Learning objectives

1. Identify cardiac devices and know their functions.
2. Explain how cardiac anatomy can be used to localize cardiac devices and surgical changes.
3. Describe imaging findings often associated with cardiac surgery and the presence of cardiac devices.

Background

The chest X-ray is the most frequently performed radiologic study, and many patients receiving chest X-rays have had cardiac surgery or have an implantable cardiac device. The radiologist can identify the cardiac device and/or surgery by being familiar with cardiac anatomy and the radiographic imaging findings that are commonly associated with the given procedure. By appropriately identifying patients' prior cardiac procedures and by understanding indications for which they are performed, the radiologist improves the utility of the chest radiograph.

Imaging findings OR Procedure details

1. Valve replacement and repair:

Many surgical methods exist for treating valve dysfunction. Here, the radiographic appearance of prosthetic valves and annuloplasty will be demonstrated.

1.1. Prosthetic valves:

Divided into mechanical and bioprosthetic valves, each having different benefits and drawbacks.

Bioprosthetic valves (fig. 1):

- Last about 10-15 years but do not require anticoagulation (1).
- Typically chosen for older patients, those with a contraindication to anticoagulation, or for lower velocity inflow valves (mitral and tricuspid).

Mechanical valves (fig. 2):
• Can last over 20 years but require anticoagulation, and therefore their use is decreasing (2).
• Typically chosen for younger patients or high velocity outflow valves (aortic and pulmonic).
• Due to low mechanical failure rate and favorable hemodynamics, the St. Jude valve is the mainstay for mechanical valve replacement, although many others have been used in the past.

1.2. Annuloplasty rings (fig. 3):
• Facilitate the approximation of valve leaflets in the setting of dilation, usually to treat regurgitation (3).
• Native leaflets & chordae are normal.

I. Aortic, mitral, tricuspid, and pulmonic valves:
• Aortic and pulmonic valves are outflow valves:
  • Smaller diameter and tolerate more inertia-have typically been replaced with mechanical valves.
• Mitral and tricuspid valves are inflow valves:
  • Larger diameter and tolerate less inertia-often replaced with bioprosthetic valves or repaired with annuloplasty.

Normal anatomy (fig 4):
The radiologist can use normal anatomy to approach the radiograph with valve replacement or repair:
• The right heart valves (tricuspid and pulmonary) are separated by the infundibulum, while the left heart valves (mitral and aortic) are immediately adjacent to each other.
• Direction of flow has been shown to be best for identifying the replaced valve (4).
  1. Aortic valve points toward the arch.
  2. The adjacent mitral valve points anteriorly and inferiorly on lateral radiograph (best seen with the prongs of the bioprosthetic valves).
  3. Pulmonic valve is the most superiorly-positioned valve and it points more posteriorly on the lateral view.
  4. Tricuspid valve is the most anteriorly-positioned valve and is seen en face on the lateral view.

i. Aortic valve replacement (AVR) (fig 5):
• Aortic stenosis is the most common surgical valve lesion in developed countries (1).

• Most common causes of aortic stenosis and regurgitation are:
  • Congenital bicuspid valve
  • Calcific valve disease
  • Rheumatic valve disease (5)

Radiographic findings:

• Prominent left ventricle and aorta.
• Valve points toward the aortic arch on lateral radiograph.

ii. Mitral valve annuloplasty (fig. 6):

• For mitral regurgitation caused by:
  • Degeneration (developed countries)
  • Rheumatic heart disease (developing countries)
  • Ischemia from prior myocardial infarction (MI)
  • Infective endocarditis

Radiographic findings:

• Left atrial and ventricular enlargement and signs of left heart failure (1).

iii. Mitral valve replacement (MVR) with bioprosthesis (fig. 7):

• For mitral stenosis:
  • Typically presumed to result from Rheumatic heart disease but can also be congenital or acquired (1).
  • Valvuloplasty is another treatment option

Radiographic findings:

• Look for the direction of flow based on the orientation of the valve to distinguish mitral from aortic repair: Mitral points anteriorly and inferiorly on lateral view.
• In this case we see sternotomy wires, scarring, and a right pleural effusion.
• Look for left atrial enlargement.

iv. Tricuspid valve replacement (TVR) and repair (fig. 8):

• Bioprostheses are almost always used in TVR: Low flow across the TV predisposes mechanical valves to thrombosis, and mechanical valves cannot be crossed for right heart catheterization or pacemaker implantation.
• Often TVR is performed in conjunction with MVR for mitral stenosis.
• **Tricuspid stenosis**: treat surgically with valve replacement.
  - From Rheumatic heart disease or carcinoid disease (1).

• **Tricuspid regurgitation**: treat surgically with annuloplasty.
  - Occurs from right ventricular dilation: pulmonary hypertension, pulmonic regurgitation, cardiomyopathy, MI, left heart failure, and infiltrative diseases such as sarcoidosis.
  - Or inherent valvular abnormality: Ebstein anomaly, prolapse, carcinoid plaque, endocarditis, etc. (1).

