

PRACTICAL SESSION 3

The cardiac cycle and noninvasive methods of investigation - the carotidogram, the apexcardiogram, the jugulogram-

Objectives:

I. The cardiac cycle:

1. Defining the concept
2. Parameters of the cardiac cycle
3. Phases of the cardiac cycle

II. Non invasive methods for exploring the mechanical activity of the heart:

1. arterial pulse – carotidogram, sphygmogram
2. apex impulse - apexcardiogram
3. venous pulse - jugulogram
4. heart sounds - phonocardiogram
5. correlation between the cardiac cycle (ECG) and mechanograms – polygram

I.1. **Definition:** The succession of one ventricular systole and diastole is called a cardiac cycle. Each time the pace-maker of the heart produces an action potential, a wave of electrical depolarization spreads throughout the myocardium, initiating contraction (systole) followed by a series of mechanical events that causes blood to flow in and out of the heart and ending with relaxation (diastole).

In the same time frame (duration of one cardiac cycle), the atria also complete a contraction (atrial systole) and relaxation (atrial diastole) cycle. Note that the atria and ventricles do not contract and relax simultaneously.

William Harvey's description of the circulation in 1628 showed that the heart worked as a pump, not as a furnace. Another important figure in cardiovascular physiology is Ernest Starling who described the "Law of the heart" in 1915, followed by Carl Wiggers responsible for the diagram that carries his name. More close to our time is Eugene Braunwald who helped narrow the gap between modern day physiology and cardiology.

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I.2. Parameters of the cardiac cycle

The heart rate is measured in beats/minute. The duration of a cardiac cycle is dependent on heart rate. The duration of a cardiac cycle = $60 \text{ seconds/heart rate}$

For a heart rate of 75 beats/minute the duration of a cardiac cycle is 800ms (0.8s) out of which 300ms represents the duration of the ventricular systole and the remaining 500 ms the ventricular diastole. The duration of atrial systole is 100ms and the diastole 700ms.

I.3. Phases of the cardiac cycle

The cardiac cycle can be divided into phases relative to the ventricular activity: ventricular systole and ventricular diastole, referring to ventricular contraction and ventricular relaxation respectively.

For practical reasons the cardiac cycle is divided into four phases:

- 1) The inflow phase: ventricles relaxed, atrioventricular (inlet) valves open, semilunar (outlet) valves closed
- 2) The isovolumetric contraction: ventricles contracting, both types valves closed
- 3) The outflow phase: ventricles contracting, semilunar (outlet) valves open, atrioventricular (inlet) valves closed
- 4) The isovolumetric relaxation: ventricles relaxed, both types valves closed

From the point of view of the atria, the atrial systole overlapped on the end of the ventricular diastole and then the atrial diastole.

All the mechanical phenomena that happen in the heart are preceded by electrical ones, so it is easier to follow the cardiac cycle events in parallel with the electrocardiographic recording.

- 1) We will start the discussion about the cardiac cycle with the inflow phase:

In this phase of the cardiac cycle the ventricles are relaxed (in diastole) and the semilunar (aortic and pulmonary) valves are closed. The atrioventricular (mitral and tricuspid) valves open when the ventricular pressure falls below the atrial pressure and the blood begins to flow from the atria into the ventricles according to the pressure gradient. Note that all the valvular events (opening /closing) are passive events brought on by pressure gradients.

There are three subphases of the ventricular filling (inflow):

- Rapid ventricular filling
- Decreased ventricular filling. Diastasis
- Atrial contraction- supplementary ventricular filling

The rapid and decreased ventricular filling are passive, according to the pressure gradient between the atria and the ventricles. At first the blood flows rapidly (rapid filling) into the ventricles causing two thirds (2/3) of all the blood to reach the ventricles in this phase. As the pressure gradient decreases so does the speed of the blood (decreased filling).

The active part of the ventricular filling phase is due to the atrial contraction that pushes all the remaining (25-30%) blood into the ventricles.

