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JAMA Surgery | Review

Comprehensive Review of Chest Tube Management
A Review

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IMPORTANCE Thoracostomy, or chest tube placement, is used in a variety of clinical indications and can be lifesaving in certain circumstances. There have been developments and modifications to thoracostomy tubes, or chest tubes, over time, but they continue to be a staple in the thoracic surgeon's toolbox as well as adjacent specialties in medicine. This review will provide the nonexpert clinician a comprehensive understanding of the types of chest tubes, indications for their effective use, and key management details for ideal patient outcomes.

OBSERVATIONS This review describes the types of chest tubes, indications for use, techniques for placement, common anatomical landmarks that are encountered with placement and management, and an overview of complications that may arise with tube thoracostomy. In addition, the future direction of chest tubes is explored, as well as the management of chest tubes during the COVID-19 pandemic.

CONCLUSIONS AND RELEVANCE Chest tube management is subjective, but the compilation of data can inform best practices and safe application to successfully manage the pleural space and ameliorate acquired pleural space disease.

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Thoracostomy tube, otherwise known as chest tube, insertion can be traced back to the fifth century BCE when Hippocrates described using a hollow tin tube to drain what was likely an empyema.[1] In 1889, valved tubes with air-tight seals were first reported to prevent outside atmospheric pressure from collapsing the lung on inspiration.[2] In 1922, chest tubes were first documented in the postoperative care of patients undergoing modern thoracic surgery.[3] They were used throughout World War II to restore lung function after traumatic thoracotomies, were used during the Korean War, and later became the standard of care for drainage of the pleural space for trauma during the Vietnam War.[4] Chest tubes and their management continue to evolve and are modified to fit modern needs, including clinical conditions associated with the COVID-19 pandemic.

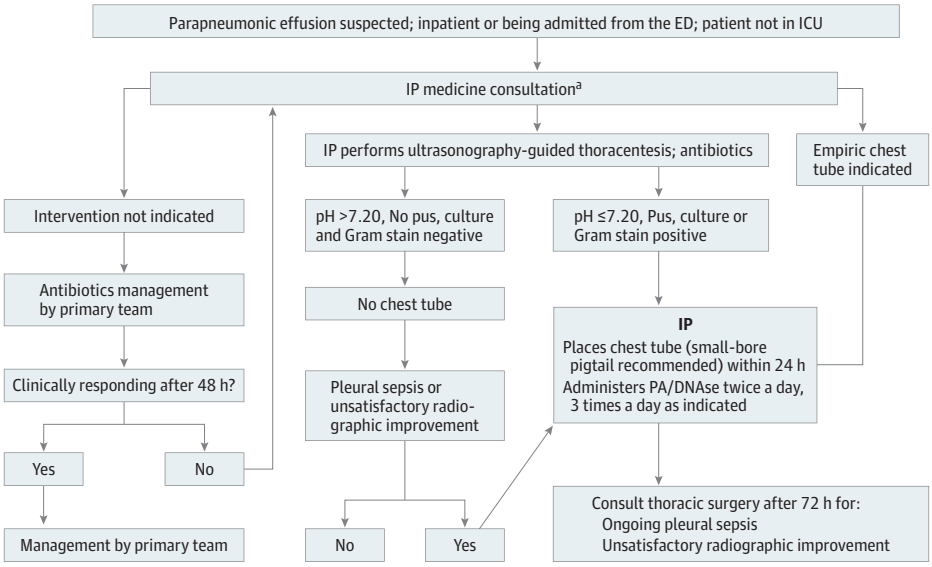
Indications

The potential space between the visceral pleura that envelops the lungs and the parietal pleura covering the chest wall, diaphragm, and mediastinum is the pleural cavity, which contains lubricating pleural fluid secreted by the parietal pleural capillaries. Air and abnormal fluid can accumulate in this space, causing mass effect and disruptions in the normal negative intrathoracic pressure.

When air fills the pleural cavity, it is called a pneumothorax, which is further categorized according to its etiology as primary spontaneous, secondary spontaneous, or traumatic.[5-7] Chest tubes are used to evacuate air in the pleural cavity and reestablish the negative intrathoracic pressure, allowing the lung to reexpand and restore physiologic ventilation and cardiac function.[6-9] A tension pneumothorax develops when air enters on inspiration and is unable to escape on expiration. This leads to effective mass effect on intrathoracic structures, such as the lung itself; mediastinal structures, such as the venae cavae; and cardiac chambers, resulting in hemodynamic compromise from restricted venous return and cardiac output. This is a medical emergency and should initially be managed with immediate needle thoracentesis to decompress trapped and expanding pleural air before the placement of a formal chest tube.

Chest tubes are also used to evacuate excessive fluid from the pleural cavity, which is known as a pleural effusion. When there is pus in the pleural cavity, then it is considered an empyema. There are several ways to evacuate fluid from the pleural cavity and chest tubes are only one of the many options. A Cochrane review from 2017[10] compared the surgical option of video-assisted thoracic surgery (VATS) with chest tube drainage of pleural empyema and found no difference in mortality or complications between the groups, but early VATS reduced the hospital length of stay. VATS has been considered the first-line treatment for retained hemothorax and empyemas with other modalities, such as intrapleural lytic therapy, reserved for poor operative candidates or as a second line treatment.[11] However, a meta-analysis by Hendriksen et al[11] found that treating retained hemothorax with lytic therapy rather than VATS allowed for an overall operative avoidance rate of 87% (95% CI, 81%-92%), with no heterogeneity in the pooled studies (Q = 10.2; df = 9; P = .33; I^2 = 15.07%). The type of intrapleural lytic treatment is also important as Hendriksen et al[11] found that using tissue plasminogen activator (t-PA) as the lytic agent allowed for a favorable number of patients to avoid surgical intervention compared with other lytic agents.

Figure 1. Parapneumonic Effusions: University of California, Davis, Pulmonary and General Thoracic Surgery Management Pathway



[a] Interventional pulmononologist (IP) recommends thoracic surgery evaluation for late presentation (>7 d from index symptoms) plus thick pleural rind or for very complex effusion. ED, emergency department; ICU, intensive care unit; PA, tissue plasminogen activator.

The combination of t-PA and dornase (DNase) was associated with a 60% reduction in pleural fluid collection as seen on imaging and with a significant reduction in pleural opacity, compared with placebo in the randomized clinical trial by Rahman et al.[12] When t-PA and DNase were used on their own as opposed to in combination, this study did not find a significant reduction in the pleural fluid collection compared with placebo.[12] The evidence supports combining t-PA and DNase for intrapleural lytic therapy. Given the effectiveness of treating early-phase empyema with a chest tube and intrapleural use of t-PA and DNase, as well as the use of VATS to reduce length of hospital stay, the authors developed a multidisciplinary protocol with general thoracic surgery and interventional pulmonary medicine for the algorithmic care of patients presenting with empyema, starting with a small-bore chest tube placement followed by intrapleural use of t-PA and DNase. If this initial step is unsuccessful, the next stage of the pathway is thoracic surgical consultation for VATS decortication (**Figure 1**).

Types of Chest Tubes

Chest tubes come in a variety of sizes and materials to best suit the clinical needs of the patient. In the US, they are generally measured by the internal diameter of the tube in units of French. One increment of the French scale is equal to a one-third–millimeter diameter, (eg, 24F is equal to an 8-mm caliber). By most prevalent convention, a tube of 20F or larger is considered a large-bore chest tube and a tube less than 20F tube is considered a small-bore chest tube, although there are some studies that define a large-bore chest tube as larger than 14F.[5,13,14] A common type of small-bore chest tube is a pigtail catheter, named because the tip coils at the end like a pig's tail to prevent dislodgement.[13]

Small-bore chest tubes are used as the first-line treatment for pneumothorax, transudative pleural effusions, and simple empyemas, whereas large-bore chest tubes are often necessary for more viscous disease processes, such as a hemothorax and complex exudative effusions and empyemas.[13,15] A meta-analysis by Chang et al[5] demonstrated that small-bore chest tubes are associated with lower complications rates and shorter drainage duration and hospital stay compared with large-bore chest tubes. A randomized clinical trial by Hussain et al[16] identified similar findings of a reduction in drainage duration and hospital stay with small-bore pigtail catheters compared with large-bore chest tubes in patients with secondary spontaneous pneumothorax. The most prominent advantage of a small-bore chest tube is its size, which allows for a smaller incision and decreased pain experienced by the patient.[16,17] The randomized clinical trial by Kulvatunyou et al[17] demonstrated a lower pain score in individuals with a pigtail catheter compared with a large-bore chest tube for traumatic pneumothorax. However, the small diameter of small-bore chest tubes may come at the cost of inefficient flow, as per Poiseuille's law ($\Delta P = 8\mu LQ/\pi R^4$, where Δp is change in pressure, μ is viscosity, Q is flow and R is radius) the decreasing radius of small-bore chest tubes can lend to a lower flow rate, which is the reason large-bore chest tubes are necessary in conditions that would otherwise clog a smaller tube, such as high-viscosity (μ) fluid.[5,13,15]

Insertion

The placement of a chest tube is important and is performed by many different specialties in various settings. The ideal point of insertion is through an external landmark space known as the triangle of safety (**Figure 2**), which is bordered by the edge of the latissimus dorsi muscle, pectoralis major muscle, the base of the axilla, and transverse to the nipple line or inframammary fold, at or above the fifth intercostal space.[13,14,18-20] However, placement of chest tubes is also influenced by the indication. For an apical pneumothorax, a chest tube

Figure 2. Triangle of Safety for Chest Tube Placement

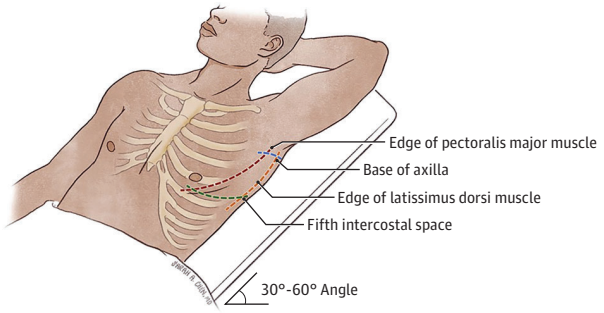
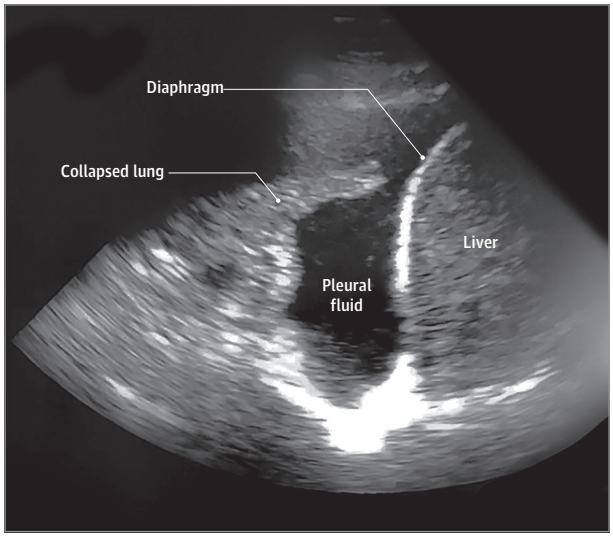


Figure 3. Representative Sonographic Image Demonstrating the Target Abnormal Collection of Pleural Fluid



