



Peer-Reviewed Review Article

Total Artificial Heart Imaging and Complications: a Pictorial Review

Carrie K. Gomez* and Susan Hobbs

Department of Imaging Sciences, University of Rochester, Rochester, NY

* Corresponding author: carrie_gomez@urmc.rochester.edu

Abstract

Heart failure is a serious cause of morbidity and mortality with many patients ultimately requiring heart transplantation. As the rate of heart failure continues to increase and surpass the number of available donor hearts, the need for cardiac assist devices is rapidly rising. The total artificial heart has emerged as an effective therapeutic option in patients with end-stage biventricular heart failure who are awaiting orthotopic heart transplantation. The TAH replaces the patient's native ventricle and valves and has one of the highest bridge to transplant rates. Many complications have been associated with the TAH including infections, bleeding, thrombosis, device malfunction, neurological complications among others. CT is the imaging modality of choice that aids in early recognition of TAH complications.

The aim of this review is to illustrate the TAH components and CT based imaging of TAH complications. Recognition of TAH complications can help to plan for early intervention and therefore improve patient's survival.

Key words: total artificial heart, Syncardia, infection, thrombosis, complications

Introduction

Heart failure is recognized as a major health problem [1-3]. According to the American Heart Association (AHA), there are approximately 5.8 million of Americans with heart failure and 500,000 new cases of heart failure are diagnosed each year [1, 2]. The prognosis of heart failure is poor with estimates rates of survival of 50% at 5 years and 10% at 10 years [4]. Orthotopic heart transplantation has been the definitive form of therapy for patients with end-stage biventricular heart failure. However, only 2200 donor hearts are available each year [5]. This discrepancy between the clinical need for donor hearts and the available supply has led to the development of devices such as the total artificial heart (TAH) [1-3, 5, 6].

Citation: Gomez, C et al (2016)
"Total Artificial Heart Imaging and
Complications: a Pictorial
Review"

The VAD Journal, 2. doi:
<http://dx.doi.org/10.13023/VAD.2016.18>

Editor-in-Chief: Maya Guglin,
University of Kentucky

Received: July 9, 2016

Accepted: August 16, 2016

Published: August 16, 2016

© 2016 The Author(s). This is an open access article published under the terms of the [Creative Commons Attribution-NonCommercial 4.0 International License](https://creativecommons.org/licenses/by-nc/4.0/) (<https://creativecommons.org/licenses/by-nc/4.0/>), which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided that the original author(s) and the publication source are credited.

Funding: Not applicable

Competing interests: Not applicable



The Jarvik 7 was the first attempt to artificial implantable hearts, but the recipients suffered major complications [7]. The Abiocr TAH was first implanted in humans in 2001 in a destination therapy trial of fourteen patients who received this device but none of the patients survived in this trial. The Abiocr device has been unavailable since then [6].

The Syncardia total artificial heart (TAH), formerly CardioWest, is the only implantable device approved by the United States Food and Drug Administration (FDA) for patients with severe biventricular heart failure [5-12]. Flow rates in the Syncardia device are normally 7-9L/min and there is very little turbulence within the device [13].

The goal of the total artificial heart is to bridge patients to heart transplantation, replace failing ventricles, malfunctioning valves and eliminate arrhythmias [5-16].

Other mechanical circulatory assist devices include short-term cardiac assist devices such as the Tandem-Heart percutaneous assist device (Cardiac Assist) and the Impella [7,17]. The Tandem-Heart is an extracorporeal continuous flow centrifugal assist device used to treat postcardiotomy shock and as to bridge to heart transplantation [7,17]. The Impella device is used as a minimally invasive option for patients requiring temporary cardiac support for acute heart failure, cardiogenic shock or patients undergoing high risk percutaneous interventions to avoid hemodynamic instability [18].

One of the mainstays for mechanical support for patients with end-stage ventricular failure are the ventricular assist devices (VADs). These can be used to assist in the function of a single ventricle (RVADs: right ventricular assist devices, LVADs: Left ventricular assist devices) or in biventricular failure (BiVAD: biventricular assist devices) [17-19].

The LVADs are used as bridge to heart transplantation, as a bridge to myocardial recovery and as destination therapy in patients who are not candidates for heart transplant. There are two main categories of LVADs : earlier generation or pulsatile flow devices (HeartMateXVE) and late generation or continuous flow devices (Jarvik 2000, VentrAssist, HeartMate II, Heartware and HeartMate III) [18-20]. Continuous devices provide an advantage to their first generation counterpart including smaller size, less noise and increased durability and reliability (Table 1) [18].

Of all these devices, the total artificial heart (Syncardia) has one of the highest bridge to transplant rate. It is reported that 79% of patients with the Syncardia TAH survive to orthotopic heart transplant [5,11,13]. In a study conducted by Copeland et al. survival after Syncardia transplantation at 1, 5 and 10 years was reported to be 76.8%, 60.5% and 41.2% respectively [21].

There have been more than 1250 implants of the total artificial heart accounting for more than 350 patient-years of life with this device [5].

Torregrossa et al. have described the use of Syncardia TAH as a destination therapy in patients not eligible for heart transplantation [16].

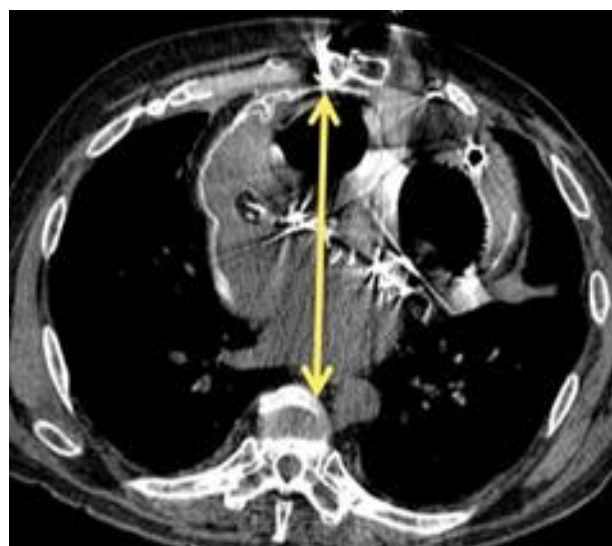


	HeartMateXVE	Jarvik	HeartMatell	VentrAssist	Heartware	HeartMate 3
Type of pump	<ul style="list-style-type: none"> Pulsatile, titanium/ pusher plate Intra-abdominal LUQ/pre-peritoneal pocket 	<ul style="list-style-type: none"> Continuous flow, axial flow pump Implanted within the left ventricle 	<ul style="list-style-type: none"> Continuous flow, axial pump 	<ul style="list-style-type: none"> Continuous flow, centrifugal pump 	<ul style="list-style-type: none"> Continuous pump, centrifugal flow Implanted in pericardial space 	<ul style="list-style-type: none"> Pump smaller Implanted in pericardial space Centrifugal flow Magnetically levitated
Inflow cannula	Present, metal	Absent	Present	Present, silicon Long, rigid.	Integrated inflow cannula	Absent
Outflow cannula	To ascending aorta	To ascending or descending aorta	To ascending or descending aorta	To ascending aorta	To ascending aorta	To ascending aorta
Bend relief-inflow	Present	Absent	Present	Absent, inflow nonbendable 90 angle	Absent	Absent, bend relief for outflow
Other features	<ul style="list-style-type: none"> Large size, Body surface 1.5 m² 	<ul style="list-style-type: none"> 5-7L/min Rotation speed: 8,000-12,000 rpm 	<ul style="list-style-type: none"> 10L/min Rotation speed: 6,000-15,000 rpm 	<ul style="list-style-type: none"> Coated with diamond-like carbon: less thrombosis 	<ul style="list-style-type: none"> 10L/min Hybrid magnetic/hydrodynamic impeller suspension 	<ul style="list-style-type: none"> 10L/min Artificial pulse ability Modular driveline, clinical trial
Anticoagulation	Yes	Yes	Yes	Yes	Yes	Yes

Table 1: First and second generation left ventricular assist devices (LVADs)

Total Artificial Heart Indications and Contraindications

Candidates for total artificial heart are those with end-stage biventricular heart failure (New York Association functional class IV) who are eligible to receive orthotopic heart transplant. The body surface area must be at least 1.7m² and the distance between the posterior cortex of the sternum and anterior cortex of T10



vertebra should be at least 10cm (Figure 1) in order to accommodate the device [5,12,13]. Contraindications to TAH include transplant ineligibility, left heart failure in absence of right-heart failure, high risk for anticoagulation, and a small thoracic cavity unsuitable to fit the device [5,12,13]. Other exclusion criteria are: concomitant use of another vascular assist device and pulmonary vascular resistance of equal or greater than 8 Wood units [13].

Figure 1. The distance between the posterior cortex of the sternum and the anterior cortex of T10 should be at least 10 cm to accommodate the TAH.



Total Artificial Heart Components

The TAH consists of two artificial ventricles and four mechanical valves: two 27 mm inflow valves (atrioventricular valves) and two 25 mm outflow valves (aortic and pulmonic valves).

Each of the two artificial ventricles (right and left) house four flexible polyurethane diaphragms including a seamless blood contacting diaphragm, two intermediate diaphragms and an air diaphragm [5,6,12].

The artificial left ventricle is connected to the native left atrium by a left atrial flexible polyurethane inflow connector (Quickconnect) and to the native aorta by an aortic outflow cannula. Similarly, the artificial right ventricle is connected to the native right atrium by a right atrial flexible polyurethane inflow connector (Quickconnect) and to the native pulmonary artery by a pulmonary artery outflow cannula (Figure 2) [5,6,12]. The two artificial ventricles housing flexible polyurethane diaphragms are connected to two pneumatic drivelines. This design allows the ventricles to fill and then eject blood when compressed by air from an external console [5,12].

There are two types of console: a standard bedside console (Big Blue) and a portable driver system (Freedom Driver) [5]. The console provides monitoring of data such as device rate, stroke volume and cardiac output as well as patient-related alarms. Each artificial ventricle of the TAH delivers a maximum stroke volume of 70mL [5,6].

