Diagnosis of acquired heart disease in adults through chest radiography and CT correlation.

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Learning objectives

- Highlight the importance of a proper systematic reading in diagnosis of chest radiograph.

- Know some of the radiological signs for suspecting heart disease in adults through chest radiograph and their correlation with CT.
Background

In the past 25 to 30 years, a major advance in imaging diagnostic techniques of cardiac pathology -cardio MRI, CT angiography, echocardiography...- has been produced. However, chest radiograph remains the most important test, because it is low cost, widely available and it permits to make a diagnostic and severity approach to illness.

Despite the contribution of chest X-ray, both at diagnosis and management of patients with heart disease, training in its interpretation is absent or limited by residents.

Cardiovascular structures have similar radiographic densities leading to a homogeneous window that prevents valuing in detail. Still, chest radiograph allows us to demonstrate cardiovascular abnormalities affecting the mediastinum, the shape of the heart, lungs, or that cause extra-cardiac pathology.

Heart is located in the middle mediastinum, between both lungs, posterior to the sternum and over the diaphragm. It assumes an oblique position in the chest with two thirds to the midline and one third to the right. It consists of four cardiac chambers; left atrium (LA), right atrium (RA), left ventricle (LV) and right ventricle (RV). The LA is the most posterior chamber of the heart and receives blood from the pulmonary veins that runs almost horizontally towards the LA. The RA receives blood from the superior vena cava and inferior vena cava. The LV is located to the left and posteriorly to the right ventricle. RV is the most anterior structure and is situated behind the sternum (figure 1).

How to make a proper systematic reading of the chest radiograph from a cardiac perspective and the radiological signs for suspecting the presence of heart disease are discussed following the background.

The radiological semiology of acquired heart disease in adults presenting with normal and increased cardiothoracic ratio (CTR), different stages of congestive heart failure and the superimposed value of the calcifications on cardiovascular structures are also described in findings and procedure details.
Fig. 1: PA and lateral view of a chest X-ray shows the anatomy of the heart. RA: right atrium, RV: right ventricle, LV: left ventricle, LA: left atrium, RH: right hilum, LH: left hilum, SVC: superior vena cava, AA: aortic arch. B: A line called Jefferson line is drawn from the apex to the carina. The aortic valve sits allow this line and the mitral one below it. AO: aortic valve, MI: mitral valve.

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Findings and procedure details

Assess the radiography technique is the first step prior to the interpretation of the plain film. An over penetration (dark films) may produce better visualization of the mediastinal structures, but underestimates a congestion of the pulmonary parenchyma, and the feeling that the pulmonary blood flow is diminished. By contrast, an underestimation (light films), results in overestimation of the unsharpness of vessels, and as a consequence an over interpretation of pulmonary vascular congestion.

It is essential to do a systematic reading in order to interpret chest radiographies. Our proposal is to study the chest wall firstly, and then assess the situs of certain structures, location, size and shape of the heart, pulmonary vasculature and finally cardiovascular calcifications (figure 2)

The study of the chest wall

The study of the chest wall allows us to demonstrate previous surgeries, rib deformities (inferior rib notching, Roessler sign, in cases of aortic coarctation) spinal deformity (scoliosis) and sternal deformities (type pectus). Pectus deformities can be a guiding sign of associated cardiac lesions (Marfan syndrome, mitral valve prolapse ...) (figure 3)

Gastric chamber, cardiac apex and aortic arch situs

Secondly, we identify the situs of certain structures such as the cardiac apex, the aortic arch and the gastric chamber. An anomalous position of such structures allows us to suspect certain abnormalities such as the right aortic arch or situs inversus (figure 4).

Location, size and shape of the heart

Under normal conditions, the heart is located one third to the right and two thirds to the left of the midline. A greater displacement to the left may indicate:

1. Study rotated to the left, which it is the most common reason.

2. Decreased anteroposterior diameter of the chest.

3. Congenital agenesis of the pericardium.
The anteroposterior diameter of the rib cage is considered narrow when:

1. The distance between the posterior lower surface of the sternum and anterior vertebral body is less than 8 cm.

2. The ratio of the transverse diameter -determined in the front projection- and anteroposterior diameter in the lateral projection exceeds 2.75.

