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ECG – Electrocardiography

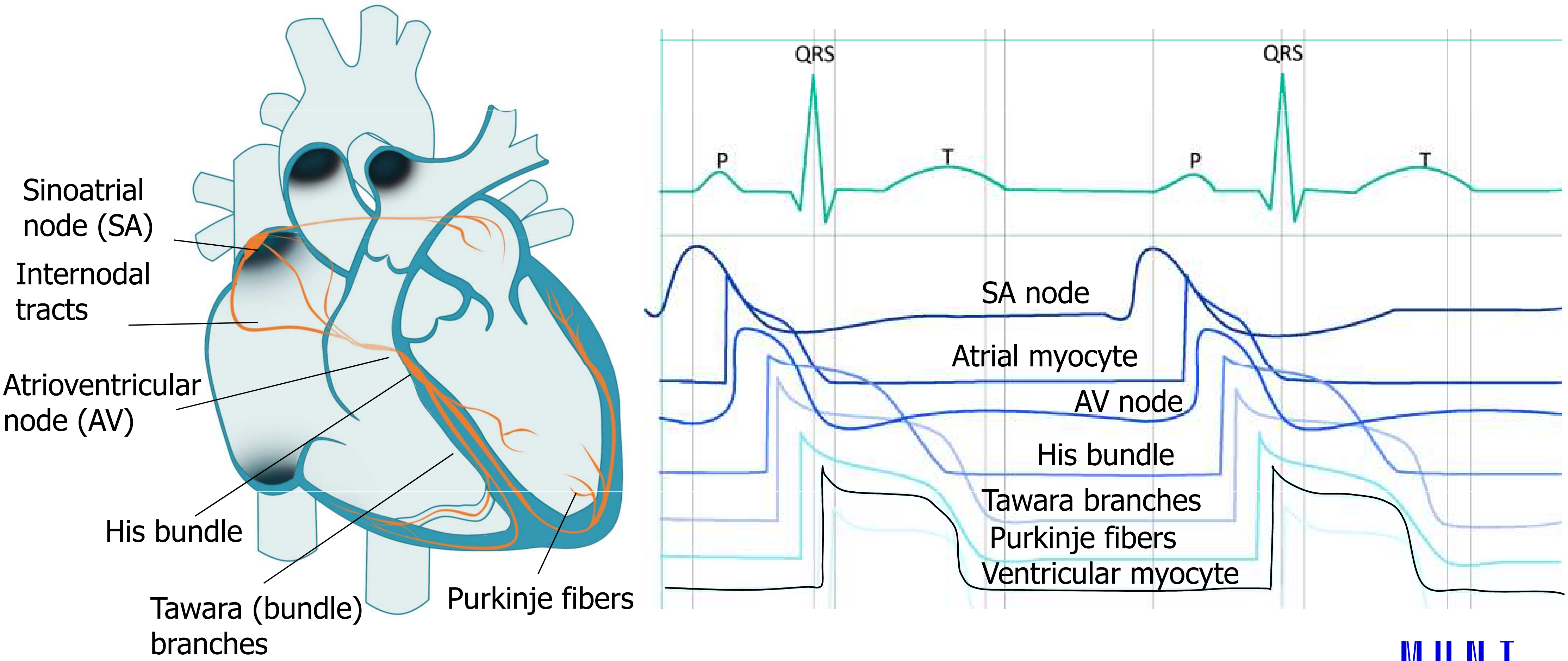
Physiology II – practice
Spring, weeks 4-6

Electrocardiography

- Definition: recording of the cardiac electrical activity from the surface of the body
  (Recording of electrical heart activity can also be obtained from the esophageal leads or the heart surface itself, but these methods are called differently)

- Key words:
  - heart conduction system
  - tools for ECG recording
  - limb and chest leads
  - unipolar and bipolar leads
  - heart vector, the electrical axis of the heart

Cardiac conduction system



Cardiac conduction system

- Function: AP formation and preferential conduction
- Atria are separated from ventricles by a non-conductive fibrous septum - the only way is through the AV node
  - Sinoatrial node (SA) – natural frequency 100 bpm (mostly under parasympathetic damping effect), conduction velocity 0.05 m/s
  - Internodal tracts – conduction velocity 0.8 – 1 m/s
  - Atrioventricular node – a single conductive connection between atria and ventricles, natural frequency 40 – 55 bpm, conduction velocity only 0.05 m/s (nodal delay)
  - His bundle – conduction velocity 1–1.5 m/s
  - Tawara (bundle) branches – conduction velocity 1–1.5 m/s
  - Purkinje fibers – conduction velocity 3–3.5 m/s

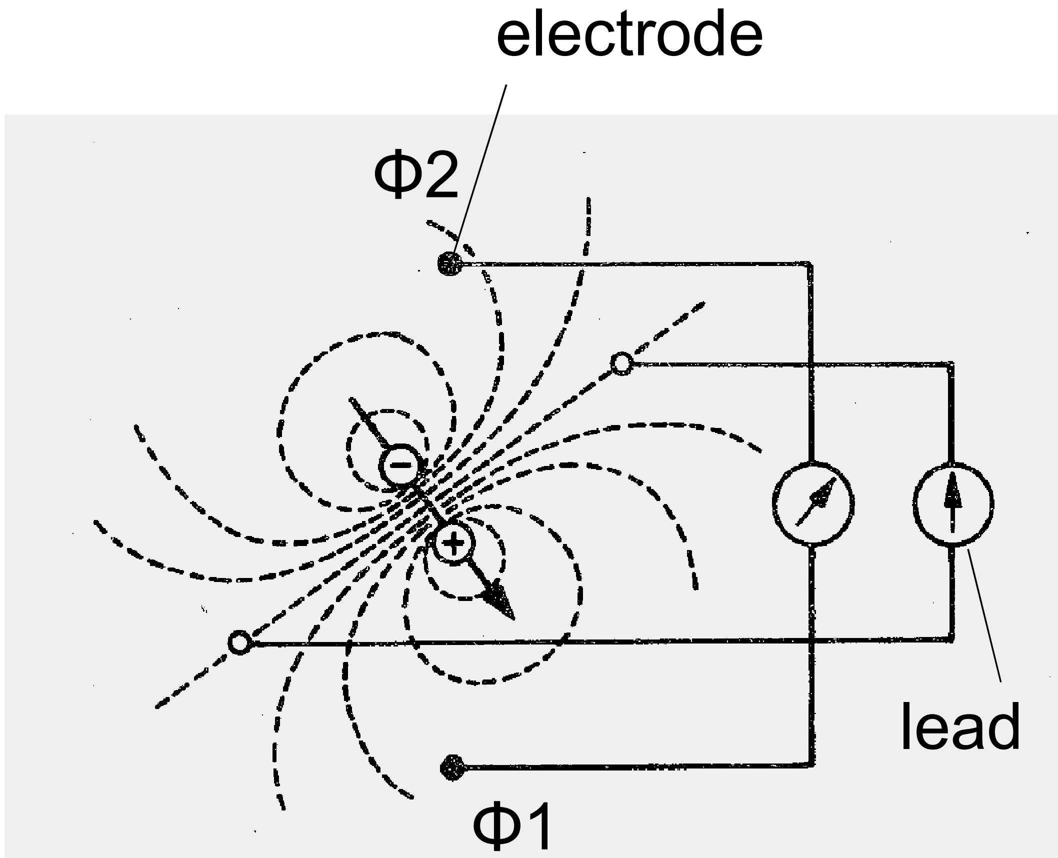
  } natural frequencies of 20 - 40 bpm, they have slow spontaneous depolarization

- Sinus rhythm – AP is formed in the SA node
- Junction rhythm – AP is formed in the AV node or His bundle
- Tertiary (ventricular) rhythm – AP is formed in bundle branches or Purkinje fiber

