ECHOCARDIOGRAPHIC EXAMINATIONS I.

STANDARD VIEWS, NORMAL VALUES

(Attila Tóth Ph.D.)

1. GOALS OF THE CHAPTER

- To gain a better understanding on the anatomy and physiology of the human heart,
- Introduction in the methodology of echocardiography (standard views),
- Understanding the limits of echocardiography and the knowledge accumulated in this basic course.

2. ECHOCARDIOGRAPHY: THEORY AND APPLICATIONS

2.1 Physical basis

The physical basis of echocardiography is the generation of sonic waves, reflection of these waves on the tissues and the detection of these reflected waves.

There are four important characteristics of sonic waves: speed (velocity) of propagation (c), wavelength (λ), frequency (f) and amplitude (A) (Fig. 1).

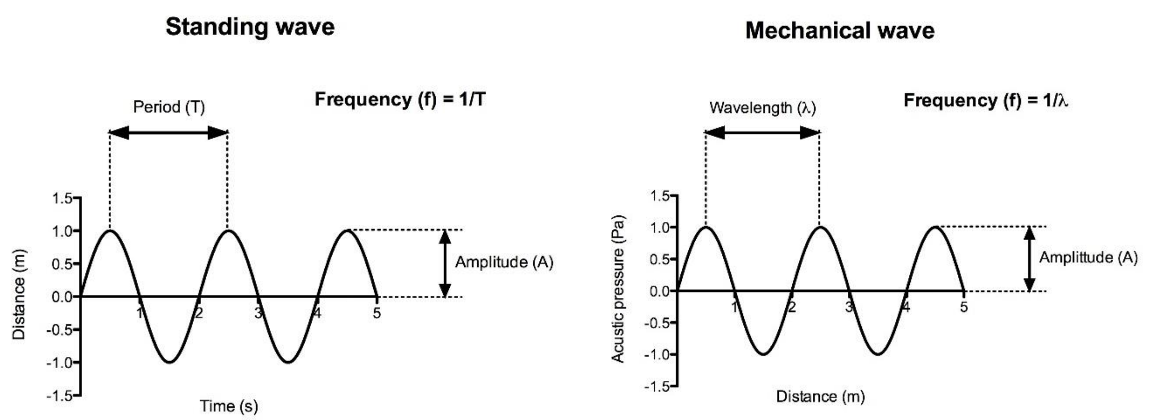

Figure 1

Properties of waves

The development of this curriculum was sponsored by TÁMOP 4.1.1.C-13/1/KONV-2014-0001. The project is supported by the European Union and co-financed by the European Social Fund.

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Propagation of acoustic waves is a cyclic change in the density of the matter, but there is no transfer of matter. There is only movement of energy, which energy is proportional with the amplitude of the acoustic waves. The speed of wave propagation depends on the type of the wave and the type of the matter conducting the wave.

The speed of the propagation of the acoustic waves in the human body is about 1540 m/s. This speed is somewhat slower in fat tissue and faster in muscle tissue. The traveling time is measured during echocardiography (from the wave generator to the detector). The transducer incorporates both the acoustic wave generator and acoustic wave detector (piezoelectric crystal), therefore the time between the generation and detection of the acoustic wave can be determined and then the distance of the tissue reflecting the generated acoustic wave can be calculated (Fig. 2)

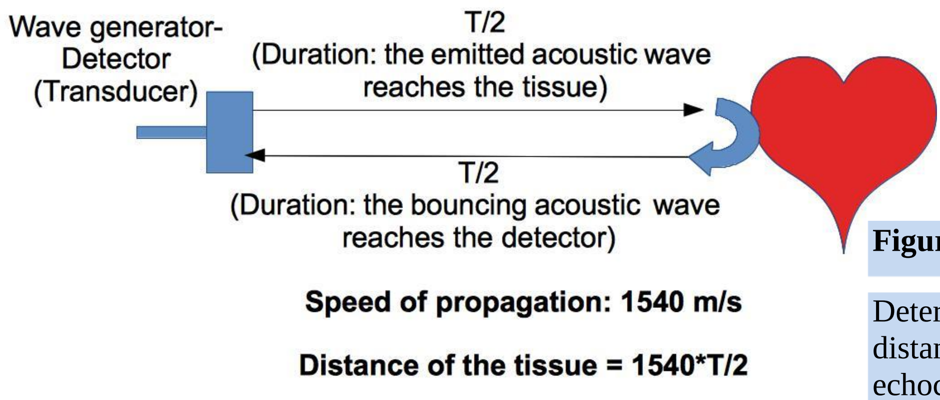


Figure 2

Determination of the distance of the tissue in echocardiography

The spatial and temporal resolution of echocardiography is proportional with the frequency of the generated acoustic wave. However, the penetration of the acoustic wave is inversely proportional with the frequency, providing a limitation for the increase of frequency. In general, acoustic wave frequency is in the range of 2-20 MHz in echocardiography.

2.2 Physical effects at the interaction of ultrasound with the tissue

2.2.1 Attenuation

It is proportional with the distance of the tissue. Some of the energy invested into the generation of the acoustic wave is transformed to heat. This is limiting the distance of tissue visualization.

2.2.2 Reflection

Some of the waves are bouncing back from the surface of tissues with different acoustic density. The reflection of acoustic wave is called echo, and the tissue examined is the heart, hence the name of the method is echocardiography. The goal of echocardiography is to detect the reflected waves. The reflected wave intensity is in the range of 0.1-5% in echocardiography. Echoes can be generated on the boundary of muscle tissue (cardiac, skeletal or smooth muscle) and blood, because these tissues have a different acoustic density. It is important to note, that there is complete reflection between soft tissues and air (if there is air between the transducer and the tissues, the examination is impossible).

2.2.3 Refraction

The acoustic wave is changing its direction upon traversing tissues with different acoustic densities. This feature can interfere with echocardiographic imaging in which case the longitudinal propagation of acoustic waves is expected.

2.2.4 Scattering

The acoustic waves can be reflected in different directions when reaching an uneven surface. This negatively affects the quality of echocardiographic image generation.

2.3 Common modes of the application of echocardiography

2.3.1 „B" mode

The intensity of the reflected acoustic wave (shown as **B**rightness) is plotted as a function of the distance. The transducer usually consists a number of crystals, resulting in the properly oriented sets of acoustic waves (tens to hundreds) making it possible to generate a "2D" image. This technique is able to give information on the acoustic density, distance and orientation of the tissues. This mode is used to visualize static or slowly motioning tissues. A technique called "speckle tracking" is based on this mode. Outlines of the tissue are defined and movement is being analyzed according to the motion of tissues in the heart by using the naturally occurring speckle pattern in the myocardium. The speckles are determined in the consecutive image frames and their apparent movement (shift in the 2D image) is correlated with the frame rate (speed) of the imaging, giving detailed information on the movement of the speckle containing tissue.

2.3.2 „M" mode

The distance from the transducer is plotted as a function of time. This mode is suitable to visualize the movement (since the name: Motion) of the tissues and generally used for the echocardiographic measurements. It can be used to measure the properties of the moving tissues (such as ventricular wall) and to perform calculations based on these morphometric data (such as calculating the ejection fraction).

2.3.1 Doppler mode

The frequency of the echo wave depends on the movement of the tissue on which the acoustic wave bouncing. When the movement occurs towards the transducer, the echo wave frequency increases, while when the tissue moves away from the transducer the frequency is decreasing (Doppler shift). Important to note, that Doppler signal is direction sensitive: it is maximal when the movement occurs in parallel with the transducer, on the other hand no Doppler shift is detected when the trasducer is prepedicular to the direction of the movement. Therefore, Doppler measurements should be taken as paralell as possible with the movement.

There are two types of Doppler measurements: pulsatile and continuous. The sonic wave is continuously emitted and detected in continuous Doppler measurements. Movement is being detected by changes in reflected wave frequencies. Movement can be observed in the full 2D field. This technique is particularly suitable for the visualization of fast (>1.5 m/s) movements. The sonic wave is being repeatedly emitted in the pulsatile Doppler. The frequency of the reflected wave is a function of the speed of the movement of the object in the beam. Pulsatile Doppler is therefore „site specific" (in contrast with the continuous Doppler), although its resolution is limited by the frequency of sonic waves. In practice, pulsatile Doppler is suitable to measure speed of movement in the lower range (<1.5 m/s).

The Doppler signal can be color-coded. Movement toward the transducer is usually represented by red, movement away represented by blue and the brightness (depth) of the colors correlate with the speed of the movement. Turbulent flow can also be visualized by yellow or green depending on the preference of the examiner or the manufacturer. Important that pulsatile

Doppler is usually used on a region of interest defined on the 2D field (hence „site specific" or directed).

The Doppler technique is well suited for the measurement of the speed of blood flow, but movement of tissue (e.g. walls of the cardiac chambers) can also be observed by this method. This application is called tissue Doppler Imaging. Tissue Doppler Imaging can be used to characterize slow movements with large amplitudes. It can also be color-coded.

2.4 Indications for echocardiography

Echocardiography is a diagnostic tool, which can be used to address various questions related to the morphology and physiology of the heart. Its simplest form (transthoracic) is a non-invasive, painless method. It is relatively commonly used, although it requires specialty equipment and relatively long to perform. As you will see, the evaluation of the most frequently used images is relatively simple, although recording of images with sufficient quality requires considerable experience.

