.9% in 2010 and then subsequently decreased to 2.9% in 2020 (online supplemental table 1). This trend is statistically significant ( $p<0.0001$ ). We conducted an ITS analysis to assess the effect of the procedure in reducing 30-day mortality (online supplemental figure 1). We observed a significant change ( $p=0.0132$ ) before (increase) and after 2011 (decrease): from 2011 onwards, there appeared to be a significant decrease ( $p<0.001$ ) in 30-day mortality, with an annual decrease of 2.45 deaths per 1000 ( $p<0.0001$ , 95% CI:  $-2.86$  to  $-2.03$ ).



During the same period, the number of major postoperative complications was 43 829. The failure-to-rescue major complications rate decreased from 12.2% in 2005 to 7.1% in 2020 ( $p < 0.0001$ ) (online supplemental table 1).

### Trends in patient characteristics

The mean age increased over time ( $p < 0.0001$ ): in 2005 the mean age was 62.3 years versus 65.7 years in 2020 (online supplemental table 2). The rate of females also increased over time ( $p < 0.0001$ ), and in 2020, 39.5% of patients who underwent lung cancer surgery were women (online supplemental table 2). All comorbidities varied over time except for liver disease (online supplemental table 2).

### Trends for procedures

The rate of overall infralobar and lobectomy surgery increased over time ( $p < 0.0001$ ) (online supplemental table 3). However, the pneumonectomy rate decreased significantly, from 18.1% in 2005 to 4.8% in 2020 ( $p < 0.0001$ ) (online supplemental table 3). The rate of VATS or robot-assisted surgery increased over time, from 5.3% in 2005 to 47.3% in 2020 ( $p < 0.0001$ ) (online supplemental table 3).

### Trends for hospital characteristics

The number of hospitals performing lung resections for cancer decreased over time: in 2020 there were 146 hospitals performing lung resections compared with 253 in 2005 (online supplemental table 4). The decrease in the number of hospitals was mainly in the private for profit sector (online supplemental table 4). One of the consequences of the reduction in the number of hospitals is the increase in the median of annual procedures. The increase in median hospital volume per year was more marked for academic and private non-profit hospitals, rising from 83 procedures per year in 2005 to 128 per year in 2020 for academic hospitals and from 16.5 procedures per year in 2005 to 159 per year in 2020 for private non-profit hospitals (online supplemental table 4).

### Multivariate analysis

For 30-day mortality, the best model, which was the multilevel Poisson regression model with the lowest AIC, is presented in table 1. The adjusted incidence rate ratio (AIRR) for VATS or robot-assisted surgery was 0.75 (95% CI: 0.69 to 0.83) (table 1). This approach was associated with a 25% reduction in the risk of postoperative death.

Bilobectomies and pneumonectomies had an AIRR of 1.43 (95% CI: 1.26 to 1.63) and 2.04 (95% CI: 1.84 to 2.25), respectively (table 1). Of the hospital characteristics, only hospital volume was significantly associated with reduced mortality (AIRR: 0.89; 95% CI: 0.84 to 0.94) (table 1). Figure 1 reports the change in mortality rates according to the different models. As shown in figure 1, the mortality rate increased until 2010 and then decreased steadily until 2020.

**Table 1** Best model analysis of 30-day mortality and failure-to-rescue for procedure, hospital characteristics and year

