Pulmonary Complications Following Cardiac Surgery

Kamyar Afshar, DO
Director, UCSD Advanced Lung Disease
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Conflicts of Interest

- There are no financials conflicts of interest to disclose for this presentation
Case 1

• 71 year old White man with ischemic cardiomyopathy undergoes heart transplant
  – Cardiopulmonary bypass used

• PMHx/PSHx:
  – Smoker 3 ppd x 40 years
  – Obesity (ate dozen doughnuts daily by the age of 34)
  – Myocardial infarction x 5 (first MI at age 37)
  – CABG/pacemaker
  – Left Ventricular Assist Device
Case 2

• 58 year old White man undergoes a quadruple bypass surgery
  – Cardiopulmonary bypass used

• PMHx:
  – Angina
  – Obesity
  – Hyperlipidemia (LDL pre-cardiac surgery 177)

• As a medicine resident, I jumped from this information to just looking for this.....
Post Cardiac Surgery CXR

Left lower lobe atelectasis

All the while forgetting about ......
Pulmonary Complications following Cardiac Surgery (Expanding Medicine Perspective)
Pulmonary Complications following Cardiac Surgery (Expanding Medicine Perspective)

• Questions to ask yourself:
  – Patient factors: Age, Lung Disease
  – Anesthesia used
  – Duration of surgery
  – Intra-operative mechanical ventilation, P/F ratio, PEEP
  – Type of surgery/Approach
  – Cardiopulmonary Bypass use
  – Hypothermia
  – Blood products
Cardiac Surgery and the Lungs

• Since the advent of cardiac surgery in the 1950s, patients are subjected to surgery related factors

  – **Post-operative pulmonary dysfunction (PPD)**
    • Expected results from the surgical process
      – *Increased work of breathing, shallow respirations, ineffective cough, lower lung functions*

  – **Post-operative pulmonary complications (PPC)**
    • Atelectasis, pleural effusion, respiratory failure
Pulmonary Dysfunction

Overview
Impact of Anesthesia on Pulmonary Function

• Administration of general anesthesia (inhaled or intravenous)
  – Immediate loss of diaphragmatic and intercostal muscle tone
  – 20% reduction in the FRC
  – Development of compressive atelectasis
• Increase in shunt fraction up to 15%
Lung Volumes Post Cardiac Surgery

- 107 patients; mean age 68 years
- CABG or valve replacement
- 40-50% reduction in FEV1 and FVC 2 days post surgery

In multivariate analysis:
- low age was associated with low vital capacity post surgery
- Males and higher BMI (> 25) was associated with low post-op inspiratory capacity

Volume 2012, Article ID 291628, 7 pages
doi:10.1155/2012/291628
Cardiac Surgery

• Lung volumes decrease by 30-50% after CABG
  – Return to pre-operative values may take several months
• Lung function decline to a greater degree when the internal mammary artery is harvested

• Atelectasis
• Contusion (intra-operative lung retraction)
• Alteration in chest wall compliance and motion
  – Division of the sternum, harvest of the internal mammary artery
Impact of Anesthesia on Pulmonary Function

• Administration of inhaled anesthesia
  – Blunts the response to both hypoxemia and hypercapnea
  – Deposition of these agents in muscle and fat may depress hypoxemic drive persist for several hours after termination of anesthesia
Pulmonary Complications

Overview
Pulmonary Complications

Overview

• Pulmonary complications are inversely proportional to the distance of incision proximity to the diaphragm
  – eg. Thoracic and upper abdominal surgery higher rate of pulmonary complications compared to orthopedics

• Longer surgical time (≥ 3-4 hours) vs. shorter time (≤ 2 hours)

• Areas affected: airways, parenchyma, pleura, vasculature
# Post Cardiac Surgery Pulmonary Complications

