Original Article

# The value of preoperative spirometry testing for predicting postoperative risk in upper abdominal and thoracic surgery assessed using big-data analysis

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**Background:** Spirometry is used to evaluate postoperative outcomes in thoracic surgery. However, the clinical utility of spirometry for predicting postoperative complications has not been determined. We used big-data analysis to examine the relationship between pulmonary function tests and postoperative complications.

**Methods:** We retrospectively analysed clinical data from 31,827 patients who underwent spirometry within the 3 months prior to their surgery between January 2000 and December 2014 at a single tertiary referral hospital. The data were extracted in de-identified form via the automated clinical research information system. Surgical procedures included thoracic and upper abdominal surgery.

**Results:** Multivariable logistic regression analysis showed that type of surgery, older age (>65 years), low albumin and smoking were associated with postoperative infections [95% confidence interval (CI) of the odds ratio (OR) 1.27–1.60 (>65 years); 1.52–1.96 (low albumin); 1.40–1.98 (current smoker)]. Notably, lower forced vital capacity (FVC) was an independent risk factor for postoperative infection, prolonged intensive care unit stay, and in-hospital death, regardless of airflow limitation [OR 95% CI: 1.31–1.69 (FVC 50–80%); 2.02–4.24 (FVC <50%)]. Lower forced expiratory volume in 1 sec ($FEV_1$) was also an independent risk factor for postoperative infection [OR 95% CI: 1.61–2.26 ($FEV_1$ 50–80%); 2.27–4.21 ($FEV_1$ <50%)]. Airflow limitation assessed by $FEV_1$ was negatively correlated with postoperative infection in multivariable analysis (OR 95% CI: 0.51–0.88).

**Conclusions:** Lower preoperative FVC could be used to predict postoperative infection and complications in thoracic and upper abdominal surgery regardless of airflow limitation.

**Keywords:** Spirometry; postoperative complications; forced vital capacity (FVC); thoracic surgery; chronic obstructive pulmonary disease (COPD)

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## Introduction

Over 230 million patients undergo surgery worldwide each year with reported hospital mortality rates of between 1% and 4% (1). Postoperative complications have an important clinical impact associated with increased rates of morbidity and mortality and longer hospital stay (1). Infectious postoperative complications are the main causes of postoperative morbidity in abdominal and thoracic

surgery (2,3). The European Society of Anaesthesiology-European Society of Intensive Care Medicine guidelines of 2015 define infectious postoperative complications as surgical site infection, pneumonia, bloodstream infection, urinary tract infection and infection of unknown source (4). Both patient-related factors (age, pre-existing lung disease, obesity, smoking, malignancy) and procedure-related factors are known to predict postoperative complications (5,6).

Spirometry is used to assess lung function, and has been widely used as a preoperative test in thoracic surgery (7). Spirometry evaluates a patient's forced expiratory volume in 1 sec ($FEV_1$) and forced vital capacity (FVC), which are used in the diagnosis of obstructive or restrictive ventilatory defects (8). Spirometry is closely associated with chronic obstructive pulmonary disease (COPD), asthma and interstitial lung disease. Airflow limitation ($FEV_1$/FVC <70% predicted) is an independent risk factor for postoperative complications in thoracic surgery (9). One systematic review identified a history of COPD as the major risk factor for postoperative pulmonary complications in non-cardiothoracic surgery (10). However, another reported that mild-to-moderate COPD, as defined by the Global Strategy for Obstructive Lung Disease (GOLD) guidelines, was not a significant risk factor for postoperative pulmonary complications in abdominal surgery (11). However, other studies showed that although FVC was an independent risk factor for postoperative pulmonary complications after abdominal surgery (12,13), $FEV_1$ was not (12). There is no consensus about the value of spirometry for predicting postoperative pulmonary complications and infection.

The use of big data in healthcare may help to identify factors associated with clinical outcomes. The application of data-driven methods to healthcare data has improved our understanding of factors driving outcomes and their relationship with disease comorbidities. Big-data researchers should be able to easily acquire the necessary clinical data from a hospital's information system to facilitate their research. In this study, we extracted the necessary clinical data from the Asan Biomedical Research Environment (ABLE) (14,15). Using these data, we evaluated spirometry results as independent risk factors for postoperative complications in thoracic and upper abdominal surgery.

## Methods

### *Data source*

We performed a retrospective analysis in the Asan Medical Center, a 2,704-bed, university-affiliated, tertiary referral hospital in Seoul. To protect patient privacy, comply with governmental regulations and facilitate research, Asan Medical Center has developed a biomedical research platform, ABLE. Patient medical record data have been stored since 2000, and the ABLE system extracts these data as categorical or continuous values. Comorbidity, smoking status and sex are extracted as categorical variables, and laboratory and spirometry data are extracted as continuous variables. Using this system, we could query patient data according to various conditions, such as date of surgery, surgical procedure or presence of spirometry data. Data cleansing was conducted using MySQL version 8.0.12 (Oracle, Cupertino, California, United States).

Clinical data extracted using ABLE are indexed by de-identified encrypted patient ID number (15,16) so that researchers cannot identify the patient.

### *Study design*

We included patients who underwent general surgery between January 2000 and December 2014 at Asan Medical Center and who had pulmonary function testing within the 3 months prior to their surgery. The following surgical procedures were included, coded by the International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM): lung lobectomy (32.0–32.4), gastrectomy (43.4–43.9), hepatectomy (50.0–50.4) and pancreaticoduodenectomy (51.5–51.7, 52.7). If a patient underwent more than one operation during the admission period, we included only their first operation. If patients underwent complex surgical procedures such as hepatectomy combined with cholecystectomy or with enterostomy or other operations that did not meet our inclusion criteria, those surgical procedures were defined as additional operations.

