Combined Mitral Valve Replacement and Ravitch Procedures in a Patient with Previous Pneumonectomy: Case Report and Review of the Literature

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Abstract
Introduction: Significant anatomical and functional changes occur following pneumonectomy. Mediastinal structures displace toward the side of the resected lung, pulmonary reserve is reduced. Owing to these changes, surgical access to heart and great vessels becomes challenging, and there is increased risk of postoperative pulmonary complications.

Methods: We performed a mitral valve replacement combined with a Ravitch procedure in a young female with previous left pneumonectomy and pectus excavatum.

Results: She was discharged on postoperative day 9 and remains symptom-free 3 months after surgery.

Conclusion: Thorough preoperative evaluation and intensive respiratory physiotherapy are essential before performing cardiac operations on patients with previous pneumonectomy.

Keywords: Chest Wall/surgery. Heart Valve Prosthesis Implantation. Mitral Valve/surgery. Funnel Chest. Pneumonectomy.

Abbreviations, acronyms & symbols
CABG = Coronary artery bypass grafting
CPB = Cardiopulmonary bypass
CT = Computed tomography
Cx = Circumflex
FEV₁ = Forced expiratory volume in 1st second
FVC = Forced vital capacity
LAD = Left anterior descending
LITA = Left internal thoracic artery
MRI = Magnetic resonance imaging

INTRODUCTION
Significant anatomical and functional changes occur following pneumonectomy. Mediastinal structures displace toward the side of the resected lung, pulmonary reserve is reduced, and the remaining lung compensatorily enlarges and herniates over the midline with elevation of the diaphragm[1,2]. Owing to these changes, surgical access to the heart and great vessels becomes challenging, and there is an increased risk of postoperative pulmonary complications.

CASE REPORT
A 24-year-old female patient presented to our clinic with dyspnea. She had undergone a left pneumonectomy for advanced and complicated bronchiectasis 10 years ago.

Clinical Findings
She had marfanoid habitus, pectus excavatum, scoliosis, and a grade 4, pansystolic, high-pitched, blowing murmur best heard at the right sternal border (Figures 1A and B).

Diagnostic Assessment
Transthoracic echocardiogram revealed severe mitral regurgitation due to myxomatous mitral valve with bileaflet prolapse and chordal elongation, secondary pulmonary hypertension, and tricuspid regurgitation with a dilated right
sternotomy was performed. Costal cartilages of the 3rd to 8th ribs were removed. The right lung was retracted from the midline. Cardiopulmonary bypass (CPB) was initiated via ascending aortic and bicaval cannulation, and cardiac arrest was obtained. We did not use topical cardiac hypothermia to prevent phrenic nerve injury. Both atria were relatively easy to expose due to leftward shift and rotation of the heart. A mitral valve replacement and a tricuspid ring annuloplasty was performed using biatrial approach. CPB was terminated. A bar was placed behind the sternum and fixed to the pectoralis muscle fibers bilaterally. After completion of the Ravitch procedure, the sternum was closed. The patient was transferred to a dedicated cardiac surgery intensive care unit and she was successfully extubated at the postoperative 6th hour. Her recovery was uneventful and she was discharged on postoperative day 9 (Figures 3A and B).

Therapeutic Intervention

The patient received intensive chest physiotherapy before surgery to reduce postoperative pulmonary complications.

A vertical midline incision on skin, subcutaneous tissues, and pectoralis fascia was made over the sternum. Following elevation of pectoralis muscles from the anterior chest wall, a median sternotomy was performed. Costal cartilages of the 3rd to 8th ribs were removed. The right lung was retracted from the midline. Cardiopulmonary bypass (CPB) was initiated via ascending aortic and bicaval cannulation, and cardiac arrest was obtained. We did not use topical cardiac hypothermia to prevent phrenic nerve injury. Both atria were relatively easy to expose due to leftward shift and rotation of the heart. A mitral valve replacement and a tricuspid ring annuloplasty was performed using biatrial approach. CPB was terminated. A bar was placed behind the sternum and fixed to the pectoralis muscle fibers bilaterally. After completion of the Ravitch procedure, the sternum was closed. The patient was transferred to a dedicated cardiac surgery intensive care unit and she was successfully extubated at the postoperative 6th hour. Her recovery was uneventful and she was discharged on postoperative day 9 (Figures 3A and B).