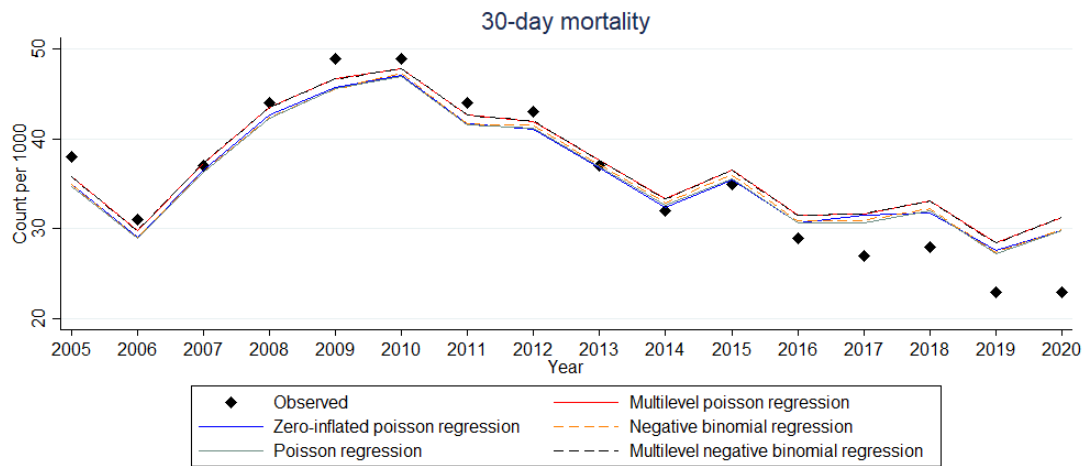
	30-Day mortality	Failure-to-rescue major complications
Year*	0.98 (0.97–0.98)	0.98 (0.97–0.99)
Approach		
Thoracotomy	Reference	Reference
VATS/robot-assisted surgery	0.75 (0.69–0.83)	0.61 (0.55–0.68)
Lung resection		
Limited	Reference	Reference
Lobectomy	0.85 (0.79–0.93)	1.13 (1.02–1.25)
Bilobectomy	1.43 (1.26–1.63)	2.02 (1.74–2.35)
Pneumonectomy	2.04 (1.84–2.25)	2.68 (2.37–3.02)
Extended resection	1.21 (1.14–1.31)	1.26 (1.16–1.37)
Type of hospitals		
Non-academic	Reference	Reference
Academic	1.01 (0.84–1.21)	0.92 (0.76–1.12)
Private no-profit	0.95 (0.76–1.17)	0.82 (0.65–1.04)
Private for profit	1.04 (0.90–1.21)	0.76 (0.65–0.89)
Hospital volume/year†	0.89 (0.84–0.94)	0.93 (0.88–0.99)
AIC	17 773.18	14 552.5

Expected events for each hospital included in model was estimated by patient characteristics (age, sex, comorbidities and Charlson Comorbidities Index).  
The model is estimated adjusted incidence rate ratio (95% CI).  
\*The year variable was considered to be continuous in the models, as we did not find any deviation from log-linearity after performing the associated test.  
†Transformed into logarithm.  
AIC, Akaike's Information Criterion; VATS, video-assisted thoracoscopic surgery.

For failure-to-rescue major complications, the best model was again the multilevel Poisson regression model with the lowest AIC (table 1). The AIRR for VATS or robot-assisted surgery was 0.61 (95% CI: 0.55 to 0.68) (table 1). This approach reduced the risk of postoperative death by 39%. Bilobectomies and pneumonectomies had an AIRR of 2.02 (95% CI: 1.74 to 2.35) and 2.68 (95% CI: 2.37 to 3.02), respectively (table 1). Of the hospital characteristics, only hospital volume was significantly associated with a failure-to-rescue major complication (AIRR: 0.93; 95% CI: 0.88 to 0.99), which decreased significantly over the years (table 1). Figure 2 reports the change in failure-to-rescue according to the different models. As shown in figure 2, the failure-to-rescue rate increased until 2010 and then decreased steadily until 2020.

### Decomposition model

We divided the time into two periods: the first period, from 2005 to 2010, before the transition period (which corresponds to the implementation of the 'Cancer Plan'