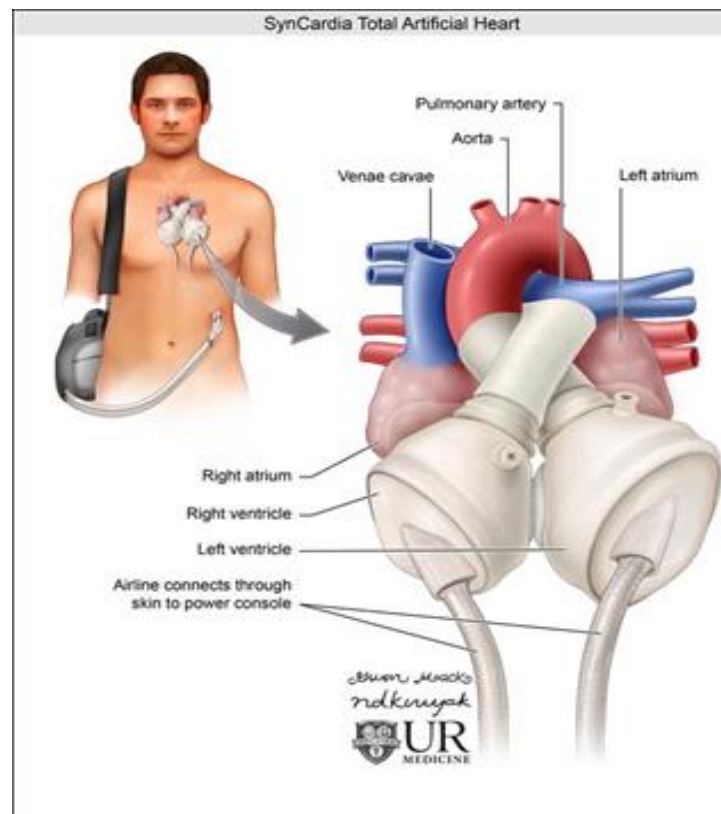


Figure 2. SynCardia TAH components.

Total Artificial Heart



Implantation

The native ventricles, ventral surface of the atria, the proximal ascending aorta and pulmonary artery are surgically removed. Inflow right and left atrial connectors are attached to the native atrial remnants. Likewise, aortic and pulmonic outflow connectors are anastomosed with the native thoracic aorta and pulmonary artery. The artificial ventricles and pneumatic drivelines are then installed (Figure 3) [5,12].

The native pericardial sac is left open and the TAH implant is enfolded polytetrafluoroethylene that functions as neopericardium which favors future explantation. A tissue expander (Mentor walled silicone filled with saline) is placed between the artificial and left ventricle to avoid contraction of the surgical cavity and to facilitate explantation for orthotopic heart transplant [5].

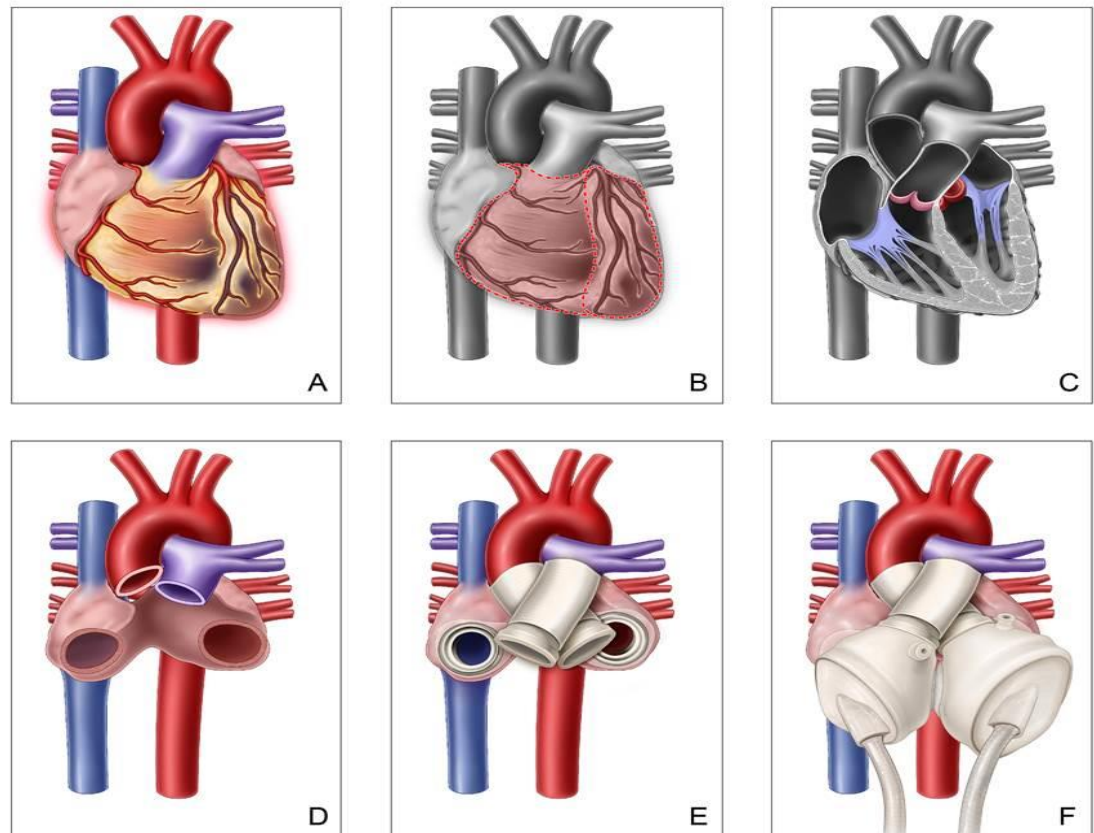


Figure 3. Steps for total artificial heart implantation. A. Failing heart end-stage biventricular failure. B. Both failing native ventricles are surgically removed. C. Excision of the atrioventricular, pulmonic and aortic valves. D. Complete removal of the ventricular chambers, ventral atria and proximal pulmonary and aorta. E. Right and left atrial inflow connectors (Quickconnect) and outflow pulmonary and aortic conduits are inserted. F. The two artificial ventricles with pneumatic drivelines are implanted.



Total Artificial Heart Imaging Modalities

Chest radiograph is utilized after TAH implantation to monitor the device and to evaluate for potential complications. The TAH mechanical valves are not situated in their expected anatomic location on a plain chest radiograph. Moreover, the air-filled ventricles seen in systole (diaphragm move inwards to empty the ventricles) can be mistaken with mediastinal air collections creating potential diagnostic errors of interpretation [5].

Echocardiogram, in particular transesophageal echocardiography (TEE) can be used pre-operatively and intraoperatively to establish a baseline to identify future valve malfunctions [22]. However, some of the limitation of TEE is the challenging evaluation of the aortic valves due to poor transgastric windows and acoustic shadowing of the device. Also, reverberation and ring artifacts generated from the TAH mechanical valves can also hinder imaging of the ventricular chambers [22].

CT is the modality of choice to assess the TAH (Figure 4) [5]. Contrast can be administered in patients who can tolerate the contrast media and those with adequate renal function. For patients who cannot receive contrast, an unenhanced CT can be performed [5]. Prospective or retrospective cardiac gating is not feasible given that there is no recordable ECG (no QRS complex) [5]. MRI is contraindicated due to unsafety which precludes MRI evaluation (Table 2).

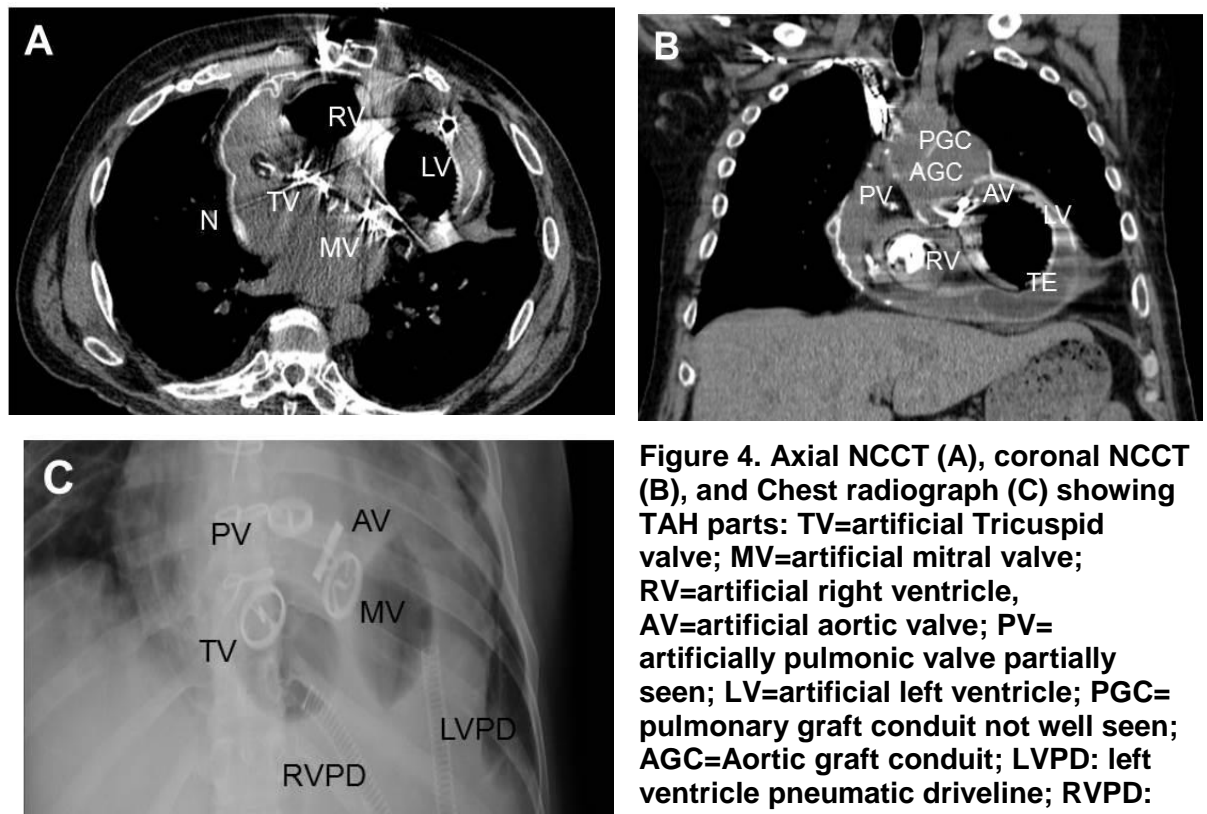


Figure 4. Axial NCCT (A), coronal NCCT (B), and Chest radiograph (C) showing TAH parts: TV=artificial Tricuspid valve; MV=artificial mitral valve; RV=artificial right ventricle, AV=artificial aortic valve; PV=artificially pulmonic valve partially seen; LV=artificial left ventricle; PGC= pulmonary graft conduit not well seen; AGC=Aortic graft conduit; LVPD: left ventricle pneumatic driveline; RVPD: right ventricle pneumatic driveline; N= neopericardium; TE=tissue expander.



