Review Article

Post-operative imaging of pulmonary vessels

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Abstract: Complications following cardiothoracic surgery are responsible for prolonged hospital stay, increase cost in patient care and increased morbidity and mortality. Vascular complications in particular are significant contributors to poor patient outcome due to either hemorrhage or thrombosis and ischemia. Evaluation of vascular complications in the postoperative patient requires a rapid and reliable imaging approach. Vascular complications after cardiothoracic surgery include pulmonary artery thrombosis, pseudoaneurysm, pulmonary vein thrombosis, vascular fistulas, stenosis and infarction. Multidetector CT (MDCT), often the imaging modality of choice, offers a one-stop-shop capability to visualize the entire cardiothoracic vasculature, airways, lung parenchyma, mediastinum and chest wall with excellent temporal and spatial resolution.

Keywords: Pulmonary circulation; pulmonary artery; pulmonary veins; thoracic surgery; tomography; X-ray computed

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Introduction

The next two to three decades will see an increase in the number of cardiothoracic surgeries primarily driven by demographic changes characterized by an increase in the elderly population. Pulmonary complications following cardiothoracic surgery lead to prolonged hospital length of stay and intensive care unit admissions, raising costs in patient care and significantly increasing morbidity and mortality. The reported incidence varies significantly among institutions depending on variables such as patient selection (age, cardiopulmonary reserve, comorbidities), type of surgical intervention, level of complexity and volume of surgeries performed.

Common complications include atelectasis, pneumonia, bronchopleural fistula, and pulmonary embolism, all of which present with respiratory changes. Vascular complications limited to the pulmonary vasculature are less common, and are usually seen following lung resection, transplantation or surgery for congenital heart disease. Even though vascular complications uncommon, they are potentially life-threatening.

Pulmonary artery pseudoaneurysm (PAP)

Bleeding after thoracic surgery, one of the most dreaded complications is rare reported in 2% following video-assisted thoracoscopic surgery (VATS) procedures, and in up to 3% after open procedures or surgery (1-3). Significant bleeding in the immediate postoperative period after lobectomy occur in <3% of lobectomy patients, and when identified in the immediate postoperative period is often managed by reintervention. The source of bleeding can be from mediastinal vessels, bronchial arteries, intercostal arteries and in less than 20% the pulmonary artery (4).

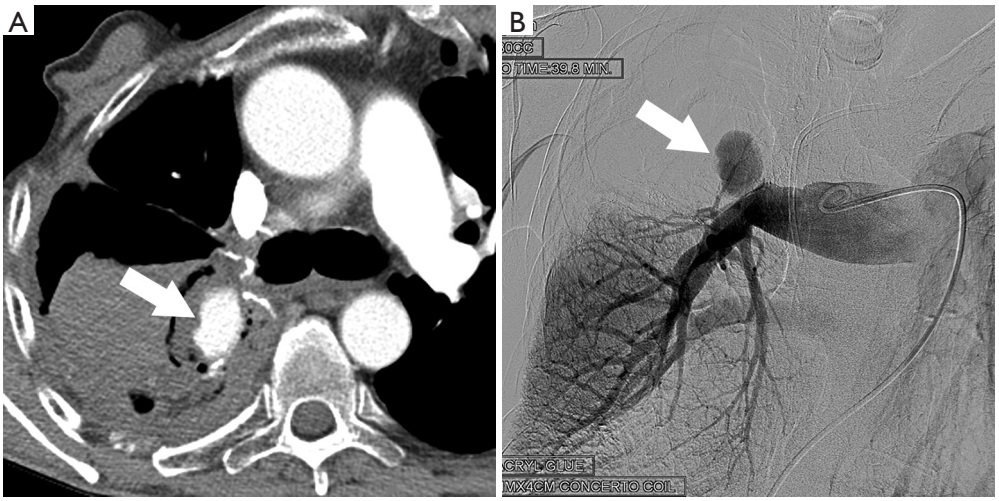

Figure 1 Pulmonary artery pseudoaneurysm in a 70-year-old patient status post right upper lobectomy for lung cancer, who presents with hemoptysis. (A) Contrast enhanced CT demonstrates a pseudoaneurysm in the posterior aspect of the right hilum (arrow); (B) digital subtraction angiography, selective injection in the right pulmonary artery confirms the pseudoaneurysm at the resection site (arrow).