We extracted patient demographic data including age, sex, smoking history, underlying disease identified by ICD-9 code, spirometry data, laboratory data [haemoglobin, albumin, creatinine, blood urea nitrogen (BUN)], admission ward type (ICU, general ward), surgery date, and type and date of antibiotics administered.

### *Definitions*

The GOLD guidelines define airflow limitation as a post-bronchodilator $FEV_1$/FVC <0.70. However, spirometry using a bronchodilator is not usually performed for

screening purposes. Therefore, we defined airflow limitation as $FEV_1$/FVC <70% predicted combined with $FEV_1$ <80% predicted without a bronchodilator (9).

Using the GOLD guidelines, we categorized the severity of patients' lung function impairment based on the $FEV_1$ % predicted: $FEV_1$ >80% (control), $FEV_1$ 50–80% (moderate impairment) and $FEV_1$ <50% (severe impairment). There were so few patients with $FEV_1$ <30% in our dataset (1.07%) that we included them in the severe group ($FEV_1$ <50%) (17).

The severity of lung function impairment based on FVC % predicted was categorized as follows: FVC >80% (control), FVC 50–80% (moderate impairment) and FVC <50% (severe impairment).

Our dataset did not include information about whether the index surgery was emergency or elective. However, we could identify whether patients were admitted to the ICU or a general ward. Surgery in patients who had been admitted to the ICU was defined as an emergency operation, because ICU admission indicated that patients had unstable vital signs or other serious conditions.

Laboratory data were recorded as continuous variables; values for creatinine and BUN had skewed distributions. We grouped the laboratory data to indicate their clinical significance as described in previous studies (9,18,19).

### *Clinical outcomes*

The primary outcome of interest was postoperative infection within 7 days. Secondary outcomes included prolonged ICU stay and in-hospital death. We presumed that patients with a postoperative infection would be treated with antibiotics. Thus, we defined a postoperative infectious complication as initiation of new antibiotics within 1–7 days post-surgery in patients who had been administered no other antibiotics except for prophylactic antibiotics (20,21). We defined prophylactic antibiotics according to guidelines (22) and as commonly used in our hospital. They included cefazolin, cefotetan, ceftezole, ceftizoxime, ceftriaxone, cefuroxime, flomoxef and isepamicin. New antibiotics commonly used for postoperative infection included antipseudomonal cephalosporins (cefepime, ceftazidime), antipseudomonal carbapenem (imipenem, meropenem), β-lactam/β-lactamase inhibitor (piperacillin–tazobactam), antipseudomonal fluoroquinolones (ciprofloxacin, levofloxacin), aminoglycosides (amikacin, gentamicin, tobramycin), linezolid or vancomycin.

Some patients underwent postoperative care in the ICU. Usually, patients without any complications or unstable vital signs were discharged from the ICU within 2 days after surgery. Hence, we defined a prolonged ICU stay as > 2 days. Another primary outcome was in-hospital death.

### *Ethics approval*

This study was approved by the ethics committee of the Asan Medical Center (approval number 2015-0656), and the need to obtain informed consent was waived because of the retrospective observational nature of the study. This study was conducted in accordance with the Declaration of Helsinki (as revised in 2013).

### *Statistical analysis*

Continuous variables are presented as means and standard deviation (SD); categorical variables are presented as numbers and percentages. Univariate logistic regression was performed to identify associations between postoperative infection and other variables. Multivariable logistic regression was performed using variables with a P value <0.1 in the univariate analysis. Missing values were dropped in multivariable logistic analysis. In multivariable logistic regression, multicollinearity between the predictor variables was assessed by calculating the variance inflation factor (VIF) (23). In general, VIF >4 warrants further investigation, while VIF >10 is an indicator of serious multicollinearity that requires correction. Using a receiver operating characteristic (ROC) curve, we explored the predictive value of variables included in the multiple logistic regression for each outcome. The prediction model was evaluated by the area under the curve (AUC). All tests were two-sided, and a P value <0.05 was considered to indicate significance. Statistical analyses were performed using R version 3.5.1.

## Results

### *Baseline characteristics*

We included 31,827 patients who underwent thoracic or upper abdominal surgery between January 2000 and December 2014 and spirometry within the 3 months prior to their surgery. There were 514 patients with a history of physician-diagnosed COPD and 3,514 patients with airflow limitation.