A narrow anteroposterior diameter may be due to pectus excavatum (figure 5) or a straight back syndrome.

One of the most important signs of heart disease is the enlargement of the heart and the change of its configuration. To assess heart enlargement, we can measure the cardiothoracic ratio (CTR) considered as the ratio of the maximal transverse cardiac diameter to the maximal distance between the internal rib margins. It is accepted that heart size is increased if the CTR exceeds >0.5 in upright position or more than 0.6 in supine, because supine projections determine a magnification of up to 10-13%.

**Global or selective growth of cardiac chambers**

On many occasions, we can only determine that the cardiothoracic ratio is increased globally. However, there are radiological signs that guide us to the selective growth of specific cardiac chambers. We will discuss these signs along the poster.

**Left atrium enlargement** (figure 6)

Due to its posterior location, the left atrium grows back, increasing both its diameter, and its radiodensity in PA projection chest X-ray, resulting in the following imaging findings:

1. Double contour of the right border of the heart.

The distance from the middle of the double density (lateral border of the left atrium) to the half of the left main bronchus is larger than 7 cm in patents with a dilated left atrium demonstrated by echocardiography.

2. Elevation of the left bronchus and widening of the carina above 65 °.
3. Left atrial appendage manifested: a prominence along the left heart border is appreciated, just below the left main pulmonary artery.

4. Left displacement of the descending aorta.

5. Posterior displacement of the left upper bronchus.

**Right cavities growth** (figure 7)

-Right atrium:

It is difficult to assess an isolated right atrium enlargement, except in cases where it is greatly increased as Ebstein's disease or tricuspid stenosis. In moderate growth of the right atrium the most reliable imaging finding is the tendency of the right cardiac border to extend upward and outward.

-Right ventricle:

It is the most anterior cardiac chamber and usually contacts with the lower third of the sternum. When the right ventricle grows, the retrosternal space is occupied by the enlarged right ventricle. Therefore, there is a growth of the right ventricle when a contact of the border of the right ventricle with more than one third of the length of the sternum is visualized.

**Left ventricle growth** (figure 8)

The left ventricle is located posterior and left to the right ventricle and tends to grow in that direction. When the left ventricle enlarges considerably, the triangle formed between the column, diaphragm, and the posteroinferior border of the heart in the lateral projection may be disappeared. In PA projection, the left ventricle expands to the left.

**Signposts in chest X-ray for cardiac valvular lesions**

Three imaging features in a chest X-ray (figure 9) will direct our suspicions about certain valvular heart disease, so in case of finding:

A. Ascending aorta enlargement.
B. Left atrial enlargement.

C. Right atrial enlargement.

We could suggest respectively:

A. Aortic valve pathology.

B. Mitral valve pathology.

C. Tricuspid valve pathology.

**Cardiopathies with CTR within normal limits and increased CTR**

Acquired adult heart disease can be divided into two groups according to the presence or not of a significant cardiomegaly (figure 10). A CTR of 0.5 is considered within normal limits, so we can distinguish:

1. Cardiopathies with normal CTR: characterized by having a normal or slightly increased heart size.

2. Cardiopathies with increased CTR: characterized by having cardiomegaly.

Pathophysiological factors associated to cardiopathies with normal CTR are decrease myocardial compliance and pressure overload. On the other hand, the pathophysiological ones associated to cardiopathies with increased CTR are volume overload and heart failure. Pericardial effusion is also included in this last group.

The types of acquired cardiopathies that lead to a greater pressure overload are hypertension, aortic and mitral stenosis. The types of acquired lesions with greater volume overload are aortic, mitral regurgitation and increased cardiac output situations. Cardiopathies that cause reduce compliance of left ventricle or reduced resistances to the total expansion of both ventricles are myocardial infarction (MI), restrictive cardiomyopathy (RCM), constrictive pericarditis, and hypertrophic cardiomyopathy (HCM).