**Figure 1** Observed and predicted mortality rate trends from 2005 to 2020 according to the different models.

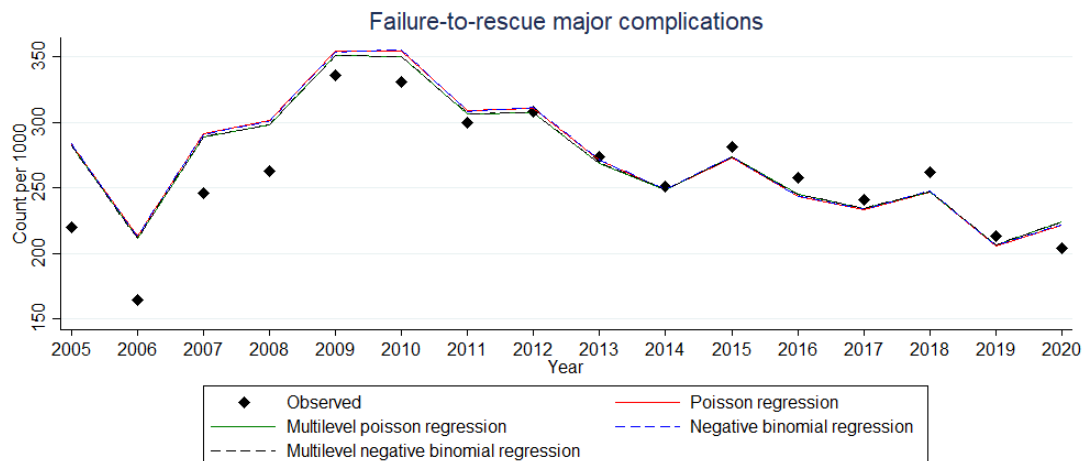
authorisations in France) and the second period, from 2015 to 2020, after the transition period. The description of patient characteristics, procedures and hospital characteristics for the two periods are reported in online supplemental table 5.

For 30-day mortality, the difference between the two periods was 0.014 (online supplemental table 6). Approximately 50% (0.00725/0.014) of the disparity between the two periods was explained by these predictors. This means that patient characteristics, type of surgery and hospital characteristics explained 50% of the difference in mortality between the two periods. Among them, pneumonectomy, hospital volume and VATS or robot-assisted surgery contributed the most (online supplemental table 6). Age, on the other hand, had a negative contribution due to the ageing of the population (online supplemental table 6). Finally, the type of hospital had no influence on the reduction in mortality over the periods. **Figure 3** shows to what extent each of the predictors were associated with the decline in mortality over the two periods.

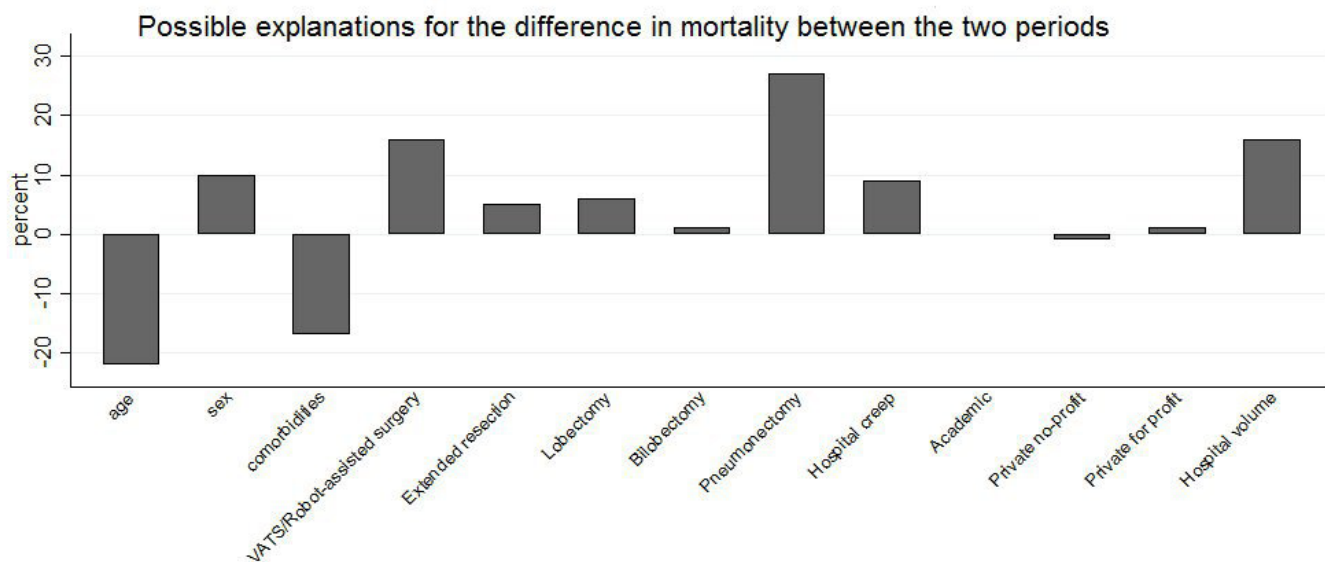
For failure-to-rescue, the difference between the two periods was 0.037 (online supplemental table 7). Approximately 36% (0.0134/0.037) of the disparity between the two periods was explained by the predictors. Among them, pneumonectomy, hospital volume and VATS or robot-assisted surgery contributed the most (online supplemental table 7). Age had the same effect as for 30-day mortality. The type of hospital was not associated with the reduction in failure-to-rescue major complications over the two periods (online supplemental table 7). The percentage of each of the predictors that explain the decline in failure-to-rescue over the two periods is reported in **figure 4**.