2.4.1 Indications for transthoracic echocardiography

- Cardiac complaints (pain, breathlessness, etc.)
- Assessment of congenital heart disease
- Evaluation of suspected myocardial ischaemia or infarction
- Examination of murmurs
- Examination of valves (either diseased or prosthetic)
- Diagnosis of endocarditis
- Evaluation of the cardiac mass (thrombus or tumor)
- Evaluation of the pericardial region (pericarditis)
- Assessment of the Marfan's disease with a particular attention to the aortic root and the mitral valve
- Assessment of the cardiomyopathy

3. TRANSTHORACIC ECHOCARDIOGRAPHIC EXAMINATION

The examination starts with overlaying an echocardiographic gel on the surface of the transducer to form a airless contact between the transducer and the body. Important, that there is a mark on the transducer to indicate the "up" direction (Fig. 3).

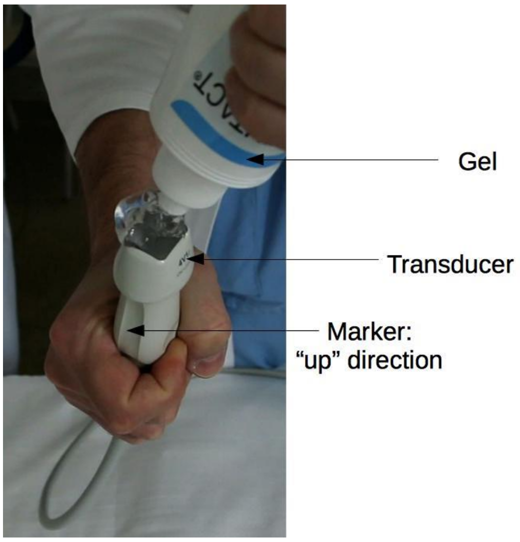


Figure 3

The transducer and the echocardiographic gel

3.1 Standard views: the position of the transducer

The patient is requested to lie on his left side (left lateral decubitus position) and put his left hand under his head. The transducer is positioned above the heart, besides to the sternum. There are two important views from this position. The transducer is positioned in parallel with the longitudinal axis of the heart (parasternal long axis view, Fig. 4). The position of the transducer is in the 3rd intercostal space leftward to the sternum. The marker ("up" sign) points toward the right shoulder of the patient: the great vessels and the atria are visualized upward, while the ventricles are downward. The position of the heart is shown by red overlay for better understanding. This view is called as long axis view, because the image is viewed from the direction of the long axis (also shown on the figure). It is therefore possible to visualize all chambers of the heart from this view. There will be a detailed description later.

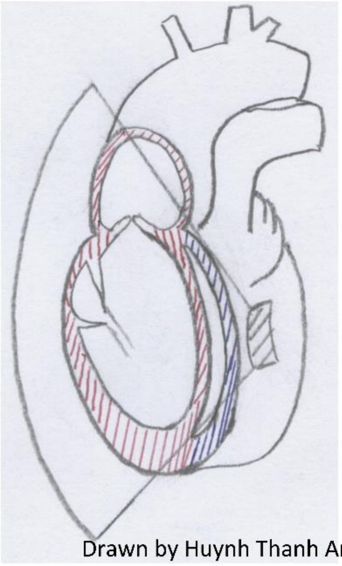


Figure 4

Parasternal long axis view

To produce the short axis views the transducer is turned perpendicular to the long axis position. Its position above the heart does not change much (although sometimes it needs to be moved to the 4th intercostal space). However, the "up" direction is toward the left side and the "down" position is toward to the right side (Fig. 5). The angle of the transducer determines what part of the heart is being visualized. The chambers of the heart as well as the valves can be examined with proper directions of the transducer.

The transducer can be positioned a little farther from the sternum to produce the apical view. In this case the transducer is above the apex of the heart (usually located at the 5th intercostal space). The "up" direction is toward the left side of the heart. Rotation of the transducer is necessary for the examination of different chambers and valves (Fig. 6).

Suprasternal and subcostal views are also important views during transthoracic echocardiography, but these are out of the scope of this introductory (basic level) chapter.

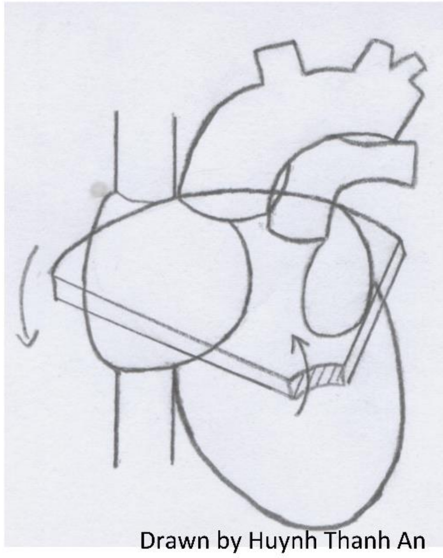
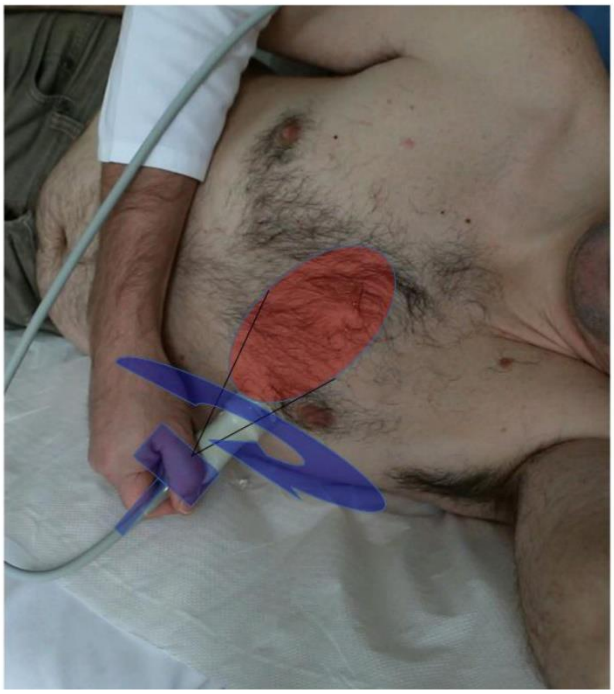


Figure 5

Parasternal short axis view



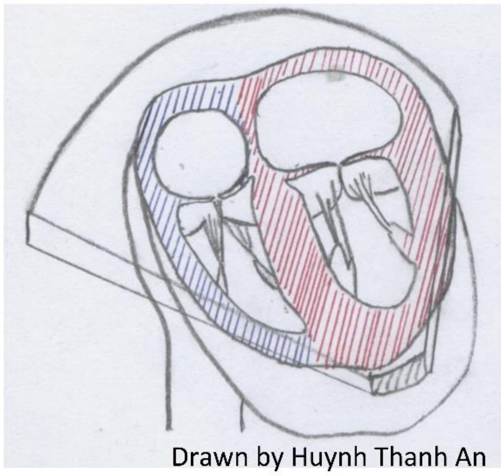


Figure 6

Apical view

3.2 Basic parameters determined by echocardiography

The standard views are used to determine the routine echocardiographic parameters, which are detailed in Table 1. Most of these numerical parameters are measured in “M” mode, but some are determined in Doppler mode.

Mode of determination	Parameter	Normal values
M-mode	Ejection fraction (%)	>50
M-mode	Thickness of the ventricular wall (diastolic, mm)	<12
M-mode	Diameter of the left ventricle (diastolic, mm)	<55
M-mode	Diameter of the left ventricle (systolic, mm)	<40
M-mode	Diameter of the left atrium (diastolic, mm)	<40
B and Doppler modes	Surface of the orifice of the aortic valve (systolic, cm^2)	3-4
Doppler-mode	Aortic pressure gradient (mmHg)	<5
Doppler-mode	E/A	1,0-1,9

Tablre 1: Basic numerical echocardiographic parameters (normal values)

4. Cases – Results of the echocardiographic examination

4.1 Fabry's disease

29 years old female patient showed up at our clinic. She is confirmed to harbor the Fabry's disease gene in a heterozygous manner. She has a single sign for the Fabry's disease: anhidrosis (lack of sweating). The goal of her visit is to assess the potential cardiac complications.

The Fabry's disease is an X-linked storage disease. The mutation is resulting in the lack of alpha-galactosidase. As a result globotriaosylceramide is accumulating in the blood vessels besides to other organs. The incidence of the Fabry's disease is 1:40-120 000. The symptoms are serious in homozygous and hemizygous individuals, while heterozygous individuals may have no apparent symptoms. Detailed examination of the individuals harboring the Fabry's disease gene is routine procedure, because of the occasional cardiovascular complications. Proper diagnosis is required for the appropriate treatment of the disease.

Symptoms include Raynaud's disease like neuropathic pain, angiokeratomas, anhidrosis, kidney failure, cardiomyopathy, etc..

4.1.1 Long axis views

The transthoracic echocardiographic examination usually starts with the long axis view. The chambers and valves can be visualized in this view. A good general picture can be gained about the morphology and functional properties of the heart. Here we show a picture, where the mitral and aortic valves can be seen and the size and function of the left ventricle can be determined. (Fig. 7). There is an ECG recorded on most pictures for better relation to the cardiac cycle.