The overall incidences of postoperative infection were

**Table 1** Baseline characteristics of patients who underwent major surgery

| Demographics | Mean ± SD or number, (%) |
|---|---|
| Age, years | 59.3±11.1 |
| Sex (male) | 20,946 (65.8%) |
| Weight (kg) | 63.2±12.1 |
| Height (cm) | 162.4±10.4 |
| Smoking history | |
| No data | 573 (2.06%) |
| Non-smoker | 12,269 (44.05%) |
| Ex-smoker | 10,542 (37.85%) |
| Current smoker | 3,250 (11.67%) |
| Comorbidity | |
| Cancer | 28,037 (88.1%) |
| Liver cirrhosis | 5,037 (15.8%) |
| Diabetes | 5,615 (17.6%) |
| Ischaemic heart disease | 730 (2.3%) |
| Cerebral artery disease | 274 (0.9%) |
| Pulmonary tuberculosis | 562 (1.8%) |
| COPD | 541 (1.7%) |
| Chronic kidney disease | 319 (1%) |
| Heart failure | 150 (0.5%) |
| Laboratory data | |
| Haemoglobin (mg/dL) | 13.1±1.8 |
| Creatinine (mg/dL) | 0.8±0.5 |
| Albumin (g/dL) | 3.8±0.5 |
| BUN (mg/dL) | 14.4±6.1 |
| Spirometry | |
| Measured FVC | 3.5±0.9 |
| Predicted FVC (%) | 90.1±14 |
| Measured $FEV_1$ | 2.7±0.7 |
| Predicted $FEV_1$ (%) | 90.3±16.2 |
| Predicted $FEV_1$ >80% (control group) | 25,992 (77.6%); 96.6%±11.4% |
| Predicted $FEV_1$ 50–80% (moderate group) | 7,662 (22.9%); 70.3%±7.7% |
| Predicted $FEV_1$ <50% (severe group) | 552 (1.6%); 42.6%±6.9% |
| Predicted FVC >80% (control) | 25,026 (78.6%); 95.3%±9.8% |
| Predicted FVC 50–80% (moderate group) | 6,482 (20.3%); 72.1%±7.0% |
| Predicted FVC <50% (severe group) | 319 (1.0%); 42.9%±6.8% |
| Airflow limitation | 3,514 (11.0%) |

Continuous variables are described as mean ± standard deviation and categorical variables are described as number and percentage. Airflow limitation is defined as the ratio of $FEV_1$/FVC <70% and $FEV_1$ predicted <80%. SD, standard deviation; COPD, chronic obstructive pulmonary disease; FVC, forced vital capacity; $FEV_1$: forced expiratory volume in 1 sec.

4.4% (n=1,414), of prolonged ICU care (>2 days) 5.4% (n=1,712) and of in-hospital death 0.8% (n=244). The mean age of patients was 59.3 years, and 28,037 (88.1%) had cancer: most of the operations were performed for cancer resection. The mean $FEV_1$ predicted was 90.3% and 7,049 (22.1%) patients had a $FEV_1$ predicted <80% (*Table 1*). Thoracic surgery accounted for approximately 20% of all operations, and abdominal surgery accounted for 80% (*Table S1*).

### *Spirometry and other risk factors for postoperative infection*

The results of univariate logistic regression analysis are shown in *Table 2*. The overall postoperative infection rate was 4.4%. Risk factors identified in the univariate analysis included type of operation, sex, older age (>65 years), laboratory results and grades of $FEV_1$ % predicted and FVC % predicted. In multivariable logistic regression, the independent risk factors for postoperative infectious complications were sex, age, smoking, operation type, laboratory data (albumin, BUN) and spirometry data (*Table 3*). The number of missing values were 1,055 (3.3%). Lower $FEV_1$ and FVC were both independent risk factors for postoperative infection [OR (95% CI): for $FEV_1$ 50–80% 1.86 (1.52–2.27); $FEV_1$ <50% 3.99 (2.86–5.57); FVC 50–80% 1.49 (1.31–1.69); FEV <50% 2.93 (2.02–4.24)]. The VIF for $FEV_1$ was 4.25 when all of the variables including FVC were included in the analysis. Therefore, separate multiple logistic regression analyses were performed

**Table 2** Univariate analysis of risk factors for postoperative infectious complications

| Variables | Without infection (n=30,413) (%) | With infection (n=1,414) (%) | Odds ratio (95% CI) | P value |
|---|---|---|---|---|
| Sex (male) | 19,894 (65.4) | 1,052 (74.4) | 1.53 (1.36–1.73) | <0.001 |
| Age >65 years | 10,336 (34.0) | 646 (45.7) | 1.63 (1.46–1.81) | <0.001 |
| Smoking (control = non-smoker) | 14,135 (46.5) | 506 (35.8) | | |
| Ex-smoker | 11,722 (38.5) | 642 (45.4) | 1.53 (1.35–1.72) | <0.001 |
| Current smoker | 3,560 (11.7) | 207 (14.6) | 1.63 (1.37–1.91) | <0.001 |
| Comorbidities at surgery | | | | |
| Cancer | 26,787 (88.1) | 1,250 (88.4) | 1.03 (0.87–1.21) | 0.713 |
| Liver cirrhosis | 4,818 (15.8) | 219 (15.5) | 0.97 (0.84–1.12) | 0.722 |
| Diabetes mellitus | 5,357 (17.6) | 258 (18.2) | 1.04 (0.90–1.19) | 0.542 |
| Ischaemic heart disease | 702 (2.3) | 28 (2.0) | 0.85 (0.58–1.25) | 0.421 |
| Cerebral infarction | 266 (0.9) | 8 (0.6) | 0.64 (0.31–1.30) | 0.223 |
| Pulmonary tuberculosis | 537 (1.8) | 25 (1.8) | 1 (0.66–1.50) | 0.995 |
| COPD | 526 (1.7) | 15 (1.1) | 0.6 (0.36–1.02) | 0.060 |
| Chronic kidney disease | 304 (1.0) | 15 (1.1) | 1.06 (0.63–1.78) | 0.821 |
| Heart failure | 142 (0.5) | 8 (0.6) | 1.21 (0.59–2.47) | 0.596 |
| Major operation | | | | |
| Lobectomy lung | 7,169 (23.6) | 381 (26.9) | 1.19 (1.06–1.34) | 0.004 |
| Hepatectomy | 7,681 (25.3) | 292 (20.7) | 0.77 (0.67–0.87) | <0.001 |
| Partial gastrectomy | 7,097 (23.3) | 274 (19.4) | 0.79 (0.69–0.90) | 0.001 |
| Total gastrectomy | 2,977 (9.8) | 183 (12.9) | 1.37 (1.16–1.60) | <0.001 |
| Pancreaticoduodenectomy | 2,068 (6.8) | 146 (10.3) | 1.57 (1.32–1.88) | <0.001 |
| Additional operation | | | | |
| Excision of bile duct | 1,339 (4.4) | 95 (6.7) | 1.56 (1.26–1.94) | <0.001 |
| Total pancreatectomy | 94 (0.3) | 5 (0.4) | 1.14 (0.46–2.81) | 0.769 |
| Total splenectomy | 1,019 (3.4) | 55 (3.9) | 1.16 (0.88–1.54) | 0.273 |
| Cholecystectomy | 8,699 (28.6) | 359 (25.4) | 0.85 (0.75–0.96) | 0.009 |
| Wedge resection lung | 1,267 (4.2) | 107 (7.6) | 1.88 (1.53–2.31) | <0.001 |
| Combined thoracic/abdominal operation | 93 (0.3) | 9 (0.6) | 2.08 (1.05–4.14) | 0.035 |
| Laboratory data | | | | |
| Haemoglobin <12 mg/dL | 7,494 (24.6) | 427 (30.2) | 1.32 (1.17–1.48) | <0.001 |
| Creatinine >1.5 mg/dL | 518 (1.7) | 30 (2.1) | 1.25 (0.86–1.81) | 0.238 |
| Albumin <3.5 mg/dL | 6,137 (20.7) | 459 (34.6) | 1.91(1.70–2.14) | <0.001 |
| BUN >21 mg/dL | 2,063 (6.8) | 140 (9.9) | 1.51 (1.26–1.80) | <0.001 |
| Spirometry | | | | |
| $FEV_1$ (control >80%) | 23,264 (76.5) | 904 (63.9) | | |
| $FEV_1$ (50–80%) | 6,698 (22.0) | 446 (31.5) | 1.71 (1.52–1.92) | <0.001 |
| $FEV_1$ <50% | 451 (1.5) | 64 (4.5) | 3.65 (2.78–4.78) | <0.001 |