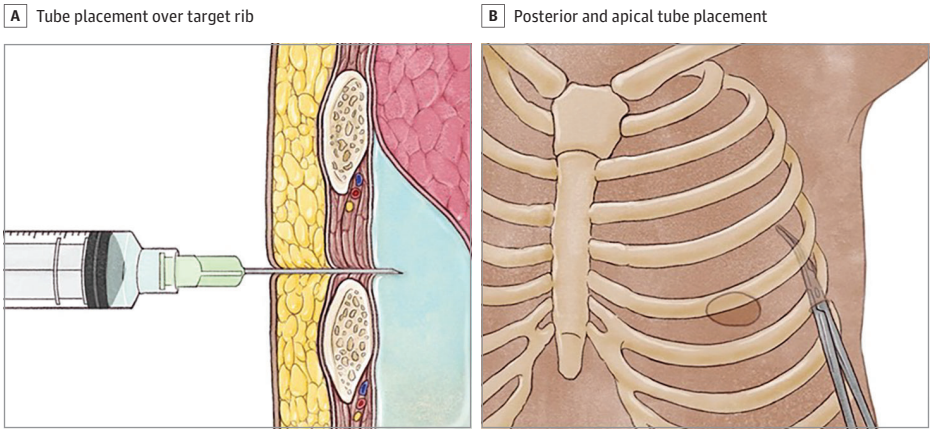
can be placed in the second intercostal space in the midclavicular line, although less comfortable for the patient, and adequate drainage of an unloculated pneumothorax can be performed via lateral insertion at the fifth intercostal space.[14,18] If the tube is placed in the triangle of safety, it is important to place it in a line anterior to the anterior superior iliac spine. Placing in the tube in a line behind this surface landmark may cause the patient to lie on the tube when in the supine position and mechanically occlude the tube. For a pleural effusion, a lower intercostal space may be used for insertion but special care must be taken to avoid penetrating the diaphragm, and subsequently the liver on the right and spleen and bowel on the left.[13]

The 3 ways to insert a chest tube are dissective, Seldinger (often ultrasonography guided), and the trocar technique, again often ultrasonography guided.[13,14,19,20] Ultrasonography can be an invaluable tool to safely identify internal landmarks for chest tube placement. **Figure 3** presents a representative sonographic image demonstrating the target abnormal collection of pleural fluid, in the right chest, for chest tube drainage, and adjacent structures of atelectatic lung, diaphragm and liver. **Figure 4**A highlights an important step for chest tube placement, which is using a finder needle (often a syringe with local anesthetic) just above the target rib to avoid the intercostal neurovascular bundle and aspirating the pleural space to confirm the location of the pleural pathology. For dissective insertion, a 1- to 2-cm incision is made overlying the rib of choice (the authors do not tunnel to a rib above), a Schnidt tonsil clamp is used to bluntly dissect through the subcutaneous tissue, the 3 muscular layers of the intercostal space (ie, the external intercostal muscle, the internal intercostal muscle, and innermost intercostal muscle), transthoracic fascia, and the parietal pleural until the clamp enters the pleural cavity. When attempting to enter the fifth intercostal space, it is important to dissect not perpendicular to the chest wall, but generally posterior and apical, the direction that most tubes should be placed (Figure 4B). Dissecting perpendicular to the chest wall and into the fifth intercostal space can lead to the tube heading directly into the oblique fissure, and then be entrapped by the subsequent expanded lung, rendering the tube ineffective after lung expansion. After successful spreading into the pleura space, a finger is used to confirm entry into the pleural space and the presence of adhesions. Adhesions are not bluntly broken with the finger, as pleural adhesions are often vascular and blunt dissection can lead to small vessel disruption and subsequently hemothorax.[13,14] The Seldinger technique uses guidewires and tract dilators to assist the tube into the pleural cavity, all under ultrasonography guidance.[19,21] Lastly, the trocar method may be used; however, it is associated with more complications owing to the rigid tip of the trocar causing intrathoracic injuries and has subsequently fallen out of favor for chest tube insertion.[19,20,22] Regardless of the insertion technique, the chest tube needs to be advanced on the superior edge of the rib to avoid the neurovascular bundle bordering the rib above.[13,14] It should also be positioned posteriorly and advanced until the tip is in a posteroapical location. The tube should also be fully inserted to ensure that the most proximal (sentinel) hole is within the pleural space to allow the chest tube to function properly.[14] Lastly, it is important to secure the chest tube with a suture to prevent it from falling out. Most tubes can be removed without suture skin closure, but in children and adults with very low body mass index (calculated as weight in kilograms divided by height in meters squared), placement of an untied adjunctive chest tube suture at the time of insertion allows for closure of skin defects at the time of tube removal, especially large-bore tubes, to prevent entraining atmospheric air with tube removal.

Management

Once a chest tube is placed, it is connected to a drainage device, which, like the chest tube itself, has evolved over the years. The first rendition was a 1-compartment system reported by Playfair[23] in 1875, which used a 1-way valve to allow air to egress from the pleural cavity during expiration without returning on inspiration. In 1926, Lilienthal[24] developed a 2-compartment system, which allowed the accumulation of fluid in the first collection bottle without compromising the efficiency of the system and its ability to drain, as would have been observed in the first model. Then, the 3-compartment system emerged in 1952 with Howe, which allowed collection, water sealing, and suction and manometer capabilities that are combined into a single pleural drainage unit (PDU).[19,25] This forms the foundation of the modern PDU devices today, some of which are digitally operated.

Figure 4. Insertion Technique



Once placed, chest tubes may be attached to a PDU and set to active suction or to water seal, which is simple dependent drainage. The phrase "place a chest tube on water seal" is a misnomer, as modern PDUs have a constitutive water seal chamber that serves as a 1-way valve, preventing air from returning into the pleural space; placing a chest tube on water seal simply means taking the tube off active suction. The randomized clinical trial by Cerfolio et al[26] found that water sealing the chest tube on postoperative day 2 after thoracic surgery resulted in a significant resolution of small air leak the following day, with the authors noting that large air leaks do not benefit from water sealing. Another randomized clinical trial[27] demonstrated similar results of a shorter duration of air leak with early water sealing for postthoracic surgery chest tubes, which subsequently decreased the duration the chest tube was needed. Both of these studies, albeit randomized clinical trials, are limited by their small sample sizes. Brunelli et al[28] performed a randomized clinical trial with a larger sample size, did not find an advantage with water seal over suction for postthoracic surgery patients and the authors favor a hybrid approach of moderate suction overnight and water sealing during the day to allow for mobilization of the patient. The systematic review and meta-analysis by Coughlin et al[29] determined that there was no advantage of suction over water seal after thoracic surgery, with the exception of suction being superior to water seal in preventing a radiographic identification of pneumothoraces.

For patients with a traumatic chest injury, the systemic review and meta-analysis by Feenstra et al[9] demonstrated evidence that favors low-pressure suction over water seal. This meta-analysis is limited in the number of studies, and therefore patient sample size, included. In addition, there are few patients with chest tubes in the setting of mechanical ventilation included in this study, which is an important subset of trauma patients. Patients who have an occult pneumothorax and are receiving positive pressure mechanical ventilation are at risk of developing a tension pneumothorax, therefore it may be necessary for a chest tube to be placed on suction in this subset of patients.[30] Overall, the management of a chest tube depends on the indication for insertion with evidence favoring suction over water seal for both postthoracic surgery patients and traumatic chest injury patients, until resolution of air leak.

Removal

There are many factors that come into play when determining the correct time to remove a chest tube. The quality of the fluid should be free of chyle, or blood suggestive of active bleeding, and be nonpurulent.[31,32] However, the quantity of fluid that is acceptable before the removal of a chest tube is without consensus, with varying recommended volume thresholds ranging from 200 mL per day to 500 mL per day.[31-33] Cerfolio et al[32] performed a retrospective cohort analysis that demonstrated that chest tube removal up to 450 mL per day was acceptable in patients who underwent elective pulmonary resection. They reported that 364 of 1988 patients (18%) were able to go home sooner owing to surgeons changing to the higher threshold (450 mL per day) and only 11 patients (0.55%) were readmitted as a result of a recurrent symptomatic effusion. Grodzki et al[34] tested this conclusion a year later and removed chest tubes at the higher threshold of 450 mL per day and found that 6 of 40 patients (15%) were readmitted with pleural effusions, thus leading the authors to revert to their original practice of following a threshold of 200 mL per day for chest tube removal. The limitation in the former study is the lack of reliable follow-up, which could account for the low readmission rate, and the limitation in the latter study is the small sample size. Larger randomized clinical trials would be helpful in clarifying this gap in our understanding.

Whether to remove the chest tube at the end of expiration or inspiration is another question that has been widely debated. Novoa et al[31] recommended removing the chest tube at the end of expiration during a Valsalva maneuver, which corresponds to the time when the difference between the atmospheric pressure and pleural pressure is at its lowest.[31] Other studies, such as French et al,[35] emphasized the importance of a Valsalva maneuver during chest tube removal regardless of the respiratory phase in which it is removed. The chest tube should be removed swiftly and the defect in the chest wall should be closed with either a suture that was placed at the time of chest tube placement or with a properly occlusive dressing.

Complications

The retrospective review by Platnick et al[36] found that certain risk factors, such as chest tube placement in the emergency department, placement by emergency medicine clinicians, and placement in patients with a body mass index greater than 30 were all associated with chest tube complications. However, the exact complication rate associated with chest tubes is variable and has been quoted as high as 40%.[36-38] The variability in the reported complication rate can be attributed to a lack of a universally accepted way to categorize the many different complications. Aho et al[20] proposed a way to standardize the reporting of complications surrounding chest tubes to allow for easier recording and collection of data. The 5 complication categories proposed were insertional, positional, removal, infectious, and malfunction. Insertional complications include injury to intrathoracic or extrathoracic organs within 24 hours of insertion, which is a complication most common with chest tubes being inserted via the trocar technique.[19,20] Positional complications are defined as occurring 24 hours after insertion, including erosions into adjacent organs or any tube kinking, obstruction, or being entrapped in the fissure after lung expansion.[19,20] Removal complications encompass failure to seal the chest defect after the chest tube is removed, resulting in entraining atmospheric air, or the retention of any foreign objects after removal.[20] Infectious complications involve any infection, either external from improper sterilizing techniques or internal with the development of an empyema.[20] Malfunction complications include problems that may arise from the health care clinician managing the chest tube or equipment issues.[20] Defining complications in these distinct categories allows clinicians to create a foundation to compare data collected in future studies and protocols to reduce the risk of complication associated with chest tubes.

COVID-19

Chest tube management during the COVID-19 pandemic, or any future coronavirus or H1N1 pandemic, is challenging owing to the risk of aerosolizing dangerous virions. Proper personal protective equipment, minimizing water seal, and using filters to decrease the number of aerosolized particles escaping into the air are modifications that have been implemented in many intensive care units around the world.[37,39] A small observational cohort study[40] found that connecting 2 closed underwater drainage systems in series with an air filter attached to the second system was associated with a decrease in the dissemination of coronavirus particles, as evidenced by a lack of COVID-19 infection reported in their health care workers during the study. However, this study was limited with its small power.

Future Directions

More recent studies are leaning toward conservative management in some specific pleural disease processes. The randomized clinical trial by Hallifax et al[41] demonstrated that the use of ambulatory devices for the treatment of primary spontaneous pneumothorax compared with usual care, which included aspiration or chest tube insertion, was associated with a significantly shorter hospital length of stay. These findings suggest that this subset of patients can be treated in an outpatient setting and that ambulatory devices should be considered as an effective treatment strategy for this disease process. However, there was an increase in the number of adverse events associated with the treatment with ambulatory devices, including enlarging pneumothorax and problems associated with the device, such as kinking or dislodgement, which will require more research if this approach is going to replace the current standard of care.

In a study by Brown et al,[42] conservative treatments, such as observation of moderate- to large-sized primary spontaneous pneumothorax, were found to be noninferior to the placement of a small-bore chest tube regarding resolution of the pneumothorax within 8 weeks. The study reports that 118 of 125 patients (94%) of patients undergoing conservative management did not require an invasive procedure, thus challenging the paradigm that all patients with a hemodynamic and respiratory stable primary pneumothorax should routinely undergo decompression with a chest tube as the first treatment option.