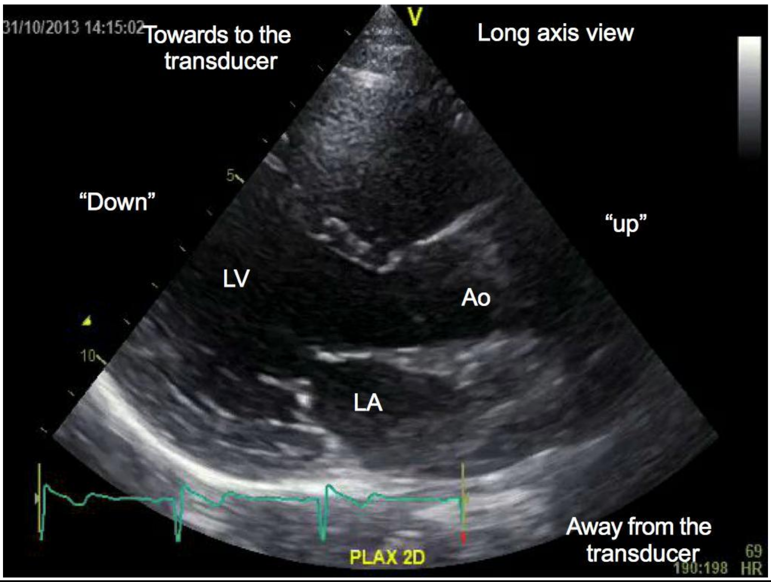


Figure 7

Parasternal long axis view

The parasternal long axis view is often used to estimate the systolic function of the heart. Measurements are being performed in a section of this view, below the mitral valve, but above of the origin of the papillary muscles, perpendicular to the long axis of the left ventricular chamber. This is being done in “M” (Motion) mode (Fig. 8). Note, that the same measurement can be performed from the short axis view, both sections are measuring the same parameters, the only difference is that they are perpendicular, but the left ventricular cavity is circular in these representations. The orientation of the sections on which the M-mode representation is made is clearly shown on Fig. 8 (dotted line on the long axis view). The M-mode results are shown on the bottom of the figure. The intensity of the reflection of the acoustic wave is represented by the brightness of the dots; and the distance of the tissues from the transducer is plotted as a function of time. The picture shows the movement of the tissues in the planar surface represented by the dotted line on the long axis view on the top. The dark region between the bright tissues represents the left ventricular cavity (chamber). The recorded ECG is also shown on the bottom of the figure. The diameter of the left ventricular chamber is maximal immediately before the QRS complexes. The left ventricular internal diameter at the end of diastole (LVIDd) is recorded at this time point. The left ventricular internal diameter at the end of systole (LVIDs) is recorded at the time when the contraction is maximal. The echocardiograph is able to calculate the ejection fraction (EF) based on these values. It is important to note, that these values are false if segmental hypokinetic movement (a sign for myocardial infarction or ischameia) is present. This view is used to measure the wall thickness in addition to the size of the left ventricular cavity. The bright tissue layer closer to the transducer represents the intraventricular septum (IVS), while the tissue layer on away from the transducer represents the posterior wall of the left ventricle (LVPW). Their thickness can be measured based on this M-mode picture during systole and diastole. The thickness is usually increasing during systole, but the normal values are for the thickness during diastole.

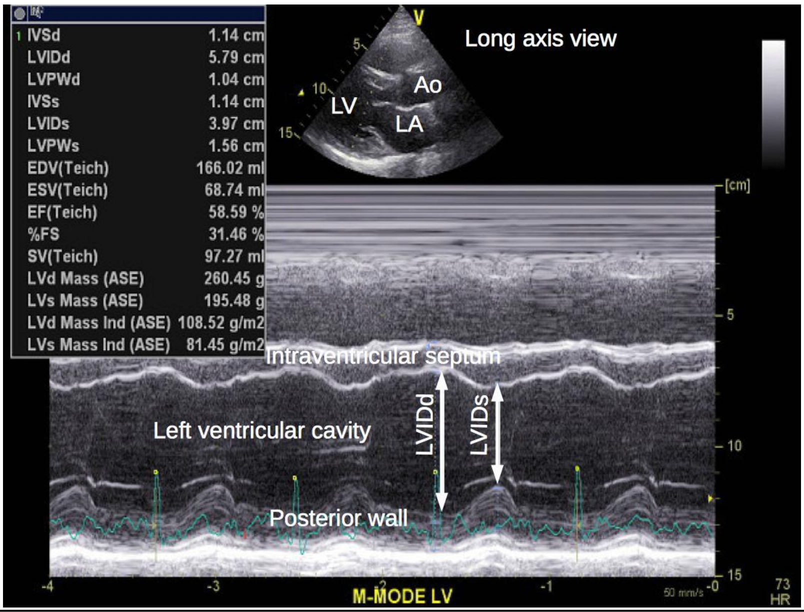


Figure 8

Parasternal long axis view, M-mode picture

The view is perpendicular to the left ventricular cavity, below the mitral valve and above the origin of the papillary muscle.

4.1.2 Parasternal short axis view

The short axis view is usually used for the assessment of the mitral stenosis and left ventricular morphology and function. Short axis view can be used to visualize the heart at different levels. The most important pictures are taken at the level of the mitral valve; somewhat below of this level and at the level of the origin of the papillary muscles. The pictures taken at the level of the mitral valve shows the orifice and the leaflets similar to the shape of the mouth of a goldfish (Fig. 9). Doppler measurements are used to evaluate the function of the valve.

Important, again, that left ventricular morphology and the ejection fraction can also be assessed from this view (based on M-mode images). These images are recorded below the mitral valve and above the origin of the papillary muscles.

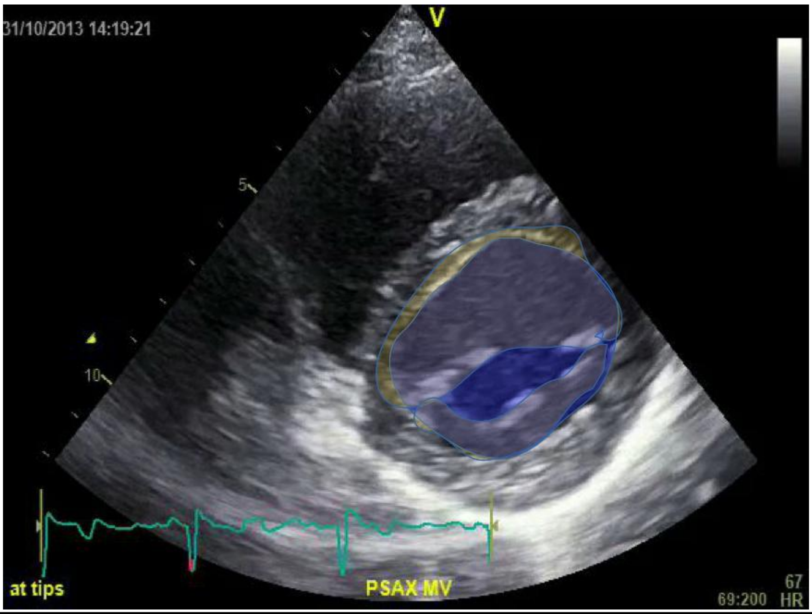


Figure 9

Parasternal short axis view at the level of the mitral valve

4.1.3 Apical view

The first apical view to be shown is the 5 chamber view (Fig. 10). All of the chamber and the aorta are shown on this single view (LV: Left ventricle; RV: right ventricle; LA: left atrium; RA: right atrium; Ao: aorta). The apical view is particularly important in the functional assessment of the aortic valve.

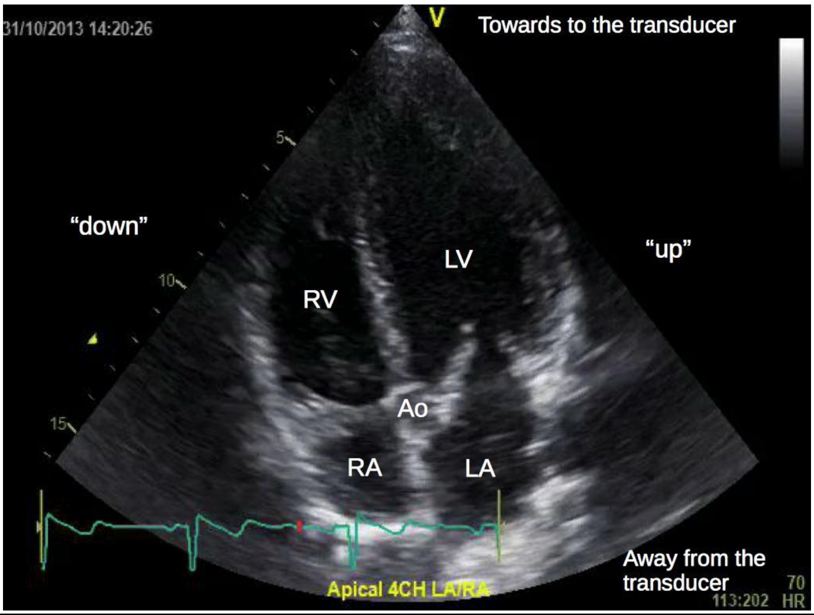


Figure 10

Apical 5 chamber view

The apical view can be adjusted to see only the four chambers without the aorta (4 chamber view, Fig. 11).