**Table 2** (*continued*)

**Table 2** (*continued*)

| Variables | Without infection (n=30,413) (%) | With infection (n=1,414) (%) | Odds ratio (95% CI) | P value |
|---|---|---|---|---|
| FVC (control >80%) | 24,077 (79.1) | 949 (67.1) | | |
| FVC (50–80%) | 6,056 (19.9) | 426 (30.1) | 1.78 (1.59–2.00) | <0.001 |
| FVC <50% | 280 (0.9) | 39 (2.7) | 3.53 (2.51–4.97) | <0.001 |
| Airflow limitation | 5,452 (17.9) | 365 (25.8) | 1.59 (1.41–1.80) | <0.001 |

SD, standard deviation; COPD, chronic obstructive pulmonary disease; FVC, forced vital capacity; $FEV_1$, forced expiratory volume in 1 sec; BUN, blood urea nitrogen.

**Table 3** Risk factors for postoperative infectious complications in multivariable logistic regression

| Variables | Odds ratio (95% CI) | P value |
|---|---|---|
| Sex (male) | 1.17 (0.99–1.39) | 0.064 |
| Age >65 years | 1.45 (1.29–1.63) | <0.001 |
| Smoking (control = non-smoker) | | |
| Ex-smoker | 1.32 (1.12–1.54) | 0.001 |
| Current smoker | 1.53 (1.25–1.86) | <0.001 |
| Operation type | | |
| Lobectomy, lung | 1.4 (1.18–1.66) | <0.001 |
| Partial gastrectomy | 1.26 (1.06–1.49) | 0.008 |
| Total gastrectomy | 1.95 (1.61–2.35) | <0.001 |
| Pancreaticoduodenectomy | 1.89 (1.54–2.32) | <0.001 |
| Excision of bile duct | 1.76 (1.39–2.23) | <0.001 |
| Wedge resection lung | 1.54 (1.18–2.02) | 0.002 |
| Laboratory data | | |
| Albumin <3.5 mg/dL | 1.62 (1.43–1.83) | <0.001 |
| BUN >21 mg/dL | 1.27 (1.05–1.53) | 0.014 |
| Spirometry | | |
| $FEV_1$ (control >80%)* | Control group | Control group |
| $FEV_1$ (50–80%)* | 1.86 (1.52–2.27) | <0.001 |
| $FEV_1$ <50%* | 3.99 (2.86–5.57) | <0.001 |
| Airflow limitation (including $FEV_1$)* | 0.71 (0.57–0.88) | 0.002 |
| FVC (control >80%)‡ | Control group | Control group |
| FVC (50–80%)‡ | 1.49 (1.31–1.69) | <0.001 |
| FVC <50%‡ | 2.93 (2.02–4.24) | <0.001 |
| Airflow limitation (including FVC)‡ | 1.11 (0.96–1.28) | 0.133 |

*, multiple variable logistic analysis was conducted including $FEV_1$ and airflow limitation. $FEV_1$ is collinear with FVC, so the two variables must be analysed separately; ‡, multiple variable logistic analysis was conducted including FVC and airflow limitation. CI, confidence interval; FVC, forced vital capacity; $FEV_1$, forced expiratory volume in 1 sec; BUN, blood urea nitrogen.