Aortic stenosis, hypertension and mitral stenosis will be discussed in this electronic presentation, because they cause greater pressure overload within cardiopathies with normal CTR. In regard to the cardiopathies with increased CTR, aortic and mitral
regurgitation will be treated, for being those that leads to a greater cardiac volume overload. Pericardial effusion will also be described due to its relative frequency in our daily clinical practice.

**Imaging findings in certain cardiopathies**

**Cardiopathies with normal CTR**

**Aortic stenosis**

Aortic stenosis is a valve disease that causes a pressure overload, whose compensatory mechanism is a concentric hypertrophy of the left ventricle that leads to a slight decrease in volume, and a small increase in heart size.

The most characteristic imaging finding is an enlargement of the ascending aorta although, it correlates slightly with stenosis severity (figure 11). The pulmonary vascularity will not present any alteration for much of the course of aortic stenosis. However, in the decompensated phase, there may be identified signs of an increased capillary wedge pressure leading to pulmonary edema due to left ventricular failure.

**Arterial hypertension**

Hypertensive heart disease causes a pressure overload and, it is associated with a normal heart size for much of the compensated phase of the disease. We cannot reliably determine the severity or even the existence of a left ventricular hypertrophy just trough chest X-ray.

**Mitral valve stenosis**

Imaging findings in chest X-ray can usually guide us as a first approximation in the mitral stenosis diagnosis, providing an important perspective on the severity (Figure 12).

Mitral stenosis causes a slight increase in the overall size of the heart during the initial phase of the disease. During its evolution, a characteristic atrium and left atrial appendage enlargement is produced, and pulmonary venous hypertension signs are identified.

**Cardiopathies with increased cardiothoracic ratio (CTR)**
Aortic insufficiency (AI)

It produces a considerable cardiomegaly, mainly at the expense of LV growth. A sign that may indicate the presence of aortic valve disease is the dilatation of the aortic knob, the ascending aorta, and often the descending aorta. The increase in heart size is related to the severity and duration of the disease because it is a volume overload cardiopathy. The pulmonary vasculature is normal for much of the course of the disease, so the existence of pulmonary venous hypertension is indicative of LV failure and therefore often associated with terminal IA (figure 13).

Mitral insufficiency (MI)

In chronic mitral insufficiency we can identify different degrees of pulmonary venous hypertension (PVH); cardiomegaly, left atrium enlargement, left ventricle growth, and dilatation of the right cavities in the advanced phase of the disease. The left atrial appendage is increased in patients with rheumatic etiology (figure 14).

PVH in mitral insufficiency is usually less severe than in mitral stenosis. It normally shows an excessive left atrium enlargement for the gravity of PVH that we would expect. As it is a volume overload condition, the overall heart size in a chest X-ray is an useful sign for the severity of the failure.

An asymmetric pulmonary edema, more severe in the right upper lobe, can be caused by rupture of the chordae tendineae, papillary muscles, ischemic dysfunction, and bacterial endocarditis. This tendency for the right upper lobe is explained by a retrograde flow from the mitral valve into the right upper lobe pulmonary veins.

Pericardial effusion

Pericardial effusion radiological findings are relatively nonspecific. A significant cardiomegaly and the absence of signs of PVH are suggestive features for pericardial effusion.

The cardiac silhouette can acquired a globular appearance with a typical configuration called water-bottle heart.

In approximately 15% of cases, we can see the “fat pad” sign on the lateral projection of chest X-rays in patients with pericardial effusion. This is a radiopaque band that separates
the pericardial fat and the subpericardial fat. This sign is very specific for pericardial effusion, and for some authors is even pathognomonic (figure 15).

**Congestive heart failure**

Congestive heart failure is the consequence of insufficient output due to high resistance in the circulation, or fluid overload or a cardiac failure.

The most common cause of congestive heart failure is a left ventricle failure that causes a decreased cardiac output and an increased pulmonary venous pressure. A left ventricle failure will lead to a leakage of fluid into the interstitium and the pleura space. In the final stage, a leakage of fluid into the alveoli resulting in pulmonary edema will be produced.