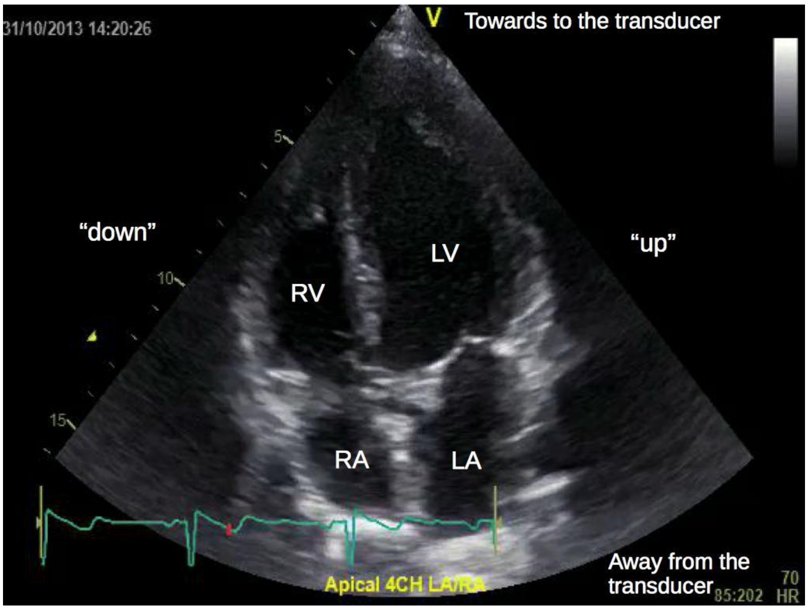


Figure 11

Apical 4 chamber view

The left ventricle and the left atrium can be assessed in detail from this view (Fig. 12). The mitral valve can be seen and its function can be assessed with some detail.

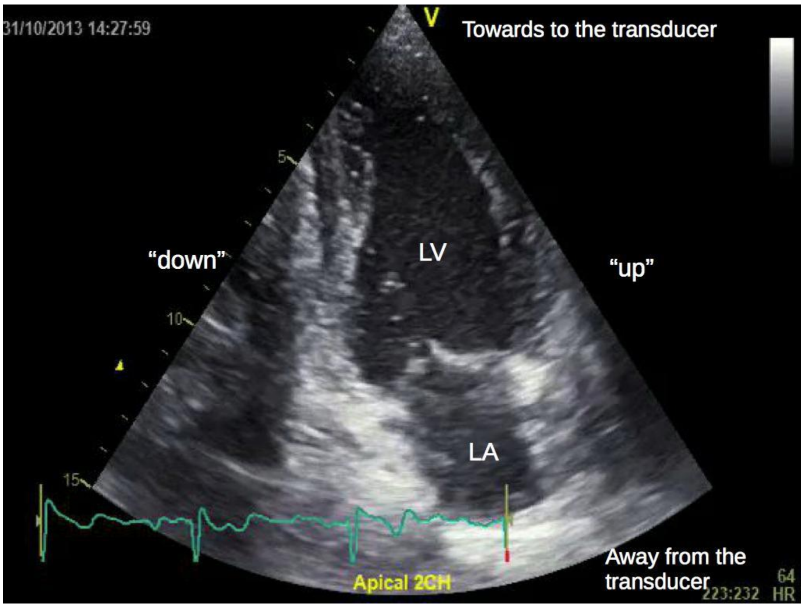


Figure 12

Apical 2 chamber view

Doppler measurement from the apical 4 chamber view is used to assess the blood flow through the mitral valve. Using this technique it is possible to estimate the role of the different phases of ventricular filling. The Early (E) phase of the filling precedes the atrial contraction, represented by the A phase (Fig. 13). The ratio of the Doppler signal intensity (amplitude) for these phases (E/A) is indicative of diastolic function. The normal range of E/A ratio is 1.0-1.9. As it is shown on the figure (Fig. 13) the apical 4 chamber view is used for the measurement. The direction of blood flow is depicted by the colors: red flows toward the transducer, blue flows away from the transducer. The brightness of the dots represents the velocity of blood flow. Important to note, that here the E/A ratio is in the normal range and that the blood flow is omnidirectional, it flows from the atria to the ventricle without turbulence.

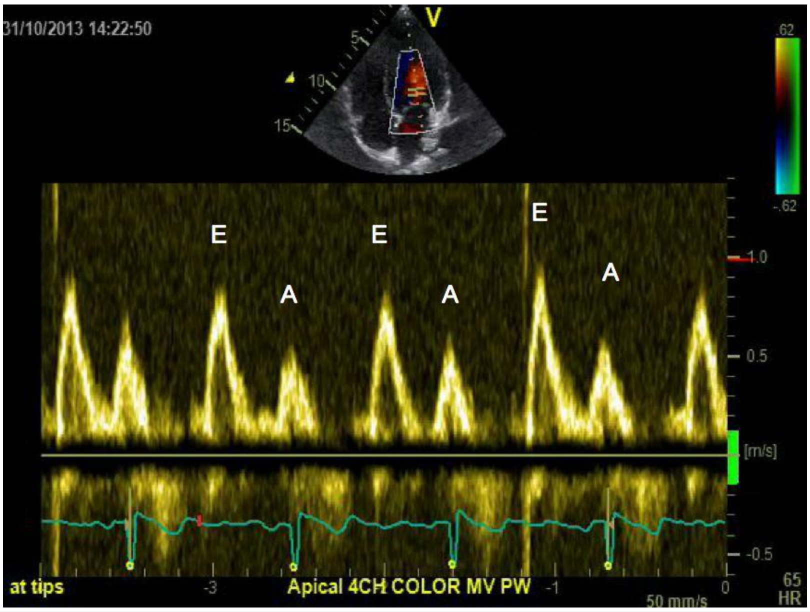


Figure 13

Apical 4 chamber view, Doppler image perpendicular to the mitral valve

Finally, the apical view is used to assess the motion of the inferior region of the heart. It needs to be noted, that description of wall motion is unequivocal for echo cardiologists with sufficient expertise, although the diagnosis itself is subjective in most of the time. There is a method (called speckle tracking), which can be used for objective assessment. The apical views should be recorded in three sufficiently different angles (by rotating the “up” mark of the transducer in apical position, Fig. 14) for that evaluation. The echocardiograph can track the motion of the dots representing the tissue on these views to generate an abstract representation of the movement of the inferior part of the heart. Such a representation can be seen on Fig. 14 by red. The homogenous red signal suggests normal ventricular motion in the inferior region. Note, that in the case of inferior myocardial infarction these regions would show inhomogeneity according to the hypokinetic wall movement of the affected regions.

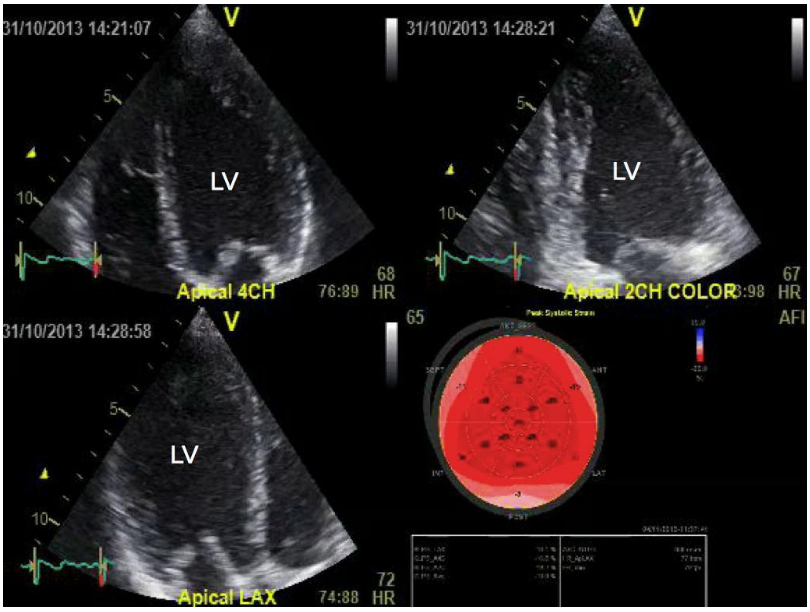


Figure 14

Apical views to detect altered contractility in the inferior region

In summary, this patient with Fabry’s disease had normal cardiac parameters. There are no echocardiographic signs for cardiac complications.

4.2 Aortic valve stenosis

67 years old male patient visited the Emergency Department with fainting (syncope). The neurological causes of fainting (stroke, brain ischemia) were ruled out, and it was revealed that the patient experiences breathlessness and chest pain upon medium scale exercise (physical activity). Moreover, the examiner observed murmur.

The aortic valve stenosis is a disease, which manifests in the form of calcifications of the aortic valve. In most of the cases the aortic valve consists of three leaflets (hence tricuspid), but in some cases (1-5% of the population) it only contains two leaflets. In these latter cases the occurrence of aortic calcification is much higher. Calcification usually occurs at the age of 70-80 for the tricuspid valves and considerably earlier (40-50 years old population) for the valves with two leaflets. In general, the aortic valve stenosis, which is the most common form of valve diseases, occurs at an average age of 65-70 years.

Calcification of the aortic valve narrows the opening of the aortic valve (orifice) and forms a barrier in the left ventricular outflow. The normal range for the surface of aortic valve orifice is 3-4 cm2 (Table 1). Aortic valve replacement or reconstructive surgery is usually indicated when this is narrowed below 1,0 cm2.