The routine placement of a chest tube after thoracic surgery is another area with emerging research. The randomized clinical trial by Zhang et al[43] showed that the placement of a novel air-extraction double-lumen catheter was noninferior to the placement of a traditional chest tube in the incidence of a pneumothorax on postoperative day 1. The use of this air-extraction catheter was also associated with a significantly lower patient-reported pain score, which supports the argument that more conservative techniques can be used to optimize patient comfort without compromising clinical outcomes.

Conclusions

With the advancement of technology and the push toward less invasive approaches, the treatment of pleural conditions that were once managed solely by chest tubes continues to evolve. However, chest tubes are likely to continue to be a vital part of a clinician's repertoire as they are still considered the standard of care for certain pleural disease processes and life-saving devices in others. It is imperative that trainees have a solid foundation on the management of chest tubes, as their use is a dynamic process that will continue to change as time progresses. This review highlights the studies that have shaped the way chest tubes are managed today and allows the reader to develop and cultivate their understanding.

ARTICLE INFORMATION

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Annals of Surgical Case Reports & Images

Volume 1 | Case Report

Robot-assisted surgery for spontaneous pneumothorax due to pneumocystis jirovecii pneumonia

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Abstract

Opportunistic infections, like Pneumocystis Jirovecii Pneumonia (PJP), in a patient with HIV has devastating outcomes if not properly treated, as the development of a spontaneous pneumothorax is a complication that is difficult to manage. This case report highlights the clinical presentation of a patient with PJP secondary to HIV with a spontaneous pneumothorax and the management algorithm to provide the best care and the feasibility of minimally invasive surgery as a safe and effective option.

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Keywords: Pneumothorax; Pneumocystis jirovecii; Thoracic surgery; Robot.

Case

A 59-year-old woman with a history of HIV was admitted to an outside hospital for almost a month for workup of shortness of breath, hypoxia, and fevers. She had acute hypoxic respiratory failure due to PJP complicated by a large spontaneous right pneumothorax, which was first managed non-operatively with a pigtail catheter. She had a persistent pneumothorax with a large air leak despite placement of the chest tube on suction, raising concern for a Bronchopleural Fistula (BPF). Thoracic surgery was initially consulted at the outside facility for surgical management of the BPF; however, the patient was deemed not a candidate for pleurodesis or VATS intervention due to the high mortality risk associated with patients with a pneumothorax secondary to PJP. She was transferred to our facility for consideration of Endobronchial Valve (EBV) placement by Interventional Pulmonology for management of the BPF. However, during the bronchoscopy it was discovered that her anatomy was not amenable to the placement of EBVs as Interventional Pulmonology was unable to isolate the locus of the BPF. Thoracic surgery was consulted for surgical management. On exam, she had a large air leak from the chest tube. Imaging was notable for diffuse cystic lung disease with a large right middle lobe cyst, which was the suspected rupture site (Figure 1). The decision was made to go to the operating room for robot-assisted wedge resection and pleurodesis. Intraoperative findings were significant for dense fibrotic cystic lung disease with firm nodules and the large, ruptured cyst on the medial inferior portion of the right middle lobe as the site of the fistula (Figure 2). The cyst was resected with a stapler. A submersion leak test was performed, which was negative for leaks, and mechanical and chemical pleurodesis were completed. Please see the attached video of the operation. A chest tube was placed at the end of the case, which was removed 72 hours later without evidence of reaccumulation of the pneumothorax. The remainder of the hospital stay was uncomplicated.

Comment

The opportunistic infection pneumocystis jirovecii is the leading cause of secondary pneumothoraces in patients with HIV with an incidence around 35% [1-3]. The subset of patients with spontaneous pneumothoraces with HIV and PJP were more difficult to treat and had worse outcomes than patients with spontaneous pneumothoraces and HIV without PJP [2,4]. Ingram et al reports 50% mortality in patients with pneumothorax and PJP compared to 25% in patients who did not have PJP [2].

The pathogenesis is postulated to be secondary to rupture of subpleural cavities due to cystic lung disease and emphysematous blebs from the underlying infection, which makes the lung parenchyma friable and not amenable to traditional forms of therapy, as the lung will fail to expand leaving a persistent air leak [1,3-6]. Alveolar-pleural fistulas also develop as a complication of the infection, contributing to the reaccumulation of the pneumothorax after failed non-operative treatment attempts [6].

A stepwise approach is implemented to manage pneumothoraces in patients with HIV and PJP, starting with thoracostomy tubes and progressing to bedside pleurodesis and Heimlich valves, which requires a re-expanded lung for pleural apposition [1,2]. An additional form of treatment is EBVs, which is effective in patients who develop alveolo-pleural fistulas secondary to PJP [6]. It is important that the patient's anatomy is amenable to this form of treatment. More invasive procedures such as VATS resection of blebs with pleurodesis, pleurectomy, and open surgical resection are also options [1,2]. Surgical intervention was the least utilized form of treatment in the literature with surgery performed in less than 3% of the cases [1,2].

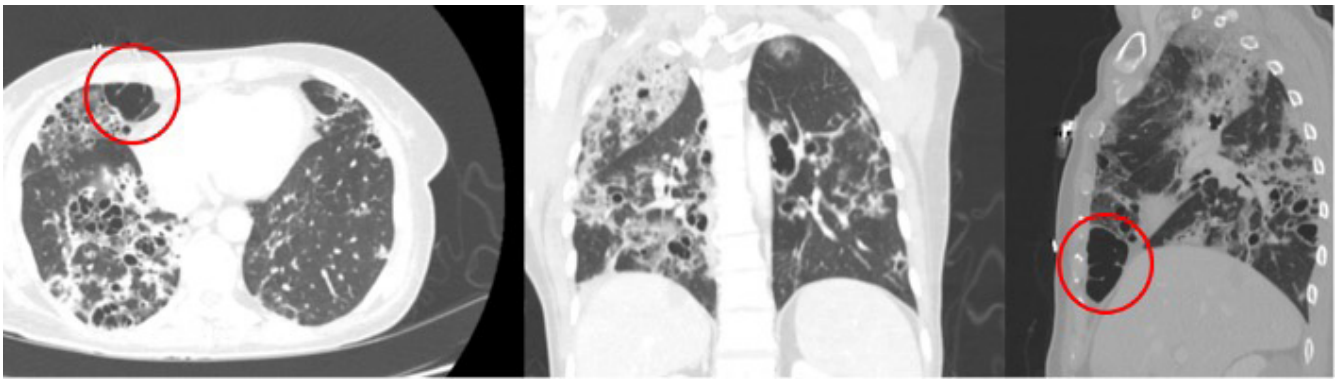

Figure 1: Pre-admission chest CT scan showing diffuse cystic lung disease with large right middle lobe cyst as the suspected site of rupture.

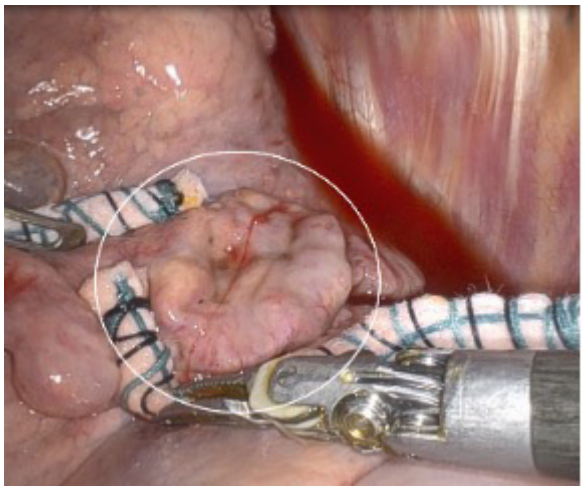

Figure 2: Intraoperative findings of large ruptured right middle lobe cyst.

Conclusion

Identifying patients with HIV and PJP who develop a pneumothorax is imperative due to the increased morbidity and mortality associated with the combination of these disease processes, in addition to the financial burden associated with utilization of resources to devise an effective treatment plan. This case reports highlights an underutilized treatment strategy for this select group of patients that will not only ameliorate the issue, but also decrease the cost burden associated with prolonged hospital stays. To our knowledge, we report the first case of robot-assisted resection and pleurodesis to manage this complex condition and have shown that it is a safe and effective option.

Declarations

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Disclosure/conflicts of interest: None.

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Keynote Lecture Series

Issues and considerations in perioperative management of robotic coronary bypass grafting

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Minimally invasive approaches to address coronary artery disease such as robotic coronary bypass grafting are an emerging field in surgery that have been shown to be beneficial with a reduction in morbidity. The perioperative management of this subset of patients is crucial to the success of the operation as there are several preoperative and postoperative issues and considerations that need to be addressed. A meticulous preoperative workup with an extensive history, physical exam, and appropriate imaging are instrumental to ensure a successful operation. Protocolized postoperative care is also essential to garnish the most benefit from this minimally invasive approach. All of these factors, in conjunction with a heart team approach and surgeon experience, are imperative for the successful outcome of robotic coronary artery revascularization.

Keywords: Robot; coronary artery bypass surgery; coronary artery bypass graft (CABG); cardiac; perioperative; management

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Introduction

Millions of people worldwide are affected by coronary artery disease, which remains a leading cause of morbidity and mortality all around the world (1). Coronary artery bypass surgery, which was first introduced in 1968, has been the gold standard of care for treating multi-vessel coronary artery disease due to the known benefits and advantages of the left internal mammary artery-left anterior descending (LIMA-LAD) graft (2-7). Traditionally, this operation has been performed through a median sternotomy, however recent trends towards endoscopic and less invasive approaches in other surgical specialties have led to the adoption of minimally invasive approaches to address coronary artery disease (2,3).

The advantages of minimally invasive coronary artery bypass graft (CABG) surgery over conventional CABG include shorter recovery time, overall reduction in morbidity, fewer blood transfusions, greater patient satisfaction, shorter hospital stay and earlier return to work. These advantages have been well established (8). These minimally invasive approaches utilize alternative sternal-sparing incisions to access the heart. The umbrella term "robotic CABG" encompasses a wide array of utilization of the robot during coronary artery revascularization, ranging from harvesting the internal thoracic arteries (ITAs) to preforming the coronary anastomoses robotically. The perioperative management of patients undergoing robotic CABG is instrumental in the success of the operation and can be divided into preoperative and postoperative care, which includes meticulous preoperative workup for patient selection and protocolized postoperative care.

Preoperative considerations

Preoperative considerations for patients who will undergo robotic CABG includes factors that are related to the patient's past medical history and current anatomy. Pre-habilitation and rehabilitation after surgery are based on each patient's specific past medical history. Other factors such as smoking status and cessation, exercise tolerance and limitations, diabetic control, and weight optimization, may

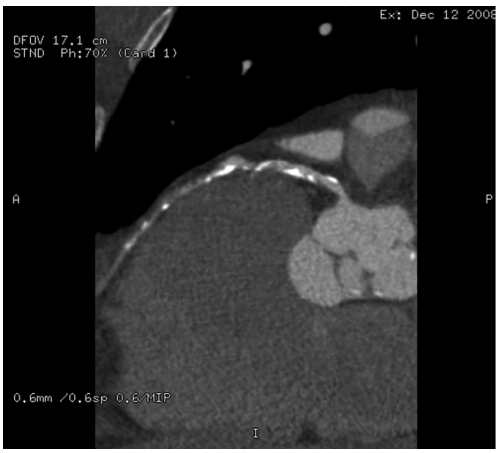

Figure 1 Preoperative CT scan of the chest identifying LAD myocardial bridging; complicating pathology of the LAD coronary artery. CT, computed tomography; LAD, left anterior descending.

guide specialized referrals to dieticians or glycemic control teams to optimize the patient prior to surgery. Elderly patients may also have geriatric needs that require specific referrals.

