Ultrasound Morphology of the Heart: Transthoracic Examination

2

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2.1 Ultrasound Morphology of the Heart: Standard Transthoracic Examination

2.1.1 Echocardiographic Anatomy

The heart is located within the chest between the lungs and in front of the esophagus. From the base toward the apex the heart is positioned:

- From top to bottom
- From back to front
- From right to left

Recalling the different structures on ultrasound images appears very complicated for the beginner operator if the various projections of the different structures are not kept in mind, according to the position of the heart within the chest under the section plane of the ultrasound scan. It should be noted that the echo image shows a thin slice of the structures crossed by the ultrasound beam. The structures first encountered by ultrasound, near the probe, are displayed at the top corner of the image and deeper structures are displayed proportionally lower on the screen, according to the progressive distance from the probe.

2.1.2 Patient Positioning

In the intensive care unit (ICU) it is not always possible to position the patient as desired. However, even small shifts can dramatically improve image acquisition. The patient should be kept with the trunk raised to 45° as is normally done in the ICU. The position on the left side or midway between the supine and the left lateral approach generally allows the heart to draw near to the chest wall, thus gaining the best acoustic windows. The patient's left arm must be raised and brought toward the head, so as to widen the left-sided intercostal spaces (Fig. 2.1) since the rib absorbs ultrasound. Aside from the ribs, aerated lung tissue is the major obstacle to the penetration of ultrasound. Therefore, patients with chronic pulmonary disease and emphysema are usually more difficult to study with transthoracic windows. Sometimes, for these patients the only approach that produces clear images is the subcostal approach. If the patient does not have acoustic windows on the chest wall and if the subcostal area is not accessible, often because of the presence of surgical wound dressings, it is essential to use transesophageal echocardiography. Nevertheless, the skilful operator, with a little patience, is almost always able to get acceptable and usable tansthoracic echocardiographic images for most patients even in the emergency and intensive care settings.

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Fig. 2.1 Position of the operator and the patient for echocardiography in the intensive care unit. (From Sarti 2009 with permission)

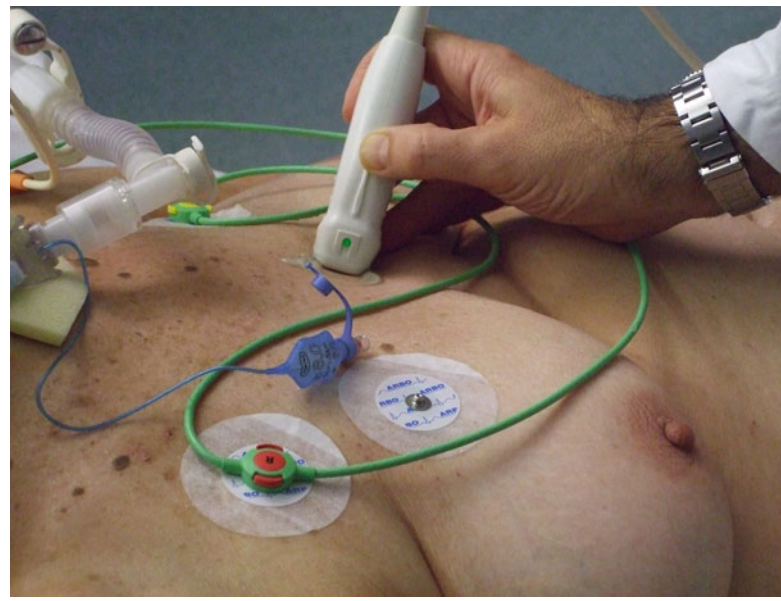

Fig. 2.2 Position of the probe for the parasternal long-axis view. Note the probe marker. (From Sarti 2009 with permission)

2.1.3 Positioning of the Probe (Acoustic Windows)

The probe, with a stream of acoustic gel at the end, is held not too tightly between the thumb and first two fingers of the gloved right hand, while maintaining contact with the chest wall with the other fingers, without causing pain or discomfort from excessive pressure, in two main locations:

1. *Left parasternal* at the second to fourth intercostal spaces (Fig. 2.2).
2. *Around the area of the apical beat,* at the fifth or sixth intecostal space along the anterior axillary line or more laterally (Fig. 2.3).

Fig. 2.3 Position of the probe for the apical four-chamber view. Note the probe marker. (From Sarti 2009 with permission)

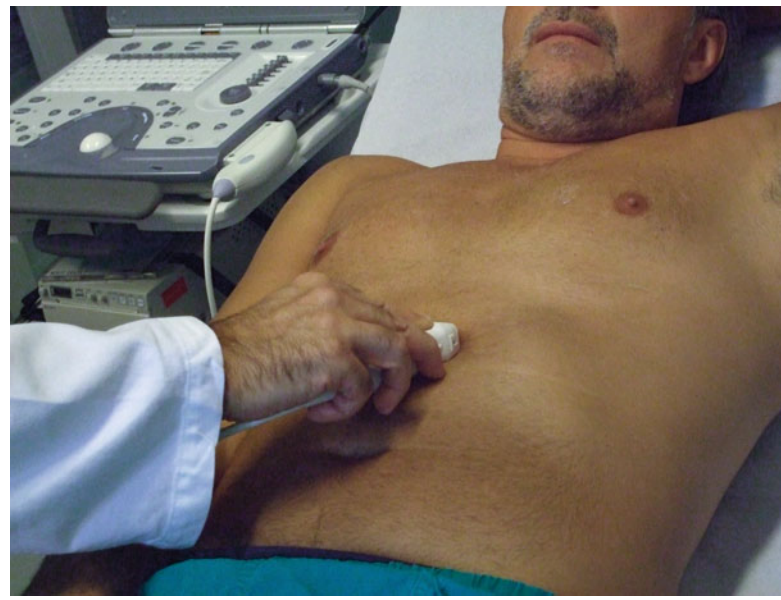

Fig. 2.4 Position of the probe for the subcostal views. (From Sarti 2009 with permission)

Another possible transthoracic location is parasternal right, which is used either in pediatrics or to assess the aortic valve (see Chap. 22).

The other basic positions of the probe, outside the chest wall, are:

- *Subcostal* central level, just below the xiphoid process (Fig. 2.4)
- *Suprasternal* level, at the jugular notch (Fig. 2.5)

2.1.4 Positioning of the Operator and the Ultrasound Machine

Most operators stay at the right side of the patient and keep the probe in the right hand. Others prefer to set themselves at the patient's left, holding the probe with the left hand, thus avoiding much contact with the patient's body. In any case, the

Fig. 2.5 Position of the probe for the suprasternal views. (From Sarti 2009 with permission)

position must be convenient, stable, and relaxed. Sitting is comfortable, but it is sometimes necessary to stand, lean, or even sit on the edge of the patient's bed; in this case a disposable gown should be worn. The ultrasound machine is usually placed to the right side of the patient's head, so that only small movements of the operator's head are needed to shift from the patient to the display and vice versa. In this arrangement the left hand is used to operate the controls. It is always useful to keep in mind the ultrasound section plane within the chest before looking at the images. The movement of the probe, as positioning, pointing, angling, or rotation (see Table 2.1), should be regulated while always considering what happens to the section plane inside the thorax.