**Table 4** Risk factors for prolonged ICU care assessed by multivariable logistic regression

| Variables | Odds ratio (95% CI) | P value |
|---|---|---|
| Sex (male) | 1.53 (1.35–1.74) | <0.0001 |
| Age >65 years | 0.75 (0.67–0.85) | <0.0001 |
| Operation type | | |
| Lobectomy, lung | 1.93 (1.60–2.31) | <0.0001 |
| Hepatectomy | 0.22 (0.19–0.26) | <0.0001 |
| Total gastrectomy | 0.48 (0.35–0.66) | <0.0001 |
| Pancreaticoduodenectomy | 1.48 (1.17–1.87) | 0.0012 |
| Emergency operation | 3.80 (3.02–4.77) | <0.0001 |
| Laboratory data | | |
| Haemoglobin <12 mg/dL | 2.07 (1.82–2.34) | <0.0001 |
| Creatinine >1.5 mg/dL | 1.55 (1.18–2.04) | 0.0016 |
| Albumin <3.5 mg/dL | 2.54 (2.25–2.88) | <0.0001 |
| BUN >21 mg/dL | 1.73 (1.44–2.07) | <0.0001 |
| Spirometry | | |
| $FEV_1$ (control >80%)* | | |
| $FEV_1$ (50–80%)* | 1.91 (1.61–2.26) | <0.0001 |
| $FEV_1$ <50%* | 3.09 (2.27–4.21) | <0.0001 |
| Airflow limitation (including $FEV_1$)* | 0.68 (0.56–0.81) | <0.0001 |
| FVC (control >80%)‡ | | |
| FVC (50–80%)‡ | 1.59 (1.40–1.81) | <0.0001 |
| FVC <50%‡ | 2.22 (1.63–3.02) | <0.0001 |
| Airflow limitation (including FVC)‡ | 0.98 (0.85–1.13) | 0.8054 |

*, multiple variable logistic analysis was conducted including $FEV_1$ and airflow limitation. $FEV_1$ is collinear with FVC, so the two variables must be analysed separately; ‡, multiple variable logistic analysis was conducted including FVC and airflow limitation. CI, confidence interval; FVC, forced vital capacity; $FEV_1$, forced expiratory volume in 1 sec; BUN, blood urea nitrogen.

including either $FEV_1$ or FVC. The effect of other risk factors was robust but the risk of airflow limitation differed between $FEV_1$ [OR (95% CI): 0.71 (0.57–0.88)] and FVC [OR (95% CI): 1.11 (0.96–1.28)]. Evaluation of the predictive power of these factors for postoperative infection showed that the 95% CI of the AUC was 0.643–0.673 (*Table 2*).

### *Spirometry and other risk factors for prolonged ICU stay and in-hospital death*

The overall rate of prolonged ICU care was 5.3%. Univariate logistic analysis showed that the type of operation and patient demographic data were associated with a prolonged ICU stay (*Table S2*). In multivariable logistic analysis, laboratory data (haemoglobin, creatinine, albumin, BUN), type of surgery, emergency surgery and grades of $FEV_1$ % predicted and FVC % predicted were independent risk factors for a prolonged ICU stay (*Table 4*). The OR of airflow limitation for prolonged ICU care was significant for $FEV_1$ [OR, 95% CI: 0.68 (0.56–0.81)] but not for FVC [OR, 95% CI: 0.98 (0.85–1.13)]. In this model, the 95% CI of the AUC was 0.839–0.862.

The overall rate of in-hospital death was 0.8% (*Table S3*). Multivariable logistic analysis showed that most of the variables produced results similar to those for ICU

**Table 5** Risk factors for in-hospital death analysed by multivariable logistic regression

| Variables | Odds ratio (95% CI) | P value |
|---|---|---|
| Age >65 years | 2.18 (1.66–2.85) | <0.0001 |
| Operation type | | |
| Lobectomy, lung | 1.46 (1.01–2.12) | 0.0464 |
| Hepatectomy | 1.78 (1.26–2.54) | 0.0012 |
| Partial gastrectomy | 0.25 (0.12–0.53) | 0.0003 |
| Pancreaticoduodenectomy | 2.74 (1.81–4.16) | <0.0001 |
| Enterostomy | 9.71 (2.62–36.01) | 0.0007 |
| Emergency operation | 6.02 (3.90–9.31) | <0.0001 |
| History of chronic kidney disease | 2.40 (1.03–5.60) | 0.0434 |
| Laboratory data | | |
| Haemoglobin <12 mg/dL | 1.46 (1.08–1.96) | 0.0125 |
| Creatinine >1.5 mg/dL | 1.70 (1.27–2.29) | 0.0004 |
| Albumin <3.5 mg/dL | 2.16 (1.28–3.64) | 0.0041 |
| BUN >21 mg/dL | 1.77 (1.19–2.62) | 0.0044 |
| Spirometry | | |
| $FEV_1$ (control >80%)* | | |
| $FEV_1$ (50–80%)* | 2.91 (1.99–4.27) | <0.0001 |
| $FEV_1$ <50%* | 5.40 (2.97–9.84) | <0.0001 |
| Airflow limitation (including $FEV_1$)* | 0.72 (0.49–1.07) | 0.1027 |
| FVC (control >80%)‡ | | |
| FVC (50–80%)‡ | 2.29 (1.69–3.11) | <0.0001 |
| FVC <50%‡ | 5.90 (3.42–10.16) | <0.0001 |
| Airflow limitation (including FVC)‡ | 1.24 (0.91–1.67) | 0.1688 |

*, multiple variable logistic analysis was conducted including $FEV_1$ and airflow limitation. $FEV_1$ is collinear with FVC, so the two variables must be analysed separately; ‡, multiple variable logistic analysis was conducted including FVC and airflow limitation. CI, confidence interval; FVC, forced vital capacity; $FEV_1$: forced expiratory volume in 1 sec; BUN, blood urea nitrogen.

stay. However, enterostomy was an additional independent risk factor for in-hospital death (*Table 5*). Patients with lower grades of $FEV_1$ or FVC had a higher risk of in-hospital death. However, airflow limitation was not a significant risk factor for in-hospital death in the multivariable model [OR, 95% CI: 0.72 (0.49–1.07) for $FEV_1$; 1.24 (0.91–1.67) for FVC]. In this model, the 95% CI of the AUC was 0.803–0.852.