Most PAP present after thoracic trauma including chest tubes placement and intravascular catheters, from septic embolism, lung cancer, or vasculitis but may also occur after lung resection, lung biopsy or radiofrequency ablation (5). PAP could represent a life threatening condition which requires prompt diagnosis and intervention with either open surgical repair or endovascular surgery (6). In cases in which PAP develop as a postoperative complication, associated infection may be a contributing factor. Postoperative PAP actually represents a contained rupture. Hemoptysis is the most common clinical manifestation, which can be associated with hemorrhagic pleural effusion. Most PAP after pulmonary resection typically involves branch pulmonary arteries, and only rarely the pulmonary trunk (7). Contrast enhanced multidetector CT (MDCT) with contrast injection is commonly the initial imaging modality to demonstrate the vascular abnormality, but selective catheter angiography is commonly performed to confirm the diagnosis and to guide endovascular treatment (8,9). On contrast enhanced CT postoperative pseudoaneurysms manifest as a round, oval or irregular shaped variable in size saccular collection of contrast density adjacent or contiguous to the pulmonary artery, typically at the resection site (*Figure 1*). In the past surgical aneurysmectomy was the preferred and often the only treatment option, but more recently endovascular embolization has proven to be a viable therapeutic approach for many cases.

Lung transplantation

Vascular anastomotic complications following lung transplantation are rare (2–15%), and may manifest as pulmonary artery or pulmonary vein stenosis, or anastomotic venous thrombosis. Even though they are not commonly seen, they are known to be associated with significant morbidity and mortality (10). Vascular complications are more common in patients with pulmonary fibrosis and more commonly manifest as a stricture involving a pulmonary artery anastomosis rather than a pulmonary vein anastomosis. Right and left pulmonary arteries are equally affected (11). In situ thrombosis of the arterial or venous anastomosis is a less common complication (12). Stricture of a vascular anastomosis should be suspected in the presence of unexplained hypoxia and/or hemodynamic instability or pulmonary edema in the early postoperative period. The risk of pulmonary infarction is greatest in these patients since the newly transplanted lung does not have the protective pathway of the bronchial circulation. Significant stricture at a vascular anastomosis is associated with increased risk for local thrombosis which may lead to pulmonary infarction in case of arterial thrombosis, or pulmonary edema in cases of venous thrombosis.

The most common vascular anastomotic strictures may result from kinking or angulation of the anastomosis, or from over-tightening of the suture line. Donor-recipient size mismatch is considered a significant risk factor for

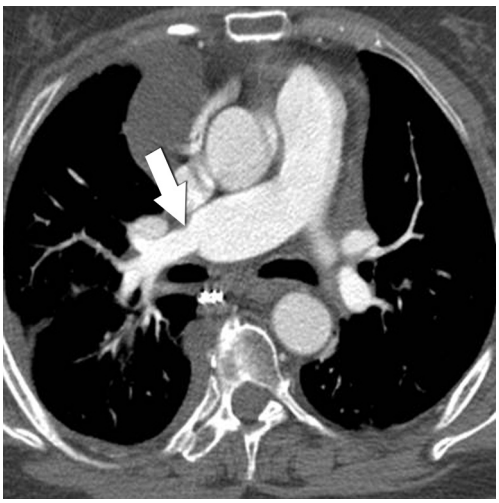

Figure 2 Pulmonary artery mismatch in a 63-year-old female patient status post bilateral lung transplant. Contrast enhanced CT shows the discrepancy in size between the recipient and donor pulmonary arteries with a step-off configuration at the level of the anastomosis (arrow).

Figure 3 Right pulmonary artery stenosis in a 61-year-old male patient status post lung transplant. Digital subtraction angiography confirms a "waist" with luminal narrowing at the right pulmonary artery anastomosis (arrow).