2) Next phase up for discussion is the isovolumetric contraction.

At this point in time the ventricles are filled with blood and they start contracting. In a very short while the intraventricular pressure exceeds the pressure in the atria and the atrioventricular valves are pushed closed. Now the ventricles are closed cavities, and they continue contracting until the pressure exceeds the aortic/pulmonary pressures and the semilunar valves are pushed open.

3) The outflow (ejection) phase takes place in between the opening and closing of the semilunar valves. It also has two sub phases:

- Rapid ejection (fast muscle shortening)
- Decreased ventricular ejection (slow muscle shortening)

During the rapid ejection the ventricular pressure continues to rise up to a peak (120mmHg), followed closely by the rise in aortic pressure. This rapid ejection is responsible for ejection of 60% of the total amount of blood although it last for only one third of all the ejection time.

After reaching the peak pressure the pressure starts gradually to decrease as the contraction is less forceful –decreased ejection.

At some point the ventricular pressure falls below the aortic/pulmonary pressure and the semilunar valves close.

4) After the semilunar valves close, the ventricles continue relaxing as closed cavities, completing the cardiac cycle with the isovolumetric relaxation phase. This phase

continues up to the point where the pressure in the atria exceeds the ventricular pressure opening the atrioventricular valves.

There are two ways of denominating the systole and diastole: physiological and clinical. The clinician at the bedside will divide the cardiac cycle into systole and diastole based on the heart sounds. For the physiologist the landmark for the beginning of the systole is the isovolumic contraction, and the diastole begins when the ventricular pressure starts to decrease.

II. Non invasive methods for exploring the mechanical activity of the heart:

II. 1. The arterial pulse – the carotidogram /sphygmogram

The purpose of the arterial system is to convert intermittent cardiac output into a continuous capillary flow

Arterial pulse wave – rhythmic expansion of arterial walls synchronous with the left ventricular contraction.

The velocity of the pulse wave as it travels down the arteries is 3-5 m/sec for large elastic arteries, and 14-15 m/sec for the small, less compliant vessels. Velocity of the pulse wave increases with age, because of rigidity of the vessels.

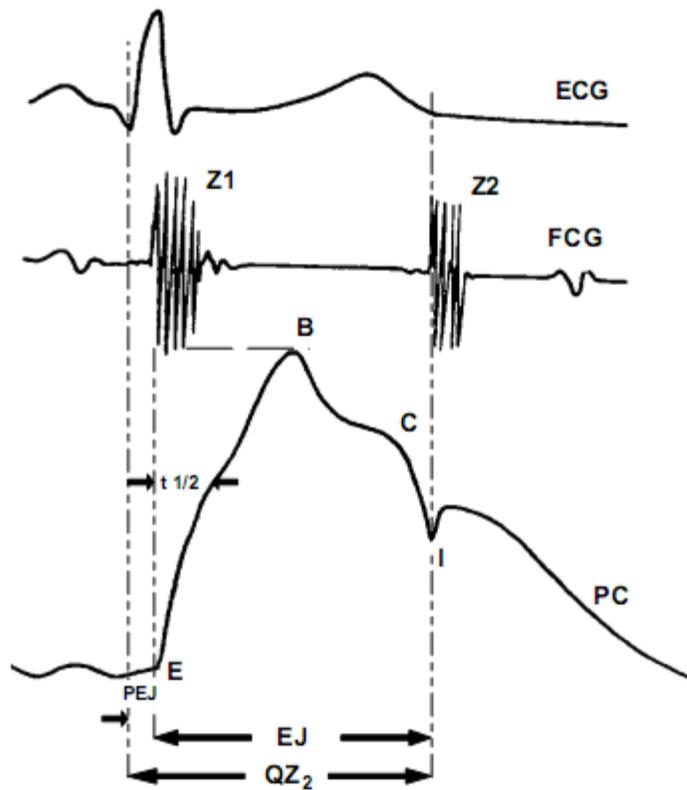
The ways to investigate this carotid pulse are:

- Inspection
- Palpation
- Recording

Note: there are no physiological auscultatory findings; auscultation of the carotid artery is useful only in pathological conditions.