- Ventricular myocardial activation – from inside to outside, synchronized, determined by the onset of a stimulus
- Repolarization of ventricular myocardium – in the opposite direction, less sharp, repolarization isles
- Note: natural frequency is the frequency of AP formation unaffected by neural and hormonal control

Electric dipole

- Electrode: records electrical potential (Φ)
- Electrical lead: a connection between two electrodes
  - It records the voltage between the electrodes
  - Voltage: difference of el. potentials (V= Φ1- Φ2)



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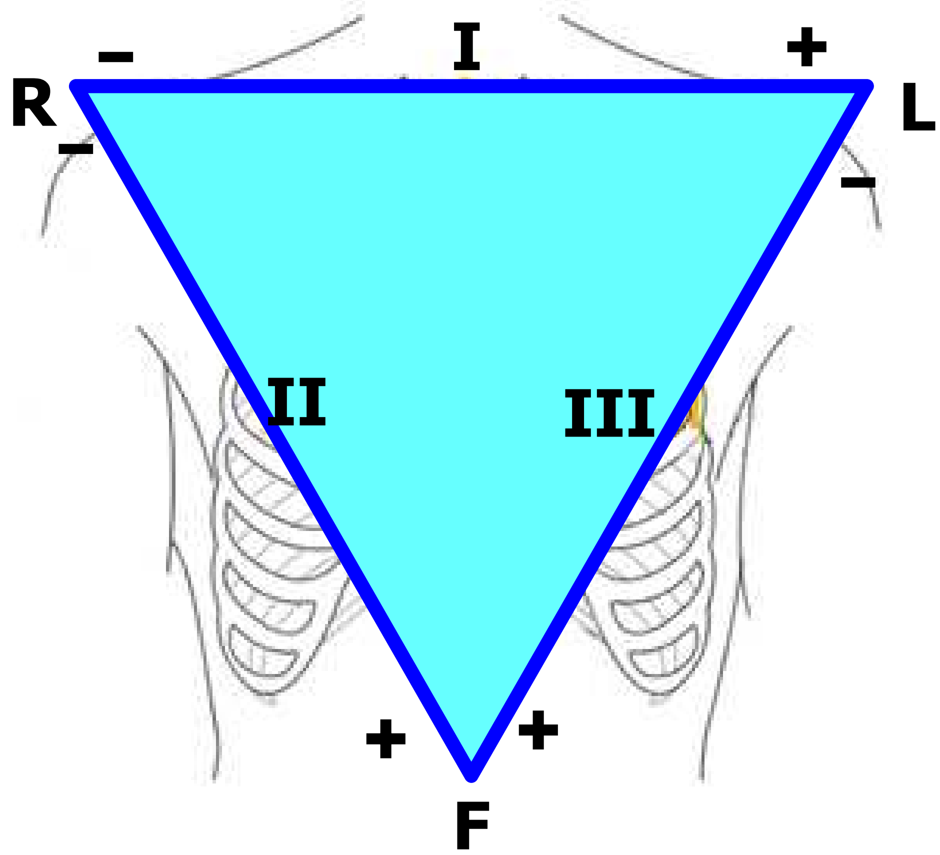
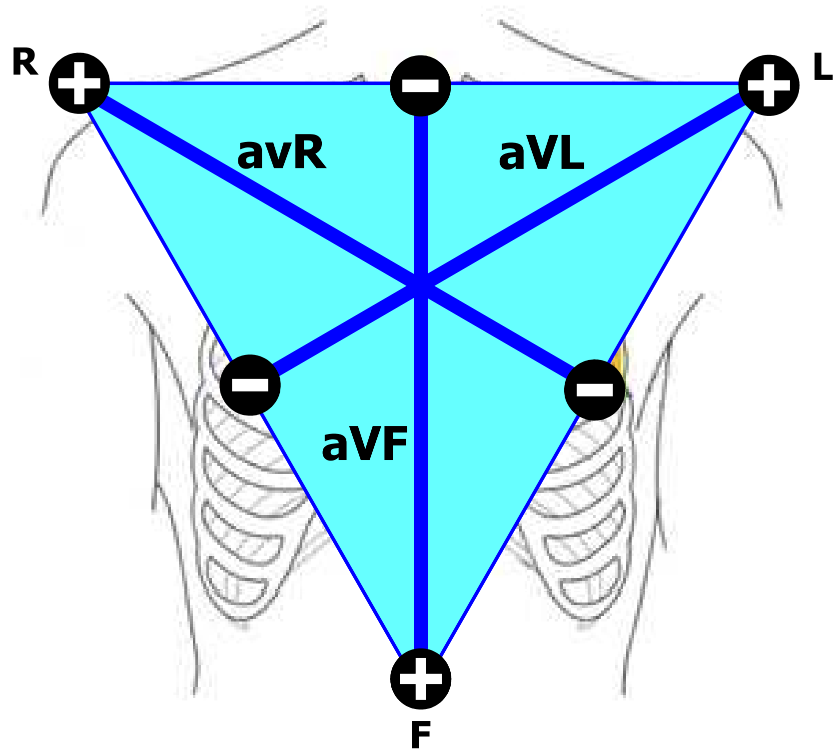
Einthoven's triangle
(standard, limb, bipolar leads)

– Bipolar leads: both electrodes are active (variable electrical potential)
– Electrode colors:
R: red, L: yellow, F: green



Goldberger leads
(augmented, limb unipolar leads)

- Unipolar leads: one electrode is active (variable electric potential) and the other is inactive (constant electric potential, usually 0 mV)
- The active electrode is always positive



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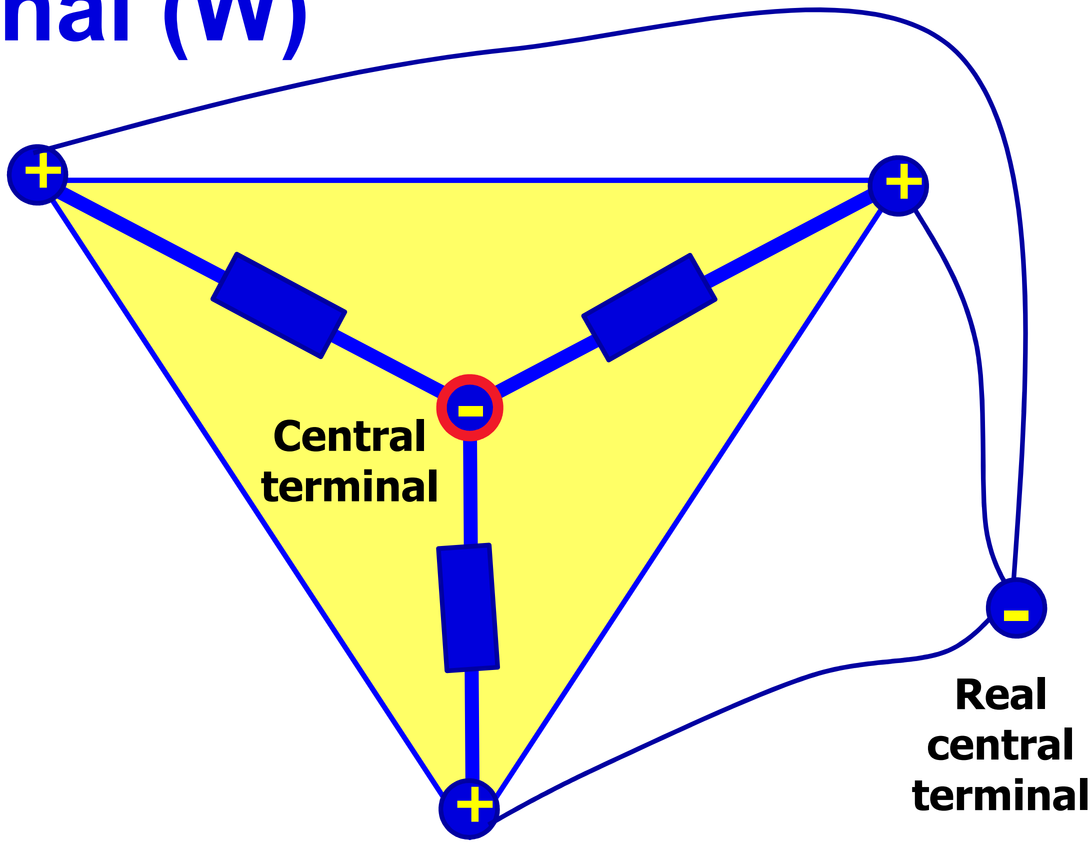
Wilson's central terminal (W)