## DISCUSSION

Our results showed a significant reduction in postoperative mortality following lung cancer surgery over time in France: the rate was 3.8% in 2005, dropping to 2.9% in 2020. However, the decrease was not uniform,



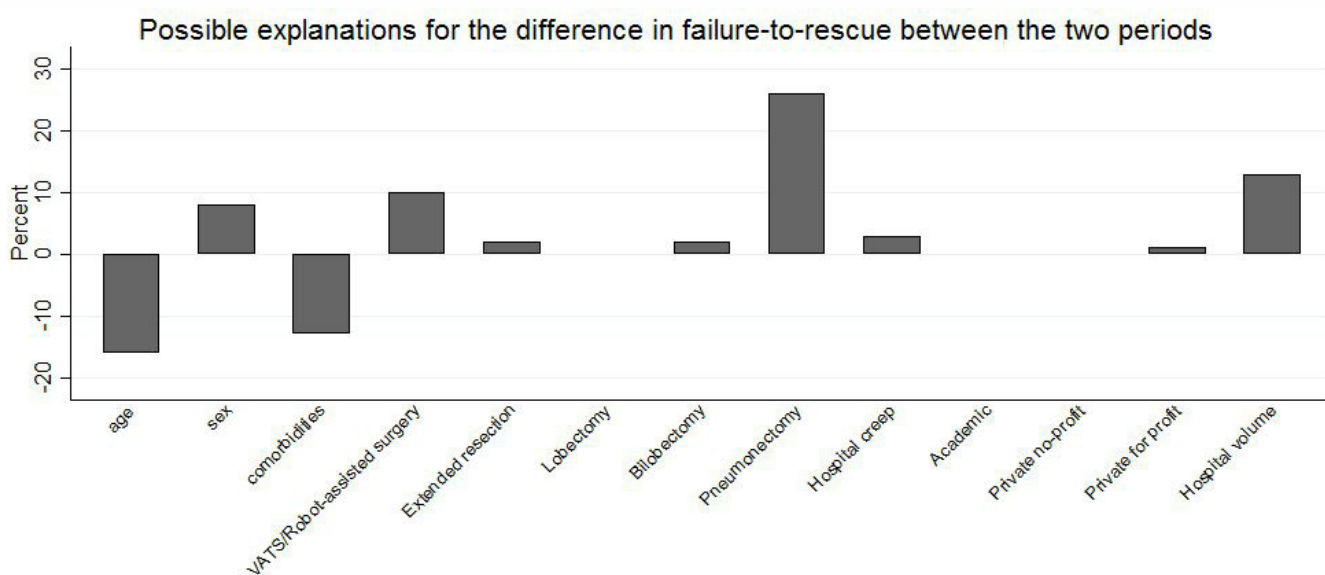
**Figure 2** Observed and predicted failure-to-rescue rate from 2005 to 2020 according to the different models.



**Figure 3** Patient characteristics, hospital characteristics and procedure contribution to the difference in 30-day mortality between 2005–2010 and 2015–2020. This figure shows to what extent each of the predictors were associated with the decline in mortality over the two periods and describes the influence of the variables on the reduction in mortality. The percentage is calculated as the ratio of the contribution to difference of each variable to the total difference. For example for pneumectomy, we found a percentage of 27.89% calculated as:  $0.0039042/0.014$  (online supplemental table 6). VATS, video-assisted thoracoscopic surgery.

as confirmed by the ITS analysis. Specifically, there was an increase in the number of deaths from 2005 to 2010, before the implementation of the 2009 ‘Cancer Plan’, and then a linear decrease from 2011 to 2020. For the failure-to-rescue indicator, we observed variations comparable to

those for the 30-day mortality indicator, including the two distinct periods. The first from 2005 to 2010, during which the number of events increased, and then the number of events decreased regularly until 2020.<sup>8</sup> We also observed a decrease in major postoperative complications, from



**Figure 4** Patient characteristics, hospital characteristics and procedure contribution to the difference in failure-to-rescue between 2005–2010 and 2015–2020. This figure shows to what extent each of the predictors were associated with the decline in failure-to-rescue over the two periods and describes the influence of the variables on the reduction in failure-to-rescue. The percentage is calculated as the ratio of the contribution to difference of each variable to the total difference. For example for pneumectomy, we found a percentage of 26.32% calculated as:  $0.0097396/0.037$  (online supplemental table 7). VATS, video-assisted thoracoscopic surgery.