**Radiographic findings:**

• The most anteriorly-positioned valve.
• Look for RV pacer lead coursing through the ring.
• In this case we see MVR and tricuspid annuloplasty, with cardiomegaly and scarring.

v. **Pulmonary valve replacement (PVR) (fig. 9):**

• Typically to treat regurgitation:
  - High pressure causes are primarily due to pulmonary hypertension.
  - Low-pressure causes are usually from a dilated pulmonary annulus, congenitally abnormal (bicuspid or dysplastic) valve, or plaque from carcinoid disease (1).

• Also for congenital pulmonic stenosis as in fig. 9.

**Radiographic findings:**

• The most superiorly-positioned valve.
• Points superiorly and posteriorly on the lateral view.
• Enlarged right ventricle.

II. **Multiple valve replacements and repairs (fig. 10):**

In this case of AVR, MVR, and tricuspid annuloplasty, we can use what we learned so far to identify the prostheses.

• The aortic and mitral valves are immediately adjacent to one another - the two are often replaced together.
  - The aortic valve points superiorly toward the arch on lateral view.
  - The mitral valve points antero-inferiorly on the lateral view.
    - The left atrium is enlarged.

• Pacing leads go through the tricuspid annuloplasty into the right ventricle, and the tricuspid valve is the most anteriorly-positioned valve.
2. Pacemakers and AICDs (automatic implantable cardioverter-defibrillators):

2.1. Cardiac pacemakers (fig.11):

- Used to treat symptomatic sinus and AV node dysfunction, including sinus bradycardia and AV block.
- Consists of an implanted pulse generator and the lead(s) through which it delivers electric stimuli to the heart (6).

Radiographic findings:

Single lead pacemaker:

- Lead terminates in the right ventricle (RV).

Two-lead pacemaker:

- Leads terminate in the right atrial appendage and RV.

2.1 AICDs (fig.12):

- Recognize ventricular tachycardia or fibrillation (VT or VF) and terminate it by delivering one or more high-energy shocks.
- Used for primary prevention of sudden cardiac death in patients at increased risk for VT or VF (Cardiomyopathy and LVEF # 30 - 35%).
- Used for secondary prevention in patients with prior VT, VF, or prior sudden cardiac death (7).

Radiographic findings:

- The "shocking coil" on the RV lead allows defibrillation and is usually seen as two areas of cylindrical thickening.

2.3. Cardiac Resynchronization Therapy (CRT): Biventricular (BiV) Pacer (fig.13):

- Typically used for patients with severe systolic heart failure with LVEF # 35% and intraventricular conduction delay (IVCD); QRS > 120ms (7).

Radiographic findings:

- AICD lead terminates in the RV.
- BiV pacing - leads terminate in the right atrium, right ventricle, and left ventricle via the coronary sinus.
3. Coronary revascularization

Percutaneous coronary intervention (PCI) and coronary artery bypass grafting (CABG) are used to improve prognosis, relieve angina symptoms, and improve functional capacity in patients with coronary artery disease (CAD).

CABG: Typically used for patients with angina or NSTEMI with multi-vessel CAD, severe proximal coronary artery involvement, or severe left main disease (7).

3.1. LIMA (left internal mammary artery) and saphenous vein bypass grafting (fig.14):

- The standard bypass operation involves LIMA-to-LAD (left anterior descending artery) graft combined with vein grafts.
- LIMA grafts maintain 90% patency, compared to 50% in vein grafts, 16 years post-intervention (8).

Radiographic findings:

- Median sternotomy wires.
- The distal LIMA is anastomosed with the post-stenotic LAD, and surgical clips extend from the apex of the aortic arch.
- Clips for the vein graft begin lower, at the sinotubular junction.

3.2. LIMA and RIMA (Left and right internal mammary artery) bypass grafts (fig.15):

RIMA grafts are used less frequently due to multiple limitations:

- Takedown of bilateral IMAs was associated with increased sternal wound infections in certain groups.
- The RIMA is shorter and usually does not reach target arteries.
- Lower patency rates at follow-up (9).

Radiographic findings:

- Median sternotomy wires.
- Clips for both the LIMA and RIMA grafts extend from the apex of the arch.

3.3. Aorta-to-coronary reversed saphenous vein graft (fig.16):

- The first CABG was performed in 1967, and in the initial procedure saphenous veins were anastomosed with the proximal aorta and the post-stenotic coronary artery.
• Localizing rings were placed on the aorta to aid in future percutaneous intervention.
• This technique is no longer used due to significant late (>5 postoperative years) graft failure, but radiographs of patients who underwent this procedure are still seen.