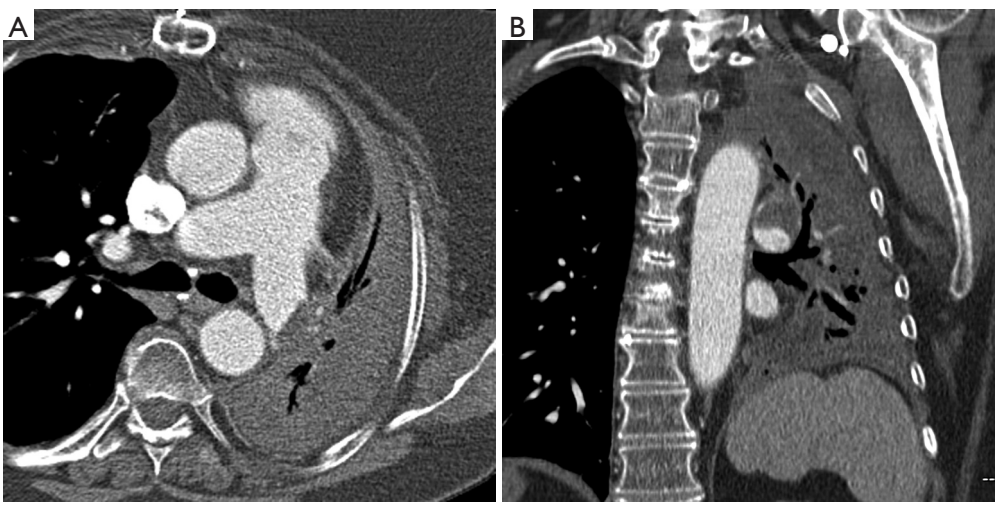

Figure 4 Post lung transplant pulmonary artery thrombosis with pulmonary infarction. Contrast enhanced CT axial image (A) and coronal reconstruction (B) demonstrate complete obstruction of the left pulmonary artery with collapse of the entire left lung.

vascular anastomotic complications.

Many centers have adopted routine use of intraoperative transesophageal echo as standard practice during lung transplantation for intraoperative recognition of vascular complications.

MDCT is considered to be the imaging modality of choice for the evaluation of the lung transplant patient when a vascular abnormality is suspected in the postoperative stage, and has replaced catheter angiography which is more commonly used to guide intervention rather than for diagnosis. MDCT with multiplanar reconstruction is the best noninvasive test than can precisely demonstrate the extent and degree of the stenosis and provides a reference baseline for follow-up. Isotope scanning may also help in the evaluation of impaired pulmonary perfusion, but has poor spatial resolution to demonstrate the anatomy, morphology and location of the vascular stricture (*Figures 2-5*).

The treatment of vascular complications range from a

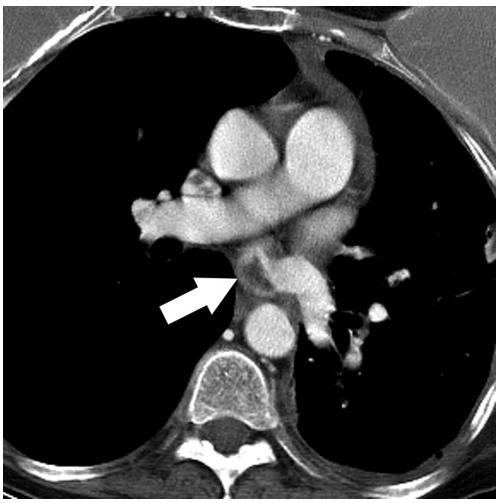

Figure 5 Pulmonary vein thrombosis in a 57-year-old female patient with single left lung transplantation. Contrast enhanced CT axial image shows filling defect in the anastomotic site between the left atrium and left lower lobe pulmonary vein (arrow).

conservative medical management, to a more aggressive approach with endovascular intervention (angioplasty/stenting) and surgical revision, depending on the degree of obstruction, time elapsed from transplantation to diagnosis, stricture morphology, overall clinical condition of the patient and available expertise. In general those cases identified with intraoperative ultrasound are treated while the patient is the operating room, whereas those diagnosed after several weeks are best treated with an endovascular intervention.

Postoperative systemic vessel to pulmonary vessel fistula

Systemic artery to pulmonary vein fistula (SAPVF) is a very rare condition which can develop as a complication of tumor, infection, inflammation, trauma or as a rare complication following thoracic surgery. They represent an abnormal communication between a systemic artery commonly an internal mammary, subclavian or intercostal artery with outflow into a pulmonary vessel, typically a pulmonary vein, and occasionally a pulmonary artery (arterio-arterial fistula). Roughly 50% of SAPVF are congenital, and occur in association with congenital heart disease or pulmonary artery hypoplasia. The remainder 50% are acquired and result from malignancy, infectious or inflammatory process with pleural involvement or from trauma or surgery (13). The anatomic connections can be quite variable, as well as their clinical manifestation.

Most post-operative SAPVF are diagnosed years after the surgical event, in some case more than 20 years later, since they are commonly asymptomatic. Patients with large fistulas with significant shunt fraction may manifest with heart failure (14). In case of a SAPVF that develops after revascularization surgery with coronary artery bypass graft (CABG) surgery a common pattern consists of fistula between the left internal mammary artery (LIMA) and a pulmonary artery or vein. When this is the case coronary steal phenomenon may manifest with worsening angina (15-17).

