Preoperative pulmonary function and mortality after cardiac surgery

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Background  The aim of the study was to examine the relationship between preoperative pulmonary function and outcomes after cardiac surgery.

Methods  We performed preoperative pulmonary function tests (PFTs) in 1,169 patients undergoing cardiac surgery at the Minneapolis Veterans Affairs Medical Center. Airway obstruction was defined as forced expiratory volume in 1 minute (FEV1) to forced vital capacity ratio <0.7.

Results  Of the 1,169 patients, 483 (41%) had a prior history of chronic obstructive pulmonary disease (COPD). However, 178 patients with a history of COPD had no airway obstruction on PFT. Conversely, 186 patients without a COPD history had airway obstruction on PFT. Thus, PFT results helped reclassify the COPD status of 364 patients (31%). Operative mortality was 2% in patients with no or mild airway obstruction versus 6.7% in those with moderate or severe obstruction (i.e., FEV1 to forced vital capacity ratio <0.7 and FEV1 <80% predicted). Postoperative mortality was higher (odds ratio 3.2, 95% CI 1.6-6.2, P = .001) in patients with moderate or severe airway obstruction and in patients with diffusing capacity of the lung for carbon monoxide <50% of predicted (odds ratio 4.9, 95% CI 2.3-10.8, P = .0001). Notably, mortality risk was 10× higher (95% CI 3.4-27.2, P = .0001) in patients with moderate or severe airway obstruction and diffusing capacity of the lung for carbon monoxide <50% of predicted.

Conclusions  These data show that PFT before cardiac surgery reclassifies the COPD status of a substantial number of patients and provides important prognostic information that the current risk estimate models do not capture. (Am Heart J 2010;159:691-7.)

A clinical history of chronic obstructive pulmonary disease (COPD) is present in 4% to 27% of patients undergoing cardiac surgery1-3 and conveys a higher risk of postoperative pulmonary and infectious complications and death.4,5,6,7 Accordingly, a history of COPD is one of the clinical variables included in the risk stratification of patients undergoing cardiac surgery.2,9-11 On the other hand, most of the current risk estimation models for cardiac surgery do not include pulmonary function test (PFT) results in their algorithms. This may lead to 2 potential problems. First, in clinical practice, COPD is often diagnosed on an empirical basis without a PFT,12-14 raising the possibility of misdiagnosis of this disease and misclassification error when this variable is used in risk stratification. Indeed, there is accumulating evidence in nonsurgical settings that a substantial number of patients with a previous diagnosis of COPD do not have an abnormal spirometry.15-19 Among patients undergoing cardiac surgery, such misclassification of COPD status, whether wrongly labeling patients with normal pulmonary function with COPD or vice versa, may alter the surgical risk estimate significantly. Second, a history of COPD alone, even when correctly diagnosed, does not provide any quantitative information on the severity of this disease. It is plausible that the perioperative risk is different in patients with mild versus severe COPD.6,20 Preoperative PFTs could avert both of these potential problems. However, PFTs are not routinely performed before cardiac surgery; and there are very few data on the relation between preoperative PFT results and outcomes after cardiac surgery. Furthermore, despite
the paucity of supporting data, certain PFT parameters are commonly used in making clinical decisions about the candidacy of patients for cardiac surgery. The objective of this investigation was to fill these gaps in knowledge. Specifically, we aimed to correlate a clinical history of COPD with the results of PFT and examine the relation between the preoperative pulmonary function and outcomes in a large cohort of patients undergoing cardiac surgery.

**Methods**

This study was approved by the research and development committee of Minneapolis Veterans Affairs (VA) Medical Center, and the requirement for individual consent was waived. No extramural funding was used to support this work. The authors are solely responsible for the design and conduct of this study, all study analyses, the drafting and editing of the paper, and its final contents.

**Study patients**

From January 2000 through September 2007, a total of 2,600 patients underwent cardiac surgery at the Minneapolis VA Medical Center, a tertiary referral center for VA facilities in the Upper Midwest Integrated Service Network. Of the 2,600 patients, 1,169 who had completed a PFT within 1 year before surgery (median 18 days, range 1-365 days) were included in the present analysis. The decision to perform PFT was made by each patient’s physician based purely on clinical indications and practice style.