	Uses	Pitfalls
Chest radiograph	<ul style="list-style-type: none"> -Non anatomic position of valves -Used immediately after TAH implantation. -Monitor for complications 	<ul style="list-style-type: none"> - Air filled ventricles are seen in systole (diaphragms move inward to empty ventricles). - Do not mistake air filled ventricles with mediastinal air collections.
CT	<ul style="list-style-type: none"> - Help recognize normal appearance of the total artificial heart and its components. 	Prospective or retrospective cardiac gating is not feasible (no recordable ECG)
MRI	Contraindicated	Contraindicated

Table 2. Imaging modalities of the TAH.

Therefore, it is important to become familiar with the normal CT appearance of the TAH and its components as well as to recognize its complications.

Total Artificial Heart Complications:

TAH Infectious complications

Infectious complications are one of the most common adverse events in TAH recipients (53-62%) and may involve the mediastinum, pericardium, driveline and respiratory tract (Figures 5-11) [5,14,16].

Torregrossa et al. reported driveline infections in 27 % of patients [16] and Copeland described postoperative infections in 77% of patients [14].

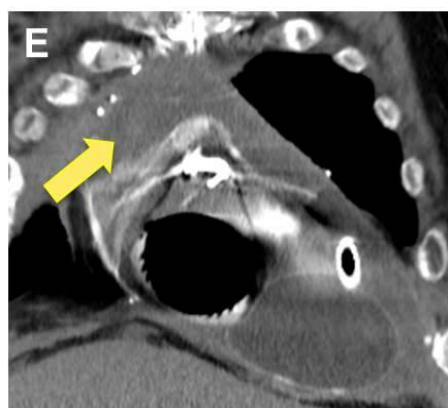
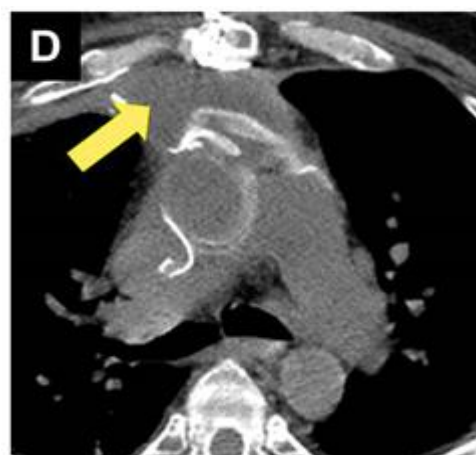
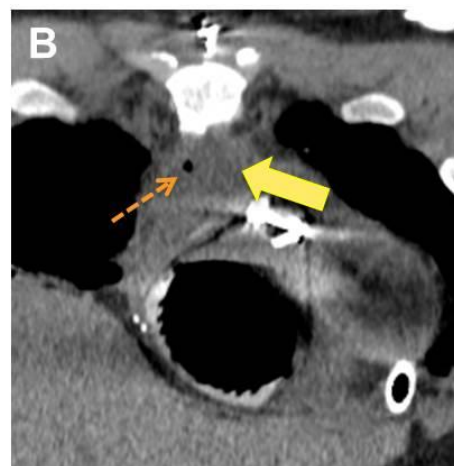
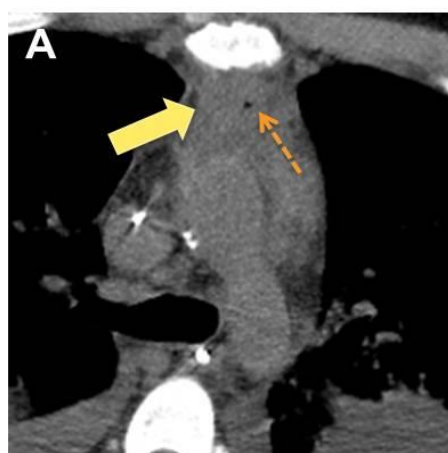


Figure 5. Infectious complications; Mediastinal abscess. A) Axial; B) coronal and C) sagittal NCCT show fluid collection in the anterior mediastinum (thick arrow) with flecks of air (thin arrow) indicating abscess. D) Axial and E) NCCT portray fluid collection in the anterior mediastinum (thick arrow) in a different patient.

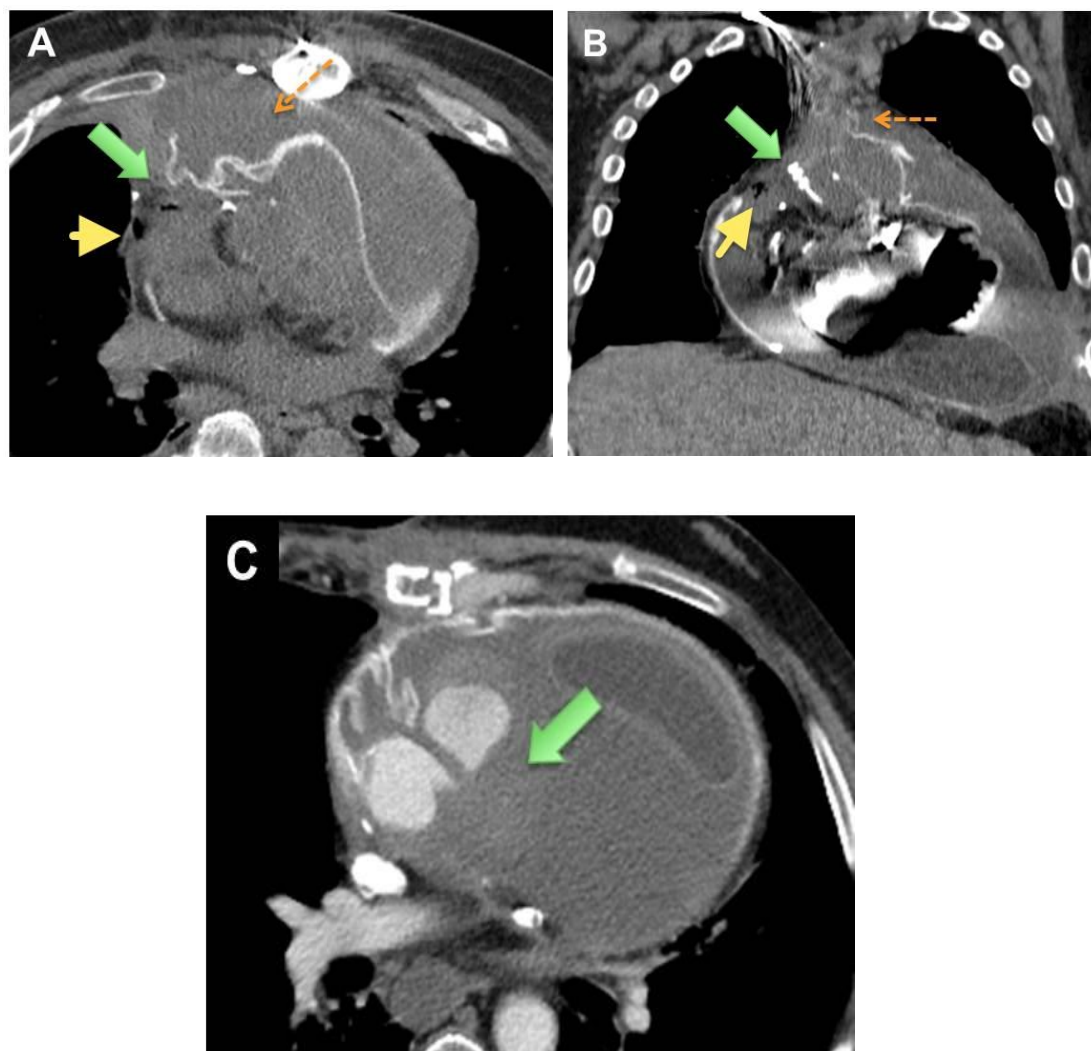


Figure 6. Infectious complications; neopericardium/ intra-cardiac infection. A) Axial and B) coronal NCCT depict mediastinal collection (dashed thin arrow) with associated disruption of the neo-pericardium (thick arrow) and flecks of air (short arrow) caused by pericardial bacterial infection. C) Ill-defined hyperdensity in the neopericardial fluid (thick arrow) proven to be fungal infection.

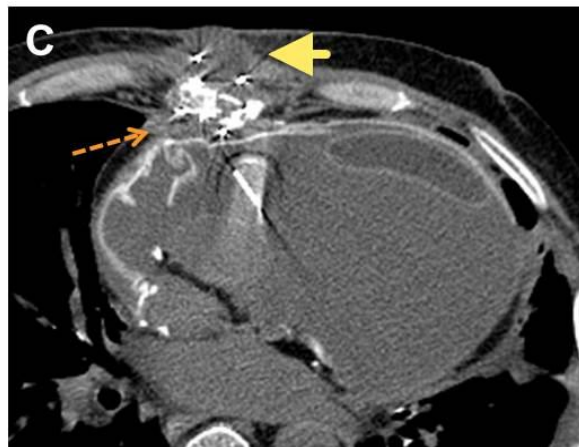


Figure 7 Infectious complications; superficial and retrosternal abscess. A) Axial and B) Axial NCCT depicts infiltrative changes overlying the sternotomy wires (thick arrow). C) Axial NCCT performed 2 weeks later shows a fluid collection superficial to the sternotomy wires (short arrow) and in the retrosternal space (dashed arrow) in the same patient consistent with abscess.