Increased pulmonary venous pressure is associated to changes in the pulmonary capillary wedge pressure. The increase of pulmonary venous pressure can be graded into stages, each with its own imaging findings on the chest X-ray. However, in daily clinical practice some of these features are not seen in this precise sequence (figure 16)

**Stages of Congestive Heart Failure:**

**Stage I: Redistribution (PCWP: 13-18 mmHg)**

The pulmonary vessels supplying the upper lung fields are smaller and fewer in number than those supplying the lung bases with the patient standing up in a normal chest X-ray.

The pulmonary vascular bed is a low resistance and low pressure system. It has an important reserve capacity available, which allows open previously non-perfused vessels and causes distension of already perfused vessels. This causes a redistribution of pulmonary blood flow, which is the first stage of the congestive heart failure.

Redistribution should be named only when a chest X-ray is taken in full inspiration in the erect position. A false impression of redistribution can be given in many chest X-rays that are taken in supine or semi-erect position.

In the supine position a false impression of redistribution may be given due to the equalization of blood flow between upper lobes and lower lobes. In these cases comparison with previous chest X-rays can be useful. In the redistribution stage there is
equalization of the number and size of the vessels of lower lobes and upper lobes firstly. Subsequently, it is in upper lobes where the number and size of the vessels are greater. Other findings identified at this stage are the increasing size of the heart and width of the vascular pedicle.

The vessels in the upper lobes are usually smaller than the accompanying bronchus, with a ratio of 0.85. In case of redistribution of pulmonary blood flow there will be an increased artery-bronchus ratio in the upper and the middle lobes, easier observed in the perihilar region (figure 17).

Stage II: Interstitial edema (PCWP: 18-25 mmHg)

Fluid leaks to the interlobular and peribronchial interstitium as a consequence of the increased pressure increase in the pulmonary capillaries. Liquid leakage to the interlobular interstitium leads to an interlobular septal thickening which is represented by Kerley lines (figure 18, 19 and 20). We can find different types of Kerley lines:

- Kerley A lines: they are oblique and run from the hilum to the periphery. They reach from 3 to 5 cm long and approximately 1 cm of thickness

- Kerley B lines: they can be seen in the periphery of the lung, perpendicular to the pleura, in both lung bases, and reach 1-2 cm long.

- Kerley C lines: they are short lines which not follow the radial pattern from the hilum to the periphery and not reach the pleura.

- Kerley D lines: they are equal to B lines; however they can be seen in the retrosternal space.

Some other findings we may see are bilateral perihilar haze, and peribronchial cuffing (bronchial wall thickening), which are produced as a consequence of the leakage of fluid to the peribronchovascular interstitium.

Stage III: Alveolar edema (PCWP>25mmHg)

In this stage, there is a constant fluid leakage to the interstitium, which is not compensated by the lymphatic drainage, which leads to alveolar edema and pleural effusion, often bilateral.
Perihilar symmetric bilateral opacities with a cotton-appearance and air-broncogram are usually seen (figure 21).

**Heart calcifications**

Calcifications of cardiovascular structures are frequent. Although, its profile or location will be pathognomonic of a cardiovascular illness in scarce occasions (figure 22 and 23). Among all kinds of cardiovascular calcifications, we may find:

1. Descending aorta calcifications

They are usually located in the anterolateral right side of the descending aorta in old people, especially in patients with an aortic valve disease.

2. Mitral annular calcification

It consists of a dense calcification mimicking a C shape of the mitral ring. It may be a casual factor of mitral regurgitation. It is often seen in asymptomatic and apparently healthy old patients.

3. Aortic annular calcification

It is a circular calcification in the location of the aortic valve and its extension into the electrical conduction system of the heart may produce global heart failure.

4. Valvular calcification (aortic and mitral)

An aortic calcification which presents enough density as to be seen in the chest X-ray is usually associated with a significant hemodynamic aortic stenosis (gradient > 50 mmHg).

5. Coronary calcifications

It is usually seen on the CT or in the fluoroscopy. The exposition time used to do the chest x-ray is too long in comparison to the cardiac motility, so the density of the calcification is similar to that of the heart and barely recognizable. Calcifications must be dense and extensive for being seen on the chest X-ray.
6. Calcification of the left ventricle wall

It is usually located in the anterolateral or apical regions of the left ventricle, and indicates the site of an acute myocardial infarction and aneurysm.