2.1.5 Parasternal Long-Axis View

This is a longitudinal section of the heart (Fig. 2.6). The probe is in the left parasternal position and the marker is placed toward the right shoulder (Fig. 2.2). Initially, instead of insisting on a single point, different intercostal spaces should be tried, sliding from the second to the fourth, sometimes down to the fifth, to find the best acoustic window. The proper image is a section that shows part of the right ventricle, the septum, in a more or less horizontal position which continues toward the aortic upper wall. Below it the aortic valve and the left atrium are on the right side of the display. The left ventricle is found in the center (Figs. 2.6, 2.7). If more than one intercostal space allows one to obtain valid images, it is often preferable to use higher spaces. The parasternal long-axis view is usually the first image sought at the beginning of the examination since it highlights many structures and provides a first general idea of the heart. Positioning the cursor on the basis of the 2D image, one can obtain M-mode echograms, which are useful for measuring the size of the cardiac chambers and the thickness and the kinetics of the anterior septum (anterior descending artery) and the posterior wall (circumflex and right coronary arteries to the apex). The diameter of the left ventricular outflow tract is also measured during the systole just before the fully opened aortic cusps. The functional anatomy of aortic and mitral valves can be studied, including forward flow and any possible regurgitation, with color Doppler imaging (color flow mapping, CFM). Continuous wave and pulsed wave transvalvular flow measurements are not possible since the blood flows more or less perpendicular to the ultrasound beam. Except for

Table 2.1 Standard views, landmarks, rotation, and angling of the probe (structures and measures)

View	Probe position	Probe marker	Probe rotation	Probe angulation	Structures	Measurements
PSLAX	Parasternal 2nd to 4th intercostal space	Right shoulder	–	Variable	Left ventricle (except apex), LV septal and posterior walls, mitral and aortic valves, mitral subvalvular structures, LA, ascending aorta, RV outflow tract	LV and RV size and thickness, LV and RV kinetics, LV outflow tract and ascending aorta sizes, CFM of mitral and aortic flows
PSLAX modified for right ventricle (tricuspid plane)	Parasternal 2nd to 4th intercostal space	Right shoulder	Slightly clockwise	Inferomedial tilting from PSLAX	RV inflow, RA, tricuspid valve	CFM, PW and CW Doppler imaging of transtricuspid flow
PSLAX modified for right ventricle (pulmonary valve)	Parasternal 2nd to 4th intercostal space	Right shoulder	Slightly clockwise	Upward tilting from PSLAX-modified RV tricuspid plane	RV outflow, pulmonary valve	CFM, PW and CW imaging of transpulmonary flow, pulmonary VTI
PSSAX papillary muscle plane	Parasternal 2nd to 4th intercostal space	Left shoulder	90° clockwise from PSLAX	–	LV and RV sizes, LV walls, papillary muscles	LV and RV kinetics, FS, FAC
PSSAX mitral plane	Parasternal 2nd to 4th intercostal space	Left shoulder	90° clockwise from PSLAX	Upward tilting from PSSAX papillary muscles	Mitral valve, let ventricle, and LV sizes	Mitral valve (P1, P2, P3 and A1, A2, A3), mitral area, LV and RV kinetics
PSSAX aortic plane	Parasternal 2nd to 4th intercostal space	Left shoulder	90° clockwise from PSLAX	Upward tilting from PSSAX mitral plane	Aortic, tricuspid, and pulmonary valves, RV outflow, pulmonary trunk	Aortic valve (all cusps), aortic valve area, CFM and PW transpulmonary Doppler imaging

(continued)

Table 2.1 (continued)

View	Probe position	Probe marker	Probe rotation	Probe angulation	Structures	Measurements
A4C	Apical 4th to 6th intercostal space along the left mid-clavicular or anterior axillary line (apical beat)	Left leg	–	–	Global vision of the heart, left ventricle, right ventricle, LA, RA, LV septal and lateral walls, RV free wall, mitral and tricuspid valves	LV and RV kinetics, EF, TAPSE, CFM, PW and CW transvalvular mitral and tricuspid flows, pulmonary pressure assessment
A5C	Apical 4th to 6th intercostal space along the left mid-clavicular or anterior axillary line	Left leg	Variable	Upward tilting	Global vision of the heart plus aortic outflow valve and ascending aorta	CFM, CW and PW Doppler imaging of LV outflow, VTI
A2C	Apical 4th to 6th intercostal space along the left mid-clavicular or anterior axillary line	Right shoulder	90° counterclockwise from A4C	–	LV, LA, LV inferior and anterior walls, mitral valve	LV kinetics, EF, CFM, CW and PW Doppler imaging of transmitral flow
A3C	Apical 4th to 6th intercostal space along the left mid-clavicular or anterior axillary line	Right hand	45° counterclockwise from A2C	–	Left ventricle, LA, mitral valve, LV anteroseptal and posterior walls	LV kinetics, CFM, CW and PW Doppler imaging of transaortic flow, VTI
SC4C	Subcostal	Left shoulder	Variable	Variable	Global vision of the heart, left ventricle, right ventricle, LA, RA, LV septal and posterolateral walls, interatrial septum, liver, and intrahepatic veins	LV and RV kinetics, possible interatrial shunt
Subcostal abdominal aorta	Subcostal	Left shoulder	Variable	Downward from SC4C	Abdominal aorta	Aortic diameter
Subcostal RV and LV outflows	Subcostal	Left shoulder	Variable	Upward from SC4C	LV and RV outflow	CFM, CW and PW imaging of LV and RV outflows (if in line)

(continued)

Table 2.1 (continued)

View	Probe position	Probe marker	Probe rotation	Probe angulation	Structures	Measurements
Subcostal IVC	Subcostal, shifted a little to the left from SC4C	Left shoulder or head	Variable	Leftward tilting	IVC, RA	IVC diameter and respiratory variations
Subcostal short axis	Subcostal	Left shoulder	Variable	90° counterclockwise from SC4C	LV and RV short axis, LV and RV kinetics	–
Subcostal apical short axis	Subcostal	Left shoulder	Variable	Right tilting	LV apex	–
Subcostal basal short axis	Subcostal	Left shoulder	Variable	Left tilting	Basal LV and RV short axis	–
Suprasternal	Jugular notch	Left shoulder	Variable	Variable	Ascending aorta and aortic arch	Aortic diameter

PSLAX parasternal long axis, *RV* right ventricular, *PSSAX* parasternal short axis, *A4C* apical four chamber, *A5C* apical five chamber, *A2C* apical two chamber, *A3C* apical five chamber, *SC4C* subcostal four chamber, *IVC* inferior vena cava, *LV* left ventricular, *LA* left atrium, *RA* right atrium, *CFM* color flow mapping, *PW* pulsed wave, *CW* continuous wave, *VTI* velocity–time integral, *FS* fractional shortening, *FAC* fractional area change, *EF* ejection fraction, *TAPSE* tricuspid annular plane systolic excursion

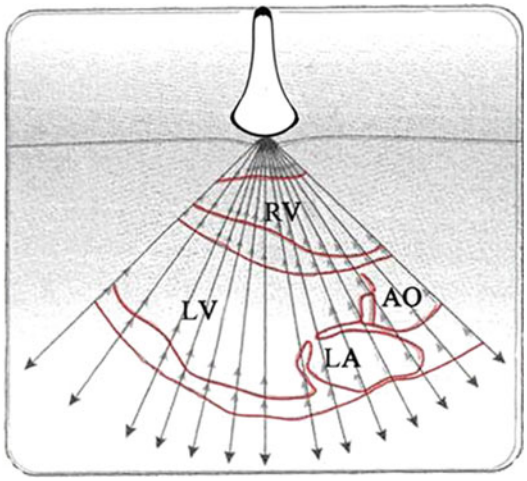

Fig. 2.6 Section plane and ultrasound beam for the parasternal long-axis view. *AO* aorta, *LA* left atrium, *LV* left ventricle, *RV* right ventricle, (From Sarti 2009 with permission)

the outflow part of the right ventricle, the right side of the heart is not generally visible. However, a broader view of the right atrium, the tricuspid valve, and the inflow tract of the right ventricle can be obtained by angling the probe down under the sternum and a fraction more medial, with a slight clockwise or, more rarely, counterclockwise rotation (Fig. 2.8), whereas an upward (cranial) angling and slight clockwise rotation from the basic parasternal long-axis view may show the right ventricular outflow tract with the pulmonary valve and the pulmonary trunk (Fig. 2.9).