<table>
<thead>
<tr>
<th>Complication</th>
<th>Frequency, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pleural effusion</td>
<td>27-95(^{118,119})</td>
</tr>
<tr>
<td>Atelectasis</td>
<td>16.6-88(^{47,50})</td>
</tr>
<tr>
<td>Phrenic nerve paralysis</td>
<td>30-75(^{54})</td>
</tr>
<tr>
<td>Prolonged mechanical ventilation</td>
<td>6-58(^{26,71})</td>
</tr>
<tr>
<td>Diaphragmatic dysfunction</td>
<td>2-54(^{55,120})</td>
</tr>
<tr>
<td>Pneumonia</td>
<td>4.2-20(^{30,121})</td>
</tr>
<tr>
<td>Diaphragmatic paralysis</td>
<td>9(^{50})</td>
</tr>
<tr>
<td>Pulmonary embolism</td>
<td>0.04-3.2(^{122,123})</td>
</tr>
<tr>
<td>Acute respiratory distress syndrome</td>
<td>0.4-2(^{6,7})</td>
</tr>
<tr>
<td>Aspiration</td>
<td>1.9(^{124})</td>
</tr>
<tr>
<td>Pneumothorax</td>
<td>1.4(^{125})</td>
</tr>
<tr>
<td>Chylothorax</td>
<td>18 individual case reports(^{126})</td>
</tr>
<tr>
<td>Trapped lung syndrome</td>
<td>Single case report(^{127})</td>
</tr>
</tbody>
</table>
Risk Factors for Postoperative Pulmonary Complications

• Factors related to the patient
  – Advanced age
  – Extensive smoking
  – Obesity
  – COPD

• Factors related to surgery
  – Thoracic and upper abdominal surgery
  – Prolonged anesthesia time (> 3 hours)
  – Large intraoperative blood transfusion requirements
Cardiac Surgery

- Cardiopulmonary bypass
  - Duration of bypass linked to severity of post-operative atelectasis
Pulmonary Complications

Pleural Disease

Transudative Effusion
Chylothorax
Hemothorax/Fibrinothorax
Pneumothorax
Pleural Effusion

General

• 75 mL ‡ barely detectable
• 175 mL ‡ obscure the lateral costophrenic sulci on the PA CXR
• 500 mL ‡ obscures the diaphragmatic contour on the PA
• 1000 mL ‡ reaches the level of the 4th anterior rib

Based on the decubitus films
1. Small effusion < 1.5 cm
2. Moderate = 1.5 – 4.5 cm
3. Large effusion > 4.5 cm
Pleural Effusion

Causes

- Non-specific
  - Can be early ( < 30 days) or late ( > 30 days)
- Post-pericardiectomy syndrome
- Heart failure
- Pneumonia
- Hemothorax
- Pulmonary embolism
Pleural Effusion

Early vs. Late

• Post CABG patients, n=71
• All patients underwent internal mammary artery grafting
• Early effusions < 30d after CABG, n=45 (63%)
  – Bloody, high eosinophil count (median 0.385), high LDH (average 3x normal)
  – bleeding
• Late effusions > 30d after CABG, n=36 (37%)
  – Predominantly lymphocytic (median 0.68), low LDH
  – Immune response; lower EF

Arch Intern Med. 2000;160(17):2665-2668
Pleural Effusion

Early vs. Late

• Retrospective study (n=356)
• 11 patients (3.1%) had pleural effusions > 30 days post CABG
  – Effusions that occurred > 90 days post CABG (Group 2) were associated with lower EF

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Compared pleural effusion occurred between group 1 (less than 90 days) and group 2 (more than 90 days)†</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Group 1 (n = 5)</td>
</tr>
<tr>
<td>Graft</td>
<td></td>
</tr>
<tr>
<td>IMA</td>
<td>1 (20)</td>
</tr>
<tr>
<td>SVG</td>
<td>3 (60)</td>
</tr>
<tr>
<td>IMA + SVG</td>
<td>1 (20)</td>
</tr>
<tr>
<td>Bloody effusion</td>
<td>2 (40)</td>
</tr>
<tr>
<td>LDH in effusion (U/L)</td>
<td>1262.0 ± 921.3</td>
</tr>
<tr>
<td>Protein in effusion (g/L)</td>
<td>32 ± 11</td>
</tr>
<tr>
<td>Side of effusion</td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>2 (40)</td>
</tr>
<tr>
<td>Left</td>
<td>3 (60)</td>
</tr>
<tr>
<td>EF (%)</td>
<td>68.8 ± 6.0</td>
</tr>
<tr>
<td>LVIDd (mm)</td>
<td>45.2 ± 6.0</td>
</tr>
<tr>
<td>LVIDs (mm)</td>
<td>28.8 ± 4.0</td>
</tr>
</tbody>
</table>
Pleural Effusion
Post-cardiac surgery