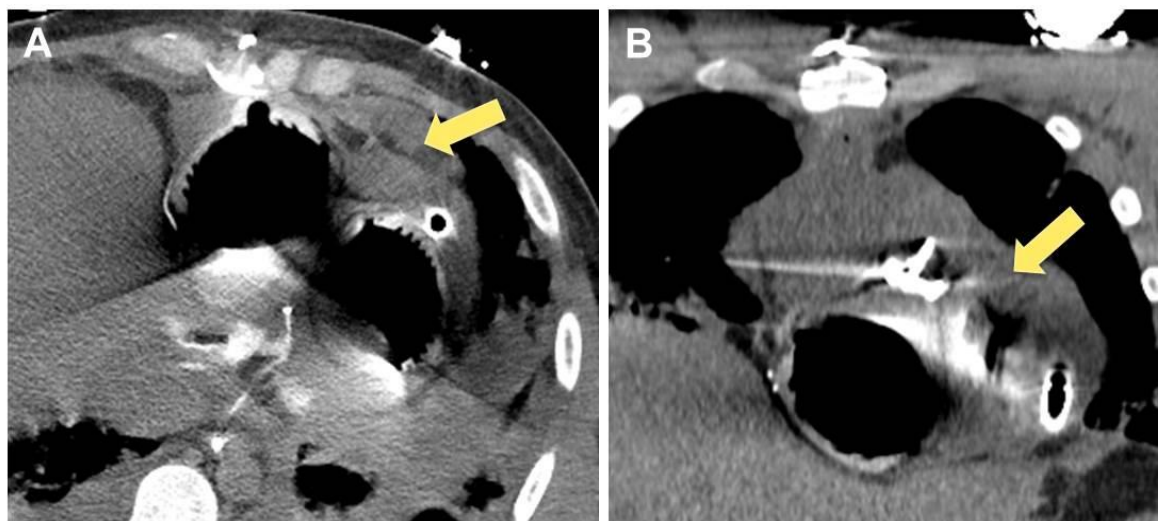


Figure 8. Infectious complications; infected pericardial fluid. A) Axial and B) coronal NCCT demonstrates a fluid collection (thick arrow) around the neopericardium proven to be infected.

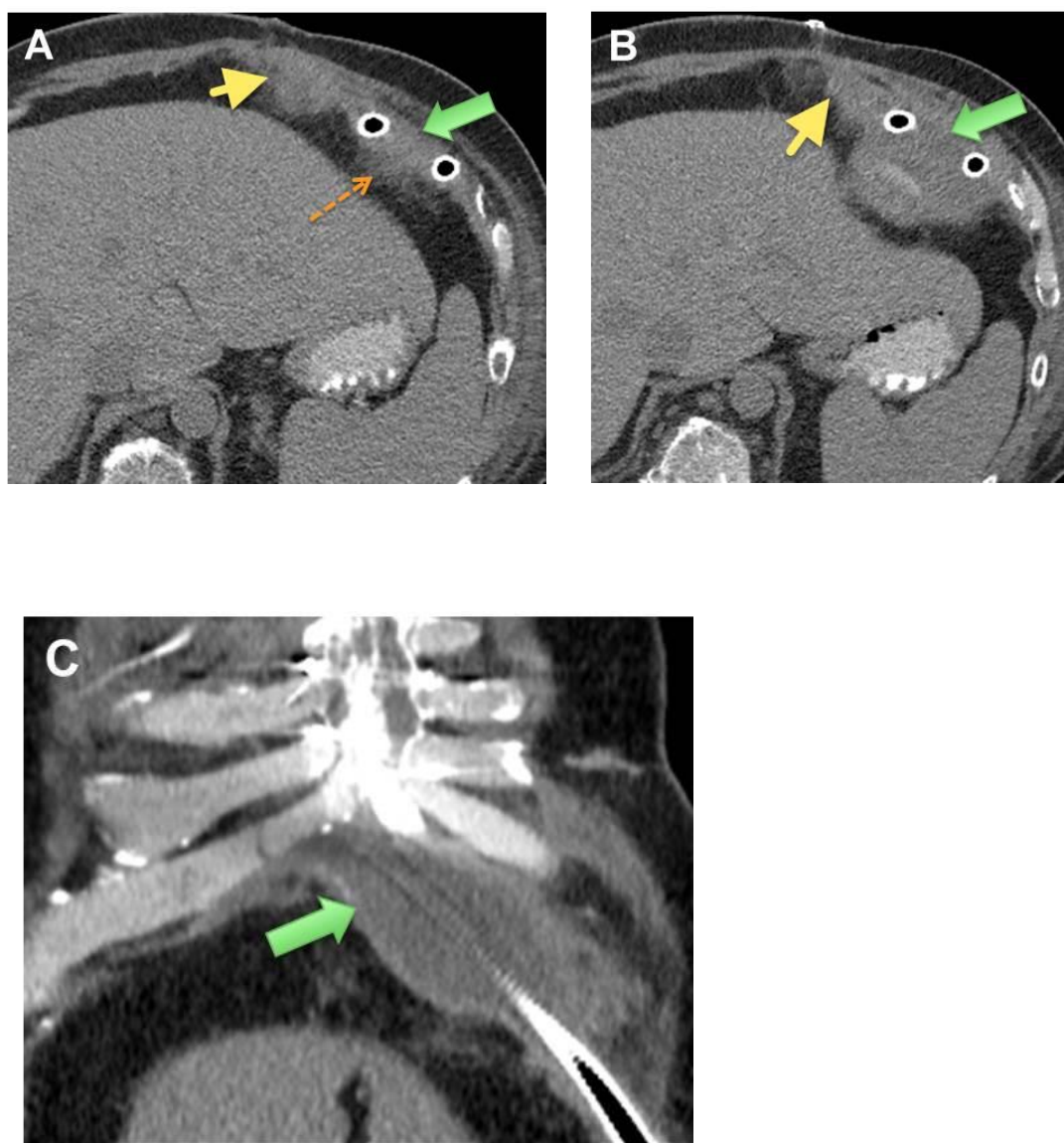


Figure 9. Infectious complication involving the pneumatic drivelines. A) Axial B) Axial and C) coronal NCCT depicts fluid collection (thick arrow) and stranding (thin dashed arrow) around the pneumatic drivelines with extension into the preperitoneal space (short arrow).

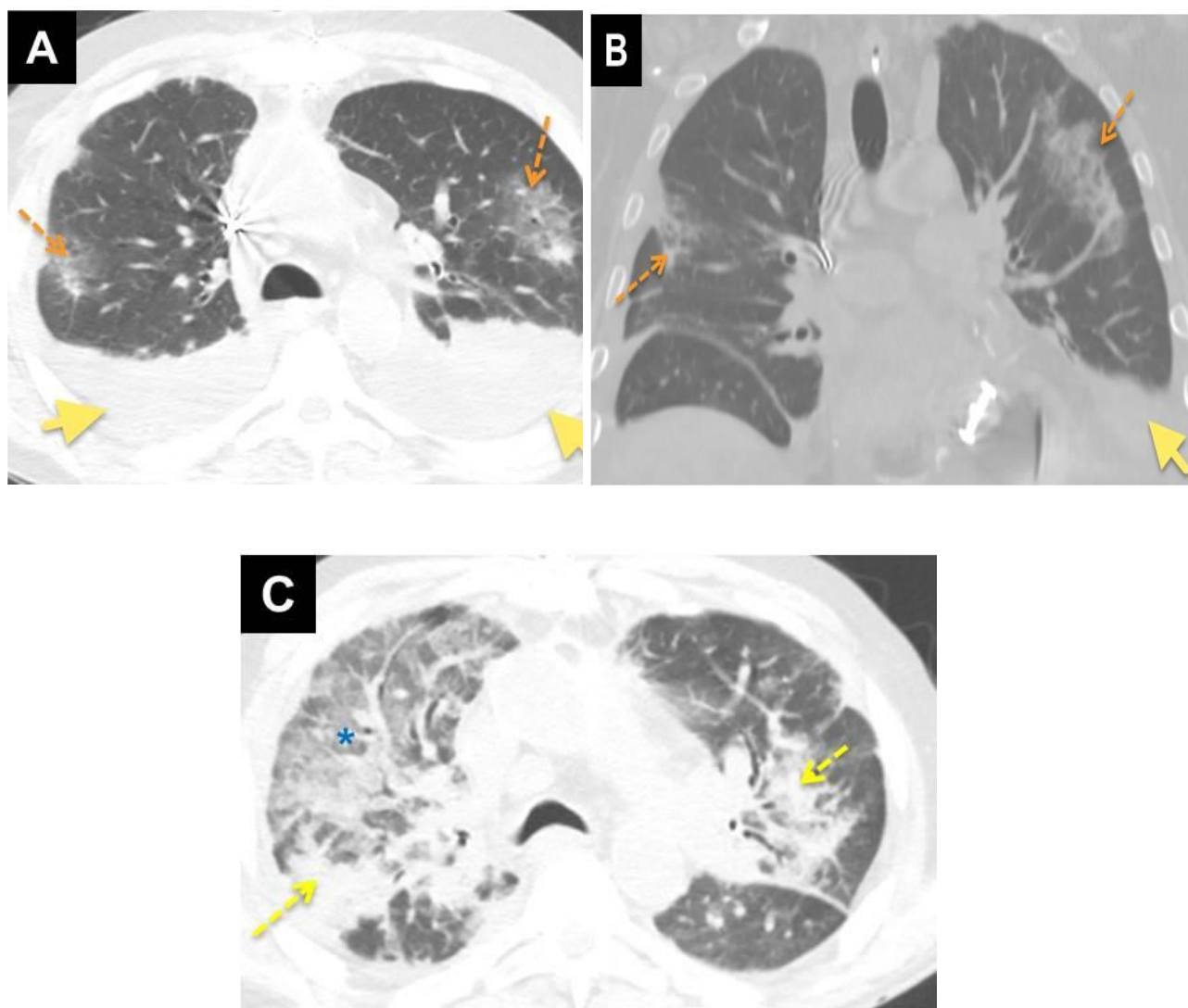


Figure 10. Infectious complications; multifocal pneumonia. A) Axial and B) sagittal NCCT depicts patchy ground-glass opacities (dashed orange arrows) and pleural effusions (short arrow) in this patient with multifocal pneumonia. C) Axial NCCT shows patchy airspace opacities bilaterally (dashed yellow arrows) representing multifocal pneumonia. Also, there are associated diffuse ground-glass opacities (asterisk) consistent with overlying pulmonary edema.