2.1.6 Parasternal Short-Axis View

The probe remains in the same position as shown to obtain the parasternal long-axis view, but is rotated 90° clockwise with the marker now pointing to the left shoulder in order to obtain a cross section of the heart (Fig. 2.10). The image shows the left ventricle as a ring, more or less thick according to the thickness of the walls, with a section of the right ventricle that presents itself as a cap attached to the left ventricle by the septum, on the upper left of the display (Fig. 2.11). We must aim to produce a well-shaped circular section, avoiding oblong or oval images of the left ventricle. The assessment of the left ventricular kinetics is best performed in a plane that highlights the sections of the papillary muscles inside the ventricular cavity (Fig. 2.12). This section examines all the walls of the left ventricle, which thickens and moves toward the center in systole, with visibility of the myocardial tissue perfused by all three major coronary trunks. The upper part of the ring, starting at the eight o'clock to ten o'clock position to the two o'clock position, is attributable to the anterior descending artery. The tissue on the right side of the ventricular ring, from the two o'clock position to the six o'clock to seven o'clock position, coincides with the circumflex artery perfusion, and the bottom of the ring, shifted slightly to the left of the image, from the six o'clock to seven o'clock position to the eight o'clock to ten o'clock position, represents the myocardium perfused by the right coronary artery.

Downward (caudally) angling of the probe shows the base of the papillary muscles and then the apex of the left ventricle. An upward angulation (cranial) of the probe moves instead the section plane to cross the mitral valve, which is cut through the opening and closing motion (Fig. 2.11). A further upward angulation (Fig. 2.13) shows a central section of the aortic outflow with the valve (the aortic box, shaped as a "Mercedes star") and its three moving cusps. On the left, the tricuspid valve and the right outflow can be seen, with the pulmonary valve and the pulmonary trunk at the top of the image, above the aortic valve.

Sweeping with the probe, from an upward left side angle progressively down toward the right side shows the various sections in succession with the structures from the base toward the apex of the heart.

2.1.7 Right Parasternal View

The probe is placed on the right side of the sternum, at the third intercostal space or one intercostal space above or below. This view is used to get a better image of the aortic valve and to measure transaortic blood flow in line with the ultrasound beam. To bring the aorta forward near the anterior thoracic wall, the patient is rolled on to the right side. The 2D image shows the aortic valve and the ascending aorta. CFM can be used as a guide to place the cursor along the transaortic flow for continuous

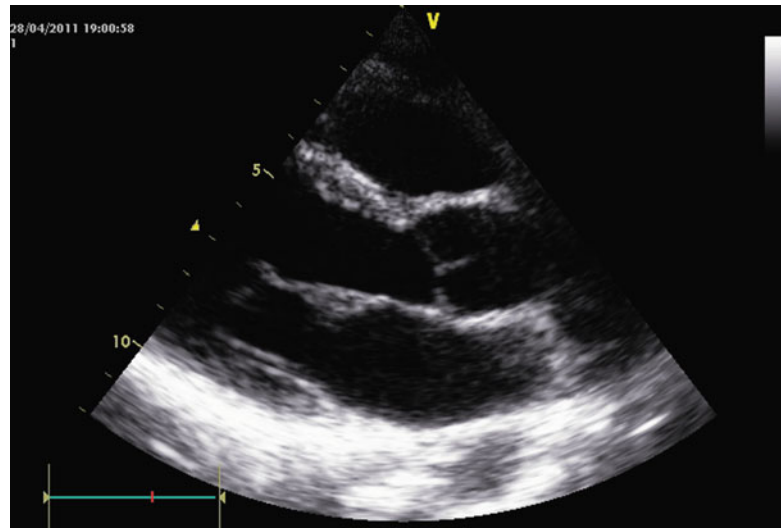

Fig. 2.7 Parasternal long-axis view

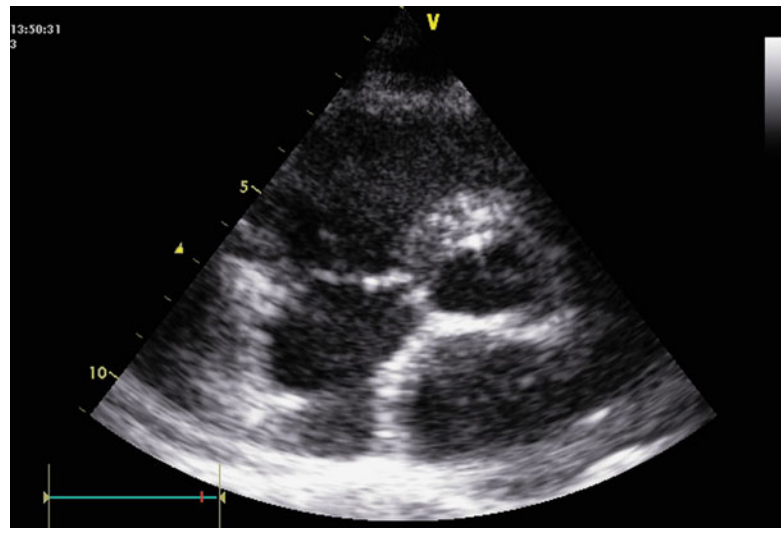

Fig. 2.8 Parasternal long-axis view modified for the right ventricular inflow tract

wave Doppler interrogation. In pediatric practice, a high right parasternal view with the marker pointing at the left leg enables examination of the right atrium, superior vena cava, and left atrium. The right pulmonary artery and upper right pulmonary vein may also be visible.

2.1.8 Apical Four-Chamber View

The probe is placed in the area of the apical cardiac beat with the marker pointing toward the left hand (raised to the head) of the patient (Fig. 2.14). The probe is slid up and down and to the side in the search for an image that dissects the heart into its four chambers with the interventricular septum in the middle, the apex at the top, the left ventricle, with its normal rugby-ball shape, on the right side, and the right ventricle, with its triangular shape, on the left of the display (Fig. 2.15). This image shows the left ventricular septal and lateral walls. Toward the bottom of the image the atrial septum can be seen, with the two atrioventricular valves

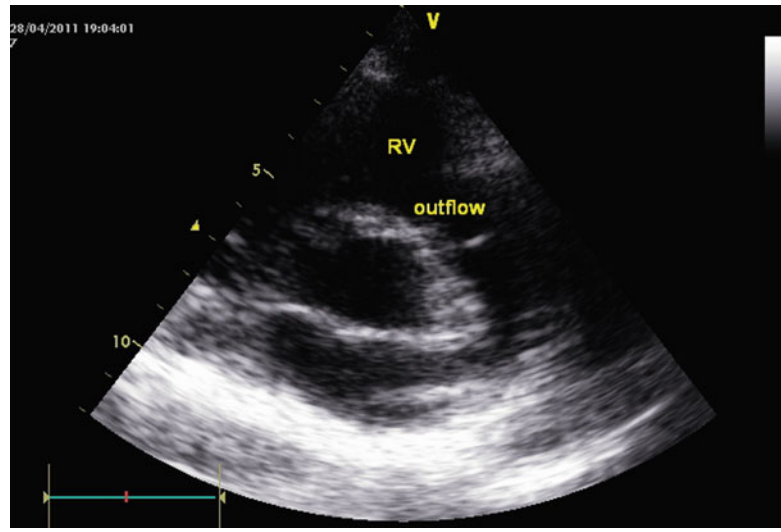

Fig. 2.9 Parasternal long-axis view modified for the right ventricular outflow tract and the right pulmonary artery. *RV* right ventricle

Fig. 2.10 Probe position for the parasternal short-axis view and the section line of the marker. (Modified from Sarti 2009 with permission)

horizontal, the mitral valve on the right and the tricuspid valve on the left. The atrial chambers, the left chamber on the right and right chamber on the left, take up the bottom of the image. The bottom right of the image often reveals one or two pulmonary veins draining into the left atrium.