Treatment options include embolization or surgical resection with arterial ligation. Because SAPVF are commonly asymptomatic, are well tolerated and complications are rare, observation and clinical follow-up is recommended in many cases.

On contrast enhanced CT, SAPVF manifest as prominent parietal pleuroparenchymal irregular and often prominent vessels originating from single or multiple systemic arteries that abnormally connect with the pulmonary circulation (*Figure 6*).

Coronary-to-pulmonary fistula (CPF)

A CPF is an uncommon coronary artery anomaly in which there is an abnormal communication between a coronary artery and the pulmonary artery. Even though most CPAF are congenital in origin, the majority are diagnosed in adulthood. A minority are iatrogenic complication from surgical intervention for lung transplantation, CABG, mitral or aortic valve replacement, septal myomectomy, or from coronary revascularization, or percutaneous biopsies (18,19). Cardiac gated CTA and intracoronary artery catheter angiography allows demonstration of the fistulous communication which manifests as an irregular and often tortuous small vessel on the surface of the pulmonary trunk or as an abnormal blush of contrast passing into the less opacified pulmonary artery (20) (*Figure 7*).

Postoperative lobar torsion

Postoperative lobar torsion following pulmonary lobectomy or lung transplantation is a rare but often serious complication associated with pulmonary ischemia, pulmonary infarction and irreversible tissue necrosis, seen in less than 0.4% of lobectomy patients and less than 0.3% of lung transplant patients. Torsion