Another aspect of the preoperative workup is the physical examination and specific imaging. Various factors that can be evaluated on physical exam, such as the external chest wall anatomy, subcutaneous tissue burden, and overall size of the thorax, are aspects that can be evaluated preoperatively and can influence the position of the robotic arms and thus affect the operation (9). Patient factors that affect whether a patient can tolerate single lung ventilation, such as chronic obstructive pulmonary disease, pulmonary hypertension, and other co-morbidities, are information that will be extracted after a thorough history (9). Pulmonary function test is another example of a necessary test that is required to be performed prior to surgery to assess whether the patient will be able to tolerate single-lung ventilation.

After a thorough history and physical exam, the next most important step in the workup of a patient prior to undergoing robotic CABG is preoperative imaging of the chest. A simple chest X-ray [anteroposterior (AP) and lateral view] is obtained; however this does not provide all the detailed information that is required prior to surgery. A more detailed imaging modality would be a preoperative computed tomography (CT) scan of the heart/chest, abdomen, and pelvis. This is crucial not only to assess the thoracic anatomy, but also to assess the peripheral vasculature in the event that the patient needs to be placed on cardiopulmonary bypass via the peripheral arteries during surgical revascularization. A complete evaluation of the intrathoracic spaces and analyzing the anatomy prior to the surgery increases the chances of success, avoids complications, and minimizes conversions. Evidence of lung disease on the chest CT scan with signs of obstructive lung disease should also be considered as an indication of the patient not being able to tolerate single lung ventilation and a relative contraindication for minimally invasive surgical approach to revascularization. Identification of the left anterior descending (LAD) coronary artery on preoperative imaging is important to assess the location and course of the artery, specific anatomic considerations such as lateral displacement of the LAD, and extent of the calcifications. Specific features that are crucial to identify are intra-myocardial or adipose location of the LAD and other coronary arteries, and extent of pericardial fat (*Figure 1*). Furthermore, evidence of chronic total occlusion (CTO) of the LAD with poor LAD target distal to the occlusion on the CT heart may also be a contraindication to minimally invasive surgical revascularization. Any of the above-mentioned features would make the surgical revascularization challenging and may be considered a relative contraindication to performing the coronary artery revascularization with the assistance of the robot as it increases the difficulty in isolating the coronary vessels and performing the anastomosis. In addition, the CT scan will provide further information regarding the anatomy of the left internal thoracic artery (LITA). Information such as the course, size, and patency of the LITA at the take off from the subclavian artery and ruling out occlusion from plaque within the subclavian artery is crucial in planning the minimally invasive surgical revascularization.

As previously demonstrated in the paper by Anderson *et al.*, information about the thoracic cavity dimensions is helpful and highlights that a distance of >1.7 cm is necessary between the chest wall and the mediastinum at the camera port insertion site in order to accommodate the endoscopic port for the insertion of the endoscope (*Figure 2*) (4). A distance <1.7 cm compromises the endoscope and other instrument maneuverability and increases the likelihood of possible conversation to non-robotic approach or median sternotomy. Furthermore, knowing the position and axis of the heart with an ideal ratio of AP distance to transverse distance >0.45, is also important to not compromise robotic instrument maneuverability and the appropriate chest cavity (*Figure 2*) (4).

Moreover, preoperative cardiac catheterization must be

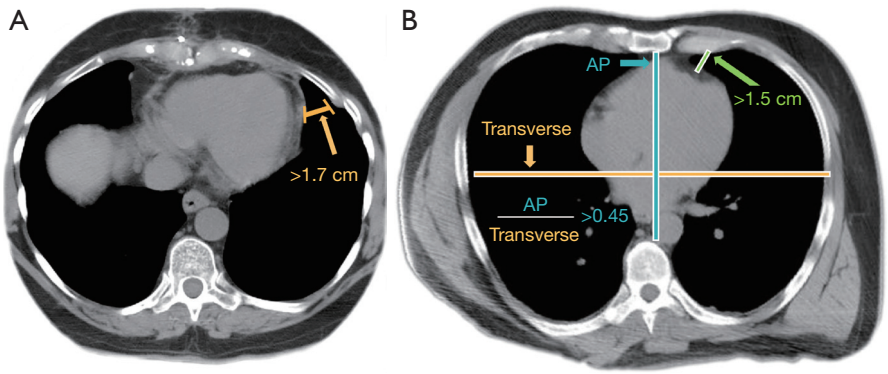

Figure 2 Obtained from the paper by Anderson *et al.* (4). (A) A distance of >1.7 cm is necessary between the chest wall and the mediastinum at the camera port insertion site in order to accommodate the endoscopic port for the insertion of the endoscope. (B) The ideal ratio of AP distance to transverse distance >0.45 to not compromise robotic instrument maneuverability. AP, anteroposterior.

reviewed to determine suitability of the patient for robotic CABG based on the location of the coronary artery disease and the distal targets. This can be reviewed with the heart team, which includes a cardiologist, an anesthesiologist, and a cardiac surgeon, to decide if the patient would be a candidate for robotic assisted revascularization and possible hybrid revascularization. Evidence of moderate to severe pulmonary hypertension may be a relative contraindication as patients with moderate or severe pulmonary hypertension will have a further increase in their pulmonary arterial pressures during single lung ventilation, which could result in acute right ventricular dysfunction and hemodynamic compromise.

The last preoperative consideration for patient selection is a holistic discussion with the patient and their family that encompasses expectation setting in terms of having the most benefit from the minimally invasive operation with arrangement for early discharge from the hospital. Shared decision making in conjunction with a collaborative approach with other members of the medical team such as anesthesiologists, allows for the selection of suitable patients by the surgeon and anesthesiologists based on grounds of compatible coronary anatomy for minimally invasive coronary artery revascularization. Careful selection of patients and a team-based approach is very important. The importance of good teamwork with experienced anesthesiologists and nurses cannot be emphasized enough.

In summary, there are physical features that can be discovered preoperatively with appropriate imaging that could be a relative contraindication for the patient to undergo robotic CABG. Specific characteristics of the LAD or other coronary vessels, such as intramyocardial location, or lack of viable targets for bypass due to size or location of the distal LAD or the other coronary vessels, all increase the potential post operative complications, risk of morbidity, and possible need for conversion to a traditional sternotomy. Inadequate space in the thorax that limits the movement of the robotic instruments also increases the chances of not being successful performing a minimally invasive approach and possible need for conversion to median sternotomy, and should be thoroughly analyzed preoperatively. Any history of prior chest surgeries or radiation to the chest will increase the chance of adhesions and could be a challenge or contraindication to undergo robotic CABG. Although no imaging can discover the presence of adhesions, it would be important to be aware of the possibility based on the patient's history. In addition to the preoperative pulmonary function tests that would indicate the inability of the patient to tolerate single lung ventilation, findings on CT scan showing evidence of obstructive lung disease should also be considered as an indication of the same, and are an additional relative contraindication for robotic CABG. Thus, the first step when performing a robotic CABG is appropriate patient selection which is of paramount importance and is augmented by a thorough preoperative work up with physical examination and specific imaging.

Postoperative considerations

After the successful completion of a minimally invasive robotic surgical revascularization, a standardized fast track postoperative protocol is implemented. This management strategy includes appropriate multi-modal pain control with utilization of non-steroidal anti-inflammatory medications

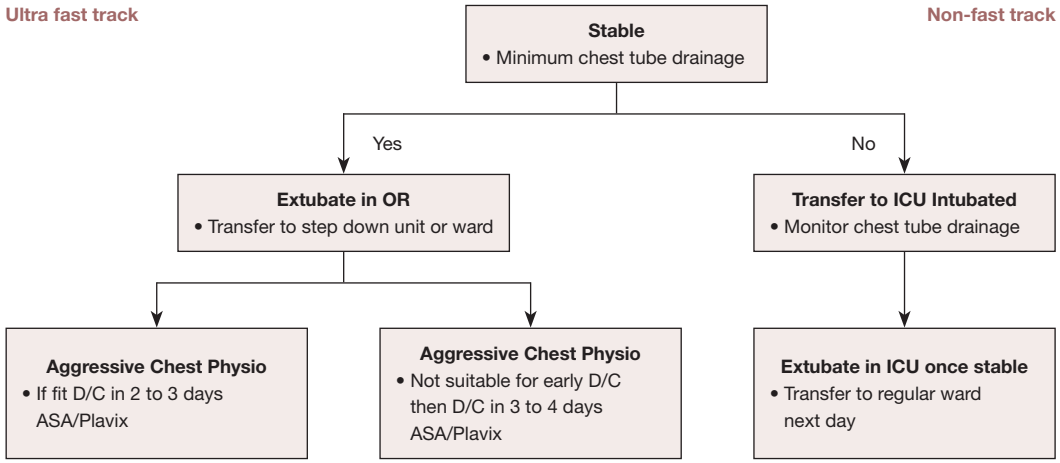

Figure 3 Graphical representation of the ultra-fast track postoperative protocol. OR, operating room; ICU, intensive care unit; D/C, discharge; ASA, acetylsalicylic acid or aspirin.

and peri-operative nerve blocks, while minimizing narcotics as much as possible. This allows the patient to be extubated intraoperatively or within 6 hours of leaving the operating room in order to advance their care and subsequently eliminating or decreasing their time in the intensive care unit (ICU). The overall goal of following a standardized fast track protocol is to decrease hospital length of stay, improve patient satisfaction, and reduce the overall costs and resources utilized by the institution, all while maintaining excellent clinical outcomes.

Fast track protocols have been implemented in cardiac surgery since the early 1990s and incorporate early extubation with lower narcotic doses to reduce post operative respiratory complications and have been shown to be safe, efficient, and cost beneficial by reducing the hospital length of stay (8,10). Patients will benefit the most from a minimally invasive procedure if they undergo an enhanced recovery after surgery by minimizing the length of stay in the ICU, or avoiding the ICU altogether, which is considered the ultra-fast track protocol (8). The ultra-fast track protocol, which is applicable to a select group of patients, reduces patient morbidity and decreases the costs accrued by the hospital for ICU stays (8). To be eligible for the fast track or ultra-fast track postoperative protocol, the patient must be hemodynamically stable with minimal chest tube output at the conclusion of the case (*Figure 3*). However, the preoperative status of the patient is just as important in the postoperative recovery phase, as critical preoperative status has been found to be a significant predictor of failure of the fast-track protocol.

Ultimately, utilizing minimally invasive techniques with the robot for coronary artery revascularization avoids the morbidity associated with median sternotomy and allows for better visualization over previous endoscopic approaches due to robotic platforms providing three-dimensional (3D) vision, magnification, and precise movements (2,3,11). Studies have shown that robotic CABG is safe and effective with reported postoperative patency rates of 97.4% which is comparable to previous studies demonstrating rates of 96.3% and 96.6% (3,12,13). The paper by Giambruno *et al.*, which is an 18-year single center experience of patients undergoing robotic-assisted CABG surgery, found that the average length of stay in the ICU was 1.2±1.4 days and the average length of stay in the hospital was 4.8±2.9 days. This was accompanied by low postoperative complications devoid of renal or respiratory failure (3). The same study also reported perioperative myocardial infarction occurring in only 1% of patients, which was similar to other published studies (3,14,15).

However, despite favorable and comparable short- and long-term outcomes in regards to overall perioperative morality, LITA patency, re-exploration rate, and postoperative myocardial infarction rate compared to the traditional sternotomy approach for CABG, there has been a slow adoption of robotic CABG (16,17). This may be in part due to the higher costs associated with robotic technology, accessibility to robotic technology, and the learning curve that needs to be overcome.