Small movements and small changes of angles are made to try and obtain the maximum possible length of the left ventricle and evidence of both endocardial and epicardial edges of the apex. The apex thickens in systole, but does not move toward the base of the heart. If the image shows that the apex actually moves

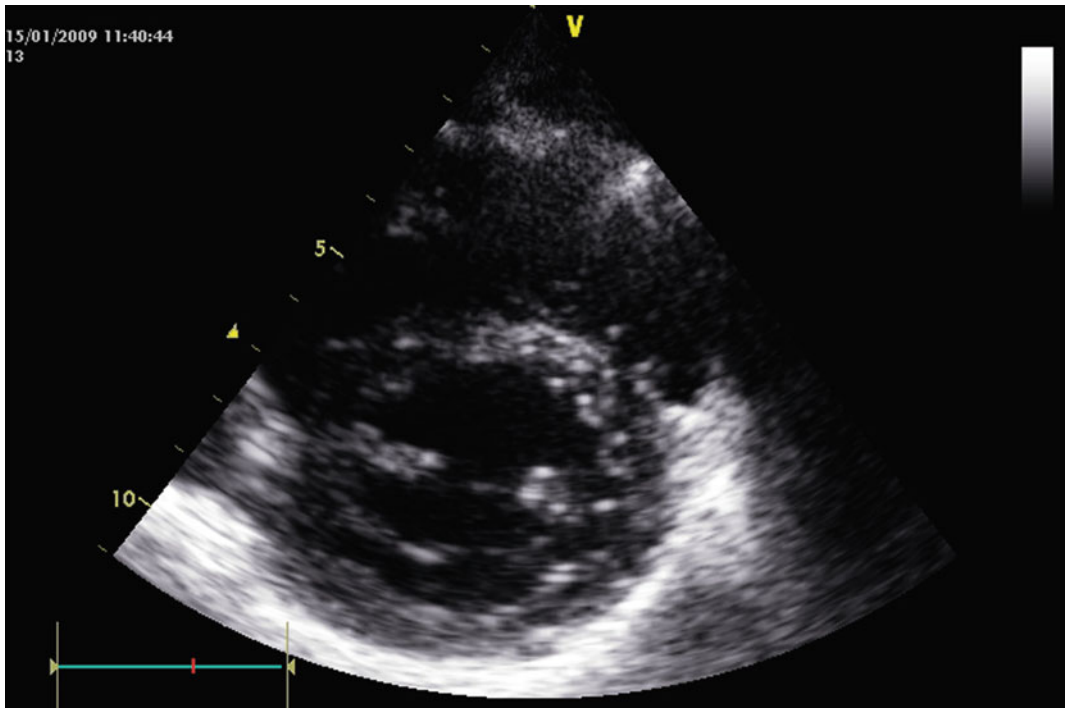

Fig. 2.11 Parasternal short-axis view at the level of the mitral valve (diastole)