## Discussion

Because the process of extracting big data has evolved, our hospital has developed an extraction system called ABLE (14). Using this system, we can easily search and extract data while protecting patient privacy. The purpose of this study was to use big-data analysis to investigate whether spirometry can be used as an independent predictor of morbidity and mortality. We found that FVC was an independent risk factor for postoperative infection and prolonged ICU care, regardless of airflow limitation. $FEV_1$ also showed a significant relationship with postoperative infection and prolonged ICU care. However, the airway limitation of the lower $FEV_1$ group had a protective effect against postoperative infection. Therefore, patients with low

$FEV_1$ but normal FVC have a lower risk of postoperative infection and prolonged ICU care than patients with low $FEV_1$ and FVC. Thus, we suggest that low FVC is a more reliable indicator of the risk of postoperative infection and prolonged ICU care.

Spirometry is not recommended for patients undergoing nonthoracic surgery, except for those with preoperative asthma or COPD (24). Huh *et al.* support this recommendation because they found that preoperative spirometry results could not be used to stratify the risk of postoperative complications in older patients undergoing laparoscopic gastrectomy (25). Other studies have attempted to evaluate the predictive power of FVC or vital capacity for postoperative outcomes; however, $FEV_1$ did not show a significant relationship with postoperative outcomes (12,13). In our study, the mean predicted $FEV_1$ and FVC were 90.2 and 90.0, respectively, which were lower than those in previous studies. Over 20% of our patients were classified with moderate or severe airway limitation. Therefore, this study has greater strength than previous studies for evaluating the risk of lower $FEV_1$ and FVC.

COPD (26) and airflow limitation (27,28) have been reported to be independent risk factors for postoperative pulmonary complications. Although airflow limitation correlates with lower $FEV_1$, these studies did not consider the relationship between $FEV_1$ or FVC and airflow limitation. In the present study, we found that although airflow limitation was positively correlated with postoperative infection in univariate analysis, in multivariable analysis it was negatively correlated with postoperative infection when $FEV_1$ was included in the multivariable model.

Infectious complications are the main causes of postoperative morbidity in abdominal and thoracic surgery (3,29). Previous studies used varying definitions of postoperative infectious complications (29-31). Although it is important to classify postoperative infections, a diagnosis for postoperative complications was rarely coded in our electronic medical records. However, if an infection occurs after surgery, the antibiotics administered to the patient should be modified. Thus, we used this to define postoperative infections.

Shifting the definition of a variable between continuous and categorical may have clinical and statistical significance. In previous studies, patient age and laboratory data used to predict postoperative complications, such as creatinine, albumin and haemoglobin, were defined using varying cut-off values (10,18,19). The cut-off values chosen affect the descriptive power by changing the distribution of binary data. For outcome prediction, we used the most appropriate cut-off values based on the distribution of our data.

It was previously reported that emergency surgery was an independent risk factor for postoperative outcomes (2), with a more than fourfold higher risk of postoperative complications compared with elective surgery. Our electronic medical record system did not allow us to distinguish emergency from elective surgery. However, we assumed that admission to ICU before surgery had the same degree of risk as an emergency operation and found that presurgical ICU care was a risk factor for prolonged ICU stay and in-hospital death.

This study had some limitations. First, we defined postoperative infection based on antibiotic use. Identification of postoperative infections such as pneumonia or surgical site infection requires clinical judgement. However, patients infected after surgery should be treated with antibiotics, and the overall incidence of postoperative complications in our study was similar to those in previous studies (32-34). Thus, it is reasonable to assume that this factor has clinical significance. Second, there is some uncertainty regarding the clinical data because the patient's history of comorbidity and the procedure code were often omitted or miscoded. In the future, natural language processing could be used to identify a history of comorbidity from the descriptive electronic medical records.

In conclusion, this study confirmed that FVC is a useful indicator of postoperative complications, regardless of airflow limitation.

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## Footnote

*Conflicts of Interest:* All authors have completed the ICMJE uniform disclosure form (available at http://dx.doi.org/10.21037/jtd-19-2687). CMC serves as an unpaid editorial board member of *Journal of Thoracic Disease* from Oct 2019 to Sep 2021. The other authors have no conflicts of interest to declare.

*Ethical Statement:* The authors are accountable for all aspects of the work in ensuring that questions related

to the accuracy or integrity of any part of the work are appropriately investigated and resolved. This study was approved by the ethics committee of the Asan Medical Center (approval number 2015-0656), and the need to obtain informed consent was waived because of the retrospective observational nature of the study. This study was conducted in accordance with the Declaration of Helsinki (as revised in 2013).