Follow-up and Outcomes

The patient remains symptom-free 3 months after surgery and she is scheduled to have a bar removal 3 months later (Figures 4A and B).
The Figure 5 presents a timeline of interventions and outcomes.

A 24-year-old female with a 10-year history of a left pneumonectomy presented to our clinic with dyspnea.

**Physical examination:**
- Marfanoid habitus
- Pectus excavatum
- Scoliosis
- Cardiac murmur
  - Grade 4
  - Pansystolic
  - High-pitched
  - Blowing
  - Best heard at the right sternal border

**Transthoracic echocardiogram:**
- Myxomatous mitral valve with bileaflet prolapse
- Chordal elongation
- Secondary pulmonary hypertension and tricuspid regurgitation with a dilated right atrium
- Ejection fraction 35%
- Left ventricle end-diastolic diameter 72 mm
- Left ventricle end-systolic diameter 59 mm
- Ascending aortic diameter 40 mm

**Pulmonary function test:**
- FVC: 1.11 L (31.7% predicted)
- FEV1: 1.05 L (34.6% predicted)

**Contrast-enhanced computed tomography scan:**
- Heart and great vessels displaced to the left
- Right lung enlarged and crossing the midline, anterior to the heart
- Proximal ascending aortic diameter 40 mm
- Chronic type B aortic dissection
- Ascending aorta, and the superior and inferior vena cavae suitable for cannulation

**Intensive chest physiotherapy to reduce postoperative pulmonary complications**

**Combined mitral valve replacement, tricuspid ring annuloplasty and Ravitch procedures**

**Successful extubation**

**Discharge from hospital**

**Symptom-free during a routine visit**

**Scheduled to have a bar removal**

**Fig. 5** – Timeline of interventions and outcomes.

FEV1 = forced expiratory volume in 1st second; FVC = forced vital capacity
DISCUSSION

After conducting a Medline search from 1966 to April 2018 using the search terms “pneumonectomy” and “open heart surgery” or “coronary artery bypass” or “mitral valve” or “aortic valve” or “revascularization”, we identified 30 articles in English language[3-14]. A total of 42 cardiac operations were performed on 38 patients, including the current one (Table 1). The mean patient age was 65.2 years (range: 24-83 years). Twenty-one (76.3%) patients were male. There were 20 (47.6%) isolated coronary artery bypass grafting (CABG) procedures, 18 (42.8%) valvular procedures, and 4 (9.5%) combined CABG and valvular procedures. Two of these operations were transapical aortic valve implantation procedures (patients 29 and 30)[26,27].

Fifteen (39.4%) patients had a previous right pneumonectomy. The most common indication for pneumonectomy was cancer (n=27, 71%), followed by tuberculosis (n=5, 13.1%), trauma (n=2, 5.2%), bronchiectasis (n=2, 5.2%), scimitar syndrome (n=1, 2.6%), and unknown etiology (n=1, 2.6%). Preoperative FEV1 values were available for 28 patients and averaged 49% of predicted (range: 21-77%). Preoperative FVC values were available for 25 patients and averaged 49.2% of predicted (range: 27-70.3%).

The preferred surgical incision was a median sternotomy in 26 (61.9%) cases, a left thoracotomy in 9 (21.4%) cases, and it was not specified in 1 (2.3%) case. Patients 35 and 37 underwent surgery utilizing video-assisted right thoracotomy[32,34]. Among 24 CABG operations, a left internal thoracic artery was used as a bypass conduit in 7 (29.1%) cases. The use of a right internal thoracic artery was not reported. Complete arterial revascularization was performed in 2 (8.3%) cases. Among 20 isolated CABG operations, 7 (35%) were carried out without the use of CPB.