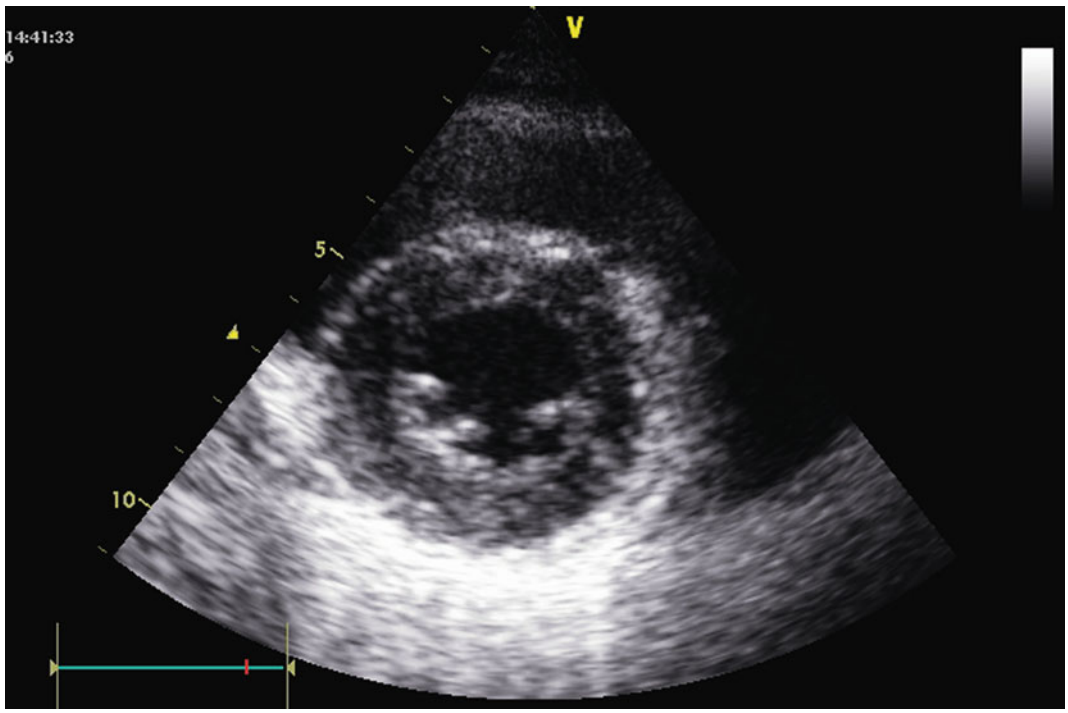

Fig. 2.12 Parasternal short-axis view at the level of the papillary muscles

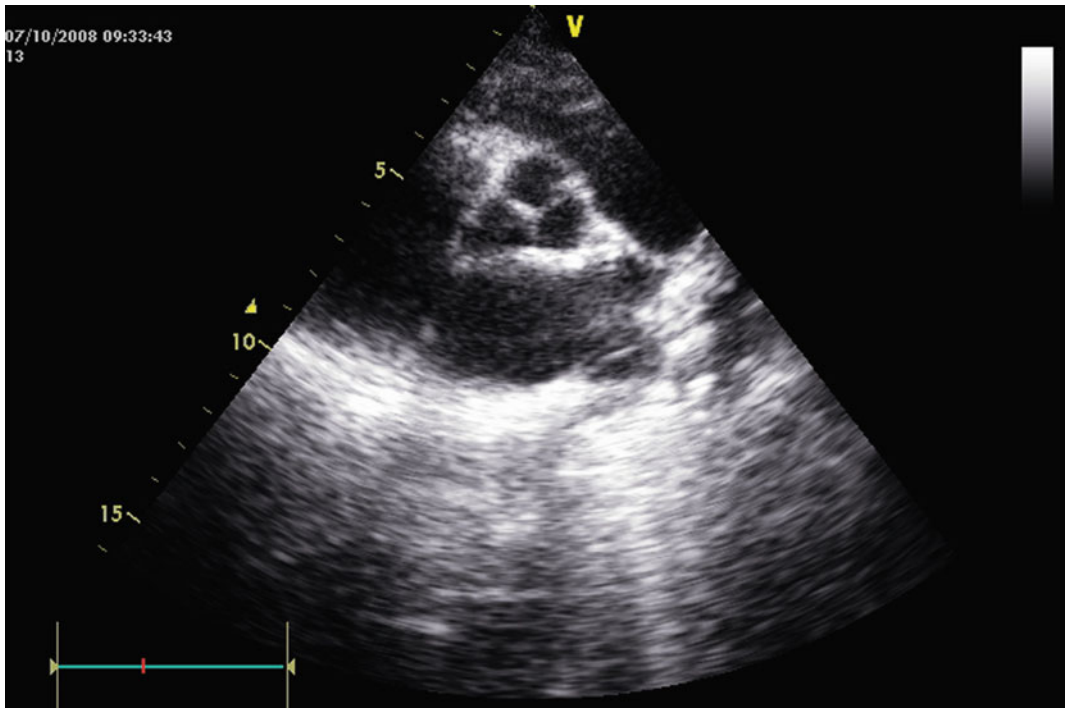

Fig. 2.13 Parasternal short-axis view at the level of the aortic valve ("Mercedes sign" in diastole) and right ventricle

Fig. 2.14 Probe position for the apical four-chamber view and the section plane. (Modified from Sarti 2009 with permission)

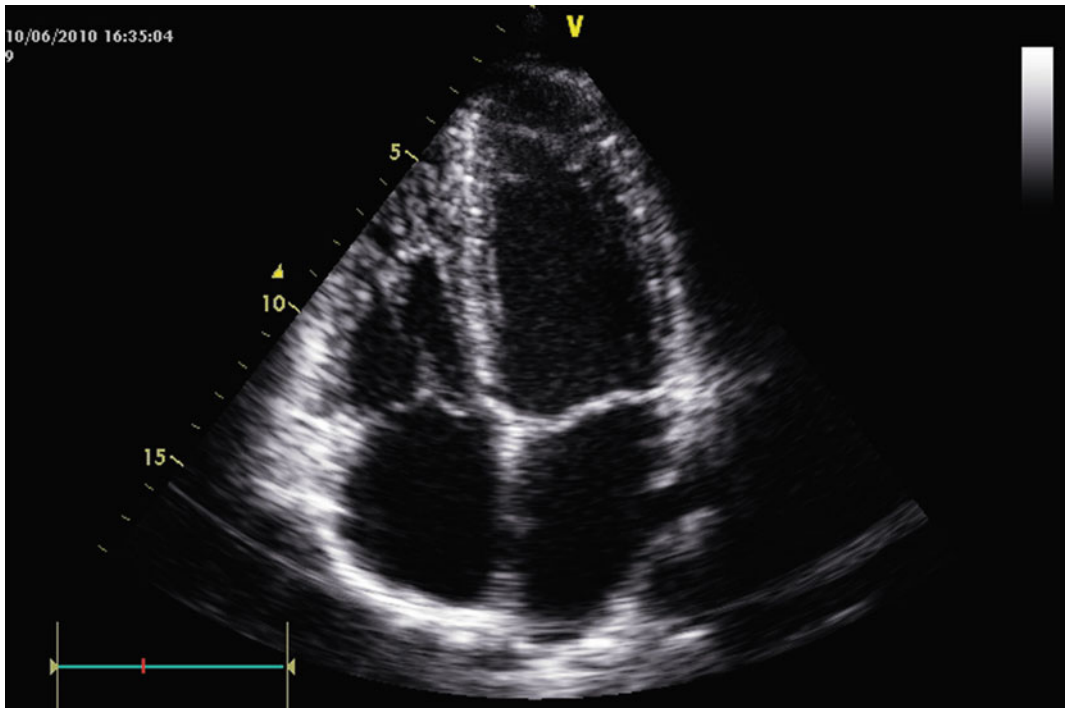

Fig. 2.15 Apical four-chamber view

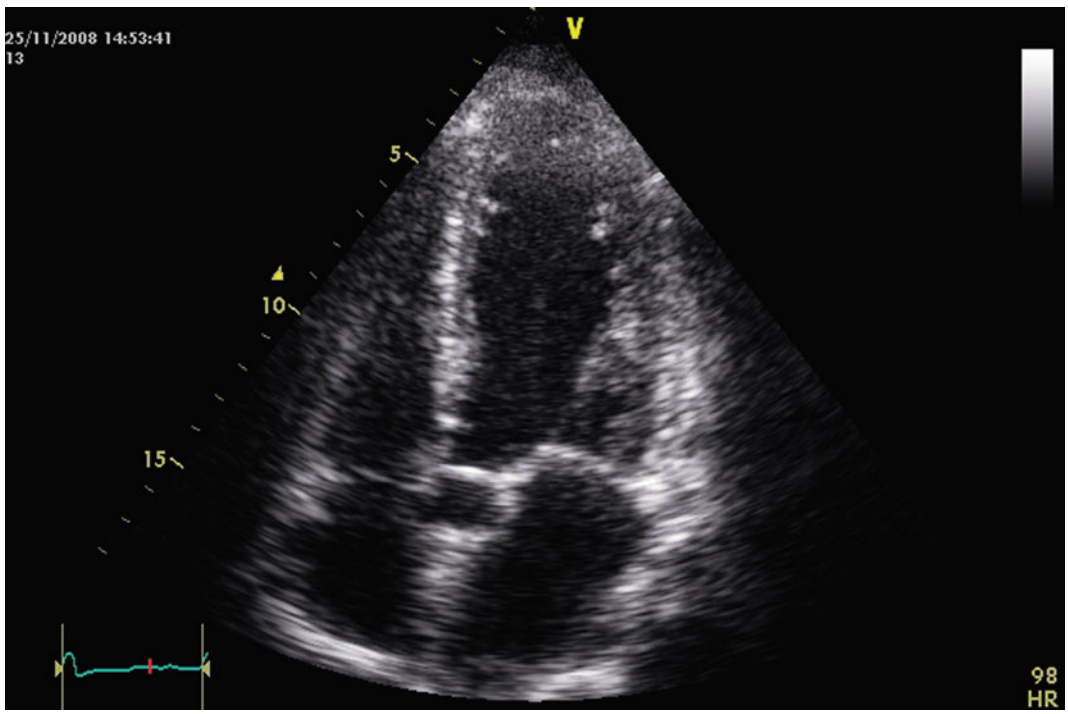

Fig. 2.16 Apical five-chamber view. (From Sarti 2009 with permission)