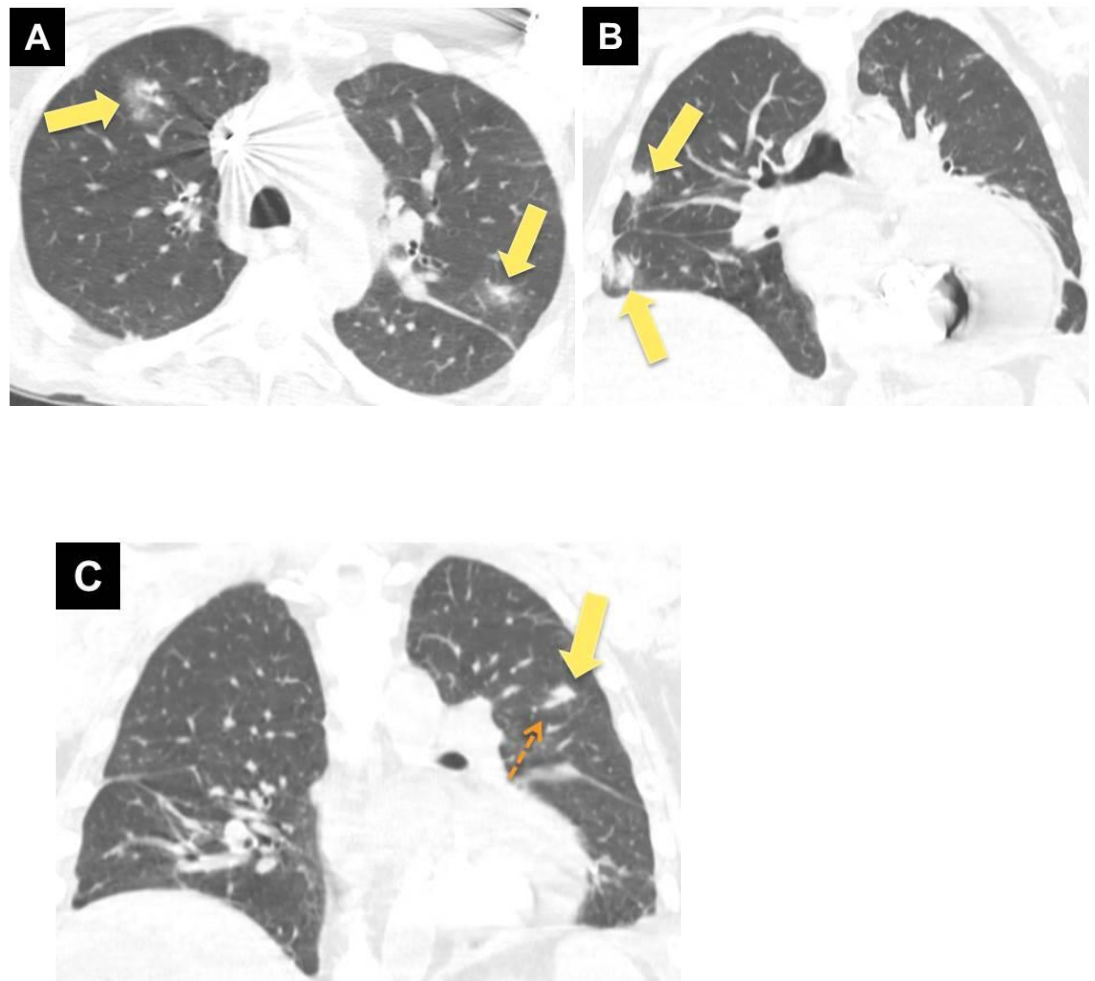


Figure 11. Infectious complications; septic emboli. A) Axial and B) sagittal NCCT portrays nodular opacities (thick arrow) in the bilateral lungs consistent with septic emboli. C) Coronal NCCT shows feeding vessel sign (dashed arrow) in the same patient consistent with hematogeneous spread of infection.

TAH Hematoma/Bleeding

Postoperative bleeding occurred in 23% and 62% of TAH recipients in the studies conducted by Parker et. al and Copeland et.al respectively. The most common sites of bleeding are the mediastinum (hemomediastinum) and thorax (hemothorax) (Figures 12-16) [5,14]. Localized right atrial tamponade has been described [5,12]. Leprince et al. reported two cases in their study of 127 patients [23].

The use of anticoagulation can predispose to delayed extrathoracic hemorrhage including subarachnoid and retroperitoneal hemorrhage [24].

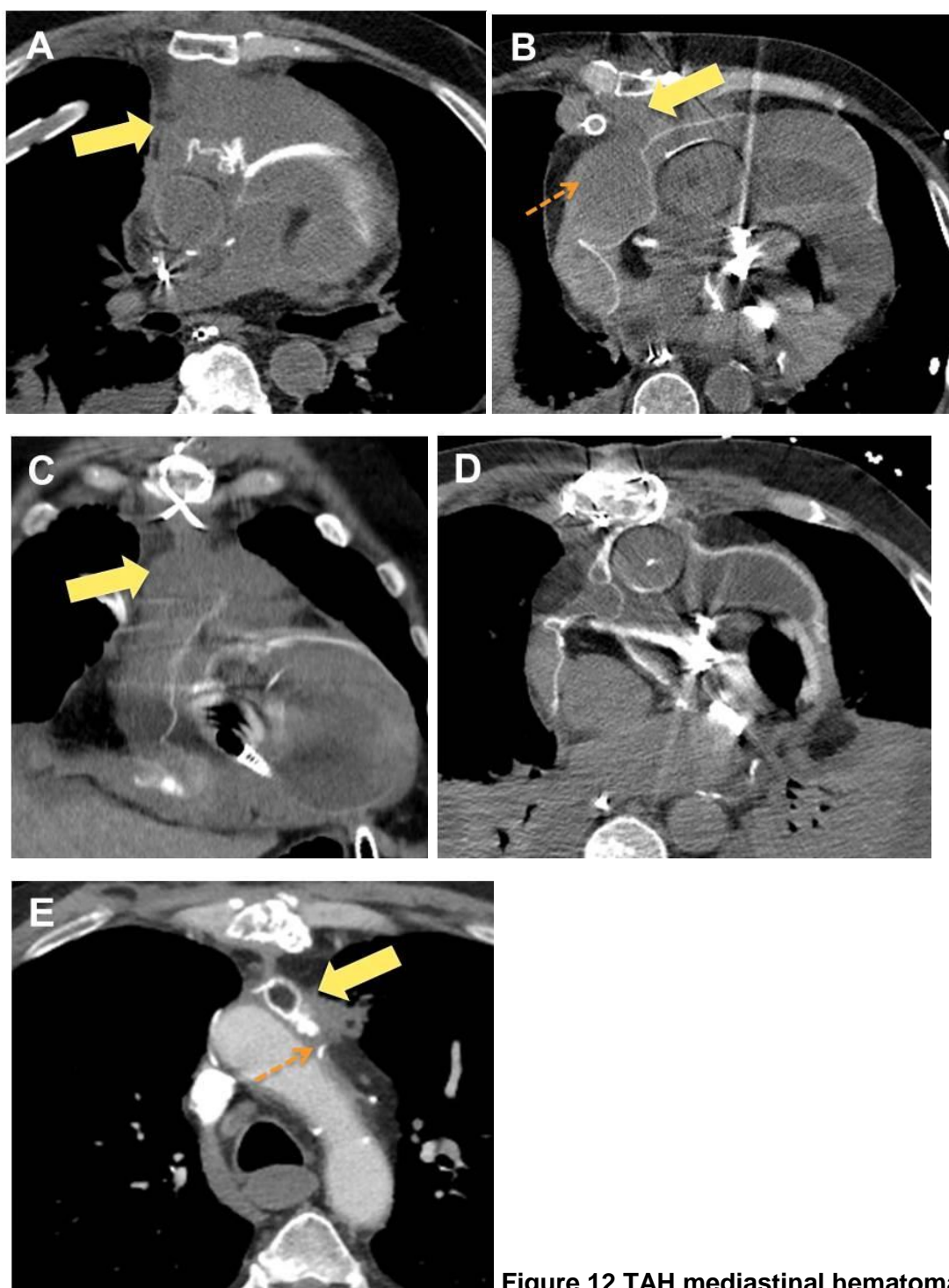


Figure 12 TAH mediastinal hematoma.
A) Axial, B) axial and C) coronal NCCT shows an anterior mediastinal hematoma (thick arrow) which compresses and causes deformity of the right cardiac chambers, predominantly of the right atrium (dashed arrow). D) Axial NCCT shows evacuation of hematoma. E) Small mediastinal hematoma (thick arrow) in a different patient with focus of suture dehiscence (short arrow).