Length of hospital stay data was available in 32 cases and averaged 12 days (range: 4-57 days). Postoperative complications were experienced after 11 (26.1%) operations. The most common complication was atrial fibrillation (n=5, 11.9%), followed by respiratory failure requiring re-intubation (n=4, 9.5%), pneumothorax (n=2, 4.7%), pneumonia (n=2, 4.7%), and bleeding requiring re-exploration (n=2, 4.7%). Two (5.2%) patients did not survive to discharge.

Previous pneumonectomy adds two major risks to cardiac operations: (1) there is an increased risk of postoperative pulmonary complications due to reduced lung capacity; (2) heart and great vessels are displaced and rotated, making surgical exposure more difficult.

Six months after pneumonectomy, FVC decreases by 36% and FEV1 by 34%. These parameters do not significantly improve beyond 6 months[35]. Considering that the pulmonary function may deteriorate significantly after cardiac surgery even in patients who have normal preoperative respiratory function, previous pneumonectomy poses a great risk of postoperative pulmonary complications[35,36]. Hulzebos et al.[36] found preoperative inspiratory muscle training to be effective in preventing postoperative pulmonary complications in high-risk patients undergoing elective CABG surgery. Conventional measures such as avoidance of phrenic nerve injury and fluid overload, early extubation, early mobilization, and postoperative chest physiotherapy should be utilized. Central venous line should be placed on the side of the pneumonectomy to avoid pneumothorax.

Considerable anatomical changes occur in long-term survivors after pneumonectomy. Smulders et al.[1] evaluated the function and position of the heart using dynamic magnetic resonance imaging (MRI) in 15 patients who underwent pneumonectomy at least 5 years ago. They reported that although varying degrees of mediastinal shift occur in all patients, right-sided pneumonectomy is mostly associated with a lateral shift and only a minor rotation, whereas left-sided pneumonectomy leads to a greater degree of rotation[11]. Whether the patient had a left or right pneumonectomy, it affects the choice of surgical approach. For instance, in the case of a previous left pneumonectomy, it may be easier to bypass left-sided coronary arteries through a left thoracotomy, rather than a median sternotomy, and mitral and tricuspid valves may be inaccessible from the usual right thoracotomy. Stoller et al.[19] reported difficult exposure of the mitral valve through a median sternotomy in a patient who underwent a left pneumonectomy 9 years ago. However, we found it relatively easy to perform a mitral valve surgery in a similar setting. Because long-term anatomical changes after pneumonectomy vary considerably among patients, preoperative CT and/or MRI should be performed to assess the exact locations of cardiac structures and cannulation sites[37]. Decision of surgical approach should only be made after carefully examining the extent of the shift and the rotation of the cardiac structures.

Another subject that needs addressing is the concomitant pectus excavatum. Schmidt et al.[38] advocate simultaneous correction of the pectus excavatum in patients requiring cardiac surgery. We resected deformed cartilages prior to sternotomy to improve surgical exposure as previously reported by Sacco-Casamassima et al.[39].

Cardiac operations on patients with previous pneumonectomy can be performed with a favourable outcome. Thorough preoperative evaluation with imaging studies to assess cardiac position and function and intensive respiratory physiotherapy are essential.