As a result of the stenosis of the aortic valve the left ventricular outflow surface is limited. As a result the left ventricle is generating a higher pressure to overcome this obstacle and to maintain the cardiac output. This results in systolic left ventricular overload. The accommodation to this elevated pressure is to increase the muscle mass, which leads to concentric cardiac hypertrophy. In a later stage of the disease, the cardiac chamber may dilate, in which case the ventricular wall thickness and the ejection fraction decrease (see systolic heart failure later).

The easiest sign for aortic valve stenosis is murmur, but its diagnosis is based on echocardiography.

4.2.1 Echocardiographic signs of aortic valve stenosis

The first view to be seen is the long axis view, as usual. Patients with aortic valve stenosis often have a hypertrophied left ventricular wall, which can be observed from this view. In addition, the morphology of the aortic valve can also be examined. In accordance with these expected signs, there is a concentric hypertrophy on the echocardiogram of our patient with preserved ejection fraction (Fig. 15). This conclusion is based on the M-mode measurement, in particular both the intraventricular septum thickness in diastole (IVSd) and the left posterior wall thickness in diastole (LVPWd) are thicker (more than 20 mm) than the normal value (less than 12 mm, Table 1). Besides to these hypertrophic signs the left ventricular internal diameter in diastole (LVIDd) or in systole (LVIDs) is normal, moreover the calculated ejection fraction (calculation is based on the measured diameter values) is also normal. The overall picture here (concentric hypertrophy with preserved ejection fraction) is characteristic for left ventricular pressure overload. This is often seen in hypertension and aortic valve stenosis.

The next view to be evaluated is the short axis view. Here the detailed morphology of the valves can be seen, therefore it can be decided whether the aortic valve has two or three leaflets. The potential deformations can also be evaluated. However, in some cases the picture quality is less than optimal in this view. Especially when the acoustically dense (bright) calcification is surrounded by dark tissue (technical issue). Measuring the orifice of the aortic valve can give an estimation of the valve stenosis, however, the diagnosis and the assessment of the severity of the disease is determined by functional measurements (pressure gradient, blood flow velocity). Finally, it is also important to note, that the detailed morphological assessment preceding the valve replacement or reconstructive surgery is being done by transesophageal echocardiography.

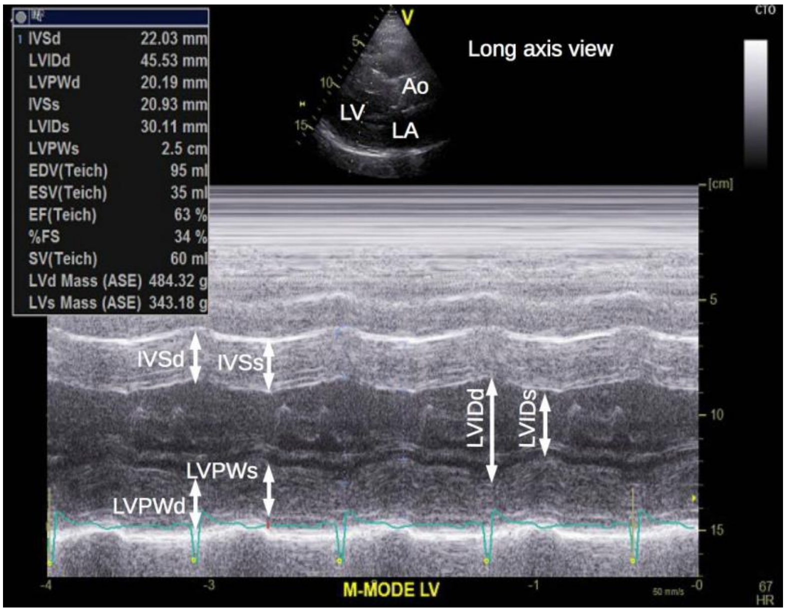


Figure 15

Long axis view evaluated in M-mode. The M-mode view is below the mitral valve and above the origin of the papillary muscles

The Doppler measurement on the apical view is used for the diagnosis. The significant ventricular hypertrophy can also be seen in the apical view (Fig. 16). The morphology of the aortic valve suggests some thickening and losing some morphological details. In this 3 chamber Doppler signal it is clear that there is a turbulent flow to the aorta, represented by green (the regular colors are red and blue, when the flow is laminar).

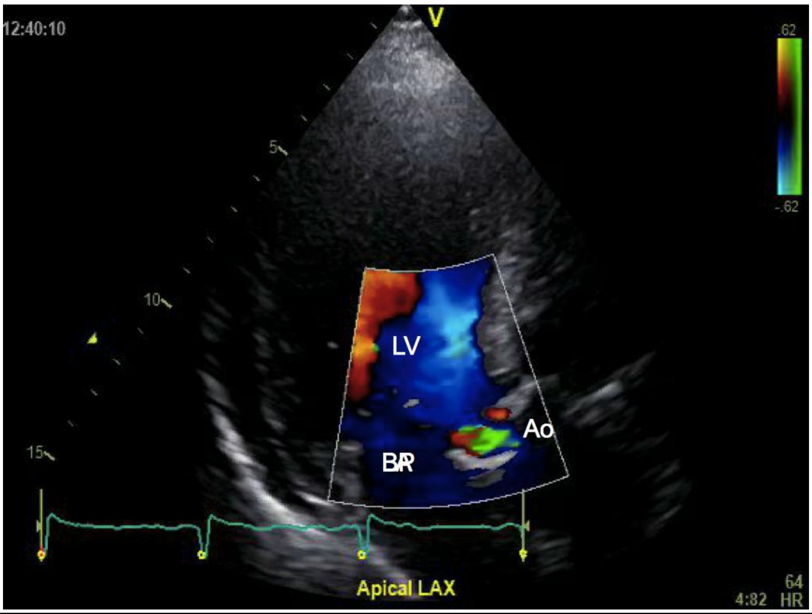


Figure 16

Apical 3 chamber view with Doppler signal

A similar representation can be seen on the apical 5 chamber view, in which case the aortic outflow can be assessed accurately (this view is almost parallel with the direction of blood flow) by Doppler method (Fig. 17). The hypertrophy of the left ventricular wall can be seen in this view, besides to the green aortic outflow, suggesting again the turbulent flow.

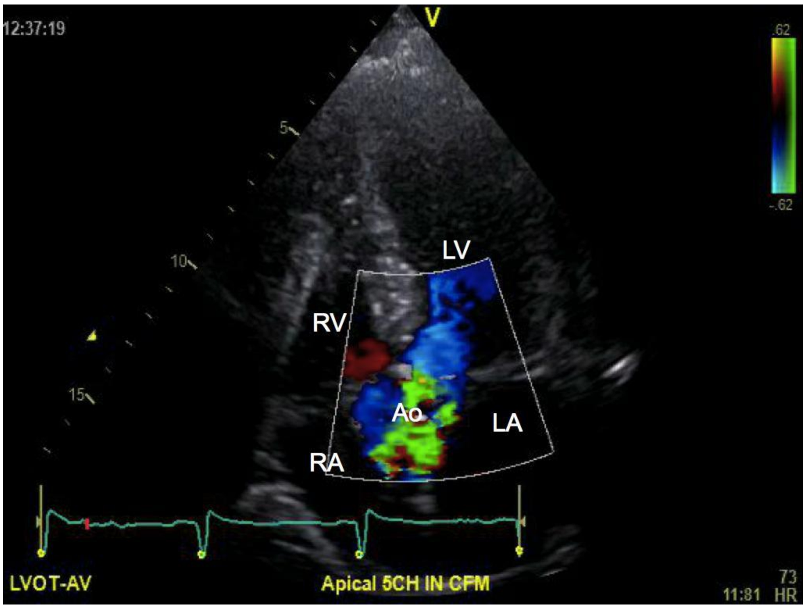


Figure 17

Apical 5 chamber view with a Doppler signal at the aortic region

The diagnosis is based on the Doppler signal in the apical 5 channel view within the aorta. The registered data clearly shows an increased blood flow reaching more than 4 m/s maximal value and about 3,5 m/s average flow velocity (Fig. 18). From this value the pressure gradient can be calculated according to the following equation:

$$\mathbf{p = 4 \bullet v^2}$$

Where **p** is the pressure gradient [mmHg], **v** is the velocity of the blood [m/s].

Taking the recorded data in this case, the maximal gradient is $4*4,52^2=81,7$ mmHg, based on which the blood pressure can be calculated. If the systemic systolic blood pressure is 120 mmHg then the left ventricular systolic pressure is 120+81,7=201,7 mmHg. Please note that this value is higher than that for most hypertensive patients, although this particular patient is normotensive. This high systolic pressure demand results in cardiac hypertrophy, similarly to the peripheral hypertension.