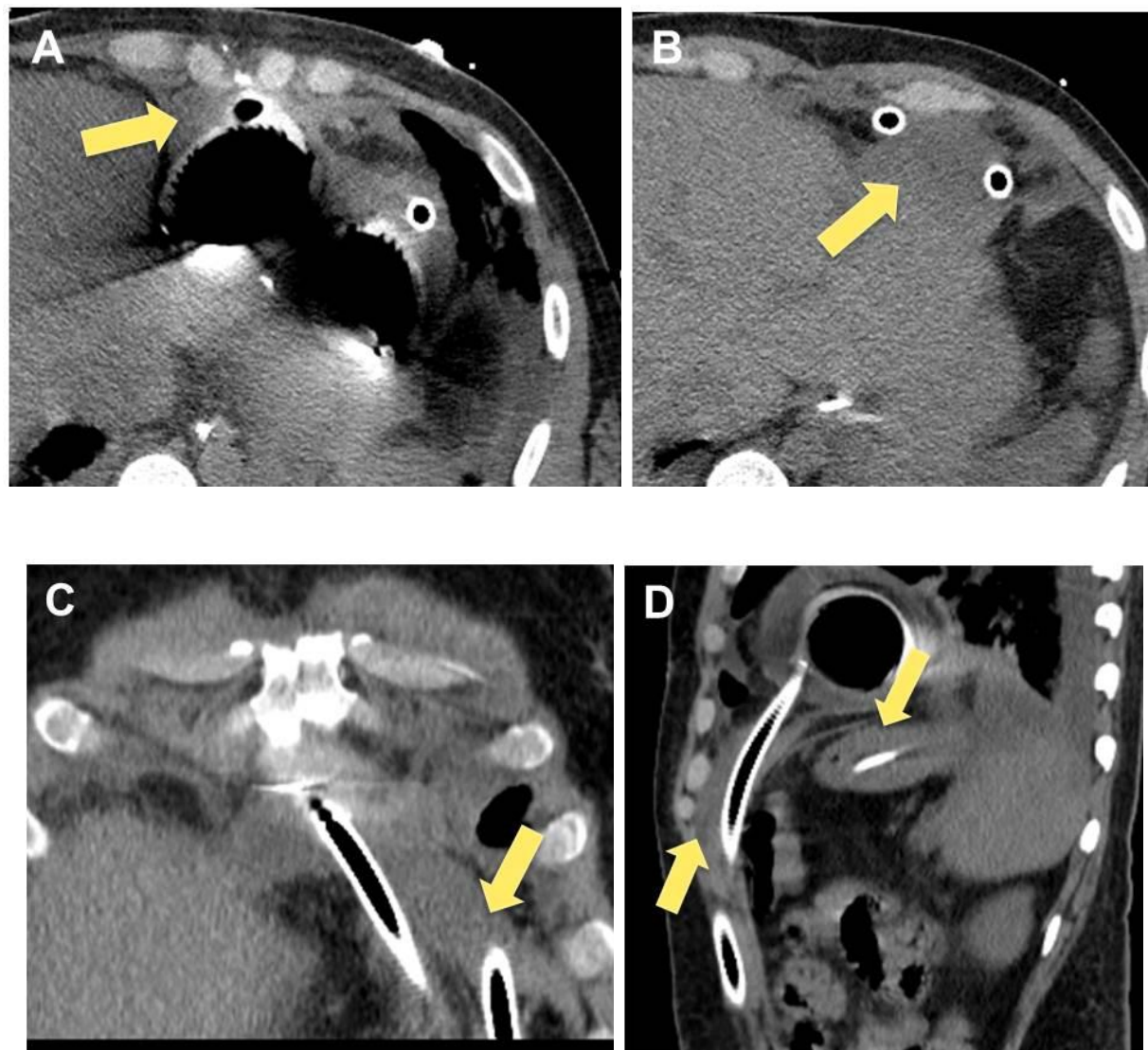


Figure 13. Hematoma around the pneumatic drivelines. A) Axial, B) axial ,C) coronal and D) sagittal NCCT depicts high density fluid surrounding the pneumatic drivelines (thick arrow) representing hematoma.

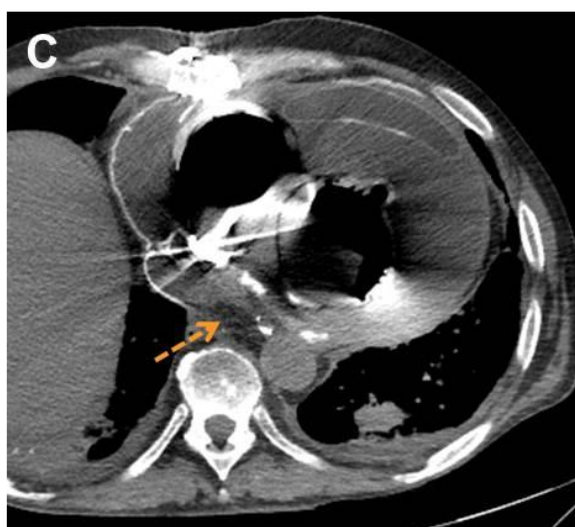
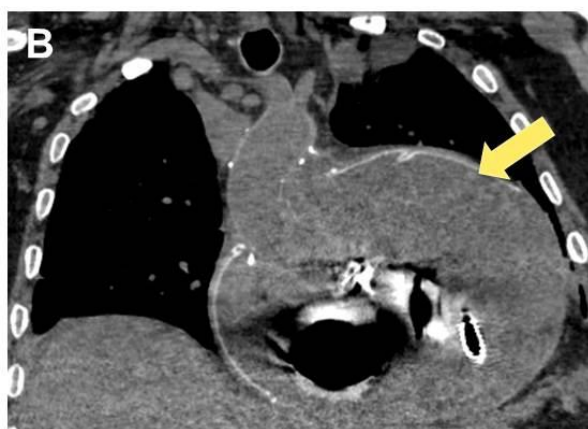
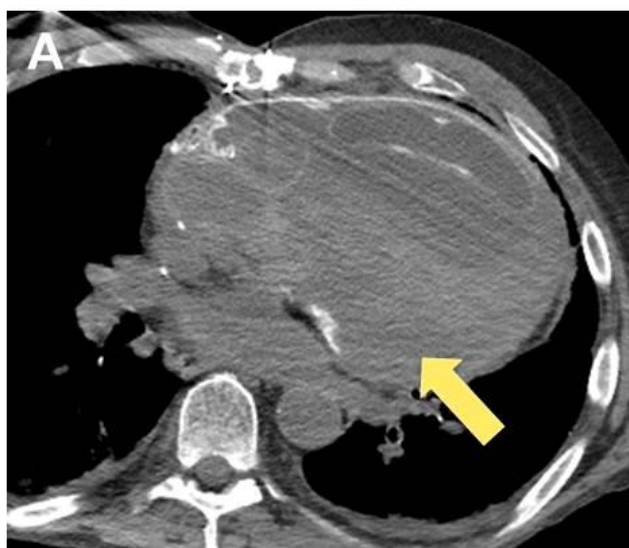


Figure 14. TAH Hemopericardium. A) Axial and B) coronal NCCT depicts high density fluid representing hemopericardium (thick arrow) with mass effect on the left cardiac chambers. C) NCCT shows suture line dehiscence in the right atrial chamber (thin arrow) which was repaired surgically.

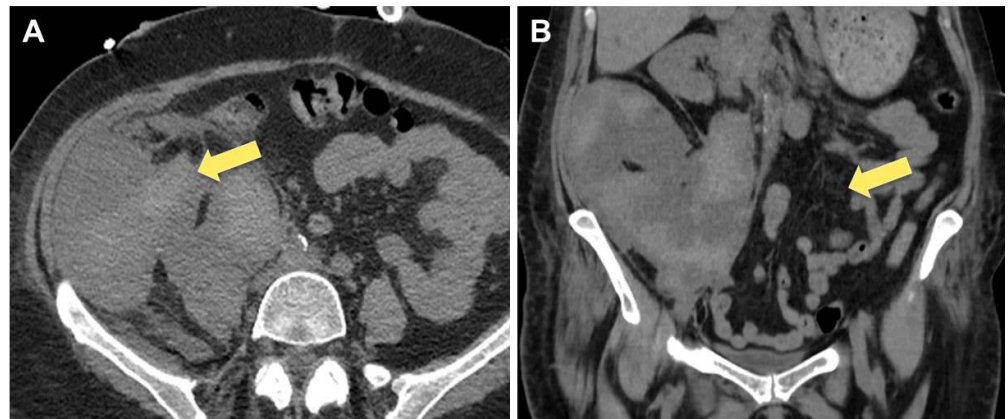


Figure 15. Retroperitoneal hematoma. A) Axial and B) coronal NCCT shows heterogeneous high density collection in the retroperitoneum (thick arrow) representing hematoma.