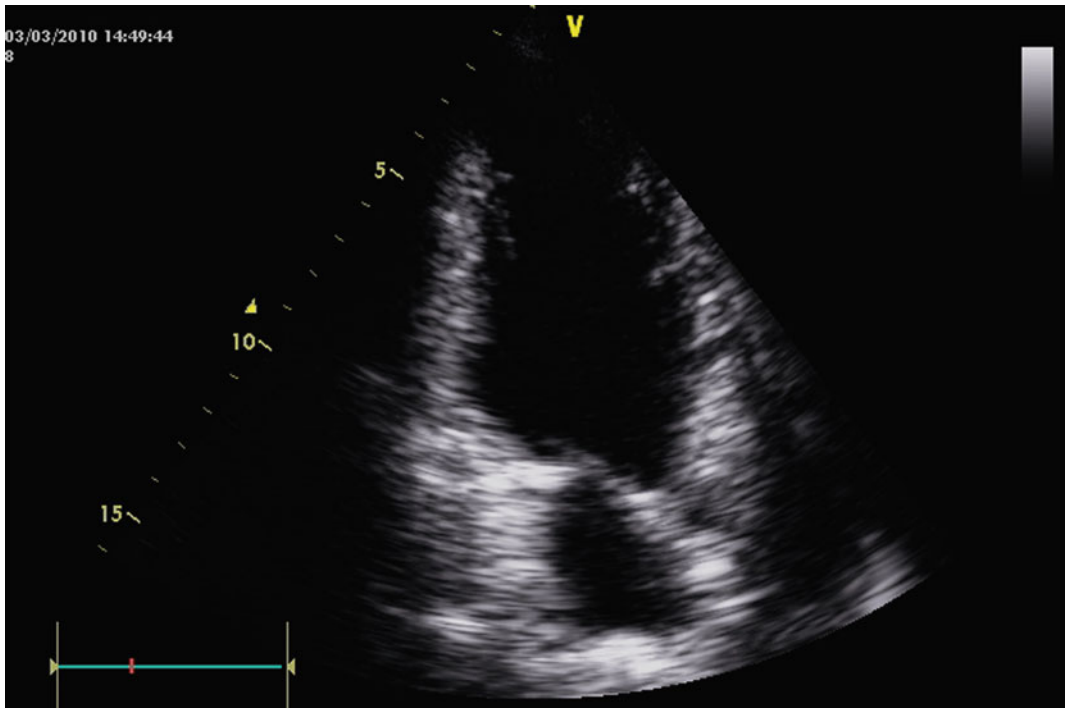

Fig. 2.17 Apical two-chamber view

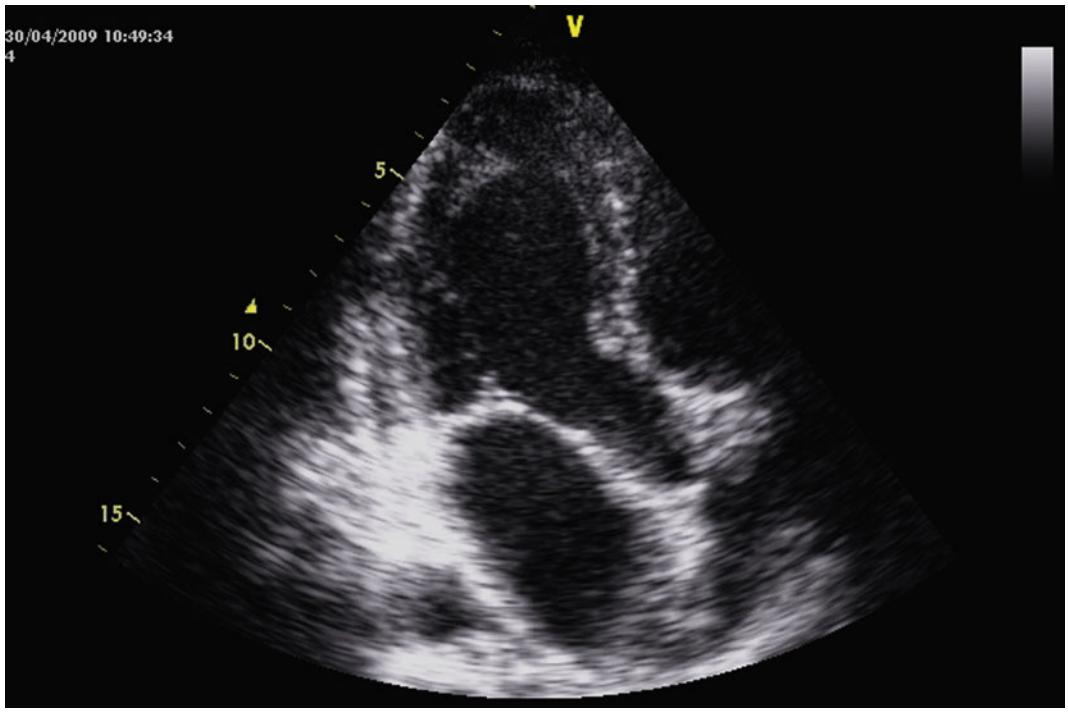

Fig. 2.18 Apical three-chamber view

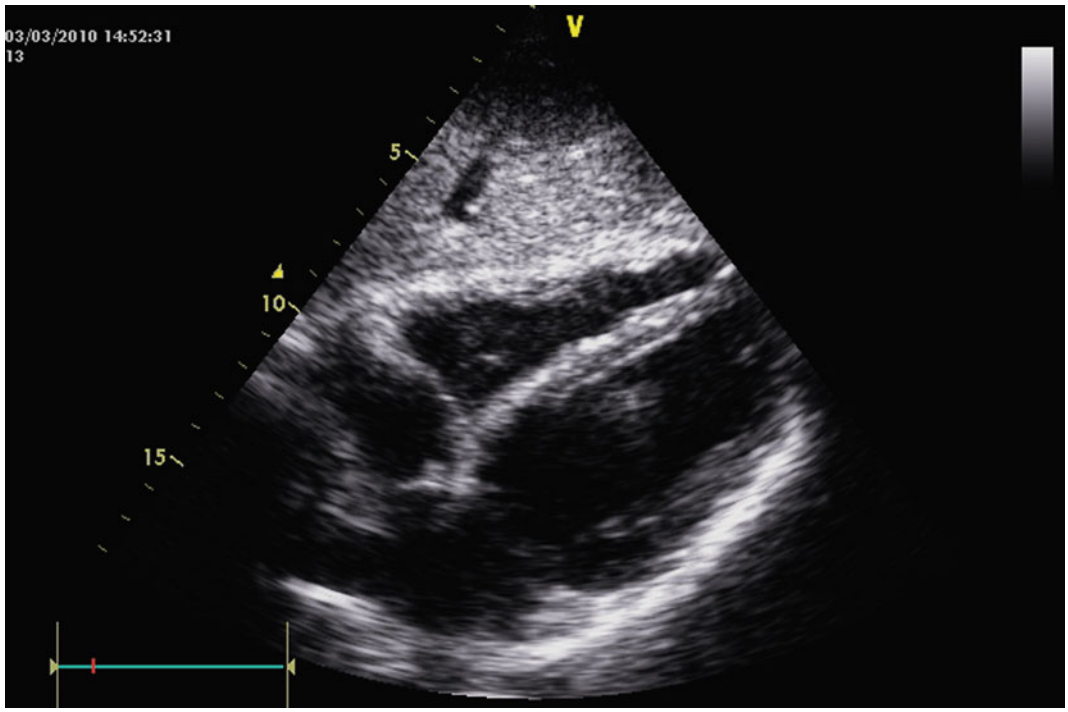

Fig. 2.19 Subcostal four-chamber view

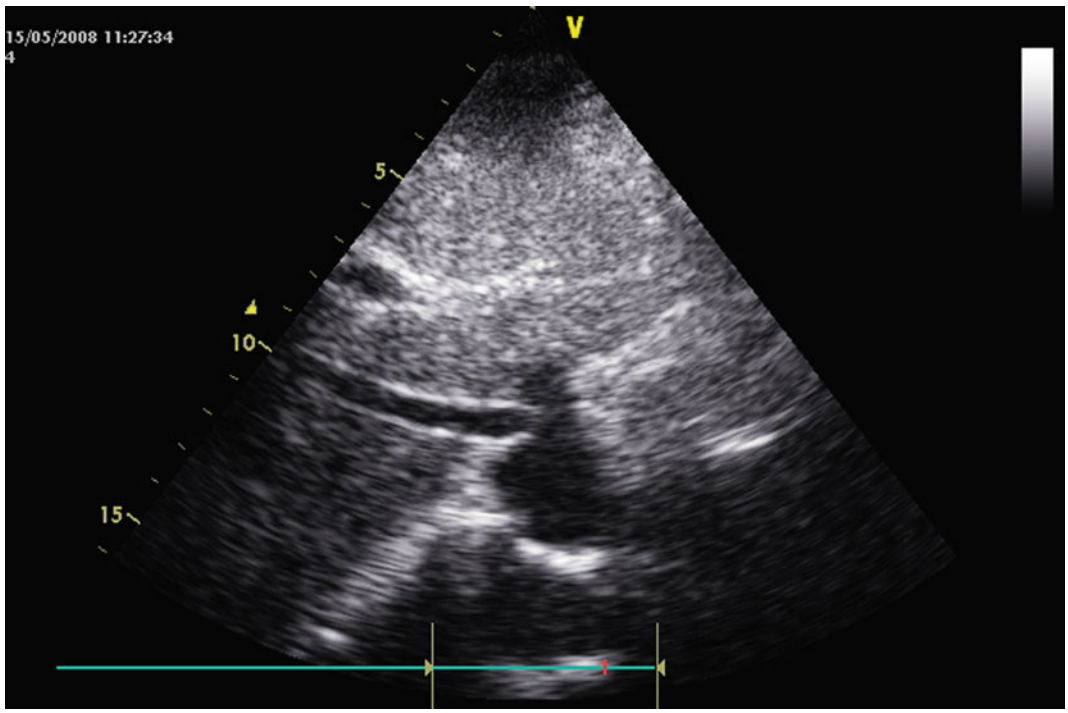

Fig. 2.20 Subcostal view modified for the inferior vena cava

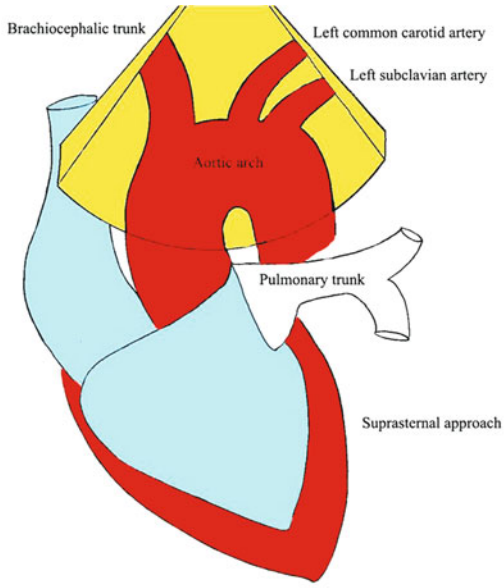

Fig. 2.21 Suprasternal view. (From Sarti 2009 with permission)

toward the atrioventricular valves, the section plane is not correct.

This view is used for various measurements, including ejection fraction, septal kinetics (right coronary artery for a short distance baseline and anterior descending artery up to the apex) and lateral wall kinetics (circumflex artery) of the left ventricle, kinetics and measurements of the right ventricle, and the morphological and Doppler study of the valves and transvalvular flows.

2.1.8.1 Apical Five-Chamber View

From the position for the apical four-chamber view, the probe is angled up slightly and sometimes rotated a little to highlight the left ventricular outflow tract (fifth chamber) with the aortic valve. This apical five-chamber view (Fig. 2.16) is used to evaluate the aortic outflow chamber and the flow toward the aorta or an aortic regurgitation because of good alignment of the ultrasound beam and thus reliable Doppler measurements.

2.1.8.2 Apical Two-Chamber View

From the position for the apical four-chamber view, the probe is rotated about 90° counterclockwise, resulting in a section plane perpendicular to the four-chamber view. Sections of the right side of the heart disappear and only the left side of the heart is now visible. The left atrium is at the bottom of the image and the left ventricle is at the top, with the mitral valve in between the two (Fig. 2.17).

The inferior wall of the left ventricle (right coronary artery from the base to the top of the apex) is on the left side of the image, and the anterior wall is on the right side (anterior descending artery).