Authors’ roles & responsibilities

| Authors’ roles & responsibilities | IK | ACT | KO | YO | AB | MY |
|-----------------------------------|----|-----|----|----|----|----|
| IK Substantial contributions to the conception or design of the work; or the acquisition, analysis, or interpretation of data for the work; drafting the work or revising it critically for important intellectual content; final approval of the version to be published | ACT Substantial contributions to the conception or design of the work; final approval of the version to be published | KO Substantial contributions to the conception or design of the work; final approval of the version to be published | YO Substantial contributions to the conception or design of the work; final approval of the version to be published | AB Substantial contributions to the conception or design of the work; final approval of the version to be published | MY Substantial contributions to the conception or design of the work; final approval of the version to be published |
Table 1. Summary of 38 patients with previous pneumonectomy who underwent cardiac surgery.

| Patient no. | Author          | Publication year | Sex | Age | Pneumonectomy site | Years elapsed after pneumonectomy | Indication for pneumonectomy | Preoperative data | Operation | Operative details | Complications | Length of hospital stay (days) |
|-------------|-----------------|------------------|-----|-----|-------------------|-----------------------------------|------------------------------|-------------------|------------|-------------------|---------------|-----------------------------|
| 1           | Berrizbeitia et al. | 1994             | M   | 61  | Right             | 42                                | Bronchiectasis               | FEV1 21            | CABG      | 3 SVGs to LAD, OMB, and PDA | None          | 8                           |
| 2           | Shibata et al.   | 1994             | M   | 67  | Left              | 13                                | Cancer                       | FVC 77, FEV1 55    | CABG      | 3 SVGs | None          | None          | 57                          |
| 3           | Medalion et al.  | 1994             | F   | 70  | Left              | 40                                | Tuberculosis                 | CABG               | LITA and 3 SVGs | CABG | None          | None          | 11                          |
| 4           | Demirtas et al.  | 1995             | M   | 63  | Left              | 20                                | Cancer                       | CABG               | - LITA and 3 SVGs | CABG | None          | None          | 12                          |
| 5           | Izzat et al.     | 1995             | M   | 65  | Right             | 10                                | Cancer                       | CABG               | N/A               | CABG | Approach to mitral valve through left atrial appendage | None          | 7                           |
| 6           | Sofanian et al.  | 1998             | F   | 70  | Left              | 19                                | Cancer                       | CABG               | N/A               | N/A | None          | None          | 7                           |
| No. | Study                      | Year | Gender | Age  | Side | Cause | Valve Procedure | Technique | Complications                                                                 |
|-----|----------------------------|------|--------|------|------|-------|-----------------|------------|-----------------------------------------------------------------------------|
| 7   | Lippmann and Au²            | 2000 | M      | 68   | Left | Cancer | CABG            | Median     | None                                                                        |
| 8   |                           |      | M      | 73   | Left | Cancer | CABG            | Median     | Postoperative bleeding requiring re-exploration |
| 9   | Golbasi et al.⁶            | 2001 | M      | 58   | Right| Cancer | CABG            | Median     | None                                                                        |
| 10  | Diab et al.¹⁵, Jamaeddine and Obeid¹⁶ | 2001 | M      | 64   | Right| Cancer | CABG            | Median     | Respiratory failure requiring re-intubation | 6
| 11  | El-Hamamy et al.¹⁷         | 2003 | F      | 65   | Right| Tuberculosis | CABG          | Median     | Pneumothorax requiring chest tube insertion |