**Data acquisition**

The PFT reports were obtained from the patient electronic medical records and the pulmonary laboratory database at the Minneapolis VA Medical Center. Clinical, procedural, and outcomes data including operative mortality were obtained from the VA Continuous Improvement in Cardiac Surgery Program database, which is an ongoing database of prospectively collected data in all patients undergoing heart surgery within the VA system.1,21,22 This database includes a validated mortality risk estimate (ie, predicted probability of operative mortality) for each patient, based on his/her preoperative risk factors. The VA mortality risk estimate is calculated based on variables including operative mortality and major complications. The PFT results are not included in this database. However, the database includes a validated mortality risk estimate (ie, predicted probability of operative mortality) for each patient, based on his/her preoperative risk factors. The VA mortality risk estimate is obtained by stepwise logistic regression analysis including all the variables entered into the national VA Continuous Improvement in Cardiac Surgery Program database. The VA mortality risk estimate has been previously validated as a predictor of postoperative mortality after cardiac surgery and shown to be superior to the Euroscore among VA patients.9,21,25

**Pulmonary function tests**

Pulmonary function tests were performed using a Sensor Medics Vmax Encore instrument (VIASYS Healthcare, San Diego, CA). Patients were asked to refrain from smoking and using bronchodilators for at least 4 hours before the testing. Spirometry and diffusing capacity of the lung for carbon monoxide (DLCO) were recorded. The forced expiratory volume in 1 minute (FEV1) and the forced vital capacity (FVC) were determined by taking the best of 3 trials.24 Predicted FEV1, FVC, and DLCO were calculated according to the formula deducted from the National Health and Nutrition Examination Survey III.25 Observed measurements were reported as a percentage of the predicted for each individual patient. Obstructive airway disease was diagnosed if FEV1/FVC <0.7. The severity of airway obstruction was categorized according to the Global Strategy for the Diagnosis, Management, and Prevention of COPD Guidelines. Thus, among patients with an FEV1/FVC ratio <0.7, those with an FEV1 ≥80% predicted were categorized as stage I (mild) obstruction, ones with FEV1 between 50% and 79% of predicted were categorized as stage II (moderate) obstruction, those with FEV1 between 30% and 49% of predicted were categorized as stage III (severe) obstruction, and patients with FEV1 <30% of predicted were categorized as stage IV (very severe) obstruction26 (Table I). Furthermore, DLCO <50% was categorized as moderate to severe reduction in diffusion capacity.26

**Outcomes**

The primary outcome variable was operative mortality, defined as death within 30 days of heart surgery due to any cause; or death at a later time occurring as a direct consequence of a perioperative complication (eg, mediastinitis). Secondary outcomes included prolonged ventilation and lengths of stay in the intensive care unit (ICU) and the hospital.

**Data analysis**

Continuous data are presented as mean ± 1 SD. Nominal data are presented as frequencies and percentages. The comparisons between binary patient groups (eg, survivors vs deceased) were performed using Student t test for normally distributed continuous variables, nonparametric Mann-Whitney U test for skewed continuous variables, and χ² test for categorical variables. Comparisons between the 3 categories based on percentage predicted FEV1 were performed using χ² test and Kruskall-Wallis test (eg, lengths of stay).

The association between the PFT parameters and operative death was examined by univariate logistic regression analysis. Patients were categorized according to their airway obstruction status as normal, mildly obstructed, or moderate to severely obstructed.26 Odds ratios were obtained in reference to patients with normal spirometry. Multivariable analysis included the PFT parameter and the validated mortality risk estimate from the VA Continuous Improvement in Cardiac Surgery Program database. The VA mortality risk estimate is calculated based on variables independently associated with postoperative death in stepwise

<table>
<thead>
<tr>
<th>Severity of COPD based on spirometry results</th>
<th>FEV1/FVC</th>
<th>Predicted FEV1 %</th>
<th>DLCO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage I: mild COPD</td>
<td>≥0.70</td>
<td>≥80% predicted</td>
<td></td>
</tr>
<tr>
<td>Stage II: moderate COPD</td>
<td>≥0.70</td>
<td>50% ≥ FEV1 &lt; 80%</td>
<td></td>
</tr>
<tr>
<td>Stage III: severe COPD</td>
<td>≥0.70</td>
<td>30% ≥ FEV1 &lt; 50%</td>
<td></td>
</tr>
<tr>
<td>Stage IV: very severe COPD</td>
<td>&lt;0.70</td>
<td>&lt;30% predicted</td>
<td></td>
</tr>
</tbody>
</table>

Table I.
logistic regression analysis in the national VA Continuous Improvement in Cardiac Surgery Program database. Thus, the VA mortality risk estimate serves as an overall risk indicator accounting for all the variables in this database. A $P < .05$ was considered statistically significant.

## Results

### Baseline characteristics

The baseline characteristics of the 1,169 cardiac surgery patients with PFT are outlined in Table II. Patients were 67 ± 10 years in age, and 99% were male. A significant minority (n = 483, 41%) had a history of COPD. However, 178 patients with a prior history of COPD had no airway obstruction on PFT. Conversely, 186 patients without a history of COPD had airway obstruction (FEV1/FVC < 0.7). Thus, after the PFT results, a total of 364 patients (31%) were reclassified with regard to their COPD status.