• Incidence post CABG – 41% - 87%.
• Post CABG pleural effusions occur more commonly when the internal mammary is used as a graft compared to a saphenous vein graft.
• This is due to the requirement of a pleurotomy to harvest the IMA.
• Most are small volume – occupying < 25% of hemithorax.
• About 10% of effusions are large volume – occupying > 25% of hemi-thorax.

Chest 2009; 136: 1604-1611
Transudative Pleural Effusion

- Clear, serous appearance
- Pleural to serum protein ratio < 0.5
- Pleural to serum LDH ratio < 0.6
- Low total nucleated cell count
  - Non-degenerative neutrophils and mesothelial cells
Exudative Pleural Effusion

- Color varies from amber to white/red
- Pleural to serum protein ratio > 0.5
- Pleural to serum LDH ratio > 0.6
- High nucleated cell count (> 7000 cells)
  - Neutrophil predominant cell count
Exudative Pleural Effusion

- N = 2908 patients

- CABG alone (77%); valve replacement alone (11%) or combined CABG and valve replacement (11%)

- 192 (6.6%) developed a clinically significant pleural effusion. 116 of 192 effusions were sent for analysis – 100% exudative
Exudative Pleural Effusion

- Significant predictors of pleural effusion included peripheral vascular dz (OR 2.17), use of anti-arrhythmics (OR 2.03), length of surgery (OR 1.18 or OR 1.38)
  - Valve replacement alone or CABG + valve replacement was more likely to lead to pleural effusions than CABG alone

- Pleural effusions increased LOS
  - ICU (142 ± 643 hours vs. 25 ± 565 hours)
  - Hospital (16.2 ± 20.9 days vs. 7.5 ± 8.6 days)
Chylous Effusion

- Chylomicron rich fluid
- Chyle normally drains in the thoracic duct into the venous system
- Can be seen post cardiac surgery or CVC placement (subclavian or internal jugular)

- > 110 triglycerides
- < 45 cholesterol
Hemothorax

• Blood accumulating in the pleural cavity
  – Torn adhesion

• Bloody – Hematocrit compared to blood
  – < 1% is not significant
  – 1-20% indicates either cancer, PE or trauma
  – > 50% indicates hemothorax

<table>
<thead>
<tr>
<th>Classification</th>
<th>Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>350 mL</td>
</tr>
<tr>
<td>Moderate</td>
<td>350-1500 mL</td>
</tr>
<tr>
<td>Massive</td>
<td>&gt; 1500 mL</td>
</tr>
</tbody>
</table>
Hemothorax

• Over time the clot, is partially absorbed, leaving behind loculated fluid and fibrinous septations

• Macro-fibrin deposition begins to provide a structural framework

• This “peel” slowly contracts to entrap the lung
Pneumothorax

- Parenchymal injury vs. tracheobronchial vs esophageal
- Blunt vs penetrating
  - CVC
- Intubation
- Barotrauma
- Operative
Treatment Goals with the Chest Tube

1. Evacuate air from the pleural space
2. Achieve pleural-pleural apposition
3. Decrease likelihood of recurrence

Wet suction

Wet suction control systems regulate suction pressure by the height of the column of water in the suction control chamber.
Dry suction

Since there is no bubbling in the dry suction control chamber, the orange bellows are used as visual indicator of suction operation.
Chest tube management

Fig. 3. Types of air leaks from smallest to largest. There are four types of air leaks, each type is scored from 1 to 7 on an air leak meter. Abbreviations: FE ¼ forced expiratory; E ¼ expiratory; I ¼ inspiratory; C ¼ continuous.
Pulmonary Complications