| 12  |                           |      | F      | 71   | Right| Tuberculosis | CABG          | Median     | None                                                                        |
| 13  | Kumar et al.¹⁸             | 2003 | M      | 70   | Left | Cancer | CABG            | Median     | None                                                                        |
| 14  | Eidil et al.¹⁵             | 2004 | M      | 51   | Right| Tuberculosis | CABG          | Median     | None                                                                        |
| 15  | Shanker et al.¹⁵           | 2005 | M      | 80   | Left | Cancer | CABG            | Median     | None                                                                        |
| 16  | Bernet et al.¹⁵            | 2006 | M      | 58   | Right| Cancer | CABG            | Median     | None                                                                        |
| Case | Last Name     | Gender | Age | Side  | Tumor | Year of Surgery | Procedure Details                                                                 |
|------|---------------|--------|-----|-------|-------|----------------|-----------------------------------------------------------------------------------|
| 17   | Hukus et al.  | M      | 74  | Left  | 15    | 2006          | - UTA and SVG to LAD, Cx, and RCA  
- Median sternotomy  
- Off-pump  
- None  
- 7 |
| 18   | F             | 54     | Left | 3     | Cancer | 61  | CABG  
- 3 SVGs to LAD, Cx, and RCA  
- Median sternotomy  
- On-pump  
- Respiratory failure requiring prolonged mechanical ventilation and extracorporeal membrane oxygenation  
- None  
- 5 |
| 19   | Stoller et al. | M      | 48  | Left  | Cancer | 2007          | - Right atriotomy and transseptal approach  
- Mitral valve replacement and tricuspid valve annuloplasty  
- On-pump, deep hypothermic circulatory arrest  
- Atrial fibrillation  
- N/A |
| 20   | M             | 71     | Left | 7     | Cancer | 33  | CABG  
- Mitral valve replacement and tricuspid valve annuloplasty  
- On-pump  
- Renal failure and atrial fibrillation  
- N/A |
| 21   | F             | 74     | Left | 37    | Cancer | 75  | CABG  
- 4 SVGs to LAD, OMBs, and RCA  
- Left thoracotomy  
- Off-pump  
- None  
- 6 |
| 22   | Slelatty et al.| M      | 71  | Right | 20    | 2007          | - SVG to diagonal artery  
- Mitral valve annuloplasty  
- Aortic valve replacement  
- Aortic valve replacement  
- On-pump, deep hypothermic circulatory arrest  
- Atrial fibrillation  
- N/A |
| 23   | Barreda et al.| M      | 68  | Left  | 4     | 2008          | - Left anterior isomyocardiectomy  
- Left posterior isomyocardiectomy  
- On-pump  
- Re-exploration for worsening of preoperative mitral insufficiency due to leaflet tethering 1 day after aortic valve replacement  
- Postoperative bleeding requiring re-exploration and atrial fibrillation  
- N/A |
| 24   | Ghoskar et al. | M      | 71  | Left  | 18    | 2008          | - SVG to LAD and PDA  
- Median sternotomy  
- On-pump  
- Bioprosthetic aortic valve  
- None  
- N/A |
| 25   | F             | 77     | Right | 1    | Cancer | 64  | CABG  
- Bioprosthetic aortic valve  
- None  
- N/A |
| No. | Authors            | Year | Gender | Age | Side | Diagnosis | Heart Rate | SBP | Procedure Details                                                                                                                                                                                                 | Postoperative Course |
|-----|-------------------|------|--------|-----|------|-----------|------------|-----|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------|
| 26  | Zhao et al.        | 2008 | M      | 57  | Left | Cancer    | 61.9       | 703 | CABG - 2 SVGs to LAD, RCA, and OMB - Left posterolateral thoracotomy - Off-pump                                                                                                                                       | None                |
| 27  | Us et al.          | 2010 | M      | 65  | Left | N/A       | 45         | 50  | Mitral valve replacement and subaortic membrane resection - transseptal approach and aortotomy - mechanical mitral valve prosthesis - median sternotomy - on-pump                                                                 | None                |
| 28  | Stamou et al.      | 2010 | M      | 83  | Left | Cancer    | 48         | N/A | CABG and aortic valve replacement - left anterolateral thoracotomy - on-pump                                                                                                                                         | None                |