It remains true that experienced surgeons, dedicated robotic staff, and established protocols for perioperative and

postoperative care are prerequisites for a safe and successful robotic CABG surgery program (18). The paper by Xue *et al.* details the tools, collaboration, and institutional support that is required to establish a successful and efficient robot-assisted mitral valve surgery program, which can be extrapolated into developing a similar program for robotic CABG surgery (18). Rodriguez *et al.* also emphasizes that surgeons need to be well versed in not only the traditional approach, but also other minimally invasive approaches on and off pump prior to taking on the robot-assisted approach to coronary artery revascularization (19).

Conclusions

As robotic CABG surgery continues to grow, there are important aspects of perioperative management that will augment the success of the operation, from an extensive preoperative workup to protocolized postoperative care. It is imperative that the surgeon and operating team be well versed in traditional and minimally invasive coronary revascularization as the experience of the surgeon is a key factor in the successful outcome of robotic coronary revascularization given its challenging nature and steep learning curve.

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Footnote

Conflicts of Interest: B.K. is a consultant with Medtronic, Johnson and Johnson, Corcym, and Abbott. The other authors have no conflicts of interest to declare.

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Perspective

The Current Status of Minimally Invasive Conduit Harvesting for Coronary Artery Bypass Grafting

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Abstract: The harvesting of conduits for coronary artery bypass surgery has evolved over the last decade to include endoscopic approaches to access the saphenous vein, radial artery, and internal mammary artery. These minimally invasive techniques reduce the morbidity associated with open procedures by decreasing pain and recovery time and increasing mobility post operatively. This review highlights the differences in morbidity, quality, and patency between the most common conduits that are harvested minimally invasively for coronary artery bypass grafting surgery.

Keywords: coronary artery bypass grafting surgery; minimally invasive; conduit; cardiac surgery

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1. Introduction

Coronary artery disease remains the most common heart disease in the United States and continues to impact the lives of millions of American yearly [1,2]. Coronary artery bypass grafting (CABG) surgery is the surgical revascularization procedure used to address this condition and is the most common cardiac surgical procedure performed in the world [1]. Traditionally, the harvesting of conduits for this procedure has been performed using an open technique; however, over the last two decades there has been an increased adoption of minimally invasive and endoscopic approaches to obtain the various conduits for coronary artery bypass grafts. The goal of this transition has been to reduce the morbidity of open procedures by decreasing pain and recovery time and increasing mobility post operatively, all of which has ultimately led to increased patient satisfaction [1,3,4]. This review highlights the differences in morbidity, quality, and patency in conduits that are harvested minimally invasively for coronary artery bypass grafting surgery.

2. Endoscopic Saphenous Vein Harvesting

The greater saphenous vein is the second most widely harvested conduit used during coronary artery bypass surgery, which can be attributed to its accessibility and the ability to harvest long segments [5]. These conduits can be anastomosed to coronary arteries with a lesser degree of native artery stenosis, which ideally would be avoided if utilizing arterial conduits. Despite these positive features, the greater saphenous vein's durability and patency has been shown to be inferior compared to arterial conduits, which can be attributed to endothelial hyperplasia or damage to the endothelial lining during the harvesting technique or during reperfusion with higher arterial pressure [6,7].

Greater saphenous vein grafts were originally harvested through a long skin incision, which contributed to longer hospital stays due to the increased incidence of wound infections and pain and subsequently decreased patient satisfaction [5]. Endoscopic subcutaneous greater saphenous vein harvesting was first described in 1996 in response to the increased interest in minimally invasive surgery at the time [8]. The ROOBY randomized trial in 2010 performed a sub-analysis on the graft patency of endoscopic vein harvesting versus open vein harvesting in patients undergoing on- and off-pump CABG and found

that saphenous veins that were endoscopically harvested had a statistically significant lower patency rate than the veins that were harvested openly; 74.5% vs. 85.2%, $p < 0.0001$ [9]. They also found a higher 1-year revascularization rate in the group of patients who had endoscopic harvesting of their saphenous vein versus open harvesting (6.7% vs. 3.4%, $p < 0.05$) [9]. The outcomes of this particular study could be secondary to the method by which the greater saphenous vein grafts were harvested endoscopically, by utilizing carbon dioxide to insufflate the subcutaneous cavity, to the use of bipolar cautery with potential thermal injury, or to the longer manipulation times with the rigid scope [9,10].

Later in 2019, the REGROUP trial, a randomized controlled trial, evaluated clinical outcomes in 1150 patients who were randomized to either endoscopic or open vein harvesting and did not show a significant difference in the rate of major adverse cardiac events amongst the two groups [10]. In addition, this trial showed a decreased incidence of leg infections in the endoscopic harvesting group (1.4%) vs. the open harvesting group (3.1%) [10]. The ISMICS systematic review and consensus paper on the endoscopic harvesting of conduits for CABG by Ferdinand et al. found that wound complications and wound infections were significantly reduced with endoscopic harvesting versus the traditional open harvesting of vein conduits after performing a pooled analysis that included over 1300 patients [1]. Based on their findings, they also recommended endoscopic saphenous vein and radial artery harvesting as the standard of care over open harvesting due to noninferiority in respect to patency rates, the quality of the conduit, and major adverse cardiac events [1]. Thus, the comparable long-term outcomes, in conjunction with decreased harvesting site complications, contributed to the adoption of the endoscopic harvesting technique for the saphenous vein grafts, despite concerns regarding increased costs [1,10,11]. However, cost analyses have shown that the cumulative costs are not statistically different between the open and endoscopic harvesting technique, as the higher equipment-related costs in the operating room associated with endoscopic harvesting are outbalanced by the costs associated with managing harvest site complications with the open harvesting technique [11–13].

Advancements in endoscopic harvesting have led to the "no touch" technique, which decreases the manipulation of the graft by harvesting the saphenous vein with a pedicle of surrounding perivascular tissue [14,15]. Studies have also shown that saphenous vein grafts with perivascular tissue left intact have superior levels of nitric oxide production, which may contribute to improved patency rates due to the protective features of nitric oxide [16,17]. The retrospective review by Sakurai et al. found that early outcomes of saphenous vein grafts harvested with the "no touch" technique had similar pathological characteristics to grafts harvested with the original open technique, with a preservation of the wall structure, normal architecture, and smooth muscle cells [18]. A randomized longitudinal trial by Souza et al. showed statistically significant improvement in patency rates in the group who underwent the "no touch" technique compared to the traditional method of harvesting saphenous vein grafts (90% and 76%, $p = 0.01$) [14,15]. As mentioned above, all of these features provide protection against the distention of the graft once it is placed under arterial pressure, and the endothelial nitric oxide activity decreases intimal hyperplasia and atherosclerosis [15–18]. The "no touch" technique also utilizes the ultrasonic scalpel, which has been reported to reduce thermal injury and subsequent injury to the graft [18]. A table of key trials and studies can be seen in Table 1.

Despite the earlier trials showing decreased patency and increased revascularization with endoscopic saphenous vein harvesting, the ultimate key to providing the best results with this procedure is to harvest the saphenous vein atraumatically. Decreasing endothelial damage and its potential downstream consequences is highly dependent on the skill level of the operator. The comprehensive review by Krishnamoorthy et al. highlights the important aspects and features that a standardized training program should encompass in order to harvest the best quality vein, as it has been shown that the number of conduit repairs is inversely proportional to the level of expertise of the harvester [17,19]. In addition, a structured and standardized training program with a set surgical skill curriculum provides consistent training and reproducible results across all of the harvesters [17,20].

Table 1. Results of key trials and studies for endoscopic saphenous vein harvesting.

Author	Year	Type of Study	Results
Zenati et al. [9] (ROOBY Trial)	2010	Randomized controlled trial	• Statistically significant lower patency rate in endoscopically harvested veins than veins that were harvested open; 74.5% vs. 85.2%, $p < 0.0001$ • Higher 1-year revascularization rate in the group of patients who had endoscopic harvesting of their saphenous vein versus open harvesting (6.7% vs. 3.4%, $p < 0.05$)
Zenati et al. [10] (REGROUP Trial)	2019	Randomized controlled trial	• No significant difference in the rate of major adverse cardiac events • Leg infections occurred in 3.1% of patients in the open harvesting group and 1.4% of patients in the endoscopic harvesting group (relative risk, 2.26; 95% CI, 0.99 to 5.15)
Ferdinand et al. [1]	2017	Systematic review and meta-analysis	• Odds of a wound infection were significantly reduced with endoscopic harvesting (OR = 0.28, 95% CI = 0.13 to 0.63, $p = 0.002$)
Souza et al. [14]	2006	Randomized longitudinal trial	• Angiographic assessment at 18 months postoperatively showed 89% conventional versus 95% no-touch grafts were patent. Repeated angiography at 8.5 years showed a patency rate for the conventional group of 76% and 90% for the no-touch group ($p = 0.01$)
Sakurai et al. [18]	2022	Retrospective review	• Similar pathological characteristics as grafts harvested with the original and no-touch technique

3. Radial Artery Endoscopic Harvesting

The known disadvantages of endothelial and medial hyperplasia that contribute to the reduction in patency of greater saphenous vein grafts, as previously described above, have paved the way for investigations into other conduit options [21]. Total arterial myocardial revascularization is a technique utilizing all arterial grafts during coronary artery bypass surgery and includes the internal thoracic artery, radial arteries, gastroepiploic arteries, and inferior epigastric arteries. There are pros and cons to each arterial conduit that are well known and have been previously described in the literature [21]. However, this section focuses on the radial artery and the endoscopic harvesting technique.

The path for endoscopic radial artery harvesting was paved by the success noted with endoscopic greater saphenous vein harvesting over the years [3]. According to the most recent 2021 ACC/AHA/SCAI guidelines for coronary artery revascularization, the current recommendation for bypass conduits in patients undergoing CABG is for the preferential use of the radial artery over the greater saphenous vein, as the conduit to the second most important, significantly stenosed, non-left anterior-descending coronary artery to improve long-term cardiac outcomes [2]. Observational studies have shown radial artery patency rates of 92% at 1 year and 80% at 5 years when the bypassed targeted vessel has over 90% native stenosis [21].

In the systematic review and ISMICS consensus statement regarding endoscopic conduit harvesting, there is a significant reduction in wound infections with endoscopic radial artery harvesting versus open radial artery harvesting, which led to a Class I recommendation for the use of endoscopic radial artery harvesting to reduce wound-related complications [1,2,22]. Although the time to harvest the radial artery endoscopically was significantly increased compared to open harvesting, the overall operative time was not statistically different [1].

Endoscopic radial artery harvesting is also associated with increased patient satisfaction compared with the open technique with regard to cosmesis and postoperative pain, again contributing to the Class I recommendation for an endoscopic approach for radial artery harvesting [1,2,21]. In addition, the length of stay was reduced with endoscopic radial artery harvesting; however, these findings were not statistically significant [1].

A known complication associated with utilizing the radial artery as a graft during CABG is that it is prone to vasospasm, especially when exposed to competitive flow. This highlights the previously mentioned point above about the careful selection of the targeted coronary vessel with severely stenotic lesions (>90%) prior to harvesting in order to mitigate competitive flow and subsequent vasospasm [3].

Additional complications that have been noted with the use of radial artery grafts are the postoperative neurologic deficits due to injury to the superficial radial or lateral antebrachial cutaneous nerves. Sensory disturbances and neurological complications have been reported at as high as 30–67% [3,23]. These symptoms are transient and self-limiting and will usually resolve with time; however, permanent neurologic impairment was quoted to be 7.4% in one study [3,24].

Overall, endoscopically harvesting the radial artery has significant benefits when compared to open harvesting of the radial artery, as reported in the literature. The radial artery is not always available for use or the most appropriate conduit for all patients; however, it is an excellent option if the patient meets all the criteria and is amenable to endoscopic harvesting.