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## Supplementary

**Table S1** Type of surgery of in patients

| Type of surgery | Number (%) |
|---|---|
| Major operations | |
| Lobectomy lung | 7,550 (23.7) |
| Hepatectomy | 7,973 (25.1) |
| Partial gastrectomy | 7,371 (23.2) |
| Total gastrectomy | 3,160 (9.9) |
| Pancreaticoduodenectomy | 2,214 (7.0) |
| Additional operations[§] | |
| Excision of bile duct | 1,434 (4.5) |
| Total pancreatectomy | 99 (0.3) |
| Total splenectomy | 1,074 (3.4) |
| Cholecystectomy | 9,058 (28.5) |
| Excision tissue of mediastinum | 341 (1.1) |
| Excision peritoneal tissue | 1,338 (4.2) |
| Local excision stomach | 385 (1.2) |
| Enterostomy | 35 (0.1) |
| Excision of pleura | 473 (1.5) |
| Other excision of abdominal veins | 289 (0.9) |
| Wedge resection of lung | 1,374 (4.3) |
| Peritoneal adhesiolysis | 986 (3.1) |
| Partial excision of large intestine | 52 (0.2) |
| Partial resection of small intestine | 111 (0.3) |
| Repair of vessel | 22 (0.1) |
| Regional lymph node excision | 17,010 (53.4) |
| Small bowel anastomosis | 675 (2.1) |
| Combined thoracic/abdominal operation* | 102 (0.3) |
| Emergency surgery[‡] | 442 (1.4) |

[§], additional operations were an operation performed on the same day as the major surgery; *, combined thoracic and abdominal surgery means that the simultaneous operation of the thoracic and abdominal surgery; [‡], patients who admit to ICU before operation were usually severe and considered to be equivalent to emergency surgery.

**Table S2** Univariate analysis of patient and procedure risk factors related to prolonged ICU care

| Variables | Control group (n=30,115) (%) | Prolonged ICU (n=1,712) (%) | Odds ratio (95% CI) | P value |
|---|---|---|---|---|
| Sex (male) | 19,679 (65.3) | 1,267 (74.0) | 1.51 (1.35–1.68) | <0.001 |
| Age >65 years | 10,473 (34.8) | 509 (29.7) | 0.79 (0.71–0.88) | <0.001 |
| Smoking (control = non-smoker) | 13,941 (46.3) | 700 (40.9) | | |
| Ex-smoker | 11,662 (38.7) | 702 (41.0) | 1.19 (1.07–1.33) | 0.001 |
| Current smoker | 3,580 (11.9) | 187 (10.9) | 1.04 (0.88–1.22) | 0.640 |
| Comorbidities at surgery | | | | |
| Cancer | 26,510 (88.0) | 1,527 (89.2) | 1.12 (0.96–1.31) | 0.148 |
| Liver cirrhosis | 4,765 (15.8) | 272 (15.9) | 1.01 (0.88–1.14) | 0.943 |
| Diabetes mellitus | 5,298 (17.6) | 317 (18.5) | 1.06 (0.93–1.20) | 0.329 |
| Ischaemic heart disease | 688 (2.3) | 42 (2.5) | 1.07 (0.78–1.47) | 0.650 |
| Cerebral infarction | 259 (0.9) | 15 (0.9) | 1.01 (0.60–1.71) | 0.944 |
| Pulmonary tuberculosis | 528 (1.8) | 34 (2.0) | 1.13 (0.8–1.61) | 0.477 |
| COPD | 514 (1.7) | 27 (1.6) | 0.92 (0.62–1.36) | 0.686 |
| Chronic kidney disease | 297 (1.0) | 22 (1.3) | 1.31 (0.84–2.02) | 0.229 |
| Heart failure | 144 (0.5) | 6 (0.4) | 0.73 (0.32–1.65) | 0.455 |
| Major operation | | | | |
| Lobectomy lung | 7,203 (23.9) | 347 (20.3) | 0.8 (0.71–0.91) | 0.001 |
| Hepatectomy | 7,753 (25.7) | 220 (12.9) | 0.42 (0.36–0.49) | <0.001 |
| Partial gastrectomy | 7,319 (24.3) | 52 (3.0) | 0.09 (0.07–0.12) | <0.001 |
| Total gastrectomy | 3,114 (10.3) | 46 (2.7) | 0.23 (0.17–0.32) | <0.001 |
| Pancreaticoduodenectomy | 2,103 (7.0) | 111 (6.5) | 0.92 (0.75–1.12) | 0.429 |
| Additional operation | | | | |
| Excision of bile duct | 1,358 (4.5) | 76 (4.4) | 0.98 (0.77–1.24) | 0.892 |
| Total splenectomy | 930 (3.1) | 144 (8.4) | 2.88 (2.40–3.46) | <0.001 |
| Cholecystectomy | 7,975 (26.5) | 1,083 (63.3) | 4.78 (4.32–5.23) | <0.001 |
| Enterostomy | 23 (0.1) | 12 (0.7) | 9.23 (4.58–18.59) | <0.001 |
| Emergency operation | 207 (0.7) | 235 (13.7) | 22.9 (18.9–27.9) | <0.001 |
| Combined thoracic/abdominal operation | 94 (0.3) | 8 (0.5) | 1.49 (0.72–3.09) | 0.272 |
| Laboratory data | | | | |
| Haemoglobin <12 mg/dL | 6,897 (22.9) | 1,024 (59.8) | 5.01 (4.53–5.53) | <0.001 |
| Creatinine >1.5 mg/dL | 384 (1.3) | 164 (9.6) | 8.2 (6.78–9.91) | <0.001 |
| Albumin <3.5 mg/dL | 7,554 (25.1) | 1,128 (65.8) | 5.77 (5.20–6.40) | <0.001 |
| BUN >21 mg/dL | 1,890 (6.3) | 313 (18.3) | 3.34 (2.93–3.80) | <0.001 |
| Spirometry | | | | |
| $FEV_1$ (control >80%) | 23,217 (77.1) | 951 (55.5) | | |
| $FEV_1$ (50–80%) | 6,485 (21.5) | 659 (38.5) | 2.48 (2.23–2.75) | <0.001 |
| $FEV_1$ <50% | 413 (1.4) | 102 (6.0) | 6.02 (4.80–7.56) | <0.001 |
| FVC (control >80%) | 24,062 (79.9) | 964 (56.3) | | |
| FVC (50–80%) | 5,823 (19.3) | 659 (38.4) | 2.82 (2.55–3.13) | <0.001 |
| FVC <50% | 230 (0.7) | 89 (5.1) | 9.65 (7.50–12.4) | <0.001 |
| Airflow limitation | 5,352 (17.8) | 465 (27.2) | 1.72 (1.54–1.92) | <0.001 |

CI, confidence interval; FVC, forced vital capacity; $FEV_1$, forced expiratory volume in 1 sec; BUN, blood urea nitrogen.