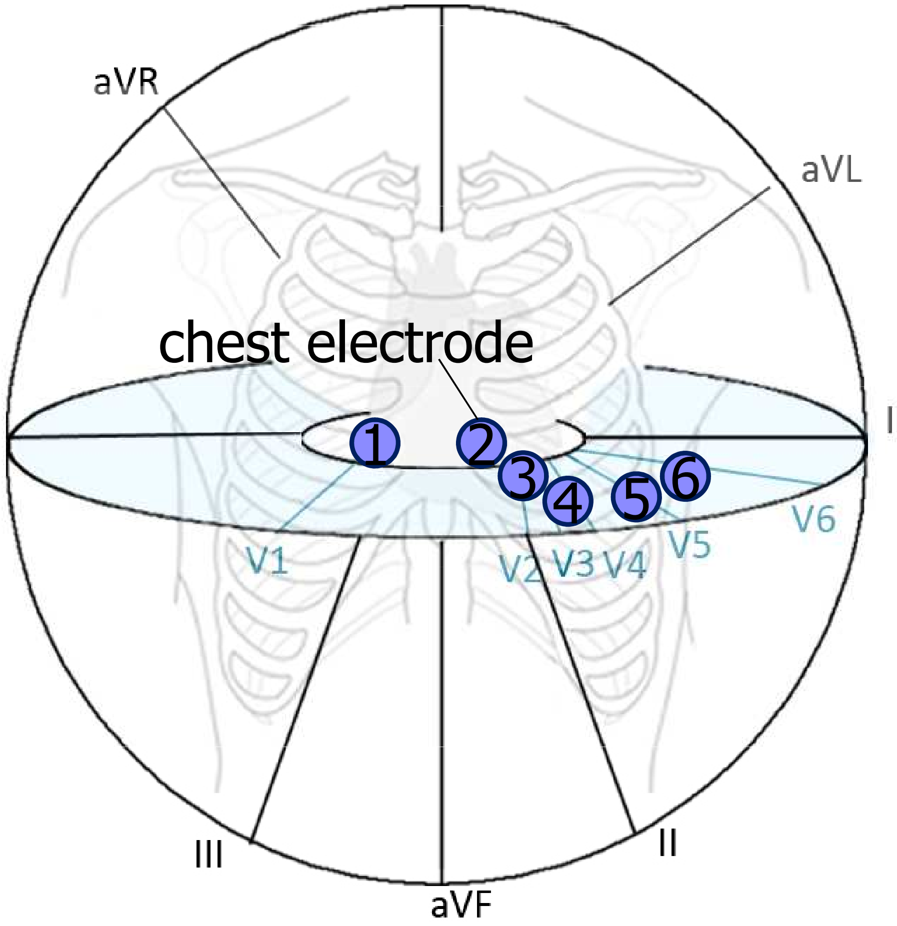
- It is formed by the connection of limb electrodes through resistors
- Electrically represents the center of the heart (it is led out or it is calculated)
- Inactive electrode (constant potential)



Chest leads

– A chest lead: a connection between a chest electrode and the central terminal

– Unipolar leads: the chest electrode is active (positive) and the central terminal is inactive (potential = 0 mV)