For the biplane method, the left ventricular measurement of the ejection fraction, already done in the apical four-chamber view, is repeated in the apical two-chamber view. The mitral valve is examined in the apical two-chamber view with another plane and at a different level in relation to the apical four-chamber view.

2.1.8.3 Apical Three-Chamber View

Further rotation of the probe, approximately 45° counterclockwise from the position for the apical two-chamber view, still shows the left ventricle and left atrium (Fig. 2.18). Furthermore, on the right of the display, the left ventricular outflow tract can be seen (third chamber). This section is similar to the parasternal long-axis view but is oriented with the apex at the top and the base of the heart at the bottom. However, in contrast to the apical three-chamber view, the parasternal long-axis view does not normally show the apex. The anteroseptal wall of the left ventricle is on the right, and the posterior wall is on the left.

2.1.9 Subcostal View

This fundamental projection must never be omitted, particularly in emergency and intensive care practice. In patients on mechanical ventilation or with emphysema and in cases where the patient cannot be moved to the side, the subcostal approach may be the only approach which allows assessable images to be obtained. The patient lies in the supine position with the trunk raised to 45°, the knees bent, and the hips flexed slightly to relax the abdominal wall. The probe, held flat with the thumb and forefinger of the right hand, is placed under the xiphoid process (Fig. 2.4), with the marker toward the left

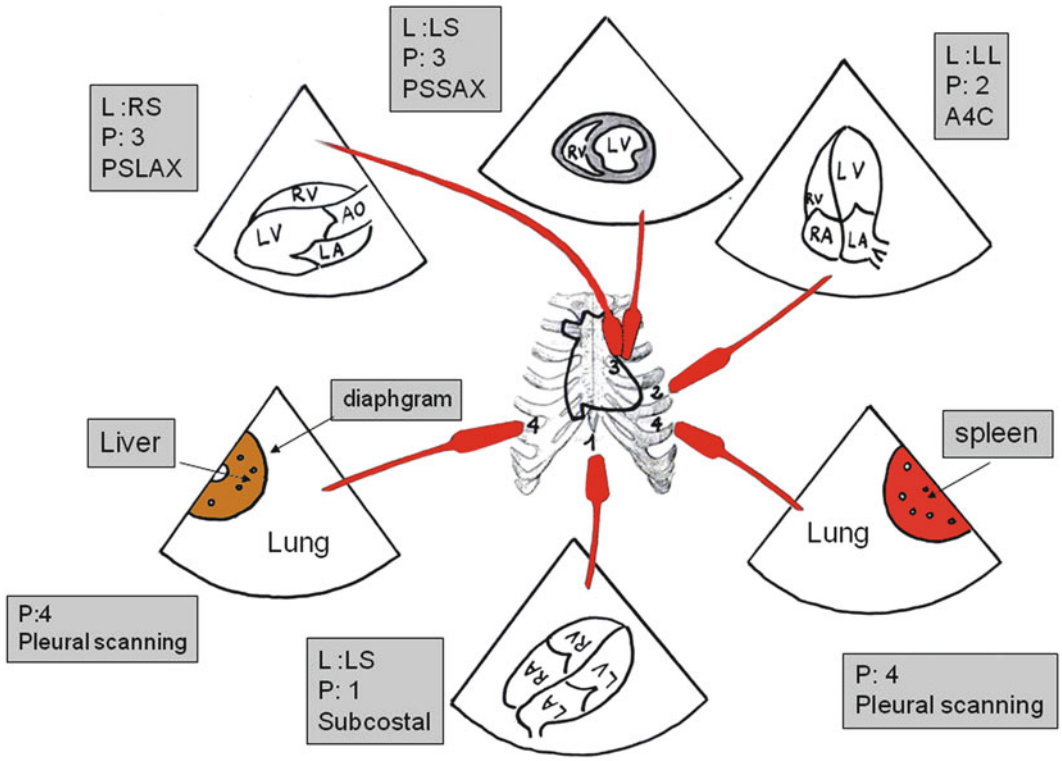

Fig. 2.22 Outline of the probe positions and main views. *L* probe landmark, *P* probe position, *RS* right shoulder, *LS* left shoulder, *LL* left leg, *PSLAX* parasternal long axis, *PSSAX* parasternal short axis, A4C apical four chamber