12.2% in 2005 to 7.1% in 2020. These results suggest that the new organisation required to obtain the cancer surgery authorisations have had a beneficial effect on patient outcomes.

The limitations of our study concern first reliance on ICD-10 codes for the selection of patients and the ascertainment of outcomes. Misclassification or underdetection of related biases is possible, especially for comorbidities. Coding practices vary greatly among institutions, which can increase the number of recorded comorbidities, but the quality of coding in the PMSI has greatly improved since the beginning of hospital data collection in 1990. It is also conceivable that there could be significant inter-hospital differences in the severity of illness, which would impact mortality and failure-to-rescue analyses. However, the modelling we have implemented (multilevel analysis) has enabled us to take variability between hospitals into account. Moreover, over-reporting of the milder forms of the complications could have a significant impact on our results. However, this over-reporting is limited by the quality controls carried out in hospitals to check the coding of discharge abstracts, in particular to ensure that complications are not forgotten, which can reduce the cost of the hospital stay: stays with major complications are classified in different Diagnosis Related Groups (DRGs) with higher tariffs. Second, the results of the present study may be specific to the French healthcare system and thus cannot be generalised to other countries or regions. Another limitation concerns the tumour, node, metastases (TNM) stage, which can influence mortality but cannot be recorded in the PMSI. This is important because it can be assumed that the changes in the characteristics of lung cancer over time, especially the decrease in tumour size, have allowed surgeons to perform fewer pneumonectomies in recent years. This finding can be tempered by the fact that metastatic stages were excluded. Moreover, it is the type of lung resection that has an influence on 30-day mortality, independently of the TNM stage.<sup>19</sup> Another limitation concerns the absence of variables such as American Society of Anesthesiologists (ASA) score, ECOG, smoking status, forced expiratory volume in one second (FEV<sub>1</sub>), prior treatment status and body mass index (BMI). However, this needs to be qualified because, as shown in online supplemental table 2, we took into account pre-existing pulmonary disease, which usually translates into impaired FEV<sub>1</sub>. We used the modified CCI, which has been validated as a preoperative risk score. We are not sure that the ASA Score would carry more weight in the model than the CCI. Moreover, BMI is an important variable, so we may consider obesity as a pejorative factor, which was included in the metabolic disease variable. No details were available in this database concerning the accommodation facilities of the centre (number of beds in the surgical department and intensive care unit, number of days spent in intensive care, number of nurses and medical practitioners) and the organisation (tumour board meeting, application of recommendations, qualification of the

surgeons and years of experience and surgery performed by residents), although these criteria could have an influence on the quality of care. However, the factors that we were able to analyse explained half of the observed difference in mortality between the two periods. Finally, as most ongoing policy initiatives have focused on hospital volume, we did not examine potential changes in surgeon volume over time. Thus, it is possible that trends towards declining operative mortality are attributable in part to increasing surgeon specialisation within hospitals.

The main strength of our results is related to the large size of our sample (157 566 patients). Our national administrative database, PMSI, is an important tool for assessing quality of care because it collects the characteristics of patients from all care centres in France, with a national recruitment over 15 years. It provides a huge amount of epidemiological information concerning hospitalised French patients.<sup>9–11</sup> Moreover, data pertaining to pulmonary resection for lung cancer are reliable enough to count such patients, as previously shown in other studies.<sup>20–24</sup>

The authorisations required by the ‘Cancer Plan’ from 2009 onwards have resulted in fewer hospitals performing lung resections for cancer, going from 253 in 2005 to 146 in 2020. However, this number remains high if we compare it to other comparable countries such as England.<sup>25</sup> The increase in hospital volume was most notable for academic and private non-profit hospitals. The multivariate analysis confirmed the data in the literature on the significant influence of hospital volume on the occurrence of postoperative deaths.<sup>20–28</sup>

There are many explanations for the variations in postoperative mortality during these two periods, which was the aim of the second part of this study. While other papers have reported a decrease in postoperative mortality,<sup>29–30</sup> they did not show two distinct periods, as we did. This is probably due in part to the long observation period, but other factors specific to the country’s practices may be another reason for the observed difference.