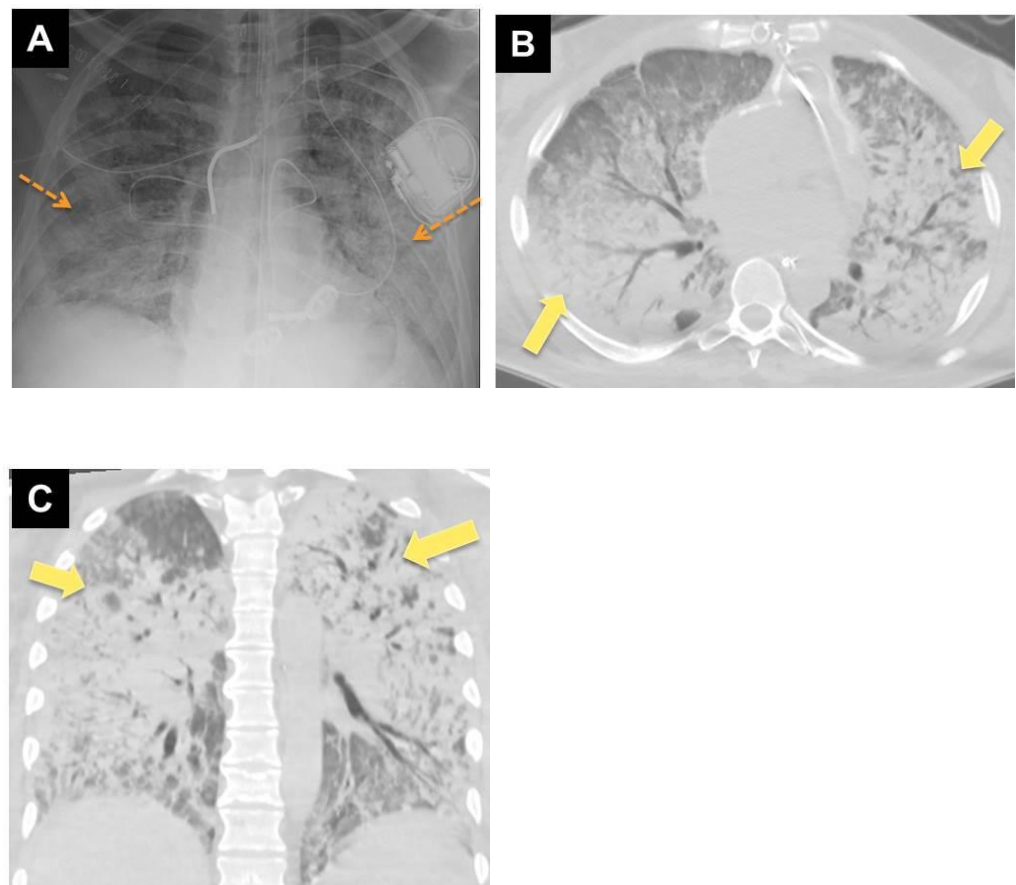


Figure 16 Pulmonary hemorrhages. A) Chest radiograph shows diffuse alveolar opacities (thin dashed arrow). B, C) Axial and coronal NCCT depicts confluent areas of consolidation and diffuse alveolar opacities (thick arrows) in the bilateral lungs proven to be pulmonary hemorrhage.



TAH Thrombosis/Infarct

The TAH has been associated with significant risk of thrombosis including the lung and solid organs (e.g. spleen, kidney) (Figures 17 and 18). Parker et al. reported 4.5 % cases of acute pulmonary embolism in TAH recipients [5]. Torregrossa et al. reported 19% of thromboembolic events in recipients 1 year post-implantation [16]. In patients with TAH, optimal anticoagulation includes both anticoagulant such as warfarin and antiplatelet therapy.

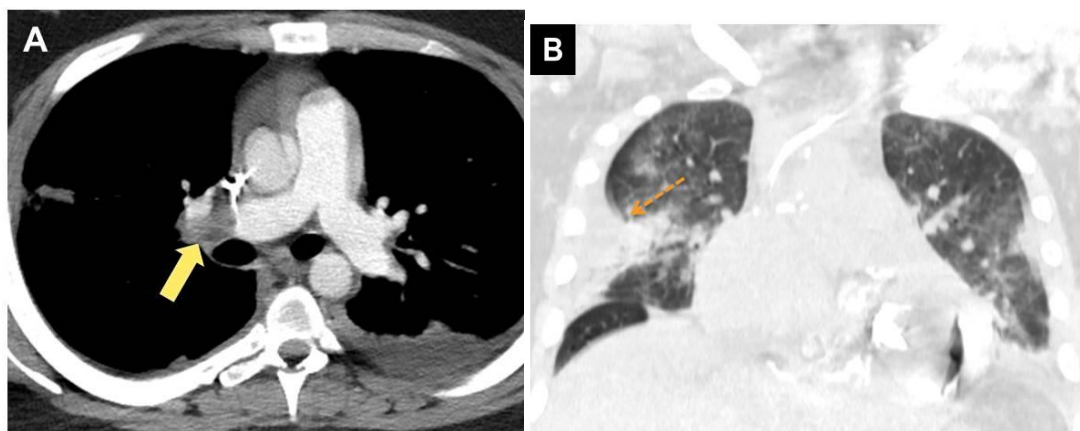


Figure 17. Pulmonary embolism/infarction. A) Axial contrast enhanced CT (CECT) shows pulmonary embolism (thick arrow) in the right main pulmonary artery extending into the interlobar artery. B) Coronal CECT shows wedge shape area of hyperattenuation in the right lung consistent with pulmonary infarct (dashed arrow).

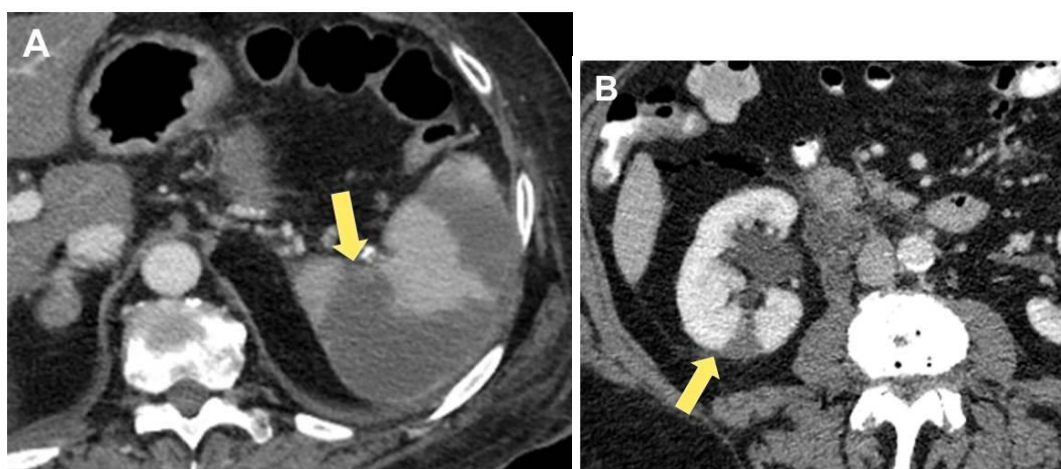


Figure 18 Solid organ infarcts. A. CECT depicts large splenic infarct (thick arrow). B. CECT portrays infarct in the right kidney (thick arrow).



TAH Device Malfunction

The surgical anastomosis between the device components including the great vessels and synthetic inflow atrial connectors and great vessel outflow connectors may become weak and break down. Surgical dehiscence require immediate repair. Other commonly encountered complication occurring with the drivelines are kinks and leaks [5].

TAH Neurologic Complications

Leprince et al. reported a low stroke rate in TAH recipient (0.2 events per patient per year) [23]. Kirsch et al. have reported 10% cases of stroke in a study conducted in 90 patients [25]. Subarachnoid hemorrhage also occurs in patient with TAH and is related to anticoagulation therapy (Figure 19) [5].

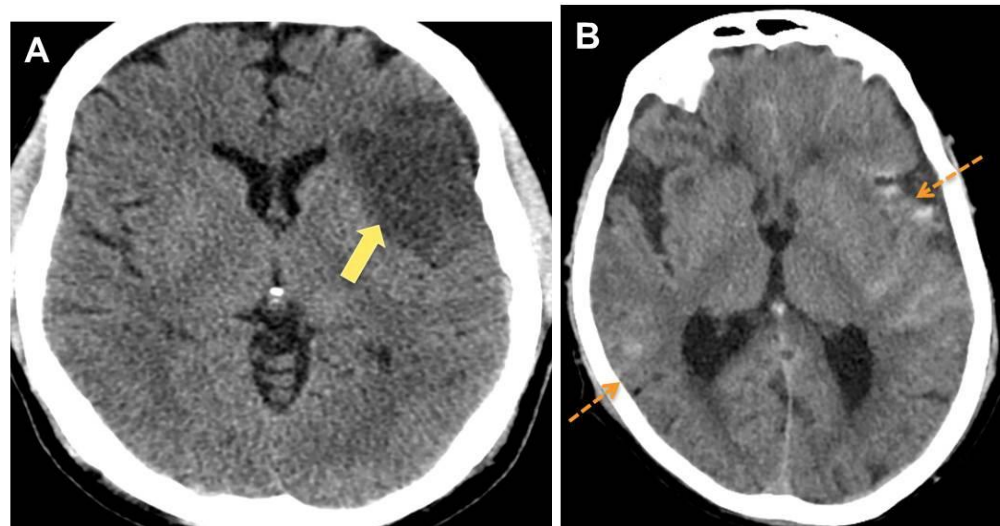


Figure 19. TAH neurologic complications. A) Non contrast head CT shows infarct in the left MCA territory (thick arrow). B) Non contrast CT shows subarachnoid hemorrhage (thin arrow) in the bilateral cerebral convexities.

Other complications seen with the TAH can be due to hypoperfusion and include mesenteric ischemia and bowel perforation (Figure 20).