Atelectasis
Atelectasis

Contributing Factors

• Usually as a result of single lung ventilation and intentional deflation
  – Compression – anatomical (pushing on the lung)

• Absorptive
  – High FiO2 causing nitrogen washout

• Loss of surfactants
  – Result of anesthesia

** Single lung ventilation may cause more harm than just atelectasis **
Atelectasis

Contributing Factors

• $N = 18$ patients
  – CABG or MVR

• CT Chest obtained 20-24 hours post surgery
  – Lung bases more commonly involved
  – Left lung $>$ Right lung involvement

Pulmonary Complications
Phrenic Nerve Injury

Chest radiograph 3 months after coronary artery bypass graft surgery showing markedly raised left hemidiaphragm.
Phrenic Nerve Injury

• Causes
  – Stretching
  – Crushing
  – Transection
  – Cardioplegia

• Effects
  – Paralysis
  – Paresis

• How to diagnose: Sniff test

• Treatment: Plication of the diaphragm
**Sniff test:** fluoroscopic exam used to evaluate whether the diaphragm moves in the proper direction during various maneuvers including normal breathing and while rapidly inhaling.
In normal diaphragmatic motion:
The diaphragm moves downward during inspiration
Both diaphragms move downward
3.6-9.2 cm of excursion is normal in deep breathing; 1-2.5 cm in quiet breathing

In abnormal diaphragmatic motion:
The affected hemi-diaphragm does not move downward with inspiration
Pulmonary Complications

Prolonged mechanical ventilation

ALI/ARDS
Pre-operative Risk Assessment for Post-operative Respiratory Failure

• There are no validated models of pulmonary risk stratification

• Based on the age and severity of the lung function, then, “This patient is at low/moderate/high risk for delayed recovery post anesthesia”

• Recommendations: “Please provide albuterol intra-operative and lung protective ventilation”

  (easy enough, right???)
Incidence of Respiratory Failure following surgery

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Incidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thoracic Aortic Aneurysm</td>
<td>8-33%</td>
</tr>
<tr>
<td>Abdominal Aortic Aneurysm</td>
<td>5-24%</td>
</tr>
<tr>
<td>Lung Resection</td>
<td>4-15%</td>
</tr>
<tr>
<td>CABG</td>
<td>5-8%</td>
</tr>
<tr>
<td>All types</td>
<td>0.8%</td>
</tr>
</tbody>
</table>
Causes of Post-operative Respiratory Failure

- **Factors extrinsic to the lung**
  - Depression of central respiratory drive (opioids, sedatives)
  - Phrenic nerve injury/diaphragmatic paralysis
  - OSA
  - Anesthesia

- **Factors intrinsic to the lung**
  - Atelectasis
  - Pneumonia
  - Aspiration
  - Acute lung injury
  - Volume overload/CHF
  - Pulmonary embolism
  - Bronchospasm/COPD
COPD and Post-op Pulmonary Complication

- 50% of respiratory failure and death in patients with post-resection FEV1 < 40% of normal
- 53% respiratory failure with Thoracic AA repair in COPD population compared to 23% in non-COPD

<table>
<thead>
<tr>
<th>Post CABG</th>
<th>Post op mech ventilation (&gt; 48hours)</th>
<th>Re-intubation</th>
</tr>
</thead>
<tbody>
<tr>
<td>COPD</td>
<td>18.9%</td>
<td>13.5%</td>
</tr>
<tr>
<td>Non-COPD</td>
<td>3.7%</td>
<td>3.7%</td>
</tr>
</tbody>
</table>
Acute Lung Injury/ARDS

• Primary ALI/ARDS (immediate)
  – Ventilator induced lung injury

• Secondary ALI/ARDS (3-12 days post surgery)
  – Blood transfusions (TRALI)
  – Cardiopulmonary bypass
  – SIRS
  – Aspiration
  – Re-perfusion injury