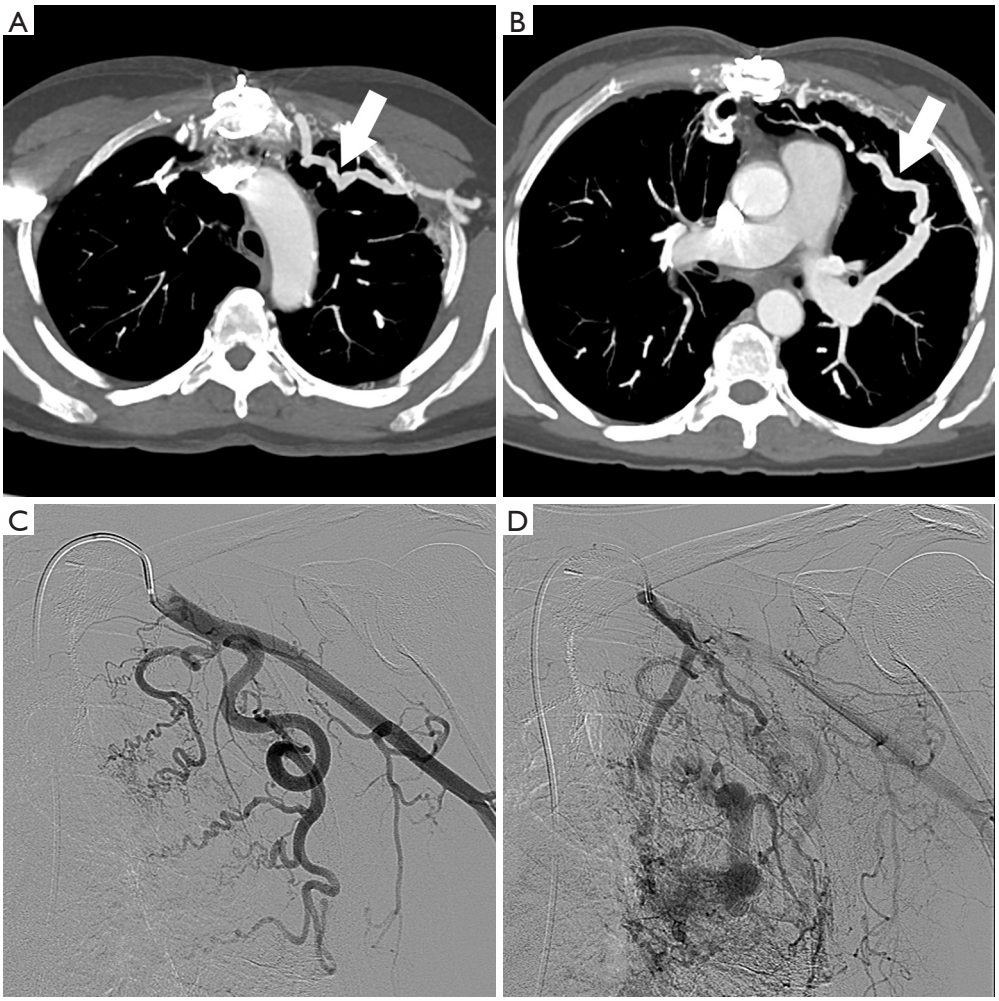

Figure 6 Systemic artery to pulmonary artery fistula in a 52-year-old female patient with history of revascularization surgery (CABG) with several complications that required surgical reintervention. (A) Contrast enhanced CT shows a tortuous intrapulmonary vessel in the anterior left upper lobe between the left internal mammary artery and the left axillary artery (arrow); (B) axial image further down reveal communication to the left pulmonary artery (arrow); (C,D) digital subtraction catheter angiography with selective injection in the left subclavian artery confirms the presence of fistulous arterial communications between the left side systemic arterial and pulmonary arterial circulation. CABG, coronary artery bypass graft.

occurs when a lobe or the entire lung partially or completely rotates around the hilum compromising arterial supply, venous and lymphatic drainage and corresponding airway. After lobectomy, the vast majority (70%) affects the right middle lobe. Lobar torsion may precipitate pulmonary artery rupture and massive bleeding (4,21).

Imaging findings suggestive of this complication include collapsed or consolidated lung in an atypical position after surgery on conventional radiograph. CT better demonstrates rotation, tapering and obliteration of the proximal pulmonary artery and bronchus of the affected lobe or lung with pulmonary venous obstruction and amorphous soft-tissue attenuation of the hilum with poorly enhancing peripheral pulmonary parenchyma (22,23) (*Figure 8*).

Pulmonary artery stump thrombosis

The exact prevalence and clinical significance of pulmonary artery thrombus formation after lobectomy or pneumonectomy is not clear. Incidental and inconsequential postpneumonectomy pulmonary artery stump thrombosis is not uncommon, and could be mistaken for pulmonary