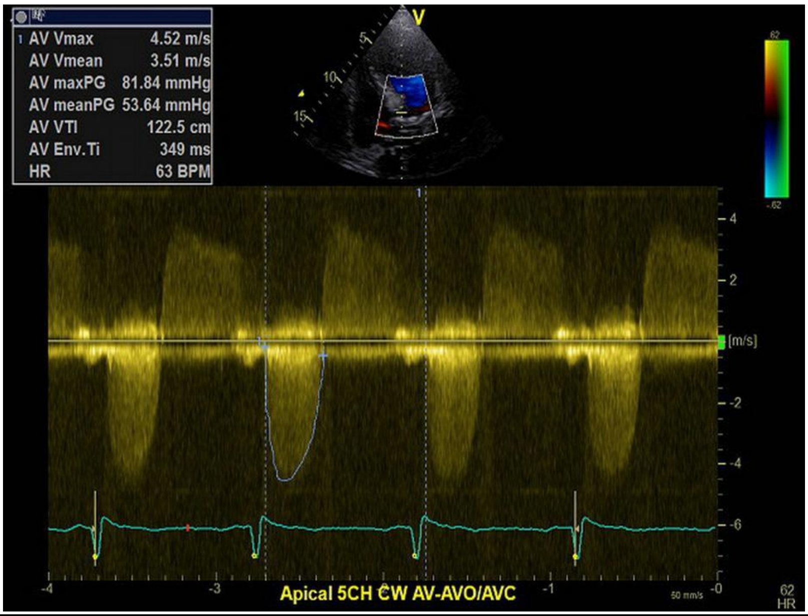


Figure 18

Apical 5 chamber view with Doppler signal at the aortic valve orifice

4.3 Abnormal left ventricular relaxation (diastolic heart failure)

59 years old female patient visited the Department of Pulmonology. Her complaints were breathlessness and coughing. There were no signs of pulmonary diseases, but it was revealed that she has occasional edema in the legs and she is suffering from hypertension for a decade or so. She was examined for these symptoms at our clinic (Cardiology).

The symptoms of heart failure often overlap with pulmonary diseases, since there is insufficient oxygen supply in both cases. The functional classification of heart failure is based on decades old subjective criteria, originally published by the New York Heart Association (NYHA):

NYHA I: There are no complaints in the case of regular activity, but breathlessness, angina occurs upon heavy physical work (exercise).

NYHA II: Mild symptoms upon regular physical activity (shortness of breath, fatigue, angina).

NYHA III: The patient is without symptoms upon rest. Even moderate physical activity causes symptoms (such as walking for 50 m or so).

NYHA IV: Constant severe symptoms even upon rest. These patients are usually bedridden.

Risk factors for diastolic heart failure consist: hypertension (especially without proper management), diabetes, smoking, sedentary life style, myocardial infections.

There is a dominant role for atrial contraction in the filling of the left ventricle. Hence these patients are more sensitive to atrial fibrillation and their symptoms can significantly worsen on the onset of atrial fibrillation. As a consequence these patients are usually complaining (and showing up in the health care system) when atrial fibrillation occurs. The diagnosis of diastolic heart failure is based on the echocardiographic evaluation of the cardiac function. This disease is usually called as Heart Failure With Preserved Ejection Fraction, according to the echocardiographic diagnostic criteria.

4.3.1 Echocardiographic signs of diastolic heart failure

Hypertrophy is often seen in diastolic heart failure, but the increased blood pressure can also lead to enlarged left atrial diameter, as it is present in this patient (Fig. 19). As a matter of the hypertrophy, the septal wall appears to be thicker than normal here and note the prominent size of the left atrium.

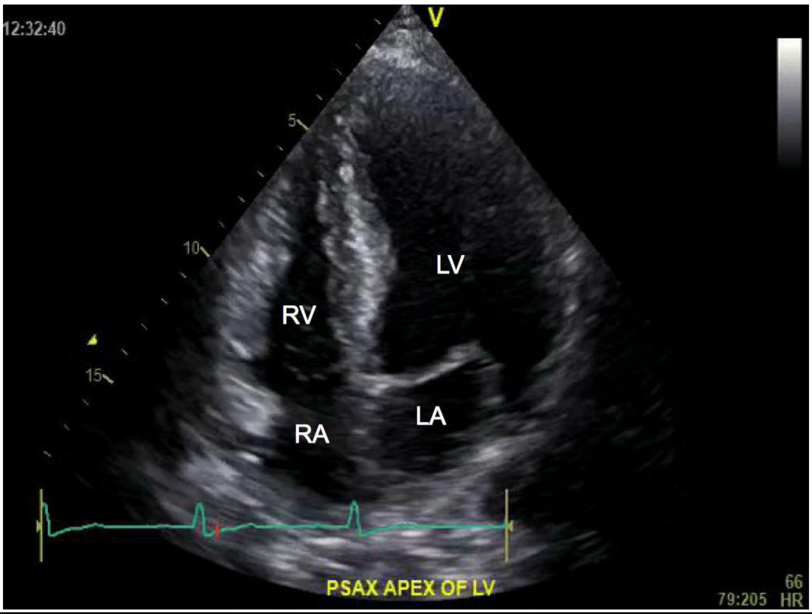


Figure 19

Apical 4 chamber view

The systolic function is normal (preserved) in diastolic heart failure, moreover the left ventricular diameters are normal. The difference is in the filling of the left ventricle. The best view to evaluate this property is the apical 4 chamber view on which the blood flow through the mitral valve is parallel with the transducer (Fig. 20). If the results are compared to the normal values (as seen in Fig. 13), then it is apparent that the amplitudes of the "E" and "A" waves are quite different. The A wave amplitude is higher in the normal heart, while it is lower here. This is characteristic for diastolic heart failure.

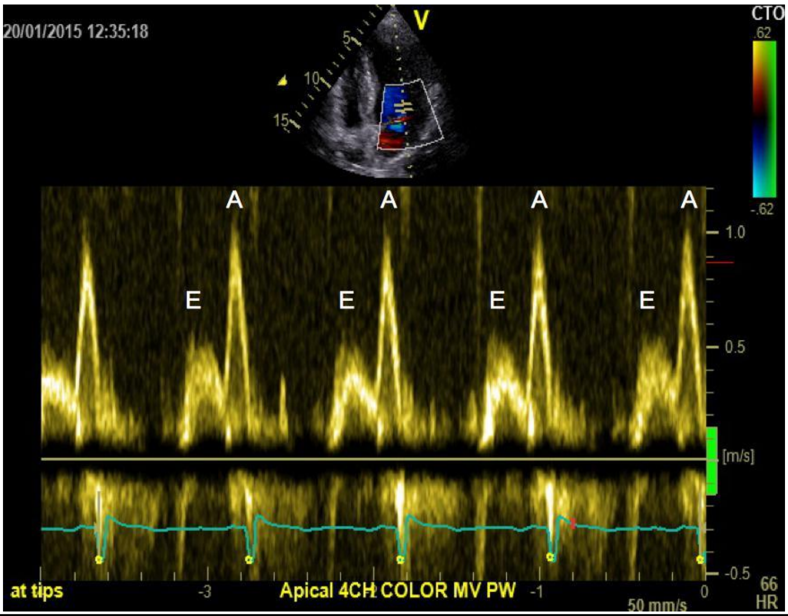


Figure 20

Apical 4 chamber view with a Doppler signal perpendicular to the mitral valve

4.4 Systolic heart failure (dilatative cardiomyopathy)

67 years old men visited our clinic. He had edema in the legs and were treated myocardial infarction a decade ago, which was successfully treated by opening of the coronary artery and stent implantation at that time. He had edema in the legs now. However there were some problems with the compliance of the patient, when his hypertension was treated in the past decade.

The symptoms of the systolic heart failure are similar to that of diastolic heart failure (see NYHA grades). It can be differentiated by echocardiographic examination. The proper diagnosis is of particular importance, since the treatment options are quite different, although the life expectancy is similar (5 year mortality is about 50%). The systolic heart failure can be successfully treated with inhibitors of the renin-angiontensin-aldosteron system or beta-blockers. These drugs are ineffective in patients with diastolic heart failure. It is therefore important to differentiate between these pathologies.

The reason of heart failure is the decreased cardiac output. This is the result of insufficient contraction in the case of systolic heart failure. This is often the consequence of dilated ventricular chamber morphology and decreased ejection fraction.

The pathomechanism of ventricular dilation is complex. In most of the cases this is the result of accommodation for the high intraventricular pressure. During the accommodation the heart first hypertrophied then the wall is being thinning in parallel with the enlargement of the ventricular chamber. This process is called "remodeling" on the lectures. Nonetheless, this dilated state can be the consequence of alcoholism, autoimmune disorders, and inherited forms are also known.

There may be electrophysiological complications at the final state of the dilation. This can lead to dissinchrony, which is deleterious for cardiac performance. Resinchronisation therapy by biventricular pacemaker implantation may be of benefit in these patients.

4.4.1 Echocardiographic signs of systolic heart failure

The diagnosis of systolic heart failure is relatively simple. The most important signs are the enlarged ventricular size and the reduced ejection fraction.

There is an enlarged ventricular chamber in the long axis view (Fig. 21).

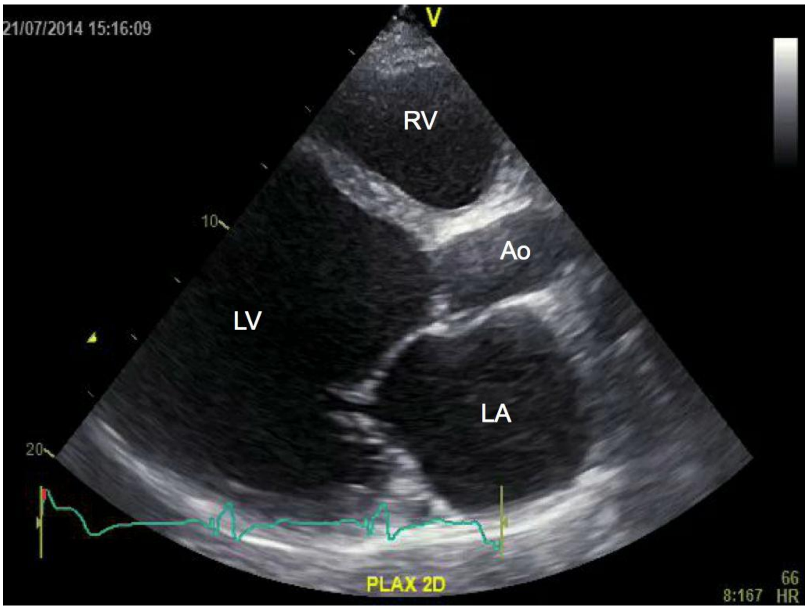


Figure 21

Long axis view

The ejection fraction is the most important parameter for the diagnosis and the assessment of the severity of the disease. Ejection fraction can be determined from the long axis and short axis views, by M-mode measurements below the mitral valve and above the origin of the papillary muscle. In this long axis view (Fig. 22) dilated left ventricular chamber and severely reduced ejection fraction (11%) can be seen. Please note apparent differences from the normal heart (Fig. 8).