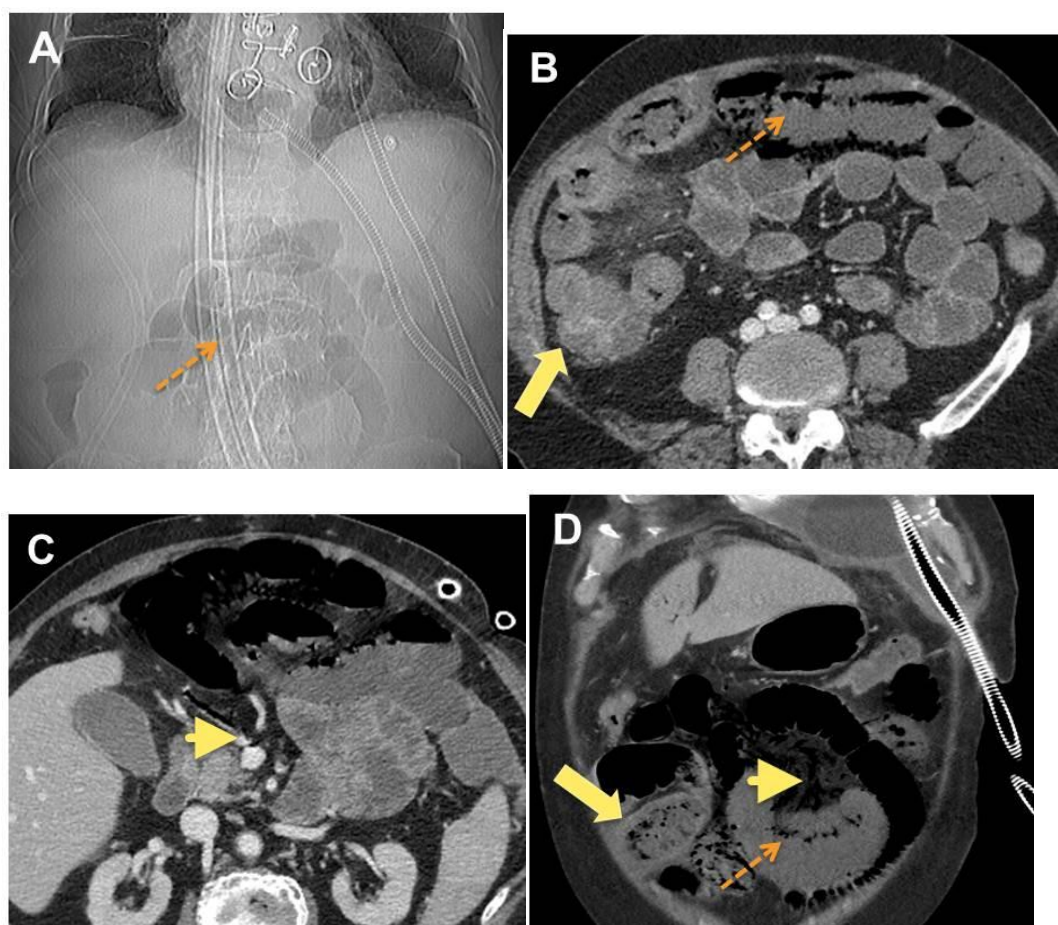


Figure 20 Bowel ischemia A) Abdominal radiograph portrays distension of small bowel loops (dashed arrow). B) CECT depicts bowel wall thickening (thick arrow), mesenteric stranding (thin arrow) and pneumatosis (thin dashed arrow) consistent with bowel ischemia. C) CECT in the same patient shows air in the superior mesenteric vein and its branches (short arrow). D) Sagittal CECT shows pneumatosis (thin dashed arrow), bowel wall thickening (thick arrow) and gas in the SMV and portal vein (short arrows)



Overload states (Figure 21) such as ascites, anasarca, pulmonary edema and effusions have also been described.

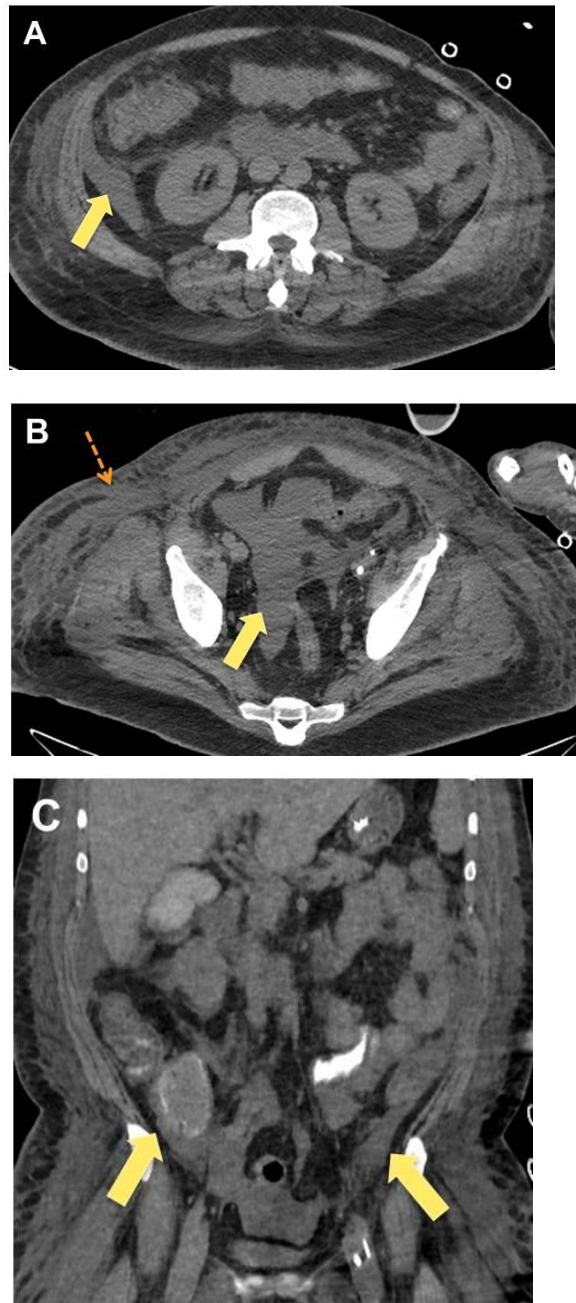


Figure 21 Ascites, anasarca. A) Axial B) axial and C) coronal NCCT shows fluid in the paracolic gutters and pelvic cavity (thick arrows) as well as subcutaneous edema (thin arrow) representing anasarca.



Conclusions

The Syncardia total artificial heart (TAH) is the only implantable device approved by the United States Food and Drug administration (FDA) for use in patients suffering from biventricular heart failure. It is a device used in patients with end-stage biventricular heart failure while waiting for orthotopic heart transplantation.

The most common complications on TAH recipients include infections, bleeding, thrombosis, liver failure, renal failure, and neurological events such as stroke and device malfunction. Infectious and hemorrhagic complications have been reported as major causes of death [5].

The role of CT imaging in the recognition of clinical outcomes associated with TAH complications is of paramount importance to guide clinicians in early therapeutic interventions to improve patient's survival ultimately yield longer survival times.

References

1. Blair JE, Huffman M, Shah SJ. Heart failure in North America. *Curr Card Rev* 2013; 9(2): 128-146
2. Bui AL, Horwich TB, Fonarow GC. Epidemiology and risk profile of heart failure. *Nat Rev Cardiol* 2011; 8(1): 30-41
3. Roger VL. The heart failure epidemic. *Int J Environ Res Public Health* 2010; 7:1807-1830.
4. Sharma V, Deo SV, Stulak JM, et al. Driveline infections in left ventricular assist devices: implications for destination therapy. *Ann Thorac Surg* 2012;94:1381-6
5. Parker MS, Fahrner LJ, Deuell BP et al. Total artificial heart implantation: clinical indications, expected postoperative imaging findings, and recognition of complications. *AJR* 2014; 202: W191-W201
6. Gerosa G, Scuri S, Iop L, Torregrossa G. Present and future perspectives on total artificial hearts. *Ann Cardiothorac Surg*. 2014; 3 (6): 595-602.
7. Hunter TB, Mihra S, Taljanovic MD et al. Medical devices of the chest. *Radiographics* 2004; 24:1725-1746.
8. Slepian MJ. The Syncardia temporary total artificial heart-evolving clinical role and future status. *US Cardiol* 2011(8):39-46
9. Slepian MJ, Smith RG, Copeland JG. The Syncardia CardioWest total artificial heart. Baughman K, Baumgartner WA (eds), *Treatment of advanced heart disease*. Chapter 26. New York, Taylor and Francis, 2006. 473-490.



10. Ryan TD, Jefferies JL, Zafar F, Lorts A, Morales DL. The evolving role of the total artificial heart in the management of end-stage congenital heart disease and adolescents. *ASAIO*. 2015; 61 (6): 8-14.
11. Syncardia systems website. Total artificial heart facts.
<http://www.syncardia.com/total-facts/total-artificial-heart-facts.html>.
Accessed November 20, 2015
12. Tangham M, Akkanti B, Natan S et al. Manifestations of atrial tamponade in a patient implanted with Syncardia total artificial heart. *The VAD Journal*.
13. Copeland J. Syncardia total artificial heart. Update and future. *Tex Heart Inst J* 2013; 40(5): 587-588.
14. Copeland JG, Smith RG, Arabia FA et al. Cardiac replacement with a total artificial heart as a bridge to transplantation. *N Eng J Med* 2004;351:859-867
15. Canter L, Howell EA, Morris R, Torigian DA. Chest radiographic and computed tomographic findings of the temporary total artificial heart (TAH-t). *J Thorac Imaging* 2008; 23 (4): 269-271
<http://dx.doi.org/10.13023/VAD.2015.16>
16. Torregrossa G, Morhuis M, Varghese R et al. Results with Syncardia total artificial heart beyond 1 year. *ASAIO* 2014; 60(6):626-34. doi: 10.1097/MAT.0000000000000132.
17. Sen A, Larson JS, Kashani K et al. Medical circulatory assist devices: a primer for critical care and emergency physicians. *Critical care* 2016; 20 (153): 1-20.
18. Amin ND, Little BP, Henry TS. Imaging of left ventricular assist devices. *Curr Radiol Rep* 2015; 3 (34):1-9.
19. Carr CM, Jacob J, Park SJ et al. CT of left ventricular assist devices. *Radiographics* 2010; 30:429-444.
20. Bourque K, Gernes DB, Loree II HM et al. HeartMate III: pump design for a centrifugal LVAD with a magnetically levitated rotor. *ASAIO Journal* 2001; 47; 401-405.
21. Copeland JG, Copeland H, Gustafson M et al. Experience with more than 100 total artificial heart implants. *J Thorac Cardiovasc Surg* 2012; 143 (3):727-734.
22. Mizuguchi KA, Padera RF, Kowalczyk A, Doran MN, Couper GS, Fox A. Transesophageal echocardiography imaging of the total artificial heart. *Echo Didactics* 2013; 117 (4): 780-784.
doi:10.1213/ANE.0b013e3182a0082f.



23. LePrince P, Bonnet N, Rama A et al. Bridge to transplantation with the Jarvik-7 (Cardiowest) total artificial heart: a single center experience. J Heart Lung Transplant 2003; 22: 1296-1303.
24. Ensor CR, Cahoon WD, Crouch MA et al. Antithrombotic therapy for the CardioWest temporary total artificial heart. Tex Heart Inst J 2010; 37: 149-158
25. Kirsch ME, Nguyen A, Mastroianni C et al. Syncardia temporary total artificial heart as a bridge to transplantation: current results at la Pitie hospital. Ann Thorac Surg 2013; 95(5): 1640-1646.