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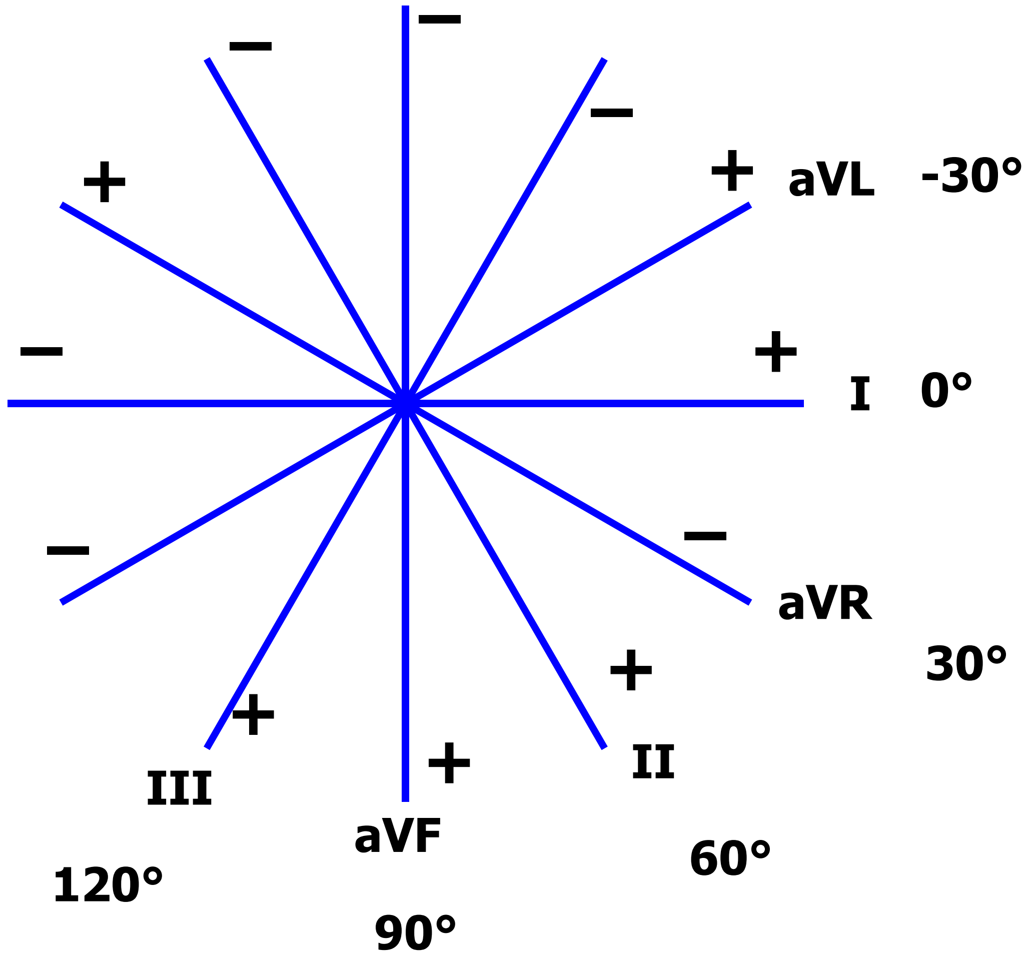
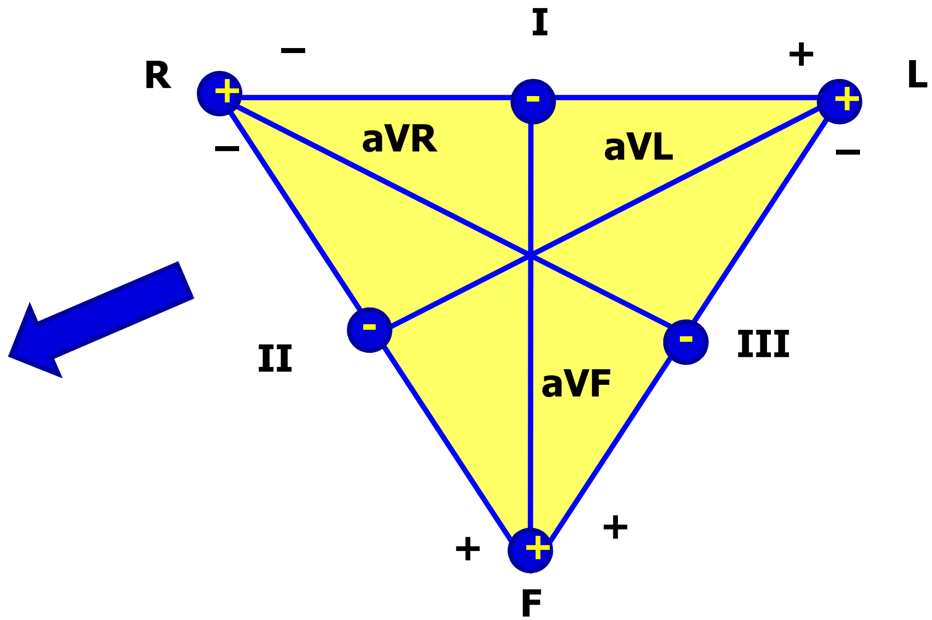
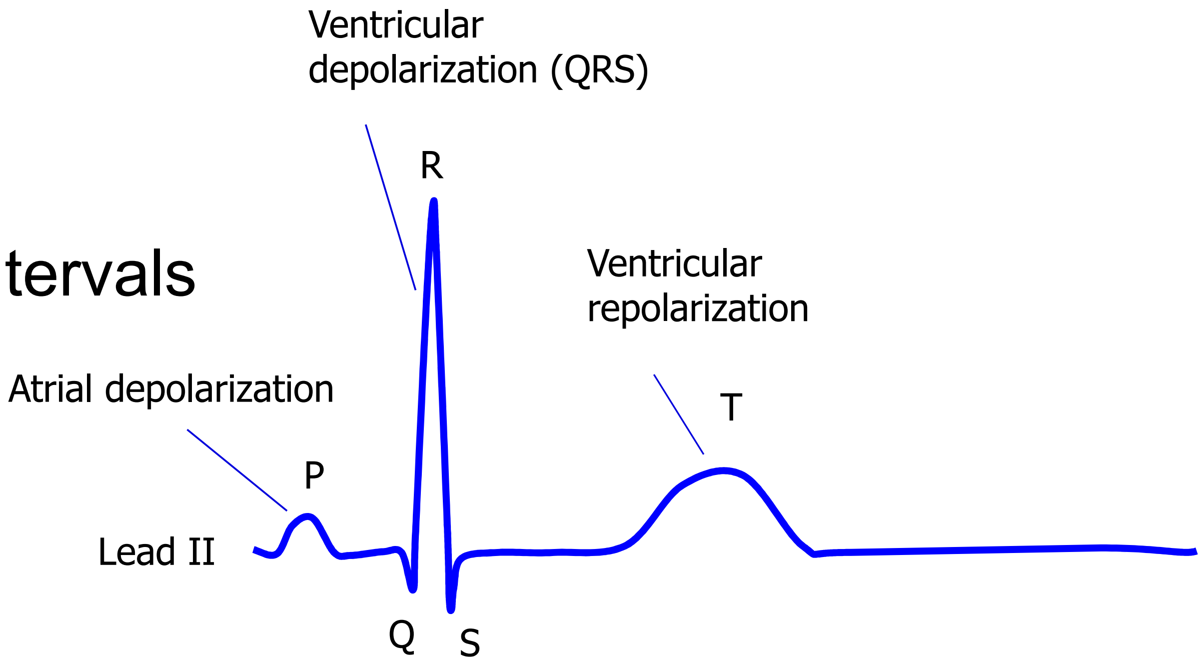
Leads according to Cabrera





Analysis of ECG

1. Heart action
2. Heart rhythm
3. Heart rate
4. Waves, segments and intervals
   - P wave
   - PQ interval
   - QRS complex
   - ST segment
   - T wave
   - QT interval
5. Electrical heart axis



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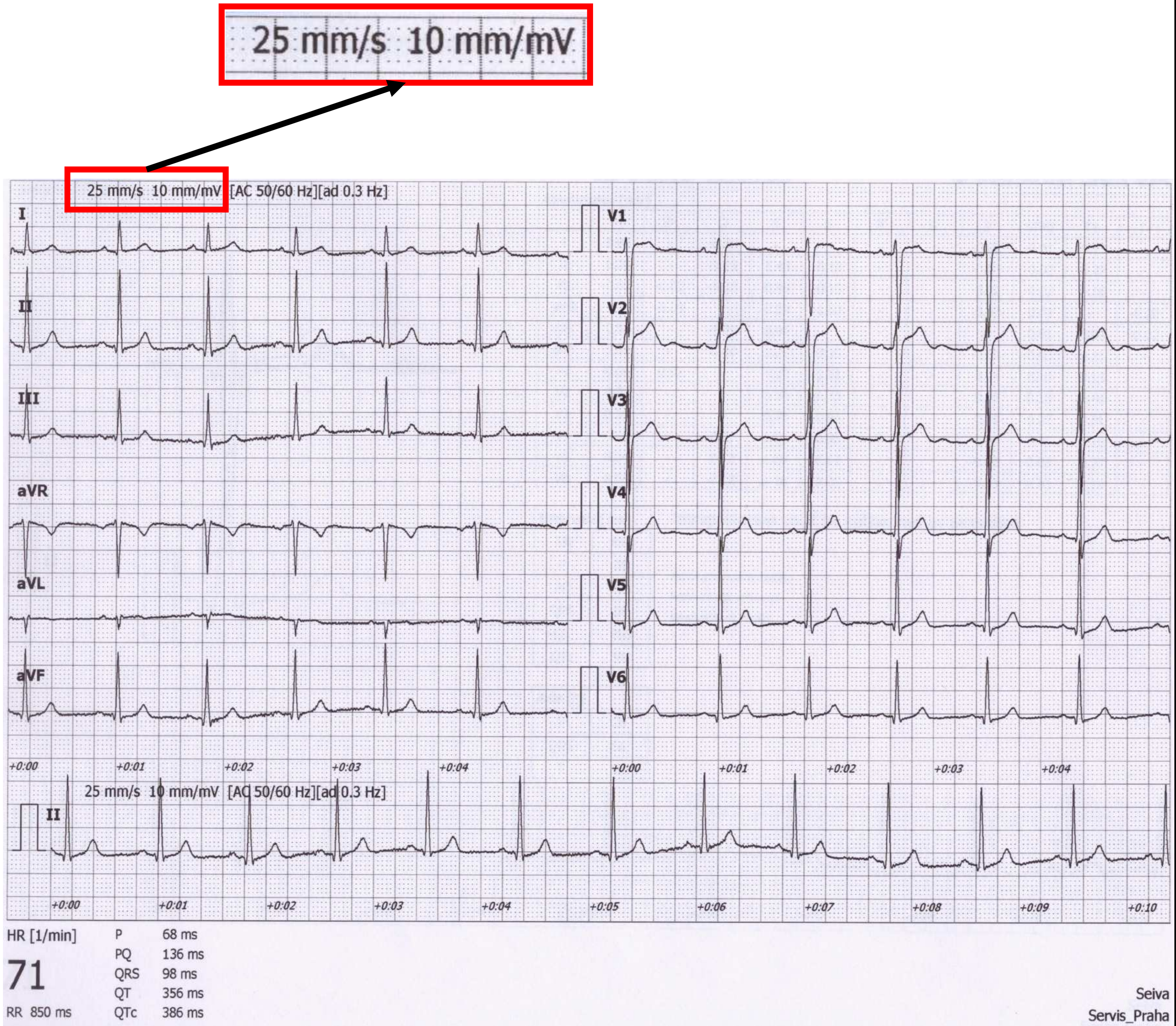
Analysis of ECG