A total of 678 patients (58%) had normal spirometry. Of the remaining patients with abnormal PFT, 150 (13%) had mild, 260 (22%) had moderate, and 81 (7%) had severe obstruction (Table I). The prevalence of moderate and severe obstruction was 14% among patients who had never smoked and 33% among those without a history of COPD.

### Operative mortality

There were a total of 41 operative deaths (3.5%). Patients who died were older (72 ± 8 vs 66 ± 10 years, $P < .0001$), had a higher prevalence of COPD by history (61% vs 41%, $P = .009$), and had a higher mortality risk estimate (11% ± 12% vs 4% ± 5%, $P = .001$) than survivors. Of the 41 patients who died, 15 had no airway obstruction, 3 had mild obstruction, 19 had moderate obstruction, and 4 had severe obstruction on preoperative PFT. Causes of death were multigorgan failure (n = 10), cardiogenic shock (n = 7), respiratory failure (n = 7), stroke (n = 6), sudden death (n = 3), infection (n = 3), and unknown (n = 5). All of the patients who died of respiratory failure had moderate or severe airway obstruction or DLCO < 50% of predicted.

### Relation of airway obstruction with surgical outcome

Operative mortality occurred in 2.2% of patients with no airway obstruction, 2% of patients with mild obstruction, and 6.7% of patients with moderate or severe obstruction ($P = .001$) (Figure 1). Among patients with moderate or severe obstruction, the odds of death was 3.2-fold higher (odds ratio 3.2, 95% CI 1.6-6.2, $P = .001$) than that in patients with no airway obstruction. In multivariable analysis, after adjusting for the VA mortality risk estimate, moderate or severe obstruction was independently associated with death (odds ratio 2.6, 95% CI 1.3-5.2, $P = .006$). Patients with moderate to severe obstruction also had longer lengths of stay in the ICU and the hospital and tended to have a higher incidence of ventilation beyond 48 hours compared with patients with no airway obstruction (Table III).

### Relation of DLCO with surgical outcome

A total of 853 patients underwent DLCO testing preoperatively. Patients with DLCO < 50% of predicted...
had a higher incidence of mortality, prolonged ventilation, and length of stay compared with those with DLCO ≥50% (Table IV). Moderate to severe reduction in DLCO was associated with an almost 5-fold increase in the odds of death (odds ratio 4.9, 95% CI 2.3–10.8, \( P = .0001 \)). In multivariable analysis, after adjusting for the VA mortality risk estimate, DLCO <50% was an independent predictor of mortality (odds ratio 3.5, 95% CI 1.5–7.9, \( P = .003 \)).

Relation of airway obstruction and DLCO with mortality

Patients were categorized into 4 groups based on the severity of their airway obstruction (ie, no or mild obstruction vs moderate or severe obstruction) and DLCO (ie, >50% vs <50%) on PFT. Mortality was higher in those with moderate or severe airway obstruction or DLCO <50% (Table V). Most notably, patients with moderate or severe obstruction and DLCO <50% had almost a 10-fold higher odds of death (odds ratio 9.7, 95% CI 3.4–27.2, \( P = .0001 \)) in comparison to patients with no or mild obstruction and DLCO >50% (Table V).

Discussion

The purpose of this investigation was to correlate a clinical history of COPD with the results of PFT and examine the relation between the preoperative pulmonary function and outcomes after cardiac surgery. Our data showed that preoperative PFTs, performed in a large cohort of patients before cardiac surgery, helped reclassify the COPD status of 30% of the patients. Furthermore, moderate or severe airway obstruction and reduction in DLCO (ie, <50% of predicted) were each independently associated with operative mortality and prolonged ventilation time and length of stay in the ICU and the hospital. Notably, patients who had moderate or severe airway obstruction and DLCO <50% of predicted had almost a 10-fold increase in operative mortality.

In clinical practice, COPD is often diagnosed clinically on the basis of dyspnea and a history of smoking without performing PFTs.\(^{12-14}\) However, dyspnea is not a symptom specific for obstructive lung disease but may be a manifestation of other medical problems such as heart failure or coronary or valvular heart disease. Thus, misdiagnosis has been noted to occur in 20% to 50% of COPD cases.\(^{15-19}\) Among patients undergoing cardiac
surgery, such misclassification of COPD status alters the preoperative risk estimate with potential consequences in clinical decisions. However, the incidence of misclassification of COPD among patients undergoing cardiac surgery has not been assessed before. In the present study, misclassification of COPD status occurred in \( \sim 30\% \) of the patients who underwent cardiac surgery in a tertiary referral center. In almost half of these cases, previous diagnosis of COPD was refuted by the PFT results; and in the remainder, a new diagnosis was made. These results suggest that performing preoperative PFTs before cardiac surgery would change the surgical risk estimate of a substantial number of patients.