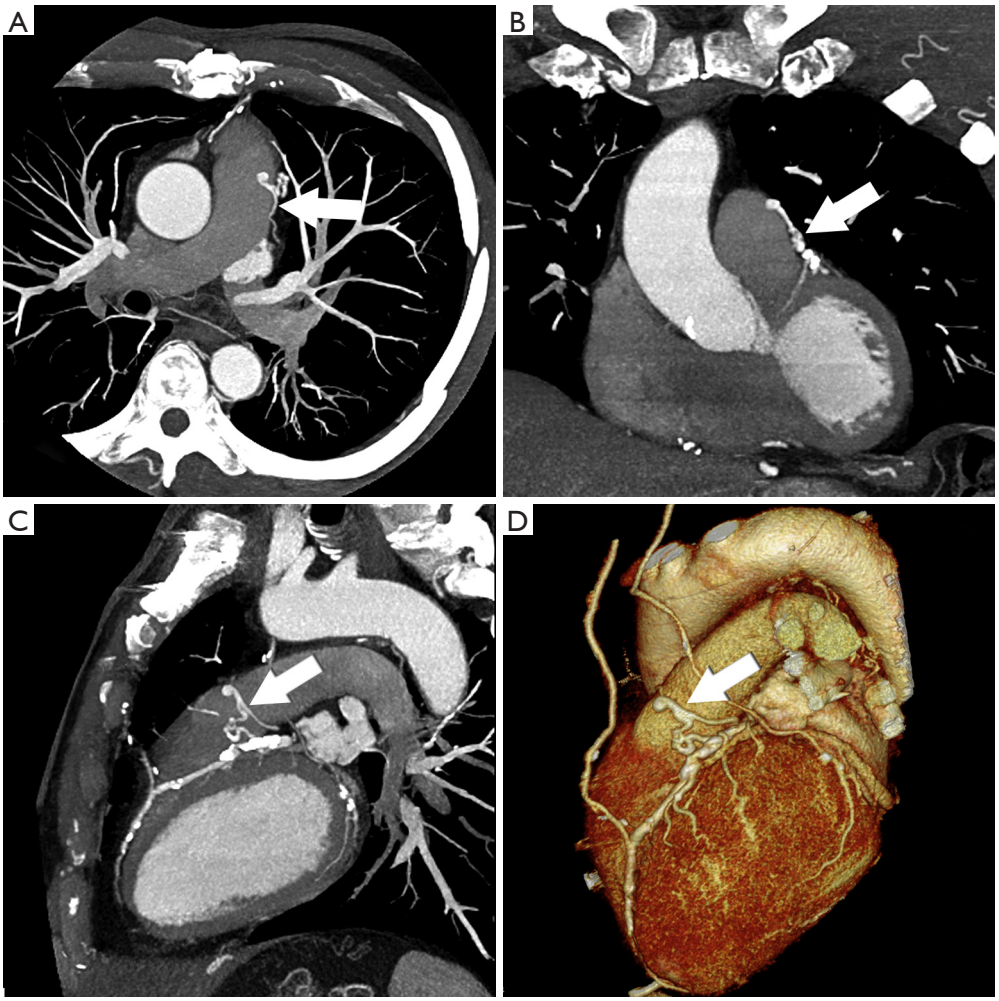

Figure 7 Coronary-to-pulmonary artery fistula after coronary artery bypass graft. (A) Cardiac gated coronary artery CT axial image shows a high density small irregular vessel on the left lateral aspect of the pulmonary trunk (arrow); (B) coronal image shows the proximity between the tortuous irregular vessel and the left anterior descending (LAD) coronary artery (arrow); (C) sagittal maximum intensity projection (MIP); (D) volume rendered 3D reconstruction. Images show the connection between the fistula on the surface of the pulmonary trunk and the left anterior descending coronary artery (arrows). Arterial grafts to the circumflex and LAD are also appreciated.

embolism on contrast enhanced CT, which is also a common complication seen in postoperative patients. The exact frequency of pulmonary stump thrombosis is not well known, but in a retrospective study in which CT was performed on average around three years after pneumonectomy in 89 patients, stump thrombosis was identified in 12% of patients. In this study a correlation between pulmonary artery stump length and thrombosis was suggested (24,25).

It is not clear whether progressive enlargement of the clot may occur and eventually embolize to the remaining portion of the lung. Symptomatic chest pain and even death associated with significant amount of stump thrombus has also been reported raising concern on when it would be appropriate to treat affected patients with systemic anticoagulation (26,27). Whether anticoagulation treatment is required in particular in asymptomatic patients remains uncertain (*Figures 9,10*).

Postoperative congenital heart disease

Multimodality imaging plays a critical role in the follow-up of patients with repaired congenital heart disease. Patients with tetralogy of Fallot (TOF) which is the most common complex congenital heart disease, have significantly

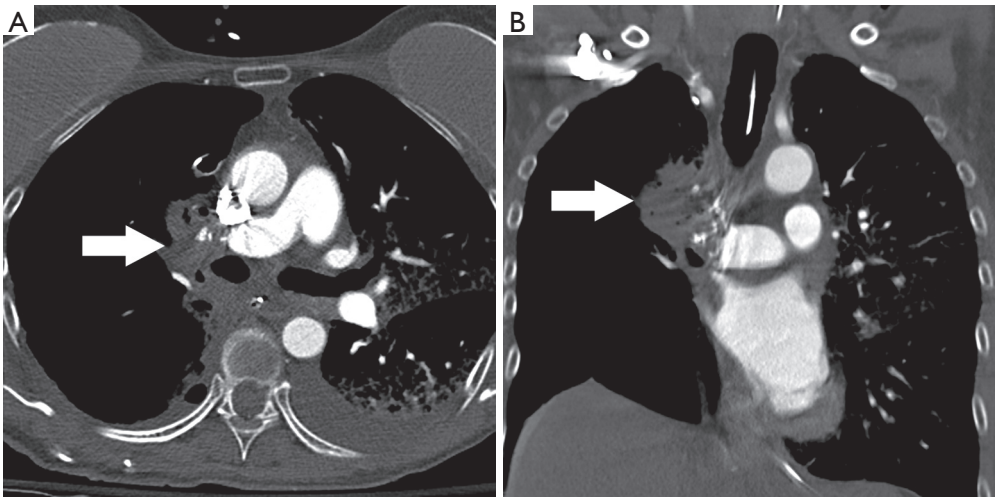

Figure 8 Lobar torsion in a 66-year-old female patient status post right upper lobectomy for lung cancer. A few days later her status worsens. (A) Contrast enhanced CT axial image; (B) contrast enhanced CT coronal reconstruction. Images demonstrate mass-like opacity of the right hilum with interruption of the right pulmonary artery, interruption of the right superior pulmonary vein and narrowing of the right middle lobe bronchi (arrows). Patient was taken to surgery and found to have devascularization of the right lung with torsion of the right middle lobe.