7. Left atrium calcification

The detection of a calcification in the left atrium has important clinical consequences and it is usually due to rheumatic endocarditis. The amount of calcium is frequently related to the evolution time of untreated illness, and the calcification itself usually has a thin and curve shape, located in the endocardial or subendocardial layer of the heart.

8. Pericardial calcifications

It indicates constrictive pericarditis. It is usually located in the interventricular or atrioventricular sulcus of the heart.

9. Infrequent locations of calcifications

They may indicate the presence of an intracardiac tumour such as a left atrium myxoma, a pericardial dermoid tumour, granulomas which have healed such as myocardial tuberculomas...etc.
Fig. 2: Illustration demonstrates our proposal for a systematic reading of a chest X-ray from a cardiac perspective.

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Fig. 3: PA chest X-ray and an amplified image of interest area show inferior rib notching, Roesler sign (black arrow), due to coarctation of aorta

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Fig. 4: A. PA chest X-ray shows that the cardiac apex and the aortic button are placed at the right (arrows) due to situs inversus. B. Coronal reconstruction CT scan at mediastinal window demonstrates a speculative image of viscera and cardiac apex as regards normality, on the right side the cardiac apex (red arrow), stomach and aorta (head arrow) are identified, while at the left the superior vena cava (red asterisk), and liver (black asterisk) are observed. C. PA chest radiograph shows the aortic knob at the right and a displacement of the trachea to the left (arrowhead). D. Axial chest CT scan at mediastinal window from the same patient than C, demonstrates a right aortic arch (red arrow) and an aberrant subclavian artery (arrowhead).

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Fig. 5: A and B: PA and lateral chest X-ray shows a pectus excavatum (black arrow) that conditions a levocardia by a narrow rib cage and an effacement of the right border of the heart. S: sternum, A: Transverse diameter. B: AP diameter <8 cm. 1C: Illustration of pectus excavatum. C: A/B > 2.75 cm.

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**Fig. 6:** A and B; PA chest X-ray and illustration exhibit a double right cardiac contour (orange and red arrow), and an increased carina angle (>65 °). A distance between the middle of the double density and left main stem bronchus of more than 7 cm has been shown to indicate a left atrial enlargement in over 90% of patients (red double arrow). C: Lateral chest X-ray from another patient showing a displacement of the upper left bronchus (black arrow) due to a left atrial enlargement. D: Axial chest CT scan at mediastinal window demonstrates a LA volume of 29 cm2.

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**Fig. 7:** A and B; PA and lateral chest X-ray exhibits a growth of right cardiac border upward and outward, and an increased RV size (contact of anterior cardiac border greater than 1/3 of the sternal length). C: Axial chest CT at mediastinal window shows a growth of the atrium and the right ventricle. D: Illustration demonstrates a contact of the anterior cardiac border greater than 1/3 of the sternal length.

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**Fig. 8:** A. PA chest X-ray exhibits a LV enlargement. B. Illustration explains how the left ventricle (LV) grows.

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Fig. 9: Diagram with designposts in chest X-ray that will direct our suspicions about certain valvular heart diseases.

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Fig. 10: Diagram for suspecting certain cardiac diseases, taking into account the cardiothoracic ratio.

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Fig. 11: A. PA chest X-ray shows a dilated ascending aorta (head arrow) because of an aortic stenosis later confirmed with echocardiography. B. CT angiography of aorta confirms a dilatation of the ascending aorta (diameter: 5 cm). C. Coronal oblique reconstruction of CT angiography of aorta exhibits a calcification of the aortic valve in a patient with aortic stenosis. D. Axial reconstruction of the aortic valve in systole manifests an image in "fish-mouthed" in a patient with bicuspid aortic stenosis.

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**Fig. 12:** A. PA chest X-ray of a patient with mitral stenosis in which a double right contour (red and orange arrows), and an increase of the carina angle are observed because of a left atrium enlargement. A peribronchial cuffing and bilateral perihilar haze (arrow head) are also observed secondary to an acute pulmonary edema in interstitial stage B. Axial chest CT at mediastinal window of another patient shows a calcification of the mitral valve (arrowhead) and cardiomegaly in a patient with severe mitral stenosis.