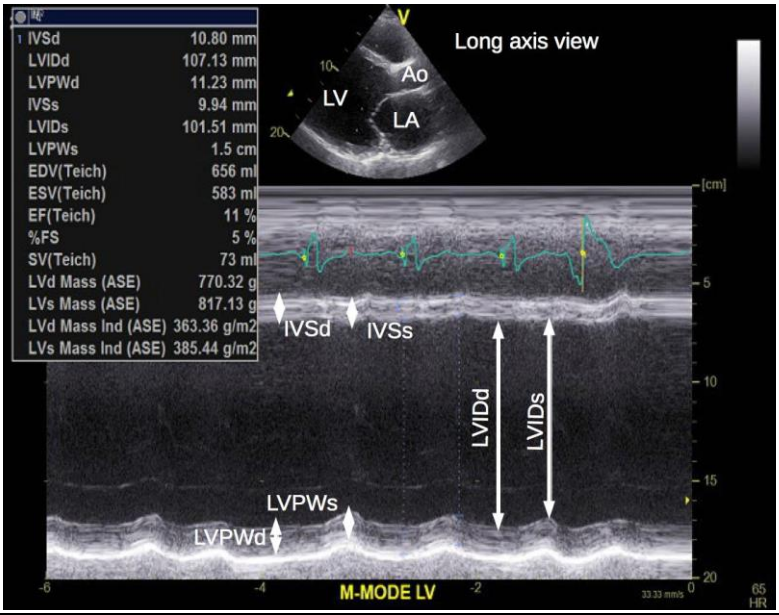


Figure 22

Long axis view with M-mode

Finally, the apical 4 chamber view is also interesting, since the left ventricle almost fills the whole view field, suggesting significant enlargement (Fig. 23). In particular, the magnification is smaller in Fig. 11, but all chambers can be clearly seen in the normal heart.

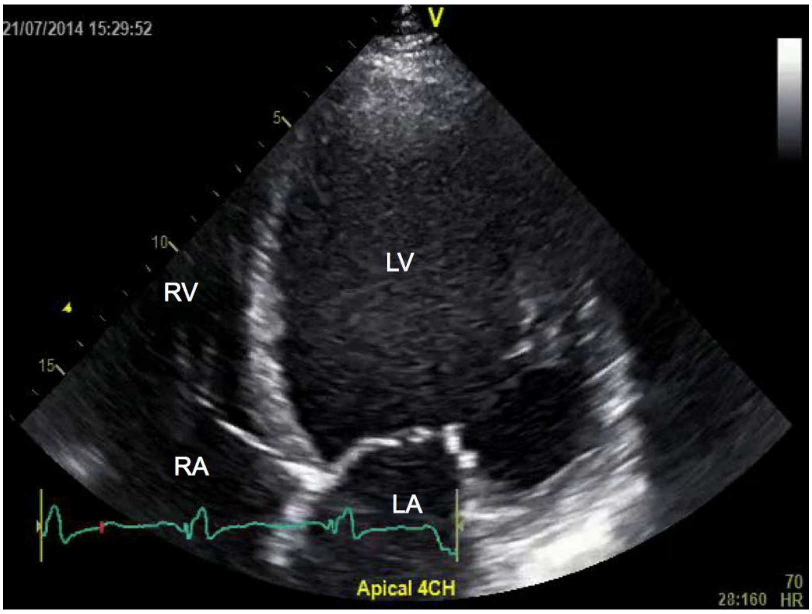


Figure 23

Apical 4 chamber view

4.5 Hypertension

44 years old men visited our clinic. His complaints include that occasionally he feels headache and under these periods his blood pressure level reaches 140/90 mmHg values. An extensive effort was made to clarify the primary reason behind his hypertension (kidney function, endocrine system, ECG and echocardiographic parameters were tested). His blood pressure was 162/87 mmHg at the visit.

The diagnosis of hypertension relies on the measurement of blood pressure. It needs to be more than 140 mmHg systolic (systolic hypertension), OR 90 mmHg diastolic values (diastolic hypertension) at least twice in a week under resting, relaxing conditions. There is no difference in the view of the diagnosis if only a single or both blood pressure values are elevated.

Surprisingly there are no obvious reasons for hypertension in the vast majority of the patients (95%). These patients are suffering from secondary (essential) hypertension. The goal of the treatment is therefore to lower the blood pressure into the normal range (below 140/90 mmHg). Treatment with a single drug is rarely sufficient; in most of the cases combination therapy is indicated. In the 5% of the hypertensive cases the reason of hypertension is clearly identified. In these cases the disease leading to hypertension should be treated.

Hypertension is called as “silent killer”. It has a single sign: high blood pressure, which can not be felt in most of the cases. Nonetheless, hypertension is a major risk factor for cardiovascular diseases, such as stroke, myocardial infarction and peripheral artery disease (besides others). These diseases represent the major reason of death in many developed countries. Proper treatment of hypertension is therefore a major challenge for the health care system, which has a huge impact on the society.

Patients are required to take pills lifelong in most of the cases after development of hypertension (if the reasons are unknown). The life expectancy is reduced by about 2-25 years without proper management of the disease.

4.5.1 Echocardiographic signs of hypertension

Hypertension increases the pressure load on the left ventricle. This has pronounced effects on the left ventricle at the beginning. The accommodation starts with left ventricular hypertrophy (Fig. 24)

This hypertrophic state can progress towards two different end stages. (i) The heart dilates and the systolic function drops in systolic heart failure (Fig. 22). This direction is dominant in patients with previous myocardial infarction. (ii) A slight majority of the patients develops diastolic heart failure (Fig. 20). Under these conditions the hypertrophic state remains dominant and the rigidity (stiffness) of the left ventricular wall increases. The filling of the left ventricular chamber is limited, hence the name diastolic heart failure. Taken together, the cardiovascular continuum (the timely set of cardiovascular diseases with increasing severity) starts with hypertension and may culminate in either forms of heart failure.

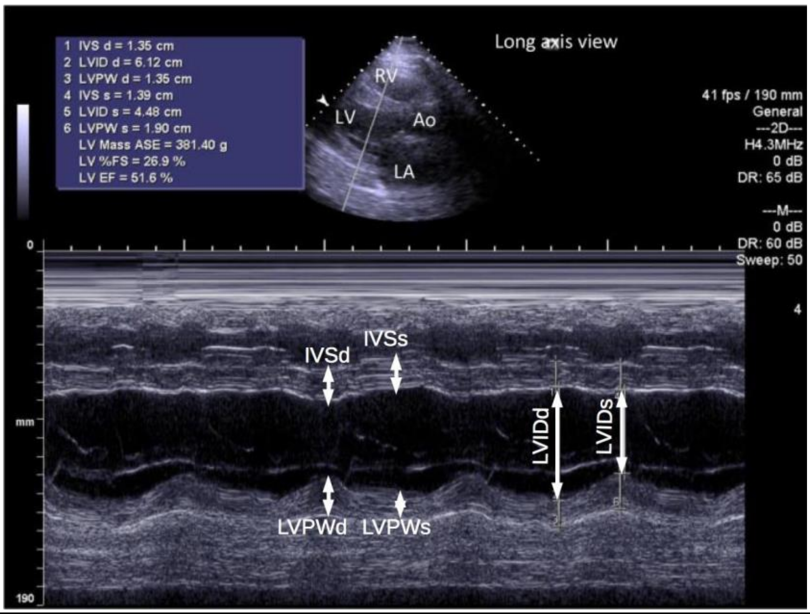


Figure 24

Long axis view with M-mode

5. Self control questions

1. What is the relationship between the frequency and amplitude of the acoustic wave? How is related the frequency of the acoustic wave and the resolution of the echocardiography? What is the wavelength range for echocardiographs?

Answer: There is an inverse relationship between the frequency and amplitude of the acoustic wave. The spatial and temporal resolution of echocardiography is proportional with the frequency of the generated acoustic wave. However, the penetration of the acoustic wave is inversely proportional with the frequency, providing a limitation for the increase of frequency. In general, acoustic wave frequency is in the range of 2-20 MHz in echocardiography.

2. What is the position of the transducer in the parasternal long axis, short axis views and in the apical views?

Answer: The transducer is positioned in parallel with the longitudinal axis of the heart (parasternal long axis view). The position of the transducer is in the 3rd intercostal space leftward to the sternum. The marker ("up" sign) points toward the right shoulder of the patient: the great vessels and the atria are visualized upward, while the ventricles are downward. To produce the short axis views the transducer is turned perpendicular to the long axis position. Its position above the heart does not change much (although sometimes it needs to be moved to the 4th intercostal space). The "up" direction is toward the left side and the "down" position is toward to the right side. The transducer can be positioned a little farther from the sternum to produce the apical view. In this case the transducer is above the apex of the heart (usually located at the 5th intercostal space). The “up” direction is toward the left side of the heart.