4. Endoscopic Internal Mammary Artery Harvesting

Endoscopic harvesting of the internal mammary artery has also gained popularity after advancements in minimally invasive cardiac surgery. This approach is used not only in patients with single-vessel disease, but also in patients undergoing hybrid treatment with stents to non-LAD vessels [25]. Minimally invasive CABG via anterolateral thoracotomy was first described by Dr. Kolessov in 1967 [26]. Endoscopic harvesting of the internal mammary artery with a sternal sparing mini thoracotomy approach and endoscopic camera, trocars, and instruments has been defined in the literature by Hrapkowicz et al. [25]. The benefits of this type of harvesting are the improved visualization of the artery and the ability to perform a full-length dissection of the internal mammary artery proximally, which is traditionally difficult with the conventional approach. The incomplete dissection of the proximal portion of the internal mammary artery can lead to "steal syndrome" [25].

In addition to improved visualization with the endoscopic approach, there is decreased postoperative pain. Statistically significant lower pain scores and decreased requirements for opioids postoperatively have been reported in patients undergoing endoscopic harvesting of the internal mammary artery versus conventional harvesting [27]. This can be attributed to the increased pain associated with rib retraction, which is required in the conventional method for harvesting the internal mammary artery [27].

An important aspect of totally endoscopic coronary artery bypass surgery is robot-assisted left internal mammary artery harvesting. As with all endoscopic harvesting techniques, there is a tremendous learning curve that needs to be overcome prior to achieving results comparable to the standard method of harvesting. The retrospective review by Oehlinger et al. found that the time to harvest the internal mammary artery decreased from 140 min in the first 10 cases to 34 min in the last 10 cases [28]. Other studies have shown decreased average IMA harvesting times, ranging from 57.8 $\pm$ 23.2 min in one study to 64.1 min in another, with the early postoperative angiogram showing patent grafts [29,30]. The utilization of devices such as the harmonic scalpel and increased experience demonstrated a 10% improvement in performance for each doubling of cases completed, which was seen in the first 20 cases [30,31].

Nonetheless, endoscopic harvesting of the internal mammary artery provides comparable results to open internal mammary artery harvesting and carries many benefits that outweigh the longer harvesting time.

5. Conclusions

Minimally invasive conduit harvesting for coronary artery bypass surgery has evolved over the last decade and continues to be modified with advancements in technology. With the more widespread adoption of the various minimally invasive techniques and increased operator expertise, the current cons associated with minimally invasive harvesting can be investigated and improved over time. It is also of paramount importance for continued institutional support to provide the necessary resources to encourage the adoption and evolution of minimally invasive approaches.

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Large Ascending Aortic Pseudoaneurysm with Focal Dissection after Coronary Artery Bypass Surgery

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Abstract

Background There are many known complications that occur after surgical revascularization for patients with significant left main coronary artery disease.

Case Description This case report highlights the preoperative workup, surgical approach, and postoperative management of a patient who presents with an aortic pseudoaneurysm and dissection 2 years after the index CABG.

Conclusion The development of an aortic pseudoaneurysm in combination with an ascending aortic dissection after prior coronary artery bypass grafting (CABG) is a rare compilation of complications that has scarcely been reported in the literature.

Keywords

- CABG
- aortic pseudoaneurysm
- aneurysm
- cardiopulmonary bypass

Introduction

Surgical revascularization is performed for patients with significant left main coronary artery disease. The risks associated with coronary artery bypass graft (CABG) surgery are well known with late dissection of the aorta and aortic pseudoaneurysm formation cited separately in various case reports and retrospective reviews; however, there is a paucity of literature on the concurrent presentation of both conditions.[1–3] This case report highlights the preoperative workup, surgical approach, and postoperative management of a patient with both an aortic pseudoaneurysm and dissection 2 years after the index CABG.

Case Report

A 65-year-old male with a history of allergic bronchopulmonary aspergillosis (ABPA) and CABG (left internal mammary artery [LIMA] - left anterior descending artery [LAD], saphenous vein graft [SVG] – obtuse marginal [OM], saphenous vein graft [SVG] – right posterior descending artery [RPDA]) 2 years prior originally presented to an outside hospital with worsening shortness of breath and was found to have a large mid-ascending aortic pseudoaneurysm measuring 78 × 53 × 92mm (►**Fig. 1**). The patient was transferred to our medical center for higher level of care and further workup in the setting of his known history of ABPA. The right coronary artery territory vein graft originated from the pseudoaneurysm sac, whereas the left circumflex artery territory vein graft, native right coronary artery, and native left coronary artery originated from the ascending aorta. Imaging did not reveal periaortic hematoma or active contrast extravasation in the mediastinum or pericardium. Coronary angiography showed patent LIMA-LAD graft with diffuse disease. The SVG to the RPDA was diffusely ectatic and the SVG to the OM had mild luminal irregularities. A preoperative echo demonstrated preserved biventricular function without valvular disease. Infectious disease was consulted

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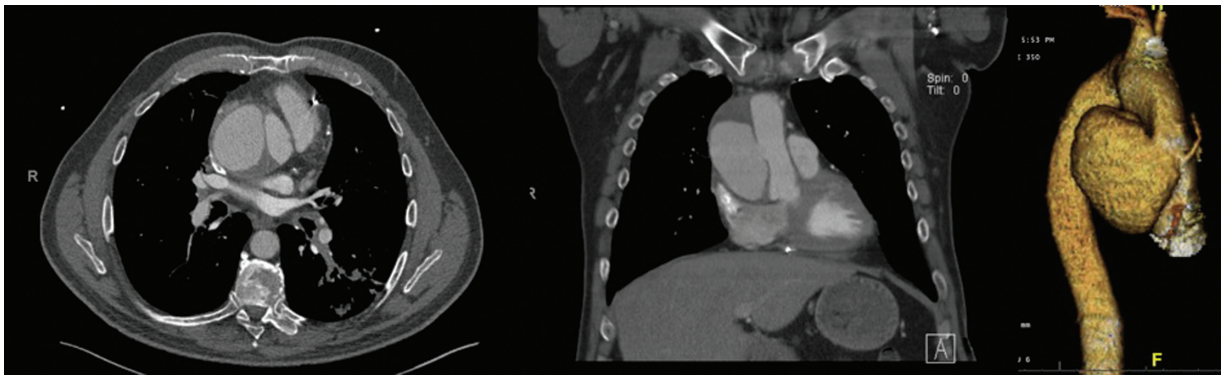

Fig. 1 Preoperative computed tomography with three-dimensional reconstruction demonstrating large pseudoaneurysm at mid-ascending aorta.

preoperatively due to the history of ABPA and did not find any contraindications to proceed with surgery as his ABPA was reported to be well controlled and he was not currently taking any medications for his diagnosis. It should be noted that this diagnosis was made at an outside hospital without histopathological evidence available to corroborate the diagnosis.

Operative notes from the index operation 2 years prior were obtained and were documented a standard median sternotomy approach to expose the heart without any significant ascending aortic atheroma visualized on epiaortic ultrasound, which would prevent safe cannulation or cross-clamping. Thus, the aorta was cannulated through a double purse string suture, an antegrade cardioplegic cannula was introduced into the ascending aorta, and an aortic cross-clamp was placed in the standard fashion.

With the above findings and details from the prior operation, the decision was made to go to the operating room for surgical repair of the large pseudoaneurysm. Peripheral access for cardiopulmonary bypass was established through the right groin and axilla. Upon entering the chest, the large 7 cm ascending aorta pseudoaneurysm with a 2 cm connection to the proximal ascending aorta was discovered, as well as a focal ascending aortic dissection flap at the proximal SVG-OM anastomosis site. The SVGs were liberated as coronary buttons and the pseudoaneurysm was resected and replaced with a 32 mm Hemashield graft (►**Fig. 2**). The venous bypass graft coronary buttons were reimplanted onto the neo-aorta. Intraoperative transesophageal echocardiogram was notable for left ventricular ejection fraction (LVEF) 65% without left ventricular dysfunction or wall motion abnormalities. Cardiopulmonary bypass and cross-clamp time were 328 and 178 minutes, respectively. The patient was transferred to the Cardiothoracic Intensive Care Unit (CTICU) in critical but stable condition and had an uneventful recovery.

Discussion

Ascending aortic dissection after CABG is a rare complication with less than 0.2% incidence.[1] The retrospective study by Eitz et al showed the majority of dissections occurred at the proximal anastomosis (41.7%), supporting the hypothesis that these types of dissections are caused by surgical trauma through manipulation of the aorta.[1] Arterial cannulation, aortic cross clamping, and graft anastomoses can weaken the aorta and disrupt the intima, causing dissections or pseudoaneurysms, as well as inadequate full-thickness bites when performing anastomoses.[2] This includes whether the operation is performed on pump or off pump with various stabilization devices to perform the anastomosis or partial aortic clamping. The initial weakening of the aorta during the operation, in addition to the common comorbidities associated with patients with coronary artery disease, such as hypertension and atherosclerosis, has been hypothesized to contribute to the late development of aortic dissection after CABG.[2]

The dissections can occur intraoperatively or as far out as 10 years after the index operation; however, late dissections are extremely rare and mainly found in case reports.[1,2] A small retrospective review by Dhadwal et al found the mortality associated with the development of a pseudoaneurysm arising from the ascending aorta after prior cardiac surgery was as high as 60% and the average time to pseudoaneurysm repair from index operation was 5 years.[3] Although this was a 10-year retrospective review study, it was underpowered with five total patients contributing to data.[3] A higher powered, more contemporary, study by Lou et al looked at mortality in 365 patients who underwent reoperative aortic arch intervention after previous cardiac surgery and found a 30-day mortality of 13.4%, and long-term follow-up mortality as high as 38%.[4]

Infections also contribute to the formation of pseudoaneurysms as Osler first coined the term mycotic aneurysm in 1885 to describe a pseudoaneurysm with an infectious etiology.[2,3,5] *Aspergillus* is a type of fungus that has been found in ascending aortic pseudoaneurysms in patients after prior cardiac surgery.[6] However, despite our patient's history of ABPA, he was not currently infected with aspergillosis at the time of his redo operation based on his lab tests showing a negative *Aspergillus galactomannan* antigen. It remains unclear whether he had an active infection after his index operation and whether that precipitated the formation of the pseudoaneurysm.

Conclusions

The development of an aortic pseudoaneurysm in combination with an ascending aortic dissection after prior CABG is rare and should be managed with prompt surgical

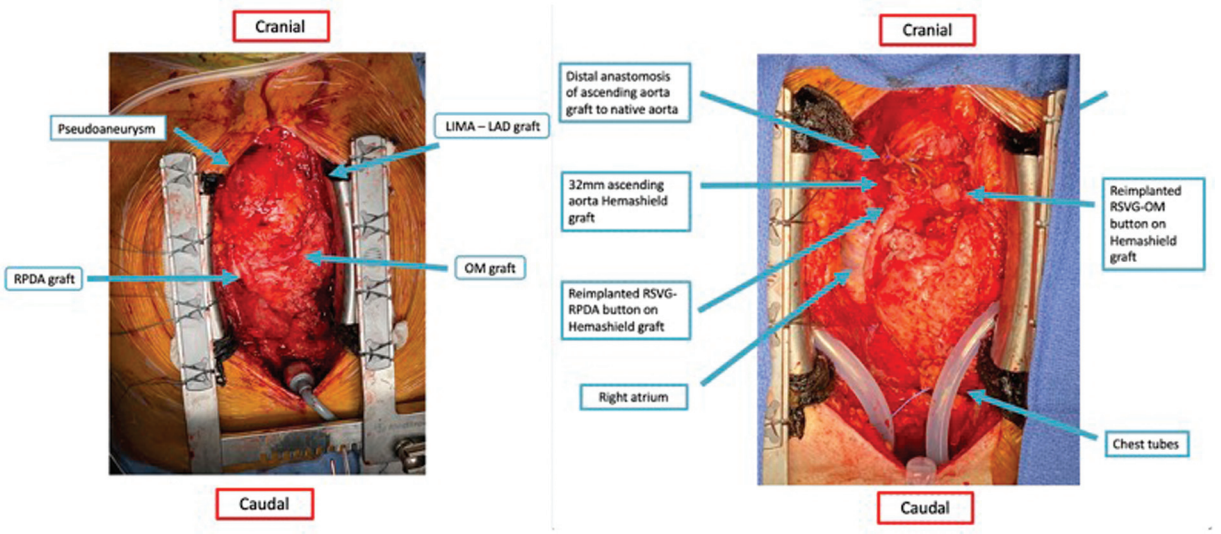

Fig. 2 Pseudoaneurysm with 2 cm connection to proximal ascending aorta.

intervention to prevent the potentially catastrophic consequences of pseudoaneurysm rupture. Providers should also be vigilant for other causes of aneurysms, such as infections, in order to adequately manage concomitant disease processes.