Radiographic Findings:
• Median sternotomy wires.
• Localizing rings on the proximal ascending aorta.

4. Septal defect repair:

4.1. Atrial septal defect (ASD) repair (fig. 17 and 18):
• Often asymptomatic.
• If there are signs of RV overload, which can lead to heart failure and atrial fibrillation, closure is indicated.
• Paradoxic right-to-left emboli also can occur (1).
• Closure can involve stitching, patching, or placement of a percutaneous closure device.

Radiographic Findings:
• Pulmonary artery enlargement from left-to-right shunt.
• Closure device best seen on lateral radiograph.

4.2. Patent foramen ovale (PFO) repair (fig. 19):
• Smaller defect than ASD, and results in trivial shunting.
• Present in 25% of the population - suspicion should be high if a patient has a cryptogenic stroke before age 55.
• Has been repaired in the setting of cryptogenic stroke, but recent research has shown no difference in outcome between patients with repair vs. medical management with anticoagulation (10).

Radiographic Findings:
• Smaller closure device compared to ASD repair.

4.3. VSD (ventricular septal defect) repair:
• Small defect may be asymptomatic, but it has endocarditis risk.
• Large defect leads to pulmonary hypertension and death usually by age 40 if not repaired (1).

4.4. Patent ductus arteriosus (PDA) repair (fig. 20):

• 60% of fetal ventricular output is directed from the pulmonary artery to the aorta via the ductus arteriosus.
• With persistent PDA after birth, a left-to-right shunt can lead to CHF.
• If the patient with PDA is unresponsive to indomethacin or ibuprofen, surgical or catheter-based intervention is pursued (11).

Radiographic Findings:

• Occlusive devise such as the coil pictured in fig. 20.
• Posterior lateral thoracotomy if surgical approach is chosen, with either staple closure or radiographically-occult suture closure.
• Median sternotomy in the case of additional cardiac or great vessel repair.

Images for this section:
Fig. 1: Hancock porcine valve, an example of a bioprosthetic valve
Fig. 2: St. Jude bileaflet mechanical valve, which has a radiodense peripheral ring
Fig. 3: Annuloplasty rings: closed and open
Fig. 4: Normal anatomy: A = aortic valve, M = mitral valve, T = Tricuspid valve, P = pulmonic valve
**Fig. 5:** St. Jude mechanical aortic valve replacement: arrow depicts direction of flow through the aortic valve

**Fig. 6:** Mitral valve annuloplasty: arrow depicts direction of flow through the mitral valve
Fig. 7: Mitral valve insufficiency status post repair with bovine bioprosthesis (windowed). Intraoperatively, the anterior leaflet was prolapsed and detached without chordal support. Arrow indicates direction of flow through the mitral valve.
**Fig. 8:** Tricuspid annuloplasty and mechanical mitral valve replacement in a patient with CHF

**Fig. 9:** Patient with congenital pulmonic stenosis had valvulotomy in distant past and later underwent PVR and TVR for right heart failure: arrow indicates direction of flow through the bioprosthetic pulmonic valve
**Fig. 10:** Aortic and mitral St. Jude valves & tricuspid annuloplasty: LA = left atrium and RA = right atrium; note is made that the LA is posterior and superior in relation to the RA on lateral X-ray

**Fig. 11:** 52F with CAD, prior NSTEMI, and atrial flutter status post ablation. Two-lead pacemaker placed for sinus pauses: RA = Right atrium and RV = right ventricle.
**Fig. 12:** 70M with CAD, prior MI, LVEF 30%, and syncope with AICD placement: note thick coils on the RV lead (arrows)
Fig. 13: Biventricular pacing with 1. lead in the right atrium (RA) via the superior vena cava (SVC), 2. AICD lead in the right ventricle (RV) via the SVC, RA and tricuspid valve (T), and 3. lead in the left ventricle (LV) via the SVC, RA, and coronary sinus (cs)
**Fig. 14:** 69F with CAD and sinus node dysfunction had dual-chamber pacemaker placement and CABG, with LIMA-to-LAD and saphenous vein to distal RCA (right coronary artery) grafts

**Fig. 15:** RIMA and LIMA bypass grafts, and bioprosthetic aortic valve
Fig. 16: 77F status post triple-vessel CABG using the aorta-to-coronary reversed saphenous vein graft technique: note localizing rings on the aorta (arrows)
Fig. 17: Amplatzer double-disc septal occluder
Fig. 18: ASD repair with closure device
Fig. 19: 65M with recurrent cryptogenic stroke; positive bubble trans-esophageal echocardiogram and subsequent PFO closure

Fig. 20: Pediatric patient with PDA pre- and post-coiling
Conclusion

The radiologist often encounters evidence of prior cardiac procedures on the standard chest x-ray. Although intimidating at times, the radiologist can systematically approach the findings to improve his or her interpretation of the films.

References


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