3. How to diagnose aortic valve stenosis by echocardiography? How to calculate the pressure gradient between the two sides of the aortic valve? How is it related to the systolic work of the heart?

Answer: Calcification of the aortic valve narrows the opening of the aortic valve (orifice) and forms a barrier in the left ventricular outflow. The normal range for the surface of aortic valve orifice is 3-4 cm2. Aortic valve replacement or reconstructive surgery is usually indicated when this is narrowed below 1,0 cm2. Nonetheless, diagnosis of aortic stenosis is based on the functional measurement of blood flow through the aortic valve. The diagnosis is based on the Doppler signal in the apical 5 channels view within the aorta. The increased blood flow may reach more than 4 m/s maximal value. From this value the pressure gradient can be calculated according to the following equation:

$$\mathbf{p = 4 \bullet v^2}$$

Where **p** is the pressure gradient [mmHg], **v** is the velocity of the blood [m/s].

Taking the maximal blood flow speed as 4 m/s the gradient is 4*4,522=81,7 mmHg. If the systemic systolic blood pressure is 120 mmHg then the left ventricular systolic pressure is 120+81,7=201,7 mmHg. Please note that this value is higher than that for most hypertensive patients, although this particular patient is normotensive. This high systolic pressure demand results in cardiac hypertrophy, similarly to the peripheral hypertension.

4. What are the consequences of long-term hypertension? How can hypertension lead to heart failure?

Answer: Hypertension is called as “silent killer”. It has a single sign: high blood pressure, which can not be felt in most of the cases. Nonetheless, hypertension is a major risk factor for cardiovascular diseases, such as stroke, myocardial infarction and peripheral artery disease (besides others). These diseases represent the major reason of death in many developed countries. Hypertension increases the pressure load on the left ventricle. This has pronounced effects on the left ventricle at the beginning. The accommodation starts with left ventricular hypertrophy. This hypertrophic state can progress towards two different end stages. (i) The heart dilates and the systolic function drops in systolic heart failure. This direction is dominant in patients with previous myocardial infarction. (ii) A slight majority of the patients develops diastolic heart failure. Under these conditions the hypertrophic state remains dominant and the rigidity (stiffness) of the left ventricular wall increases. The filling of the left ventricular chamber is limited, hence the name diastolic heart failure. Taken together, the cardiovascular continuum (the timely set of cardiovascular diseases with increasing severity) starts with hypertension and may culminate in either forms of heart failure.

5. What are the characteristics of heart failure? How can it be diagnosed by echocardiography?

Answer: The symptoms of heart failure often overlap with pulmonary diseases, since there is insufficient oxygen supply in both cases. The diagnosis of heart failure is based on decades old subjective criteria, originally published by the New York Heart Association (NYHA):

NYHA I: There are no complaints in the case of regular activity, but breathlessness, angina occurs upon heavy physical work (exercise).

NYHA II: Mild symptoms upon regular physical activity (shortness of breath, fatigue, angina).

NYHA III: The patient is without symptoms upon rest. Even moderate physical activity causes symptoms (such as walking for 50 m or so).

NYHA IV: Constant severe symptoms even upon rest. These patients are usually bedridden.

The diagnosis of systolic heart failure requires the parasternal long (or short) axis view evaluated in M-mode to determine the ejection fraction. The ejction fraction is lower than 50% in systolic heart failure.

The diagnosis of the diastolic heart failure is based on the examination of the left ventricular filling. The first sign of relaxation disturbance is decreased (<1.0) E/A ratio, which can be determined from the apical views in Doppler mode.

6. What diseases can be diagnosed from the parasternal long axis view?

Answer: Myocardial infarction and ischameia, (B-mode, altered wall motion), systolic heart failure (M-mode, ejection fraction), left ventricular hypertrophy (M-mode, wall thickness).

7. What diseases can be diagnosed from the apical view?

Answer: Aortic stenosis (Doppler-mode, 5 chamber view), myocardial infarction and ischameia, (B-mode, altered wall motion), diastolic dysfunction (Doppler mode).

8. What are the indications of transthoracic echocardiography? How reliable the information obtained by echocardiography?

Answer: In the case of ECG alterations suggesting ischemia, cardiac murmur, upon decrease in cardiac function, after stroke and in sudden worsening of health state.

The echocardiography is important in the diagnosis of the following conditions: cardiac hyprtrophy, valve diseases, heart failure (systolic as well as diastolic). In addition to the cases mentioned here echocardiography is useful in the diagnosis of shunts, valvular disease and pericardial fluid besides others.

9. What are the most important data of the echocardiographic examination? What are the normal values and what conclusion can be drawn from the deviations (either lower or higher values)?

Answer: The most important values are summarized below. Decrease in the ejection fraction is a sign for systolic heart failure. The wall thickness increases in cardiac hypertrophy (e.g. in hypertension, diastolic heart failure, aortic stenosis). The diameter of the left ventricular cavity increases in dilatative cardiomyopathy (often seen in systolic heart failure). The stenosis of the aortic orifice and increased pressure gradient (through the aortic valve) are signs for aortic stenosis. Finally, decreased E/A ratio suggest diastolic dysfunction.

Mode of determination	Parameter	Normal values
M-mode	Ejection fraction (%)	>50
M-mode	Thickness of the ventricular wall (diastolic, mm)	<12
M-mode	Diameter of the left ventricle (diastolic, mm)	<55
M-mode	Diameter of the left ventricle (systolic, mm)	<40
M-mode	Diameter of the left atrium (diastolic, mm)	<40
B and Doppler modes	Surface of the orifice of the aortic valve (systolic, cm^2)	3-4
Doppler-mode	Aortic pressure gradient (mmHg)	<5
Doppler-mode	E/A	1,0-1,9

6. TEST QUESTIONS

Multiple choice questions

A: The statement is true; the explanation is correct and gives a valid logical explanation for the statement.

B: The statement is true; the explanation is correct, BUT it does NOT give a valid logical explanation for the statement.

C: The statement is true; the explanation is NOT correct.

D: The statement is FALSE; the explanation is correct.

E: The statement is FALSE; the explanation is NOT correct..

1. The blood flow velocity decreases in the case of aortic stenosis, because the pressure gradient is increased between the left ventricular chamber and the aortic root. (D)

2. Hypertrophy of the ventricular wall is characteristic for systolic heart failure, because the heart is accommodating to the increased pressure by initially increasing its muscle mass. (D)

3. The thickness of the left ventricular wall is not affected in diastolic heart failure, because the role of the heart in the determination of diastolic blood pressure is minimal. (C)

4. The left ventricular wall can be thickened upon hypertension, because more muscle mass is required for the maintenance of cardiac output. (A)

5. The size of the ventricular chambers can increase after myocardial infarction, because the lack of perfusion in the affected tissue results in the death of the cardiac muscle cells. (B)

6. Dilatative cardiomyopathy often occurs in the same family, because inherited factors are major risk factors in the development of some forms of the disease. (A)

7. The average 5 year mortality is 50% in systolic heart failure, because the ejection fraction continuously decrease. (A)

8. The life expectancy in diastolic heart failure is better than that for systolic heart failure, because the ejection fraction is maintained in diastolic heart failure patients (D)

9. The Doppler images recorded during echocardiography are important in the diagnosis of systolic heart failure, because they can be used to estimate the velocity of the blood flow from the left ventricle. (D)

10. The M-mode recording from the apical 5 chamber view is used for the diagnosis of diastolic heart failure, because this view and mode is optimal to assess the left ventricular performance. (E)

11. The echocardiography is useful in the diagnosis of myocardial infarction, because it can be used to assess the regions where the ischaemia affects the heart (eg. hypokinetic). (A)

12. Ejection fraction can be determined from the parasternal long axis view and the parasternal short axis view, because both view is optimal for the determination of the left ventricular diameter in M-mode recordings. (A)

13. The size of the ventricular chambers is measured on M-mode images, because M-mode is optimal for the assessment of blood flow velocity. (C)

14. The diagnosis of the diastolic heart failure is based on the apical 4 chamber view, because the transducer position is optimal in this view to measure the blood flow velocity through the mitral valve. (A)

15. The assessment of the severity of aortic valve stenosis is based on M-mode recordings, because the dimension of the aortic valve can be measured on these recordings. (E)

7. List of abbreviations

EF: Ejection fraction

IVSd: Thickness of the intraventricular septum in diastole

IVSs: Thickness of the intraventricular septum in systole

LVIDd: Diameter of the cavity of the left ventricle in diastole

LVIDs: Diameter of the cavity of the left ventricle in systole

LVPWd: Thickness of the posterior left ventricular wall in diastole

LVPWs: Thickness of the posterior left ventricular wall in systole

NYHA: New York Heart Association

8. Additional information

http://www.echobasics.de/english.html

http://www.wikiecho.org/wiki/Main_Page

http://www.escardio.org/communities/EACVI/education/Pages/basic-echocardiography-course.aspx

https://www.youtube.com/watch?v=7WNc2ND32Hk

https://web.stanford.edu/group/ccm_echocardio/cgi-bin/mediawiki/index.php/Main_Page

https://123sonography.com