Conflict of Interest

None declared.

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Right Coronary Artery Dissection After Ross Procedure

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The Ross procedure is a surgical option for the treatment of aortic valve stenosis that is performed in a select subset of patients. This case report highlights the rare complication of a coronary artery dissection that occurred in the early postoperative period after a Ross procedure. The importance of timely recognition, swift intervention, and multidisciplinary team collaboration is discussed in the postoperative management of this complex cardiac surgery patient.

(Ann Thorac Surg Short Reports 2022;■:1-3)

Patients who present for surgical intervention of aortic valve stenosis receive a mechanical valve, bioprosthetic valve, aortic valve homograft, or pulmonary autograft (also known as the Ross procedure).[1] There are risks and benefits associated with each procedure and valve type. Postoperative complications of aortic valve surgery include hemorrhage, sepsis, heart block, arrhythmias, stroke, and reexploration for bleeding.[2] A less common postoperative complication is coronary artery dissection. We describe the rare complication of a right coronary artery (RCA) dissection that manifested in the early postoperative period after the patient underwent a Ross procedure.

A 47-year-old woman with a history of hyperlipidemia, prediabetes, and known congenital bicuspid aortic valve was found to have severe symptomatic aortic valve stenosis. Outpatient echocardiography revealed a mean gradient of 46 mm Hg across the valve, aortic valve area of 0.6 cm^2, and ejection fraction of 66%. Symptoms included shortness of breath, chest pain with exertion, and presyncope. Preoperative cardiac catheterization confirmed severe aortic stenosis and normal left ventricular and right ventricular function with mild (30%) stenosis of the proximal RCA.

After multidisciplinary conferences, she underwent an uncomplicated supported Ross procedure. The pulmonary autograft was harvested and sewn into a 26-mm Dacron graft to replace the aortic root, and she received a 23-mm pulmonary homograft to restore continuity between the right ventricle and branch pulmonary arteries. The left main coronary artery was noted to come off close to the commissure in the bicuspid aortic root; therefore, it was anastomosed close to the commissure of the autograft after a circular opening was made in the Dacron graft and pulmonary autograft wall. The RCA was anastomosed in a similar fashion. Coronary ostial cannulation was performed during the implantation of the coronary buttons for the delivery of cardioplegia. After the procedure was completed, transesophageal echocardiography showed good biventricular function without aortic insufficiency or pulmonary insufficiency. Total cardiopulmonary bypass time and cross-clamp time were 196 and 126 minutes, respectively. Postoperatively, she was taken to the cardiothoracic intensive care unit for recovery and was extubated without complications.

On postoperative day (POD) 1, she was hypotensive with increased central venous pressures and increasing pressor requirements. Bedside echocardiography showed poor right ventricular function compared with intraoperative echocardiography. She was urgently taken to the cardiac catheterization laboratory and found to have 70% proximal RCA stenosis due to RCA dissection as seen on intravascular ultrasound (Figure 1). She underwent percutaneous coronary intervention to the proximal/ostial RCA with a drug-eluting stent, with excellent angiographic results (Figure 2). Shortly thereafter, she demonstrated tamponade physiology and was found to have a large pericardial effusion on bedside ultrasound. She was emergently transported to the operating room for mediastinal exploration. She was found to have an extremely tense and dilated right atrium with bleeding from the inferior vena cava cannulation site, which was repaired with a suture. After the operation, she was placed on venoarterial extracorporeal membrane oxygenation and transferred to the cardiothoracic intensive care unit for recovery. Four days after the index procedure, she was successfully weaned from extracorporeal membrane oxygenation. She was extubated on POD 8 and discharged on POD 15.

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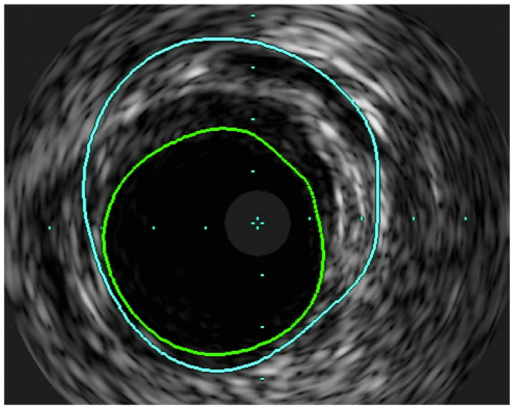

FIGURE 1 Intravascular ultrasound image showing right coronary artery dissection (green, area of coronary artery lumen; blue, area of dissection plane).

COMMENT

The Ross procedure, first described by Donald Ross in 1967, involves replacing the aortic valve with a pulmonary autograft and placing a homograft in the pulmonary position.[1,3] The advantages of replacing the aortic valve with a pulmonary autograft include low valve gradients and the freedom from anticoagulation.[4,5] Studies have shown an improved life expectancy and better quality of life with the Ross procedure compared with other forms of aortic valve replacement.[4,5] This procedure is ideal for young (≤50 years) patients with isolated aortic valve disease, small annulus, and active lifestyle and for those who wish to avoid anticoagulation and to have long-term freedom from redo operation.[1] Despite the benefits associated with the Ross procedure, The Society of Thoracic Surgeons National Database showed that <0.5% of the aortic valve procedures performed between 1994 and 2010 were Ross procedures.[5] This is in part due to the technical complexity of the Ross procedure as well as the wide range of morbidity and mortality associated with the operation. Single centers of excellence have reported <1% mortality, whereas other meta-analysis papers have reported 3.2% mortality.[5] Other known deterrents to this procedure include the risk of reintervention and giving the patient "2-valve disease" with late autograft valve failure and the need for replacement of the pulmonary homograft.[1,2,6] Dilation of the neoaortic root with subsequent autograft insufficiency can lead to a redo aortic root surgery or Bentall procedure, which is a high-risk operation in patients who have previously undergone cardiac surgery. This can be mitigated by performing the procedure in patients with a small annulus and externally reinforcing the pulmonary autograft with a Dacron graft, which is called a supported Ross procedure.[4,6] The wide range of mortality, the risk of reintervention, and the complexity associated with this operation account for the low number of Ross procedures performed by surgeons.

Dissection of the RCA can be iatrogenic after manipulation around the coronary artery ostium or occur spontaneously. In spontaneous coronary artery dissection, an intramural hematoma creates a false lumen in the arterial wall and compresses the true lumen, which obstructs coronary blood flow.[7,8] An intimal tear is not always visible in patients with spontaneous coronary

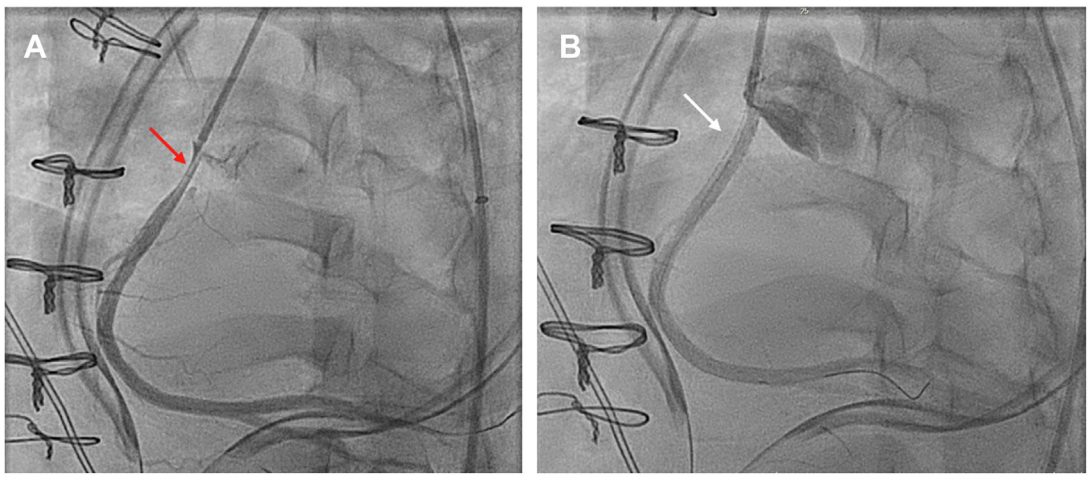

FIGURE 2 Cardiac catheterization (A) before and (B) after percutaneous intervention with drug-eluting stent (red arrow showing 70% proximal right coronary artery stenosis; white arrow after stent placement).

artery dissection as it may be due to ruptured vasa vasorum bleeding into the arterial wall.[7] The decreased blood flow can lead to myocardial infarction and is seen in younger women and usually not associated with atherosclerotic plaques.[7,8] Iatrogenic coronary artery dissection occurs during instrumentation, such as during a cardiac catheterization or with the antegrade cardioplegia catheter during cardiac surgery. The intima of the vessel is disrupted, which leads to the dissection of tissues that can propagate into the ascending aorta, into the arch, or around the pericardium, causing cardiac tamponade.

Our patient had an RCA dissection and RCA flow disruption on POD 1. This resulted in right ventricular failure and elevated central venous pressure, which led to dilation of the right atrium and disruption of the inferior vena cava cannulation suture site, leading to cardiac tamponade. This unusual sequence of events probably resulted after instrumentation of the coronary ostium during delivery of cardioplegia in a diseased vessel. The timing suggests that there was progression of the dissection or late dissection of the vessel in the early postoperative period.

Certain postoperative complications associated with aortic valve surgery are well described. However, this case report highlights the rare complication of an RCA dissection that occurred in the early postoperative period after a supported Ross procedure. The importance of multidisciplinary team collaboration, timely recognition, and expeditious intervention highlights valuable aspects of the postoperative management of complex cardiac surgery patients. These operations should be performed at centers of excellence to mitigate and to overcome such complications.

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DISCLOSURES

Bob Kiaii reports a relationship with Medtronic that includes: consulting or advisory. Bob Kiaii reports a relationship with Johnson & Johnson that includes: consulting or advisory. Bob Kiaii reports a relationship with Abbott that includes: consulting or advisory. Jeffrey Southard reports a relationship with Edwards Lifesciences that includes: consulting or advisory. Jeffrey Southard reports a relationship with Boston Scientific that includes: consulting or advisory. Jeffrey Southard reports a relationship with Abbott that includes: consulting or advisory.

PATIENT CONSENT

Obtained.

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CASE REPORT

JOURNAL OF CARDIAC SURGERY WILEY

Multidisciplinary approach to coronary artery revascularization: Optimal strategy for high-risk patients

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Abstract

High-risk patients that are not candidates for conventional coronary artery bypass grafting surgery can undergo coronary artery revascularization through less invasive procedures. Hybrid approaches have emerged to address coronary artery disease in this subset of patients. This case report highlights the successful application of a multidisciplinary heart team approach for hybrid coronary revascularization in a very high-risk patient with complex coronary anatomy, who would not otherwise be a candidate for conventional modalities of revascularization. The optimal workup, selection criteria based on anatomy, anticoagulation strategies, and timing of intervention of hybrid coronary revascularization are outlined in this case report.