Figure 9 Post-lobectomy pulmonary artery thrombosis. Contrast enhanced CT, coronal reconstruction in a patient with right lower lobe and middle lobe resection demonstrates right pulmonary artery stump thrombosis (arrows).

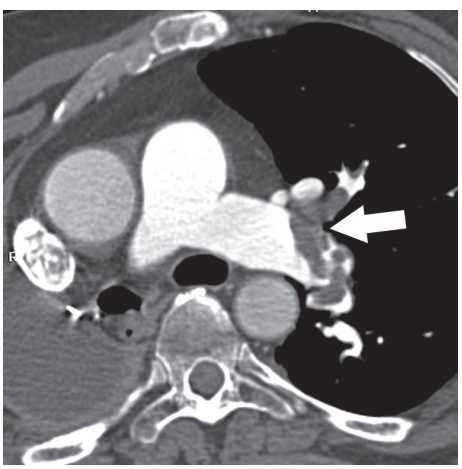

Figure 10 Post-pneumonectomy pulmonary embolism. Contrast enhanced axial image at the level of the left hilum shows extensive filling defect in the left pulmonary artery (arrow) in this patient with previous right side pneumonectomy.

improved survival rates into adulthood after total repair which includes ventricular septal defect closure, and relief of pulmonary outflow obstruction. Pulmonary regurgitation occurs in a large number of patients (80%). True and false aneurysms of the pulmonary infundibulum are well known complication after surgical correction of congenital heart disease, reported in as much as 25% of TOF patients. These typically occur at the level of the trans-annular patch repair or infundibular muscle resection. These have also been reported following surgical correction of transposition of the great arteries (Bidirectional Glenn), and single ventricle (Fontan operation). Right ventricular outflow tract

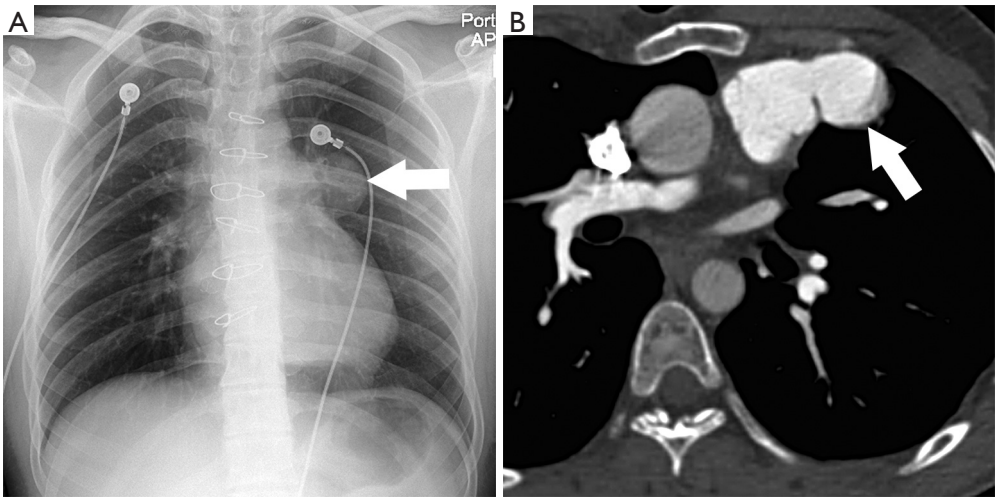

Figure 11 TOF post RVOT repair with pseudoaneurysm at the suture line. (A) Chest radiograph shows an abnormal round mass-like opacity projecting on top of the left hilum (arrow); (B) contrast enhanced CT reveals a pseudoaneurysm of the anterolateral aspect of the right ventricular outflow tract (arrow). TOF, tetralogy of Fallot; RVOT, right ventricular outflow tract.