**Table S3** Univariate analysis of patient- and procedure-related outcomes with postoperative in-hospital death

| Variables | Control group (n=31,583) (%) | Prolonged ICU (n=244) (%) | Odds ratio (95% CI) | P value |
|---|---|---|---|---|
| Sex (male) | 20,766 (65.8) | 180 (73.8) | 1.46 (1.1–1.95) | 0.009 |
| Age >65 years | 10,845 (34.3) | 137 (56.1) | 2.44 (1.89–3.15) | <0.001 |
| Smoking (control = non-smoker) | 14,554 (46.1) | 87 (35.6) | | |
| Ex-smoker | 12,252 (38.8) | 112 (45.9) | 1.52 (1.15–2.02) | 0.003 |
| Current smoker | 3,732 (11.8) | 35 (14.3) | 1.56 (1.05–2.32) | 0.025 |
| Comorbidities at surgery | | | | |
| Cancer | 27,817 (88.1) | 220 (90.2) | 1.24 (0.81–1.89) | 0.317 |
| Liver cirrhosis | 5,001 (15.8) | 36 (14.8) | 0.92 (0.64–1.31) | 0.645 |
| Diabetes mellitus | 5,574 (17.6) | 41 (16.8) | 0.94 (0.67–1.32) | 0.730 |
| Ischaemic heart disease | 726 (2.3) | 4 (1.6) | 0.7 (0.26–1.90) | 0.495 |
| Cerebral infarction | 272 (0.9) | 2 (0.8) | 0.95 (0.23–3.84) | 0.944 |
| Pulmonary tuberculosis | 562 (1.8) | 0 (0) | | |
| COPD | 534 (1.7) | 7 (2.9) | 1.71 (0.80–3.65) | 0.161 |
| Chronic kidney disease | 313 (1.0) | 6 (2.5) | 2.51 (1.11–5.70) | 0.027 |
| Heart failure | 149 (0.5) | 1 (0.4) | 0.86 (0.12–6.22) | 0.888 |
| Major operation | | | | |
| Lobectomy lung | 7,487 (23.7) | 63 (25.8) | 1.12 (0.84–1.49) | 0.440 |
| Hepatectomy | 7,896 (25.0) | 77 (31.6) | 1.38 (1.05–1.81) | 0.019 |
| Partial gastrectomy | 7,363 (23.3) | 8 (3.3) | 0.11 (0.05–0.22) | <0.001 |
| Total gastrectomy | 3,149 (10.0) | 11 (4.5) | 0.42 (0.23–0.78) | 0.006 |
| Pancreaticoduodenectomy | 2,175 (6.9) | 39 (16.0) | 2.57 (1.82–3.63) | <0.001 |
| Additional operation | | | | |
| Excision of bile duct | 1,408 (4.5) | 26 (10.7) | 2.55 (1.69–3.85) | <0.001 |
| Total splenectomy | 1,059 (3.4) | 15 (6.1) | 1.88 (1.11–3.19) | 0.018 |
| Cholecystectomy | 8,958 (28.4) | 100 (41.0) | 1.75 (1.35–2.26) | <0.001 |
| Enterostomy | 32 (0.1) | 3 (1.2) | 12.27 (3.73–40.3) | <0.001 |
| Emergency operation | 406 (1.3) | 36 (14.8) | 13.2 (9.20–19.1) | <0.001 |
| Combined thoracic/abdominal operation | 100 (0.3) | 2 (0.8) | 2.6 (0.63–10.6) | 0.182 |
| Laboratory data | | | | |
| Haemoglobin <12 mg/dL | 7,795 (24.7) | 126 (51.6) | 3.25 (2.53–4.19) | <0.001 |
| Creatinine >1.5 mg/dL | 519 (1.6) | 29 (11.9) | 8.07 (5.42–12.0) | <0.001 |
| Albumin <3.5 mg/dL | 8,537 (27.0) | 145 (59.4) | 3.95 (3.06–5.11) | <0.001 |
| BUN >21 mg/dL | 2,150 (6.8) | 53 (21.7) | 3.79 (2.79–5.16) | <0.001 |
| Spirometry | | | | |
| $FEV_1$ (control >80%) | 24,054 (76.1) | 114 (46.7) | | |
| $FEV_1$ (50–80%) | 7,034 (22.2) | 110 (45.0) | 3.3 (2.53–4.29) | <0.001 |
| $FEV_1$ <50% | 495 (1.5) | 20 (8.1) | 8.52 (5.25–13.8) | <0.001 |
| FVC (control >80%) | 24,916 (78.9) | 110 (45.0) | | |
| FVC (50–80%) | 6,369 (20.1) | 113 (46.3) | 4.02 (3.08–5.23) | <0.001 |
| FVC <50% | 298 (0.9) | 21 (8.6) | 15.96 (9.9–25.81) | <0.001 |
| Airflow limitation | 5,731 (18.1) | 86 (35.2) | 2.45 (1.88–3.19) | <0.001 |

CI, confidence interval; FVC, forced vital capacity; $FEV_1$, forced expiratory volume in 1 sec; BUN, blood urea nitrogen.