- A millimeter grid of paper will help in fast analysis
- See the paper speed (here 25 mm/s)
  - How many ms is one mm?
  - It is good to know how much mV is one mm



1) Heart action

- Regularity of distances between QRS complexes - RR intervals
- Calculate difference: RR – mean RR
  (you only need to choose the shortest and longest RR in the record)

- Regular action: difference < 0,16 s
- Irregular action: difference > 0,16 s
  - Usually pathological
  - Beware of significant sinus respiratory arrhythmia - it is very physiological. If you are unsure, ask the patient to hold their breath during the recording

- Note: if one extrasystole is present, but otherwise the action is regular, it is called regular

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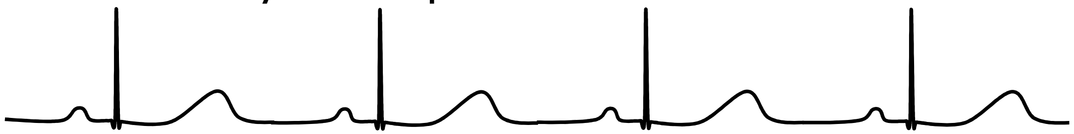
2) Heart rhythm

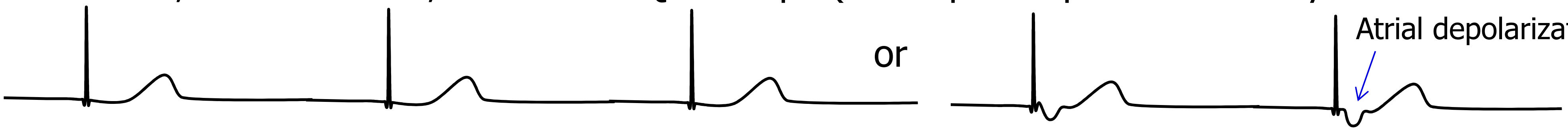
- Heart rhythm is determined by the source of action potentials that lead to ventricular depolarization
  ventricular depolarization is crucial because it determines cardiac output
- **Sinus rhythm**
  - AP begins in the SA node
  - ECG: P wave (atrial depolarization) precedes QRS complex
- **Junction rhythm**
  - AP begins in the AV node or His bundle, and the frequency is usually 40-60 bpm
  - P wave does not precede QRS complex, QRS shape is normal (narrow)
  - Heart rate is low (40-60 bpm)
  - Atrial depolarization can be present in the ECG if the ventricular impulses are transferred to the atria - wave is after QRS and has opposite polarity because it runs in the opposite direction
- **Tertial (ventricular) rhythm**
  - AP begins in other parts of the conduction system, frequency of 30-40 bpm
  - QRS has a strange shape (wider) because it spreads in a non-standard direction in the ventricles

2) Heart rhythm

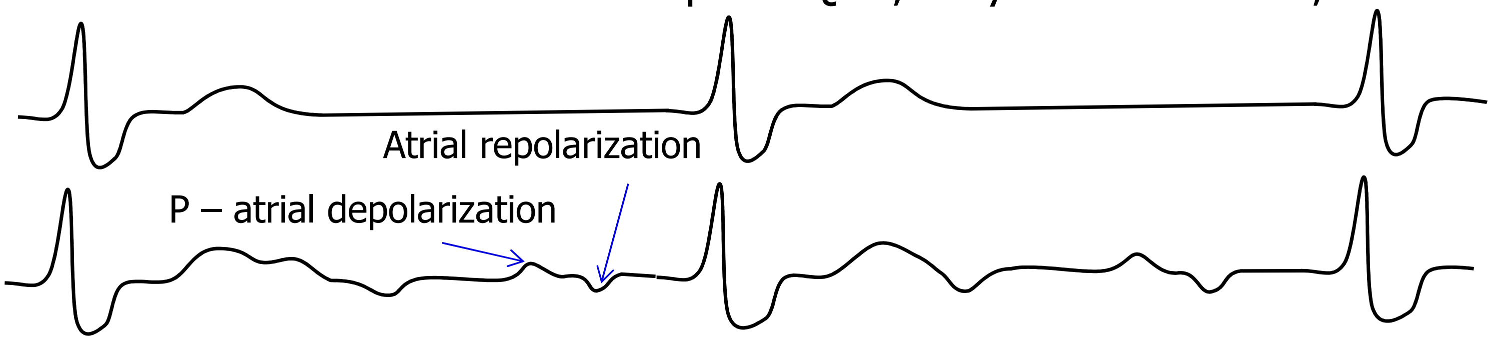
Sinus rhythm – P wave precedes each QRS complex – the impulse begins in the SA node, it is followed by the depolarization of the ventricles



Junctional rhythm – normal P waves do not precede QRS – the impulse begins in the AV node or His bundle, low heart rate, but normal QRS shape (the impulse spreads normally in the ventricle)



Tertiary (ventriclular) rhythm – there are no P waves bound to QRS, the impulse begins somewhere in the ventricles – a deformed shape of QRS, very low heart rate, for example, 3rd-degree AV block



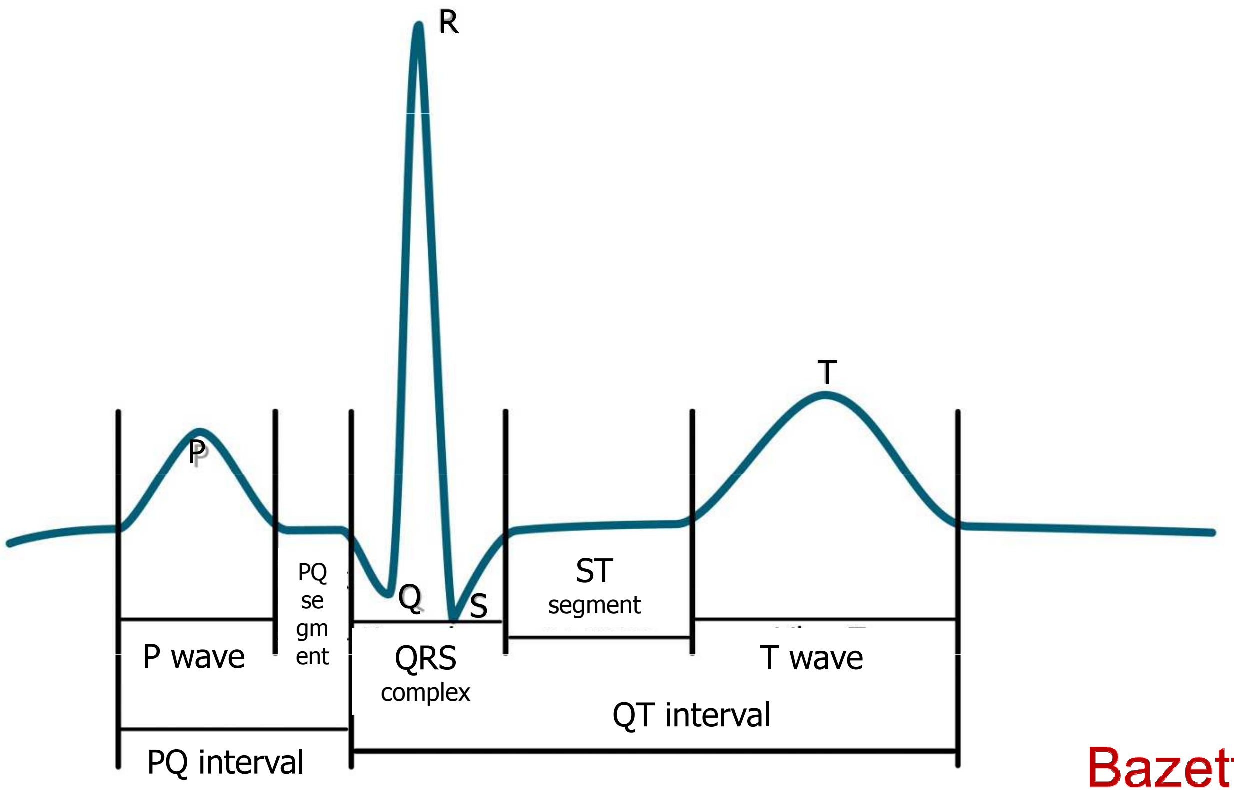
3rd-degree AV block – tertiary rhythm in ventricles, faster rhythm in atria determined by the SA node, but the stimulus is not transferred to the ventricles