The carotidogram/ sphygmogram are recordings of the pressure changes in the carotid artery/any artery during one cycle of the heart.

The recording technique : a pulse transducer placed over the carotid artery , near the sternocleidomastoid muscle.



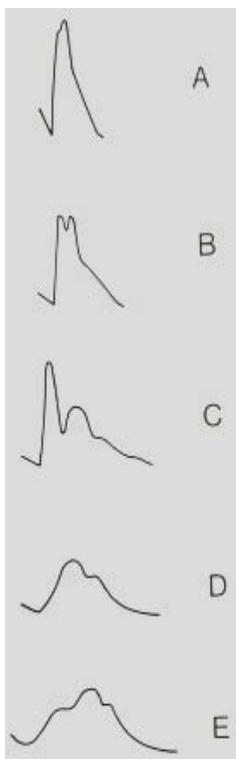
The arterial pulse wave begins with opening of the aortic valve (E point) and ejection of blood from the left ventricle. Before this wave there is a small wave (a wave) produced by the atrial systole. The pressure pulse increases sharply as the blood enters the aorta faster than it flows away to the periphery. This ascending portion of the carotid pressure curve is called the anacrotic limb. The left ventricle ejects most of its stroke volume quite rapidly and produces a pressure peak in early systole (P point), referred to as the percussion wave; a second, smaller peak, the tidal wave, representing a reflected wave from the periphery, possibly from the upper part of the body can often be recorded but is not normally palpable. An anacrotic notch lies between the two waves. While the upstroke of the carotid pulse reflects the driving force and vessel compliance, the downstroke reflects the distensibility of vessels and the peripheral resistance. After the aortic pressure curve peaks, it begins to decline (catacrotic limb) as ventricular ejection slows down. During the initial phase of ventricular relaxation, there is a momentary reversal of blood flow from the compliant central arteries back toward the ventricle. With this reversal of flow, the aortic valves close. A notch (dicrotic notch/incisura) on the descending limb of the aortic pressure curve is associated with this transient reversal of blood flow. The

subsequent smaller secondary positive wave (dicrotic) has been attributed to the elastic recoil of the aorta and aortic valve. Following this small wave, the aortic pressure declines as peripheral runoff continues. The descending limb of the central aortic pulse is less steep than is the ascending limb.

The carotid pulse gives information about the left side of the heart.

Types of carotid pulses:

A. *Hyperkinetic pulse* - increased velocity and amplitude of the upstroke. For example: water-hammer pulse, or Corrigan's pulse has a brisk upstroke, large amplitude, and rapid collapse; it is an extreme form of the hyperkinetic pulse. Associated with aortic regurgitation, anxiety, exercise, fever, thyrotoxicosis, hypertension, arterio-venous fistula, and patent ductus arteriosus.



B. *The pulsus bisferiens (bifid)*, two narrowly separated positive waves during systole. The bifid pulse often occurs in patients with aortic regurgitation and is a common finding in patients with combined aortic stenosis and aortic regurgitation.

C. The bifid pulse is also characteristic of idiopathic hypertrophic subaortic stenosis.

D. *The hypokinetic pulse* (is found in patients with a reduced stroke volume. This group includes patients with hypovolemia, left ventricular failure, and mitral stenosis.

E. *Pulsus parvus et tardus* is a slow rising, small and delayed arterial pulse; it is characteristic of severe valvular aortic stenosis. It must be recognized, however, that the absence of this finding, particularly in an elderly patient with noncompliant vasculature, does not exclude severe aortic stenosis.

F. *Pulsus paradoxus* is a characteristic pulse pattern in which there is marked attenuation in the amplitude of the pulse during the inspiratory phase of usual respiration. A paradoxical pulse must be measured with the sphygmomanometer and should be greater than 10 mm Hg to be significant. Pulsus paradoxus is common in pericardial tamponade but can also be seen with asthma, chronic obstructive airway disease, and superior vena cava obstruction.