shoulder and a variable angle, moving slightly left or right of the midline, in the search for a subcostal four-chamber view (Fig. 2.19). The liver, with its characteristic echo structure, is the essential reference. The right side of the heart is placed at the top of the image, and the left side is placed at the bottom. The observable walls of the left ventricle are the septal and posterolateral walls. The interatrial septum is seen here in its full length with good definition of the thin foramen ovale. Any possible shunt through the open foramen ovale can be studied with this approach with CFM and pulsed wave imaging. A right-to-left shunt can also be demonstrated with the microbubble contrast produced by the quick injection of agitated saline into a vein and flowing from the right atrium to the left atrium.

A greater upward angulation of the probe shows the outflow of the left ventricle and the structures of the right side of the heart with the inflow and outflow of the right ventricle and valves. In contrast, angling the probe downward toward the abdomen may show the abdominal aorta. A shift of the probe to the left, toward the right side of the patient, brings out the inferior cava vein and hepatic veins, which enter horizontally into the right atrium (Fig. 2.20). The size of the inferior cava vein and the respiratory changes of its caliber provide information on the venous filling and blood volume of the patient. In this view, the intrahepatic veins run vertically down to reach the inferior vena cava in line with the ultrasound beam. Thus, pulsed wave Doppler echocardiography can be used to show venous intrahepatic blood flow.

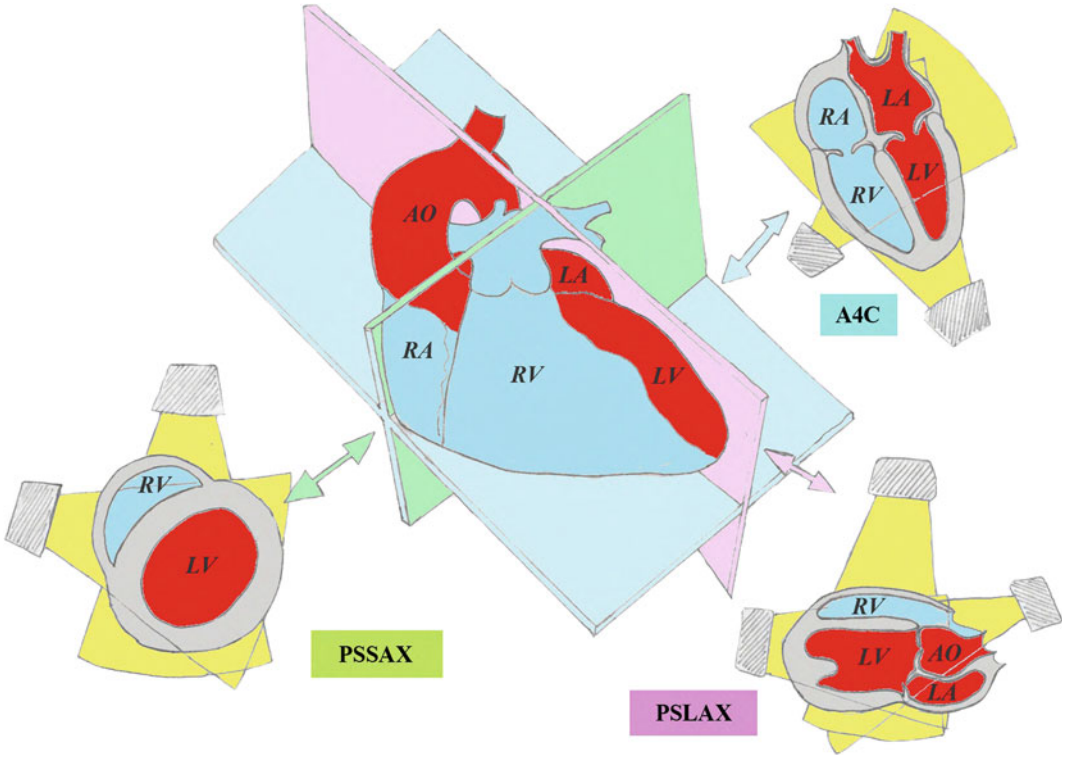

Fig. 2.23 Outline of the echocardiographic section planes and views. *A4C* apical four chamber, *AO* aorta, *LA* left atrium, *LV* left ventricle, *PSLAX* parasternal long axis, *PSSAX* parasternal short axis, *RA* right atrium, *RV* right ventricle. (Modified from [1] with permission)

A rotation of 90° counterclockwise starting from the baseline subcostal four-chamber view produces subcostal cross sections of the heart, similar to those obtained with the parasternal short-axis view. An inclination to the right gives sections toward the apex of the heart, whereas an inclination to the left explores sections of the base.

2.1.10 Suprasternal View

To obtain suprasternal images the patient is raised to at least 45°, with the head extended on the neck. In certain circumstances this approach is not easily done in the ICU or is clearly contraindicated (neck trauma). The probe is placed on the supraclavicular area just above the sternal manubrium, directed toward the chest with the marker pointing at the left shoulder (Fig. 2.5). A little movement or angulation is used to find part of the aortic arch and descending aorta (Fig. 2.21). Manipulating the probe to the right can show the ascending aorta. CFM is then used to define the aorta and its branches. A slight rotation of the probe may show the left atrium and pulmonary veins. The right branch of the pulmonary artery often appears below the aortic arch. This view is not always used. It may allow evaluation of the aorta in thoracic trauma or suspicion of dissection, but transesophageal echocardiography is far more effective for this purpose.

2.1.11 Overview

Figure 2.22 shows a summary diagram of the various probe positions with corresponding images. Fig. 2.23 outlines the main transthoracic views according to the section planes. Table 2.1 describes the movement of the probe, as position, pointing, angling, and

rotation, the structures to be seen, and the main measurements to be done.

The first echo examination of an ICU patient should include most of these views in regular sequence. Even if not all views are obtainable, a routine sequence must be tried all the same to avoid missing important unexpected information. All the structures should be identified to discriminate between normal and any deviation from normal using each usable echo modality, including M-mode echocardiography, Doppler echocardiography, and tissue Doppler imaging. Afterward, at the end of the first examination or during another assessment, the examiner focuses on particular views for specific purposes or monitoring.

Reference

1. Sarti A (2009) Ecocardiografia per l'intensivista. Springer, Milan

Further Reading

Feigenbaum H, Armstrong WF, Ryan T (2005) Feigenbaum's echocardiography. Lippincott Williams & Wilkins, Philadelphia

Oh JK, Steward JB, Tajik AJ (2007) The Echo manual, 3rd edn. Lippincott Williams & Wilkins, Philadelphia