A clinical history of COPD is a known risk factor for complications and death after cardiac surgery,\(^{4,6,20,27}\), however, it provides no information about the severity of this disease. Our data show that the mortality risk of patients with mild airway obstruction is similar to those with normal pulmonary function. However, mortality risk sharply increases in those with moderate or severe airway obstruction (i.e., \( \text{FEV}_1/\text{FVC} < 0.7 \) and \( \text{FEV}_1 < 80\% \) of predicted). Previously, Fuster et al\(^{28}\) had shown that patients with \( \text{FEV}_1 < 60\% \) of predicted had a significant increase in postoperative mortality (from 1.4% to 24%) and complications after coronary artery bypass graft surgery. These data suggest that assessment of the severity of COPD with a preoperative PFT would have additional impact on risk stratification in patients scheduled to undergo cardiac surgery.

Reduction in DLCO occurs in COPD, interstitial lung disease, anemia, vascular abnormalities, effective reduction of lung volumes, smoking, and heart failure.\(^{29,32}\) However, the relation between DLCO and outcomes after cardiac surgery has not been examined before. The present data show that a DLCO \(< 50\% \) of predicted on preoperative PFT is an independent risk factor increasing the risk of mortality \( \sim 3\)-fold after adjusting for a validated mortality risk estimate. Furthermore, the risk conferred by reduced DLCO was additive to that brought by airway obstruction, increasing mortality risk by 10 times among patients with both airway obstruction and reduced DLCO. Previously, Fuster et al\(^{28}\) assessed the impact of restrictive lung disease as defined by spirometry and lung volumes on mortality after coronary artery bypass graft surgery. They found that patients with moderate or severe restriction had a substantial increase in perioperative mortality. However, the DLCO results were not included in that report.

In addition to helping patients and clinicians make more informed decisions about the risk of cardiac surgery by diagnosing and quantifying the severity of COPD, PFTs may also help improve patient outcomes. Previously, Stein and Cassara\(^{33}\) and Gracey et al\(^{34}\) had shown that optimization of disease management preoperatively by smoking cessation counseling, improvement of pulmonary hygiene, and treatment with appropriate respiratory medications reduces complications in COPD patients undergoing thoracotomy. Although our study does not provide any evidence on whether surgical outcomes would improve with such interventions, one may speculate that patients with moderate to severe airway obstruction and those with DLCO \(< 50\% \) may benefit from them.

Our study has several notable strengths. Correlation of COPD history with PFT results and examining the relation between DLCO and surgical outcome were performed for the first time in cardiac surgical patients in this study. Almost all of the previous studies evaluating the relationship of COPD with mortality in cardiac surgery patients were performed without a PFT, based on the clinical history of this disease.\(^{4,6,20,27}\) Other notable strengths include our large sample size and the multivariable regression analysis in which we adjusted for a validated mortality risk estimate, thereby accounting for multiple other factors that predict mortality in these patients. This analysis demonstrated that the severity of COPD and the DLCO are independent risk factors. A few limitations are also notable. Preoperative PFTs were performed based on the request of the clinicians, potentially selecting a higher-risk cohort with greater prevalence of COPD history. Furthermore, clinicians were not blinded to the results of the PFTs. Thus, the possibility that a patient’s management was influenced by the PFT results cannot be excluded. Finally, veterans have a high prevalence of smoking and may have been exposed to fumes, dust, or other environmental offenders that were not captured in this data set. In addition, almost all of our study patients were male. Thus, the results may vary for nonveteran patient cohorts and female patients.

In conclusion, in this large cohort of cardiac surgery patients, performing PFT before surgery provided valuable information about the presence and severity of COPD in cardiac surgery patients. We found that preoperative PFTs reclassified the COPD status of one third of patients. Furthermore, moderate or severe airway obstruction and DLCO \(< 50\% \) were independent strong predictors of operative mortality, prolonged ventilation, and longer length of stay. These data suggest that PFT should be performed routinely in patients undergoing cardiac surgery and that predicted \( \text{FEV}_1 \) and DLCO should be included in clinical decisions and statistical models estimating operative risk.

Acknowledgements

We are indebted to Kathrine K Apple, BS, for collection of data.

Disclosures

Author contributions:

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Salima Mithani: acquisition of data, analysis and interpretation of data, revision of the manuscript for critical and important intellectual content, and final approval.

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Jana Bonawitz-Conlon: acquisition of data, revision of the manuscript for critical and important intellectual content, and final approval.

Herbert B. Ward: conception and design, analysis and interpretation of data, revision of the manuscript for critical and important intellectual content, and final approval.

Edward O. McFalls: conception and design, analysis and interpretation of data, revision of the manuscript for critical and important intellectual content, and final approval.

Michael A. Kuskowski: conception and design, analysis and interpretation of data, revision of the manuscript for critical and important intellectual content, and final approval.

Rosemary F. Kelly: analysis and interpretation of data, revision of the manuscript for critical and important intellectual content, and final approval.

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