G. *Pulsus alternans* is a beat-to-beat variation in the amplitude of the pressure pulse. It may be accentuated following a premature contraction. This pulse abnormality is usually best appreciated in distal arteries that have a wider pulse pressure than the carotid artery. Pulsus alternans is a manifestation of severe depression in left ventricular systolic function.

II. 2. Apexcardiogram

The apex beat, or the point of maximum impulse, is the furthestmost point outwards (laterally) and downwards (inferiorly) from the sternum at which the cardiac impulse can be felt. The cardiac impulse is the result of the heart rotating, moving forward and striking against the chest wall during systole.

The ways to investigate this apex beat are:

- Inspection
- Palpation
- Recording

Location of the apex beat is normally in the left 5th intercostal space on the mid-clavicular line. In children less than 7 years of age, the apex beat is located in the 4th intercostal space, lateral to the mid-clavicular line.

- Inspection:

On inspection of the chest, particularly in thin people, there can be a visible apex beat on the location already specified.

- Palpation

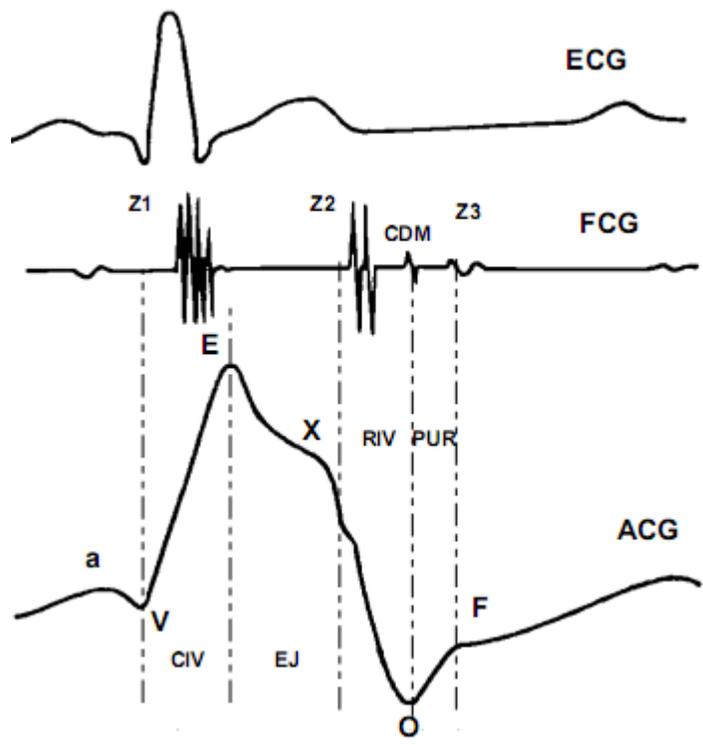
Only part of the recorded apex beat can be normally palpated. Put your hand with the middle finger on the left 5th intercostal space of the patient, parallel with the ribs. And with the other fingers positioned on the spaces above and below.

- Recording

The apexcardiogram is recorded with a transducer placed in the specific area where the apex beat is felt, that is in the 5th intercostal space on the midclavicular line.

The first wave that appears is a small wave generated by the atrial systole, the a wave. It appears after the middle of the p wave on ECG. The c point marks the beginning of the isovolumetric contraction. E point represents the end of the isovolumetric contraction, opening of the aortic valves and the beginning of the ejection period. With point H the isovolumetric relaxation starts. Point O (opening) marks the opening of the mitral valve and point F (filling) represents the rapid filling phase and SF the slow filling phase.

The apexcardiogram, like the carotidogram gives information about the left side of the heart.



Causes for absence of apex beat:

A. Physiological causes:

1. Dextrocardia. The apex beat will be present on the right side.
2. Apex behind a rib. Moving the patient to a left lateral position might solve the problem and reveal the apex beat.