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**Fig. 13:** A. PA chest X-ray of a patient with aortic insufficiency exhibits a lateral and caudal displacement of the left ventricular contour, indicating a LV growth. The ascending aorta (arrowhead) and aortic knob (arrow) are dilated. A concavity (red line) visualized along the top and left cardiac border indicates a LV enlargement. B. Rx PA chest of another patient with an advanced aortic regurgitation shows a cardiac decompensation in interstitial phase; bilateral hilar haze, peribronchial cuffing (arrowhead) and bilateral pleural effusion.

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Fig. 14: A: PA chest X-ray of a patient with chronic mitral insufficiency exhibits a cardiomegaly with a double right cardiac contour (black arrows) indicating a LA growth. B. Portable chest X-ray shows right perihilar consolidations mainly located in the right upper lobe (RUL), associated with hilar haze due to acute pulmonary edema. The patient was exitus. In this case we have to considerate an acute mitral insufficiency because of the typical predominant distribution in the RUL.

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**Fig. 15:** A and B; PA and lateral chest X-ray exhibits an increase of CTR, without any sign of pulmonary venous hypertension and the cardiac silhouette acquires a "water bottle" configuration. In the lateral projection, a radiopaque band between the pericardial fat and the subpericardial fat (discontinuous black lines), called "fat pad sign" (arrow). C; Coronal reconstruction CT scan at mediastinal window of another patient with a large pericardial effusion (asterisk). D; Axial CT scan at mediastinal window of the same patient than C with pericardial effusion (arrowhead)

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Fig. 16: Diagram illustrating the different stages of congestive heart failure and their imaging features. Note that not all these features follow this strict sequence in the daily practice. PCWP: pulmonary capillary wedge pressure

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**Fig. 17:** A. PA chest X-ray shows an increased number and size of the vessels of the LLSS compared with the lower (arrow), an increase of cardiothoracic ratio, and a broad vascular pedicle (red line) comparing with previous studies of the same patient. B. Increased artery (head arrow)/bronchus (arrow) ratio in the perihilar region.

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Fig. 18: A and B; PA and lateral with bilateral congestive hilium (arrows), a thickened interlobar fissure (arrow), and a fine linear pattern secondary to an acute pulmonary edema in interstitial phase

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**Fig. 19:** Amplified images from the same patient than figure 18, showing Kerley lines (C, D, E) and resolution after treatment (c´, d´, e´). C: Kerley B lines (arrow), Kerley C lines (head arrow), D: Kerley A lines, E: Kerley D lines.

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**Fig. 20:** CT scan at lung window demonstrates a smooth thickening of the axial (arrowhead) and interlobulillar (arrow) interstitium in the context of acute interstitial pulmonary edema. B. CT scan from the same patient after treatment shows a left pleural effusion (asterisk), but a normal interstitium.

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Fig. 21: A and B; PA and lateral chest X-ray demonstrates bilateral consolidations with haze of both hila, and bilateral pleural effusion due to alveolar edema.

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**Fig. 22:** A and B; lateral chest X-ray and sagittal reconstruction CT scan at mediastinal window of a patient where an extensive calcification of the ascending aorta is observed. C; PA chest shows a calcification of the annulus of the mitral valve in the shape of a ‘C’ (arrowhead). D; Coronal reconstruction CT scan at mediastinal window exhibits a calcification of the annulus of the mitral valve (arrowhead)

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Fig. 23: A and B; PA and lateral chest X-ray demonstrates an extensive calcification of the pericardium in a patient with a previous history of constrictive pericarditis. C and D; PA and lateral chest X-ray where an extensive calcification of the left atrium (arrowhead) is observed.

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Conclusion

-Chest x-ray provides valuable additional information for the diagnosis and management of patients with heart disease.

-A proper systematic reading is essential in diagnosis of chest radiograph.

-Know some of the radiological signs in a chest X-ray helps to suspect certain heart diseases in adults.

-Despite the contribution of chest X-ray, both at diagnosis and management of patients with heart disease, training in its interpretation is absent or limited by residents.


References