3) Heart rate (HR)

– A frequency of ventricular contractions (it determines cardiac output); on ECG – a frequency of ventricular depolarizations
– HR = 1 / RR bpm (beats per minute)
– Physiological values: 60-90 bpm at rest

– Tachycardia: > 90 bpm at rest
  – It can be sinus rhythm (due to increased sympathetic activity, medication, …)
  – Tachyarrhythmias: rhythm is not sinus rhythm
  – If higher than 180 bpm, it isnť probably sinus rhythm
– Bradycardia: < 60 bpm
  – It can be sinus rhythm (increased parasympathetic activity, athlete‘s heart - physiological)
  – If HR < 50 bpm, it isnť probably sinus rhythm (but junctional or ventricular rhythm)

4) Waves, segments, intervals



Name	Norm
P wave	80 ms
interval PQ (PR)	120-200 ms
segment PQ (PR)	50-120 ms
Q	-
complex QRS	80-100ms
R	-
S	-
segment ST	80-120 ms
interval QT	< 420ms
wave T	160 ms

Bazett´s formula: $QTc = \frac{QT}{\sqrt{RR}}$

QT depends on RR interval – correction of QT to RR

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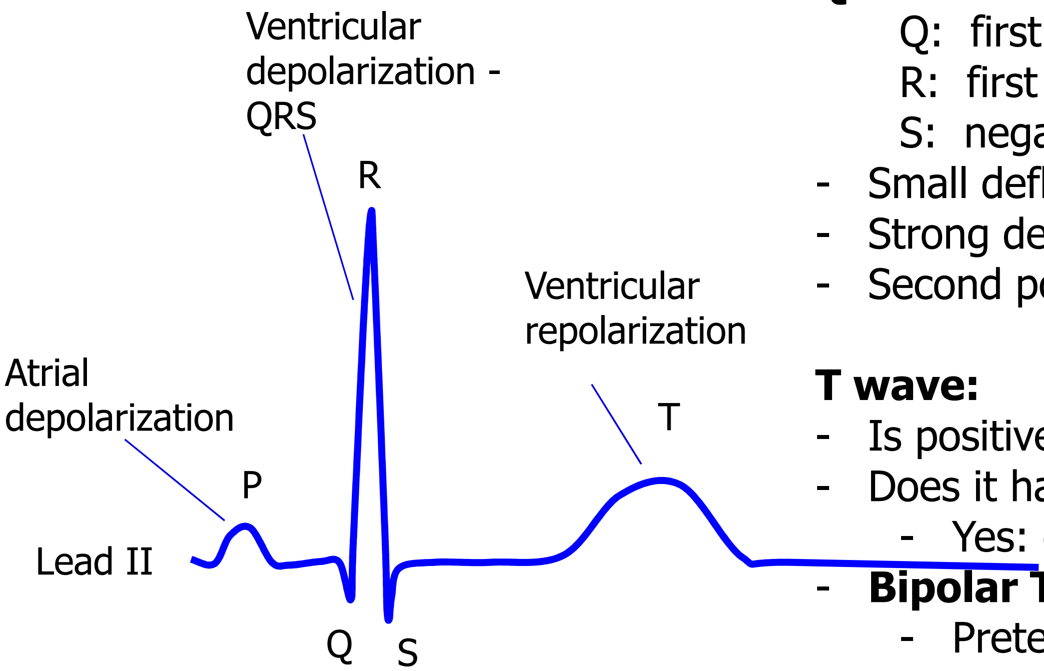
4) Waves, segments, intervals

name	Place and description	Physiological background	Norm
Wave P	First-round wave (negative or positive)	Atrial depolarization	80 ms
Interval PQ (PR)	The interval from the beginning of P wave to the beginning of Q (or R, if Q is not present)	The time interval from SA node activation to the Purkinje fibers activation	120-200 ms
Segment PQ (PR)	From P wave‘s end to the beginning of Q (or R, if Q is not present)	Complete atrial depolarization, the AP transfer from the AV to ventricles	50-120 ms
Q	First negative deflection	Depolarization of septum and papillar muscles	-
Complex QRS	From the beginning of R to the end of S	Ventricular depolarization	80-100ms
R	Positive deflection	Main ventricular depolarization	-
S	Negative deflection after positive deflection.		-
Segment ST	The interval of isoelectric line between the end of QRS and the beginning of T wave	Complete depolarization of ventricles	80-120 ms
Interval QT	From the beginning of Q (or R) to the end of T wave	Electrical systole	< 420 ms
Wave T	Second round wave (negative or positive)	Ventricular repolarization	160 ms

4) Waves

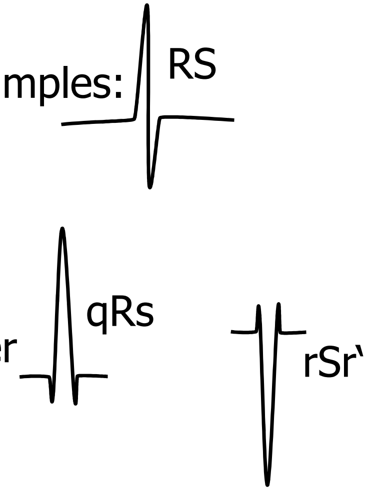


P wave:
- Is it present?
- Is it positive/negative, one-peak/two-peak, high (>0,25 mV)/normal/low?

QRS:

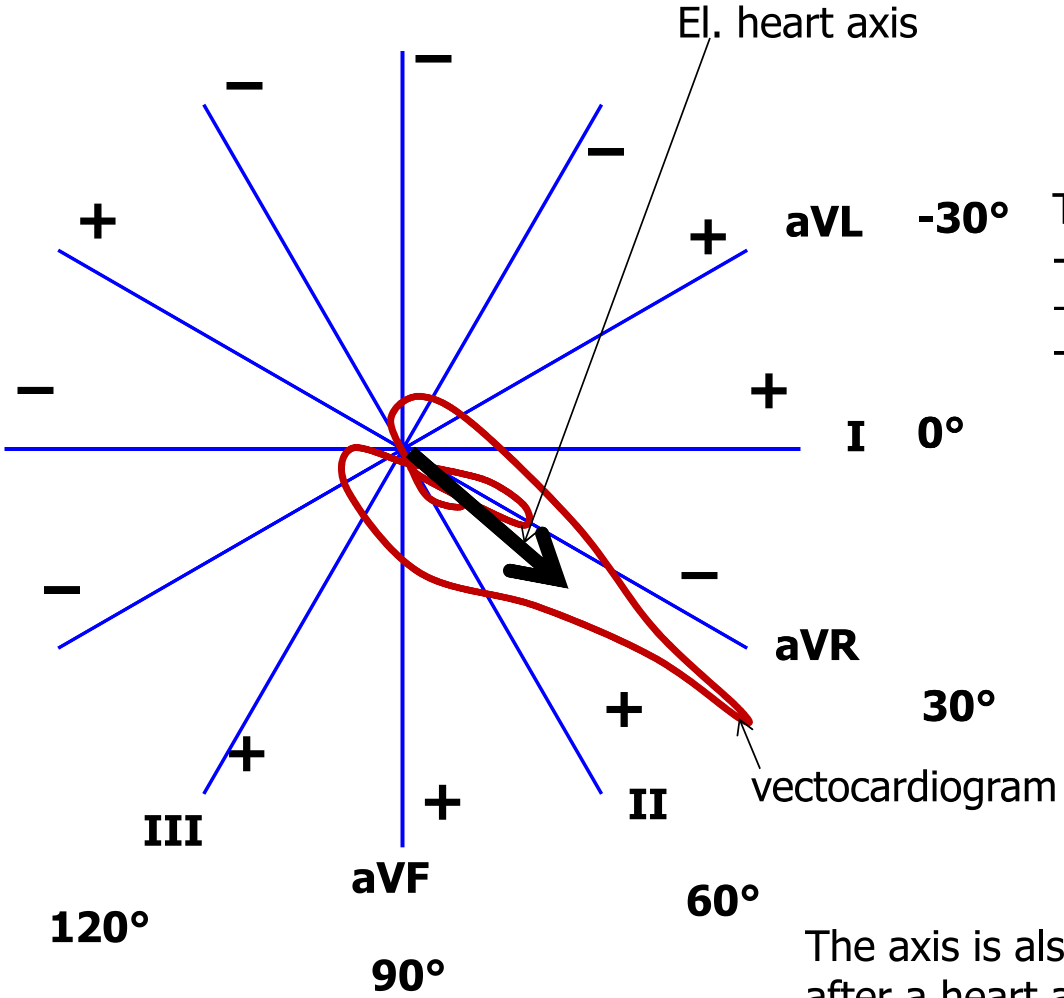
Q: first negative deflection
R: first positive deflection
S: negative deflection after positive deflection
- Small deflection (less than 0,5 mV) – small letter
- Strong deflection (5 mm and more) – capital letter
- Second positive deflection (‛)

Examples:



T wave:
- Is positive/negative/bipolar?
- Does it have the same polarity as the strongest QRS deflection?
    - Yes: concordant (ok), No: discordant (pathology)
- **Bipolar T:**
    - Preterminal negative (-/+)
    - Terminal negative (+/-)

5) Electrical heart axis



Electrical heart axis: average direction of the electric heart vector during ventricular depolarization (QRS complex)
(can also be determined for atrial depolarization: P, or ventricular repolarization: T, but in practice, we will analyse ventricular depolarization)

The heart axis is physiologically directed down, left, and back - refers to the real placement of the heart in the chest.

- Here, we solve only the frontal plane (limb leads)
- The heart axis direction is influenced by bigger muscle mass. In a healthy heart, mostly the left ventricule, in pathological hypertrophy, the direction of pathological muscle mass prevails

Physiological range:
Middle type 0° – 90°
Left type -30° – 0°
Right type 90° – 120°

Pathological range:
Right deviation: > 120 ° (right ventricular hypertrophy, dextrocardia)
Left deviation: < -30° (left ventricular hypertrophy, pregnancy, obesity)

The axis is also changed if Tawara branches are blocked or after a heart attack, el. activity of part of chambers is missing

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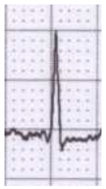
Electrical heart axis – calculation

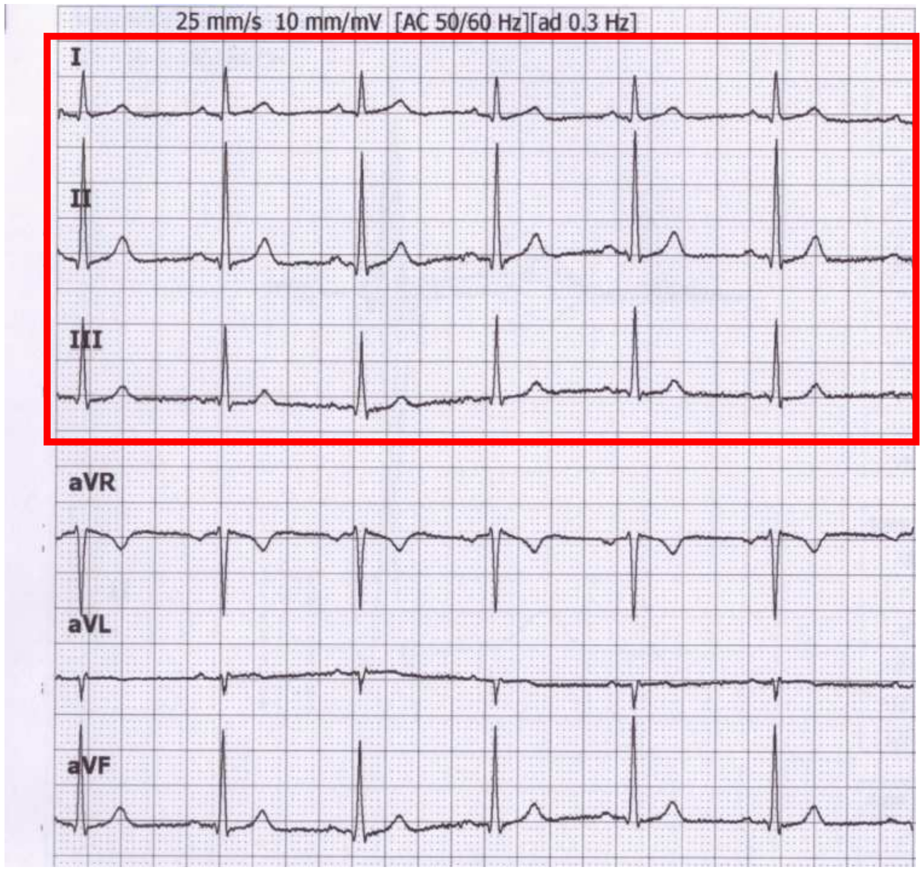
- Because the el. axis is related to ventricular depolarization in the frontal plane, for calculation, use QRS in limb leads: I, II, III.
- Calculate the sum of QRS oscillations in leads I, II, III.
  When the oscillation goes downward, it is negative. When the oscillation is upward, it is positive. Use a millimeter grid.