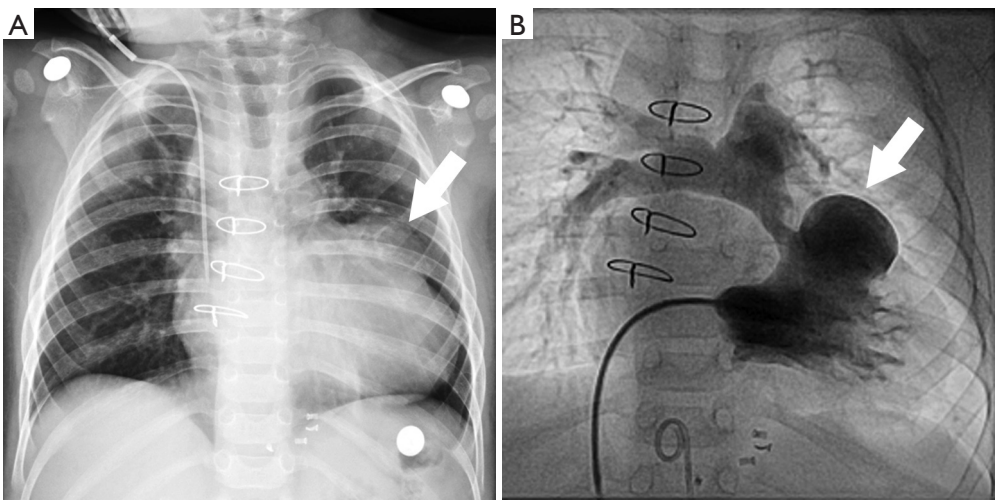

Figure 12 RVOT pseudoaneurysm in a 15-month-old girl status post TOF repair. (A) Chest radiograph shows an abnormal bulge on the lateral aspect of the cardiac silhouette (arrow); (B) digital subtraction angiography with right ventricular injection confirms pseudoaneurysm of the RVOT (arrow) with severe pulmonary artery stenosis. TOF, tetralogy of Fallot; RVOT, right ventricular outflow tract.

obstruction and pulmonary artery stenosis (15%incidence), are also common and require imaging for appropriate diagnosis and treatment (28). Both CTA and MRI are very useful in the follow-up of these patients providing detail anatomic (CTA) and functional information (MRI) of the heart and great vessels (29-31) (*Figures 11*,*12*).

Central or peripheral pulmonary artery branch stenosis is also common in patients with TOF, or may develop as a postoperative complication of arterial switch procedure (Jatene arterial switch), which is the surgical procedure of choice for neonates with D-transposition of the great arteries. Similarly CTA and MRI are good imaging modalities for the diagnosis and assessment of this complication (32) (*Figures 13*).

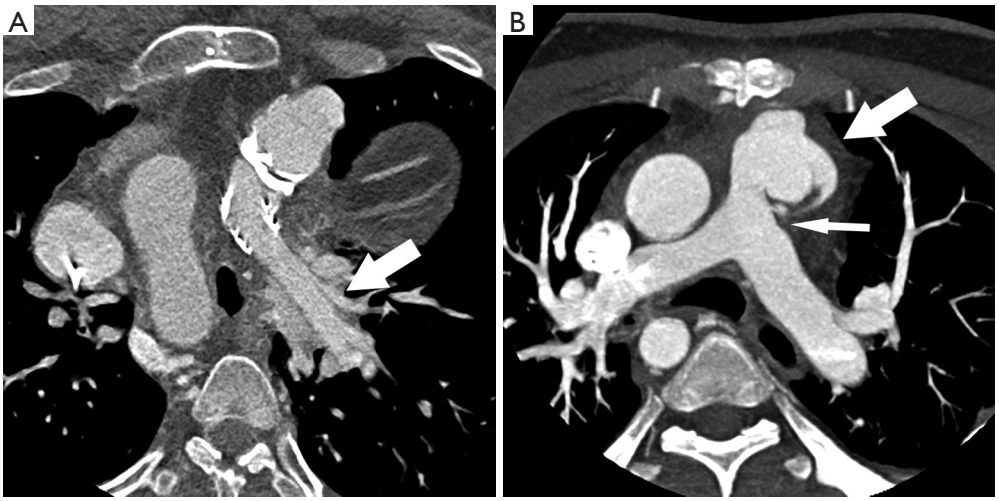

Figure 13 Pulmonary artery stenosis in two different patients, status post repaired TOF. (A) A 22-year-old male, contrast enhanced CT shows long segment stenosis of the left pulmonary artery with surgical changes in the pulmonary trunk and proximal left pulmonary artery (arrow); (B) a 22-year-old male, contrast enhanced CT shows a pseudoaneurysm of the pulmonary trunk (large arrow) with distal stenosis (small arrow). TOF, tetralogy of Fallot.

Conclusions

The evaluation of vascular complications in the postoperative patient often requires a rapid and reliable imaging modality for the assessment of these potentially life-threatening conditions. Multidetector CT (MDCT) has become established as an invaluable imaging option—often the preferred imaging modality and best option—due to its ability to directly visualize the entire cardiothoracic vasculature, airways, lung parenchyma and mediastinum with good temporal and spatial resolution.

Acknowledgements

None.

Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

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