KEYWORD
coronary artery disease

1 | INTRODUCTION

CABG became the standard of care for treating multivessel CAD due to the advantages of the LIMA-LAD graft.[1,2] High-risk patients that are not candidates for median sternotomy and conventional CABG undergo coronary artery revascularization through less invasive procedures such as PCI, which portends to less complications and faster recovery.[1] Hybrid approaches have emerged to address CAD in high-risk patients that utilize the advantages of the LIMA-LAD graft and benefits of PCI.[1,2] This case report highlights the successful application of a multidisciplinary heart team and methodical approach for HCR in a very high-risk complex patient and describes the optimal preoperative workup, selection criteria, anticoagulation strategies, and timing of intervention.

2 | CASE REPORT

A 66-year-old male with a history of COPD, 30-pack-year smoking history, diabetes (HbA1c 7.1, not on insulin), and CKD presented with SOB and chest pain. A cardiac catheterization showed multivessel disease (80% stenosis distal left main, 80% stenosis ostial LAD, 70% stenosis ostial circumflex, 70% stenosis ostial ramus). Preoperative echo showed EF 25% and he had a SYNTAX score of >32. CT imaging demonstrated severe circumferential calcification of the ascending aorta and PET/CT showed viable myocardium in all territories. The decision was made to pursue HCR after multidisciplinary heart team discussions given his poor ventricular function, calcified ascending aorta, and chronic kidney disease that placed him at high risk for developing complications with alternative surgical revascularization

Abbreviations: AP, anteroposterior; CABG, coronary artery bypass grafting; CAD, coronary artery disease; CKD, chronic kidney disease; COPD, chronic obstructive pulmonary disease; CPB, cardiopulmonary bypass; CT, computerized tomography; CTICU, cardiothoracic intensive care unit; DAPT, dual anti platelet therapy; DES, drug eluting stent; EACTS, European Association for Cardiothoracic Surgery; EF, ejection fraction; ESC, European Society of Cardiology; HbA1c, hemoglobin A1c; HCR, hybrid coronary revascularization; IABP, intra-aortic balloon pump; ITA, internal thoracic artery; LAD, left anterior descending; LIMA, left internal mammary artery; PCI, percutaneous coronary intervention; PET/CT, positron emission tomography/computed tomography; POD, postoperative day; SOB, shortness of breath.

methods, such as standard CABG or aortic no-touch multivessel off-pump CABG. Preoperative imaging supported his candidacy for robotic-assisted LAD revascularization with his favorable AP/transverse ratio, adequate intrathoracic space, and nonintramyocardial LAD as visualized on the cardiac gated CT scan.

He underwent a staged HCR with an IABP placed preoperatively to optimize his coronary perfusion and cardiac output support given his low EF during the off-pump minimally invasive surgical revascularization. A robotic-assisted LIMA harvest and off-pump CABG (LIMA-LAD) via left anterior mini-thoracotomy was performed to avoid excessive heart manipulation and dislocation. Postoperatively, he was extubated and transferred to the CTICU. On POD2, the IABP was removed, and clopidogrel was started. He underwent a complex PCI to the ramus and circumflex arteries with DES on POD3. He was discharged on POD7 on DAPT with an EF of 40%.

3 | DISCUSSION

Hybrid coronary revascularization refers to the combination of minimally invasive surgical revascularization of the LIMA-LAD, in conjunction with PCI of the remaining non-LAD vessels to treat multivessel CAD.[1,2] Combining these two methods capitalizes on the proven long-term survival and patency of the LIMA-LAD graft, while implementing smaller incisions, faster recovery, reduced postoperative pain, and avoids a sternotomy with CPB.[1,2]

This case report emphasizes the use of a methodical multidisciplinary heart team approach and the hybrid technique that enables the heart team to provide care to a very complex high-risk patient with left main coronary artery disease, circumferentially calcified aorta, very poor left ventricular function, and chronic kidney disease. An alternative choice for surgical revascularization of this high-risk patient includes an off-pump no aortic touch multivessel CABG, however, this is associated with the added risk of dislocating the heart for an off-pump revascularization in a patient with very poor LV function. This ultimately increases the chance of the patient not tolerating the off-pump procedure and requiring conversion to an on-pump approach, despite having the support of the intra-aortic balloon pump. Performing the minimally invasive revascularization of the LAD through an anterior thoracotomy avoids having to dislocate the heart. According to the 2018 ESC/EACTS guidelines, there is class I evidence for off-pump CABG and no-touch techniques in patients with significant atherosclerotic aortic disease and Class IIb evidence for a hybrid approach in a specific subset of high-risk patients, such as our patient, at experienced centers.[3] After our heart team discussion, which consists of cardiac surgeons, cardiologists, cardiac anesthesiologists, and radiologists, we believed that avoiding the risk of dislocating the heart for an off-pump revascularization in a patient with very poor LV function to revascularize both the LAD and circumflex territory would be beneficial. In addition, we wanted to avoid intraoperative hypotension with a multivessel off-pump CABG to prevent further deterioration of his chronic kidney disease. Based on this strategy, we proceeded with the hybrid coronary revascularization.

To become a candidate for HCR, the patient undergoes rigid anatomical and clinical screening. The most suitable patients have high (>32) SYNTAX score and ostial/complex or occluded LAD with simple lesions of the other coronary arteries that are amenable to PCI. Preoperative anatomic imaging is crucial for determining appropriate patient selection and port placement for robotic procedures.[4] Requirements for a successful robotic ITA harvest include adequate space around the heart, normal axis, and no overt complicating pathology.[4] A distance of >1.7 cm between the lateral pleura and mediastinum and AP/transverse ratio >0.45 is ideal to not compromise instrument maneuverability (Figure 1).[4]

HCR can be performed as a simultaneous or staged procedure. Advantages of the staged procedure include decreased time under general anesthesia, increased anticoagulation options, and potential for more complex PCI procedures. Disadvantages include two separate procedures and longer hospital stay.[2] Advantages to the simultaneous approach are complete revascularization with one procedure, assessing the patency of the LIMA graft, and reduced hospital stay.[1,2] This requires a hybrid suite to accommodate the surgical and interventional portions, which is not available at all institutions.[1] There is an added disadvantage of balancing antiplatelet

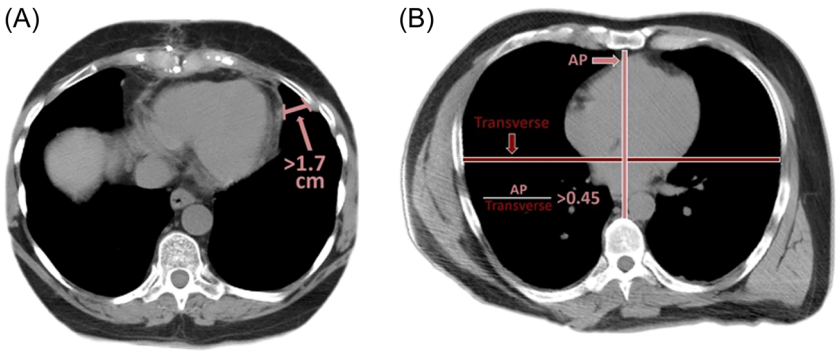

FIGURE 1 (A) Screening imaging shows the ideal distance between the lateral pleura and mediastinum; a distance >1.7 cm is necessary for a successful internal thoracic artery harvest. (B) Screening imaging determines intrathoracic measurements that are favorable for a minimally invasive approach; a ratio of AP distance to transverse distance >0.45 is preferred to avoid compromising instrument maneuverability.

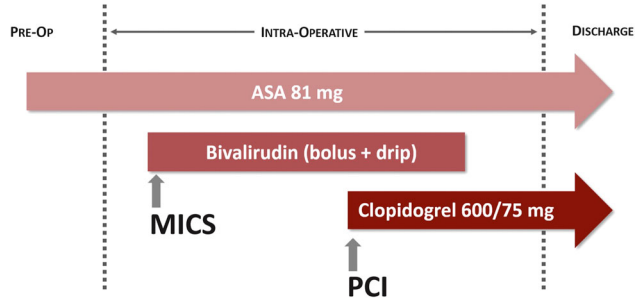

FIGURE 2 A representation of the timeline of anticoagulation administration for the simultaneous approach.

therapy to prevent stent thrombosis and risk of surgical bleeding. Although we performed a staged procedure with this case report, if we were to perform the simultaneous approach, we would consider bivalirudin during the operation (Figure 2). It is a short-acting direct thrombin inhibitor that inactivates bound and unbound thrombin and has been demonstrated to be a safe and effective anticoagulant in patients who undergo PCI or off-pump surgeries.[5,6] Studies have shown that it is noninferior to heparin and is associated with significantly reduced bleeding rates when compared to heparin.[5]

The pitfalls of HCR include longer operative times with minimally invasive CABG, possible higher cost, and technical difficulty.[2] These barriers account for the slow growth of HCR and lack of utilization as <1% of total CABGs performed are HCR.[1] Lack of large randomized controlled trials involving different risk groups hinders the identification of an HCR target population, therefore more studies need to look at HCR in high-risk groups of patients. Proper hybrid facilities for same-setting PCI, as well as learning opportunities to overcome the steep learning curves are necessary to encourage HCR.

4 | CONCLUSION

This case highlights the methodical properly planned heart team approach in the management of a very complex high-risk patient with complex coronary anatomy, who would not otherwise be a candidate for conventional modalities of revascularization. This approach warrants the need for a dedicated and committed heart team.

CONFLICTS OF INTEREST

Dr. Kiaii is a consultant with Medtronic, Johnson and Johnson, and Abbott.

ETHICS STATEMENT

The Institutional Review Board (IRB) did not approve this study. Patient written consent for the publication of the study was not received. Oral consent was obtained from the patient to report this case.

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VIDEOSCOPY

Giant Paraesophageal Hernia with Intrathoracic Spleen

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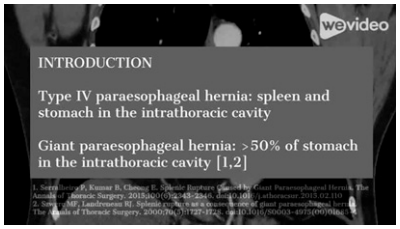

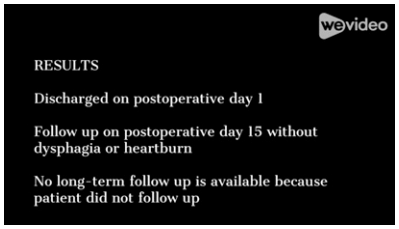

Abstract

This is a 63-year-old man with a history of hypertension, hyperlipidemia, diabetes, and prior coronary bypass grafting who developed progressive dyspnea on exertion. Workup demonstrated a giant type IV paraesophageal hernia involving his stomach and spleen. He underwent a robot-assisted paraesophageal hernia repair with partial (270-degree) fundoplication and gastropexy after reduction of the intraabdominal contents from the left chest, which required the splitting of the left crus. He did well postoperatively. Our video illustrates highlights from this unusual case.

Video: Preoperative images and intraoperative video highlighting the important aspects of a robot-assisted paraesophageal hernia repair with partial fundoplication and gastropexy in a patient with a giant type IV paraesophageal hernia involving the stomach and spleen.

The authors have no conflicts of interest or financial ties to disclose.

Runtime of video: 3 mins 59 secs

Keywords: hiatal hernia, hernia, foregut, robotic surgery, diaphragm

Cite this video

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