• 45% mortality rate

Acute Lung Injury/ARDS
Role of Anesthetics (animal models)

- Ketamine, midazolam and ketamine/xylazine had a significant prophylactic effect on pleural effusion
  - Ketamine caused a significant reduction of inflammation, hemorrhage and edema scoring
  - Midazolam (2 mg/kg) and ketamine/xylazine caused a significant reduction of inflammation and edema scoring

Acute Lung Injury/ARDS
Role of Anesthetics (animal models)

- Propofol attenuates endotoxin-induced ALI in a murine model of sepsis and inhibits LPS-induced nitric oxide production and biosynthesis of the inflammatory cytokines, TNF-α, interleukin (IL)-1β, and IL-6 in macrophages.

Acute Lung Injury/ARDS
Role of Anesthetics (animal models)


Sham surgery

One lung ventilation

One lung ventilation + sevoflurane

Marked RBC and inflammatory cells in the alveoli
Pulmonary Complications

Pneumonia
Post Cardiac Surgery Pneumonia

• Most common infection post cardiac surgery

• Microorganisms: Enterbacteriaceae (40%), Pseudomonas (18%), Haemophilus (17%), Streptococcus (10%), Staph aureus (5%)
Post Cardiac Surgery Pneumonia

- Traditional risk factors:
  - COPD
  - Smoking
  - Older age (> 70 years)
  - Low EF

### TABLE 3. Multivariable Analysis With Interactions of Risk Factors for Postoperative Pneumonia in the Training Set

<table>
<thead>
<tr>
<th>Patient Characteristics</th>
<th>OR</th>
<th>95% CI</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>1.02</td>
<td>1.01–1.03</td>
<td>0.049</td>
</tr>
<tr>
<td>Chronic obstructive pulmonary disease (yes)</td>
<td>2.97</td>
<td>1.8–4.71</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Preoperative left ventricular ejection fraction (%)</td>
<td>0.98</td>
<td>0.96–0.99</td>
<td>0.01</td>
</tr>
<tr>
<td>RBC transfusion during surgery (yes) and duration of cardiopulmonary bypass &gt; 60 min (yes)</td>
<td>2.98</td>
<td>1.96–4.54</td>
<td>&lt; 0.0001</td>
</tr>
</tbody>
</table>

OR = odds ratio.
Post Cardiac Surgery Pneumonia

• Median time to developing PNA after cardiac surgery: 7.2 ± 4.9 days \(^1\)
• Nosocomial Pneumonia incidence up to 8.3\% \(^2,3\)

• In-hospital mortality  
  – 15.3\% PNA vs 4.8\% no PNA (p < 0.001) \(^2\)

• 30 day mortality  
  – 8.0\% PNA vs. 4.6\% no PNA (P=0.01) \(^2\)

### TABLE 1. EFFECT OF PATIENTS’ CHARACTERISTICS AND PERI-OPERATIVE VARIABLES ON DEVELOPMENT OF PNEUMONIA POST CARDIAC SURGERY