B. Pathological causes:

1. Cardiogenic shock

2. Emphysema
3. Obesity and thick chest wall
4. Pericardial effusion
5. Pleural effusion on the left side

Causes for displaced apex beat:

1. Left ventricular enlargement - the apex will be displaced downwards and laterally.
2. Right ventricular enlargement - the apex will be displaced laterally.
3. Situs inversus/ dextrocardia
4. Pectus excavatum

II. 3. The venous pulse

The venous pulse reflects the pressure changes in the right atrium, being the only mechanogram to explore the right side of the heart.

The ways to investigate this venous pulse are:

- Inspection
- Recording

Unlike the other two mechanical expressions of the cardiac activity (carotid pulse and apex beat), the venous pulse is not palpable.

Inspection

The internal jugular vein is examined to estimate venous wave height and waveform. The height is proportional to right atrial pressure and the waveform reflects events and pressure changes in the right side of the heart.

The jugular veins are usually examined with the patient reclining at 45°. The top of the venous column is normally just below the clavicles (upper limit of normal: 4 cm above the sternal notch in a vertical plane). The venous column is elevated in heart failure, volume overload, reduced compliance of the RV, cardiac tamponade, constrictive pericarditis, tricuspid stenosis, superior vena cava obstruction. The venous column is low in hypovolemia.

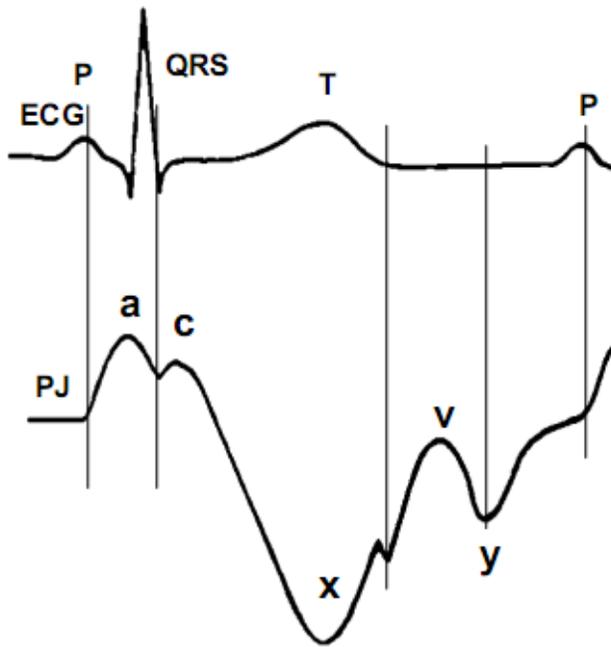
On inspection we might not see as much as the jugulogram can record. The descents or downward collapsing movements of the jugular veins are more rapid, produce larger

excursions, and are therefore more prominent to the eye than are the ascents. The normal dominant jugular venous descent, the x' descent, occurs just prior to the second heart sound, while the y descent ends after the second heart sound. With an increase in central venous pressure, the v wave becomes higher and the y collapse becomes more prominent. The a wave occurs just before the first sound or carotid pulse and has a sharp rise and fall. The v wave occurs just after the arterial pulse and has a slower, undulating pattern.

Recording

The recording technique is based on placing a transducer over the right jugular vein.

The a wave in the venous pulse results from venous distention due to right atrial systole, while the x descent is due to atrial relaxation and descent of the floor of the right atrium during right ventricular systole. The c wave, which occurs simultaneously with the carotid arterial pulse, is an inconstant wave in the jugular venous pulse and an interruption of the descent following the peak of the a wave. The v wave results from the rise in right atrial pressure when blood flows into the right atrium during ventricular systole when the tricuspid valve is shut, and the y descent, the downslope of the v wave, is related to the decline in right atrial pressure when the tricuspid valve reopens. Following the bottom of the y descent and beginning of the a wave is a period of relatively slow filling of the atrium or ventricle, the diastasis period, a wave termed the H wave.



Graph of height of JVP with time