First, the number of pneumonectomies performed has decreased significantly over time. In 2005, 18.1% of pulmonary resections were pneumonectomies, but the proportion fell to 4.8% in 2020, with other authors<sup>3–31</sup> reporting the same results. The other striking fact concerns the significant increase in minimally invasive approaches. For instance, in 2020 47% of pulmonary resections were performed by VATS or robot-assisted surgery. This finding is reported by many authors in the literature.<sup>32–35</sup> We tried to take into account the learning curve associated with the adoption of minimally invasive techniques. We left an interval between the first period (2005–2010) prior to the implementation of minimally invasive techniques and the second period (2015–2020) so as not to include in our analyses the 2010–2015 period, which in our view corresponds to the learning curve phase. However, there was still an uptick in mortality at the end of the first period and, because the uptick correlates with the growing use of minimally invasive surgery, we may think that this early



increase in mortality may be associated with a learning curve. Multivariate analysis confirmed that pneumonectomy multiplies the risk of dying postoperatively by 2 and the risk of dying from a major postoperative complication by 2.68, which reinforces the literature data.<sup>36 37</sup> Our work confirms the reduction in postoperative mortality and failure-to-rescue in association with minimally invasive approaches compared with thoracotomy. The introduction of screening could also be cited as a potential explanatory factor for the improvement in mortality and failure-to-rescue because the stage shift could have been an impacting factor in the reduction in mortality and failure-to-rescue. If screening had been organised during the period, it could also have been accompanied by less technically complex surgery, due to diagnosis at an earlier stage. However, the development of minimally invasive approaches during the second period cannot be explained by screening as lung cancer screening was not organised in France as it was in other countries at this time.

Second, to estimate the factors contributing to the reduction in postoperative mortality, we used the Blinder-Oaxaca decomposition method, which is mainly used for economic studies.<sup>18</sup> The Blinder-Oaxaca method is a labour-economics technique that was initially developed to examine the contribution of factors responsible for wage disparities according to race and sex, but it has more recently been applied in research related to health services. There have been a few publications using this methodology for surgery.<sup>19 30</sup> The first period in our study (2005–2010) corresponds to a period during which no authorisation or particular hospital volume was required for hospitals performing lung cancer surgery.<sup>4</sup> The second period (2015–2020) corresponds to the advent of new technologies and the generalisation of cancer surgery authorisations in France. The in-between transition period, which was not included in the study, corresponded to the roll-out of new technologies and the rise of organisational changes.

Patient characteristics, type of surgery and hospital characteristics explained 50% of the difference in mortality between the two periods. The differential effect of pneumonectomy (0.0039/0.014=27.8%) had the greatest contribution to this part of the disparity. The use of VATS or robot-assisted surgery contributed to 16% (0.0023/0.014=16%) of the observed difference in mortality between the two periods. Hospital volume had a greater weight than the variable volume creep in the reduction of mortality between the two periods. Our results differ from those of Finks *et al*,<sup>30</sup> who used the same method where volume creep had a greater weight in reducing mortality. However, Finks *et al*<sup>30</sup> did not include other variables in the decomposition model. Our work seems to confirm that hospital volume has an influence on mortality reduction in contrast to another publication<sup>38</sup> in which the authors used a different methodology over a period of only 5 years. Furthermore, lung cancer surgery was not among the 10 procedures that were analysed.<sup>38</sup>

## Conclusion

In conclusion, some indicators of quality of care (postoperative mortality, failure-to-rescue) in lung cancer surgery have improved significantly since 2011 in France. This work showed that the change in surgical practice, particularly the reduction in pneumonectomies, could be one of the main reasons for the reduction in postoperative mortality and failure-to-rescue. Our study confirms that hospital volume is also an important factor in reducing postoperative mortality.

Our findings should encourage the use of technological or organisational innovations, such as changes in surgical practice and cancer surgery authorizations, to improve quality of care.

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