<table>
<thead>
<tr>
<th>Intra-operative variables</th>
<th>Patients without pneumonia (n = 141)</th>
<th>Patients with pneumonia (n = 21)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Off pumpn, n (%)</td>
<td>13 (9.2)</td>
<td>3 (14.3)</td>
<td>0.469**</td>
</tr>
<tr>
<td>Cross-clamp time (min)</td>
<td>36.2 ± 10.8</td>
<td>37.8 ± 9.8</td>
<td>0.552*</td>
</tr>
<tr>
<td>CPB time (min)</td>
<td>60.4 ± 16.9</td>
<td>61.2 ± 15.0</td>
<td>0.859*</td>
</tr>
<tr>
<td>Total operation time (min)</td>
<td>114.9 ± 20.3</td>
<td>114.8 ± 15.0</td>
<td>0.971*</td>
</tr>
<tr>
<td>Need for inotropic support, n (%)</td>
<td>30 (21.3)</td>
<td>8 (38.1)</td>
<td>0.091**</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Postoperative variables</th>
<th>Patients without pneumonia (n = 141)</th>
<th>Patients with pneumonia (n = 21)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extubation time (hour)</td>
<td>7.5 ± 2.8</td>
<td>25.0 ± 21.3</td>
<td>&lt; 0.001*</td>
</tr>
<tr>
<td>Chest tube drainage (ml)</td>
<td>610.6 ± 286.0</td>
<td>733.3 ± 287.4</td>
<td>0.069*</td>
</tr>
<tr>
<td>Units of transfused FFP</td>
<td>2.9 ± 1.5</td>
<td>4.8 ± 3.3</td>
<td>&lt; 0.001*</td>
</tr>
<tr>
<td>Units of transfused pRBC</td>
<td>5.8 ± 1.6</td>
<td>10.8 ± 3.3</td>
<td>&lt; 0.001*</td>
</tr>
<tr>
<td>Urea (mg/dl)</td>
<td>45.2 ± 15.7</td>
<td>57.8 ± 21.6</td>
<td>0.001*</td>
</tr>
<tr>
<td>Creatinine (mg/dl)</td>
<td>1.1 ± 0.4</td>
<td>1.3 ± 0.5</td>
<td>0.009*</td>
</tr>
<tr>
<td>Potassium (mmol/l)</td>
<td>3.7 ± 0.7</td>
<td>4.1 ± 1.0</td>
<td>0.008*</td>
</tr>
<tr>
<td>Atrial fibrillation, n (%)</td>
<td>25 (17.7)</td>
<td>13 (61.9)</td>
<td>&lt; 0.001**</td>
</tr>
</tbody>
</table>

*Student’s t-test, **Fisher’s exact test.

COPD: chronic pulmonary obstructive disease, CPB: cardiopulmonary bypass, FFP: fresh frozen plasma, pRBC: packed red blood cells.
Post Cardiac Surgery Pneumonia
Reducing the risk

• 279 COPD patients undergoing CABG
  – 140 randomized to pre-op inspiratory muscle training
  – 139 usual care

• Outcomes: post-op PNA
  – Intervention group (6.5%) vs. usual group (16.1%)

*Inspiratory muscle training = Incentive spirometry, active cycle breathing techniques, forced exhalation techniques daily for at least 2 weeks prior to surgery*
Pulmonary Complications
Cardiopulmonary Bypass Effects
Complications related to Cardiopulmonary Bypass

- Bleeding
- Difficulty with insertion of cannulas
- Intramural or malposition of the cannula tip
- Atheromatous emboli
- Air emboli (failure to remove all air from the arterial line after connection)
- Aortic dissection
- Inadequate or excessive cerebral blood perfusion
Pulmonary Effects of Cardiopulmonary Bypass

• Lung fluid exchange: excessive pulmonary capillary fluid filtration due to capillary damage induced by complement release and/or activation of coagulation cascade

• Hemodilution reduce complications of intravascular coagulopathy

• Pulmonary capillary hydrostatic pressures

• Interacting causes of alveolar collapse
Severe Protamine Reaction

- Anaphylactoid reaction with pulmonary HTN, edema and systemic hypotension

- Treatment: 100% FiO2, iv fluids, steroids, antihistamines, bronchodilators and vasopressors
Case 1 Revisited

• 71 year old White man with ischemic cardiomyopathy undergoes heart transplant
  – Cardiopulmonary bypass used
  – No immediate pulmonary complications

• Remains at risk for pulmonary infections from bacteria, fungi and viruses

• Today he remains active……
Case 2 Revisited

• 58 year old White man undergoes a quadruple bypass surgery
  – Cardiopulmonary bypass used
  – No immediate pulmonary complications
• 6 months later, he developed a left sided pleural effusion/fibrinothorax – surgically corrected
• 10 years after original graft surgery, he required 2 cardiac stents
• Today he remains active......
Summary

• There is more complications than simply atelectasis following cardiac surgery
• Risk assessments will need to consider age, FEV1 as well as the potential complications given inherent risk to the surgical approach, anesthesia, blood transfusions, etc.
• Political party affiliation does not impact outcomes