| 29  | Ferrari et al.     | 2011 | M      | 64  | Left | Cancer    | N/A        | N/A | Transapical aortic valve implantation - left anterolateral thoracotomy - off-pump                                                                                                                                     | None                |
| 30  | Raja et al.        | 2011 | F      | 67  | Right| Cancer    | 49         | N/A | Transapical aortic valve implantation - right posterior thoracotomy - off-pump                                                                                                                                       | None                |
| 31  | Ushijima et al.    | 2011 | M      | 82  | Left | Cancer    | 63.8       | 63.8| CABG - LITA, RA and RGEA to LAD, PL, and PDA - left thoracotomy - off-pump                                                                                                                                          | None                |
| 32  | Wilhelmi et al.    | 2013 | M      | 68  | Right| Cancer    | 56         | 58  | Aortic valve replacement - bioprosthetic aortic valve - right anterolateral thoracotomy - on-pump                                                                                                                     | None                |
| 33  | Dag et al.         | 2013 | M      | 72  | Left | Cancer    | N/A        | N/A | CABG and mitral valve replacement - SVG to LAD and RCA - standard left atrial approach - mechanical mitral valve prosthesis - median sternotomy - on-pump                                                                        | None                |
|   | Author(s) | Year | Gender | Age | Side | Diagnosis | Mitral Valve Procedure | Tricuspid Valve Procedure | Access | Approach | Adjuvant Procedure | Complications |
|---|-----------|------|--------|-----|------|-----------|------------------------|--------------------------|-------|----------|-------------------|---------------|
| 34 | Gennari et al. [31] | 2014 | M | 71 | Left | Cancer | Mitral and Tricuspid Valve Repair | - Median Sternotomy - On-Pump | None | None | 11 |
| 35 | Rose et al. [32] | 2015 | M | 31 | Right | Cancer | Mitral Valve Repair | - Left Atrial Approach - Video-Assisted Right Thoracotomy - On-Pump | None | None | 8 |
| 36 | Takahashi et al. [33] | 2016 | M | 72 | Right | Tuberculosis | Mitral Valve Replacement | - Right Thoracotomy - On-Pump | Periprosthetic Leak | N/A |
|   |   |   |   |   |   |   | Repair of Mitral Periprosthetic Leak (2 Months After Valve Replacement) | - Right Thoracotomy - On-Pump | None | N/A |
|   |   |   |   |   |   |   | Repair of Mitral Periprosthetic Leak (8 Years After Valve Replacement) | - Cranial-Sided Approach to Left Atrium - Median Sternotomy - On-Pump | None | N/A |
| 37 | Sinha et al. [34] | 2016 | M | 61 | Right | Scimitar Syndrome | Mitral Valve Repair | - Left Atrial Approach - Video-Assisted Right Thoracotomy - On-Pump | None | None | 5 |
| 38 | Current Patient | 2018 | F | 24 | Left | Bronchiectasis | Mitral Valve Replacement and Tricuspid Valve Annuloplasty | - Standard Left Atrial Approach - Median Sternotomy Combined with Ravitch Procedure - On-Pump | None | None | 9 |

CABG = Coronary artery bypass grafting; Cx = Circumflex; FEV1 = Forced expiratory volume in 1st second; FVC = Forced vital capacity; LAD = Left anterior descending; LITA = Left internal thoracic artery; OMB = Obtuse marginal branch; PDA = Posterior descending artery; RAs = Radial arteries; RCA = Right coronary artery; SVG = Saphenous vein graft
| Year | Authors | Patients | Side | Disease | Procedure | Operative Access | Associated Procedures |
|------|---------|----------|------|---------|------------|------------------|----------------------|
| 2015 | Gennari | 34       | None | 11      | Mitral repair | Approach         |                      |
| 2015 | Rose et al. | 32       | Right | Cancer | on-pump right thoracotomy |              |                      |
| 2015 | Shibata T, Sueno S, Kimura E, Nishizawa H, Minamimura H, Kinoshita H | 35 | Mitral coronary valve bypass grafting | 13 years after pneumectomy |  |                      |
| 2016 | Takahashi et al. | 33       | Right | Scimitar syndrome | Mitral valve replacement | Median sternotomy |                      |
| 2018 | Current patient | 2018 | Left | Bronchiectasis | Mitral valve annuloplasty | Right thoracotomy |                      |

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