  - Lead I: Q_I=-1; R_I=6; S_I=0; QRS_I=5

  - Lead II: Q_{II}=-1; R_{II}=17; S_{II}=-1; QRS_{II}=15

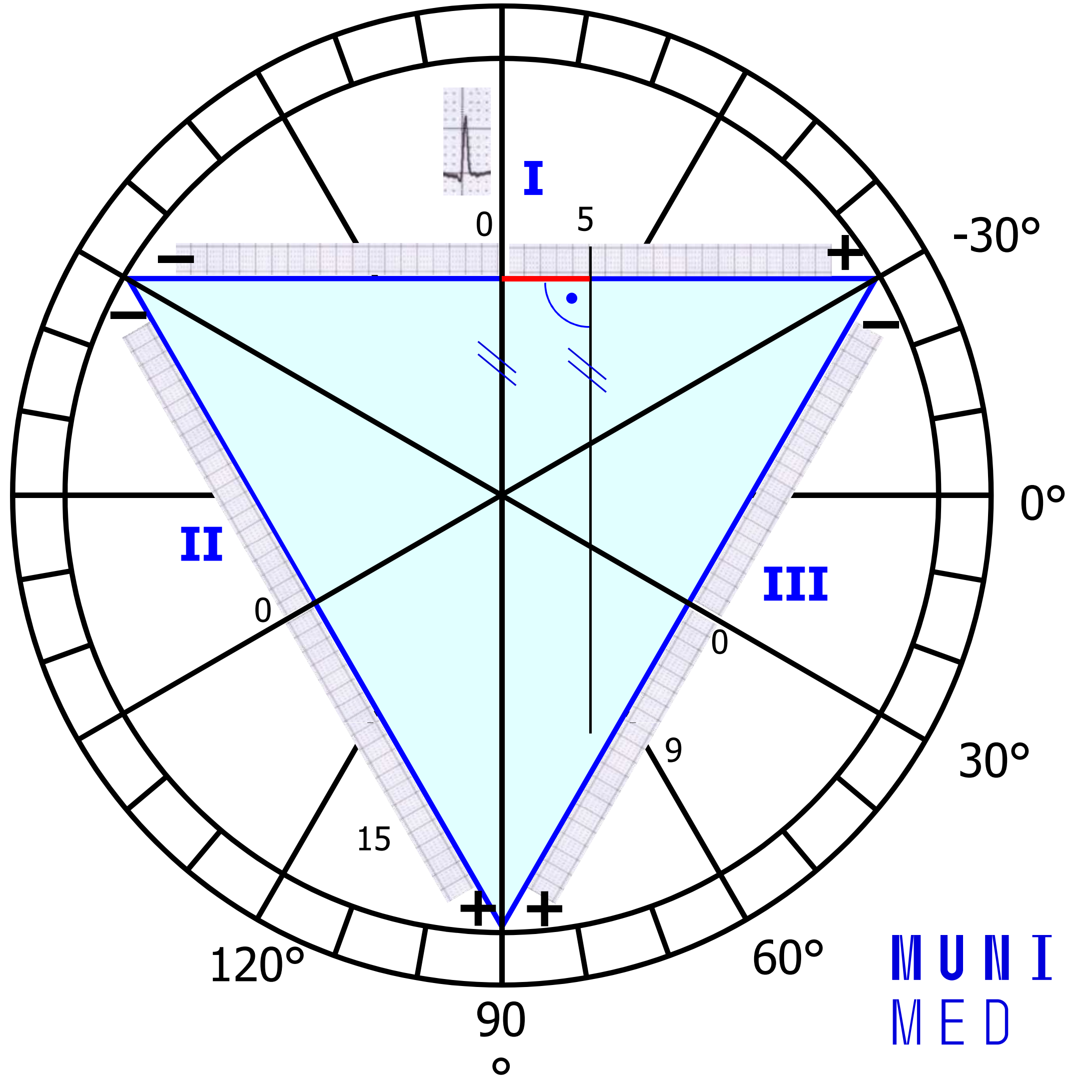


  - Lead IIII: Q_{III}=0; R_{III}=10; S_{III}=-1; QRS_{III}=9



Electrical heart axis – calculation

- Draw the Einthoven triangle with Goldberger augmented leads
- Mark the angles around the triangle (in the circle)
- Lead I:
  - 0 at lead I is in the center of lead
  - QRS_I = 5, so from 0, measure 5 mm towards the positive electrode, make a mark (or any other units, a ratio is important)
  - If the sum of QRS is negative, you will go towards the negative electrode
  - Run a line from the mark perpendicular to the I lead (parallel to the aVF lead)



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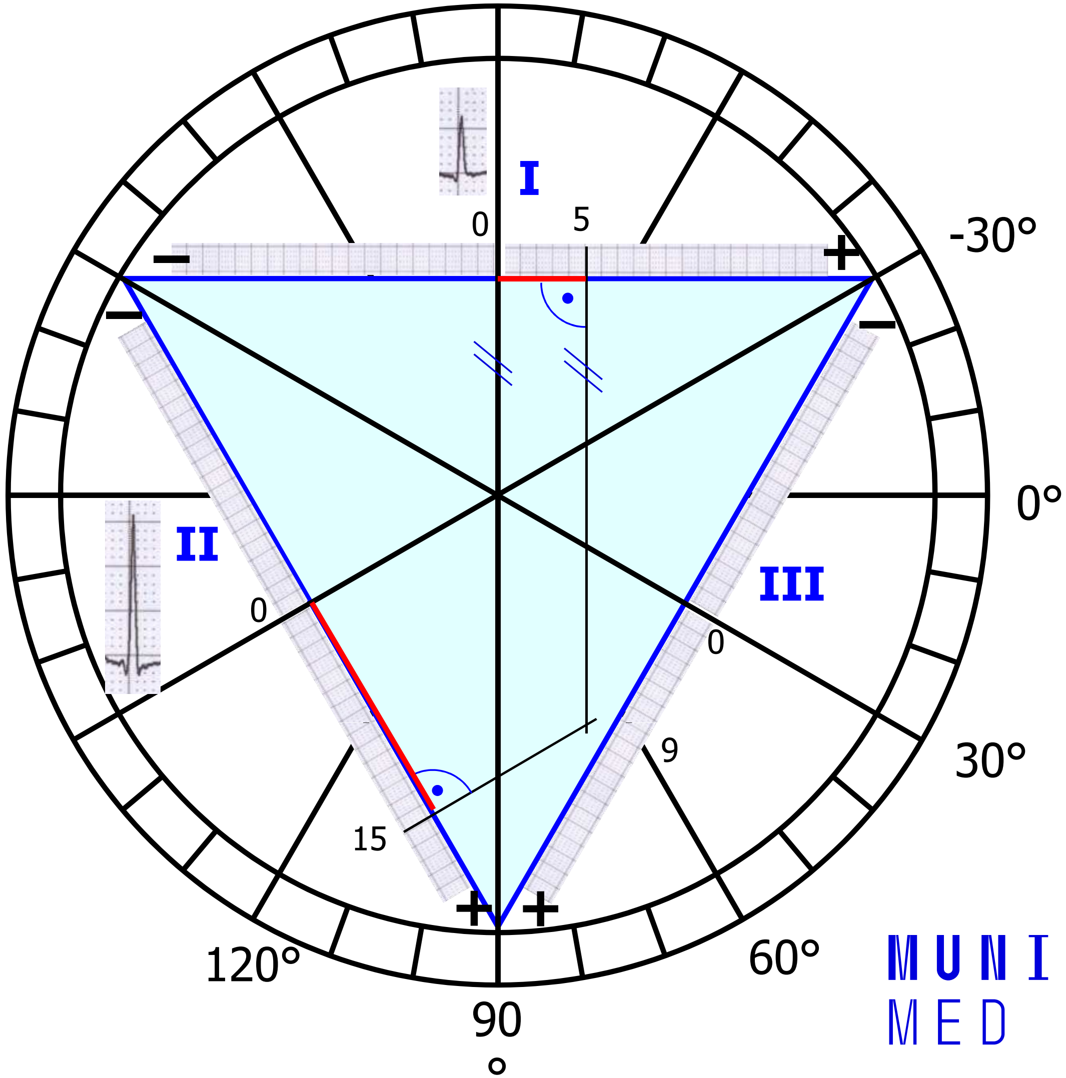
Electrical heart axis – calculation

- Lead II:
  - 0 at lead II is again in the center of lead
  - QRS $_{II}$ = 15, so from 0, measure 15 mm towards the positive electrode, and make a mark (again, if the sum of QRS is negative, you will go towards the negative electrode)
  - Run a line from the mark perpendicular to the II lead (parallel to the aVL lead)
- Draw an arrow that starts at the center of the triangle and passes the cross of the drawn lines



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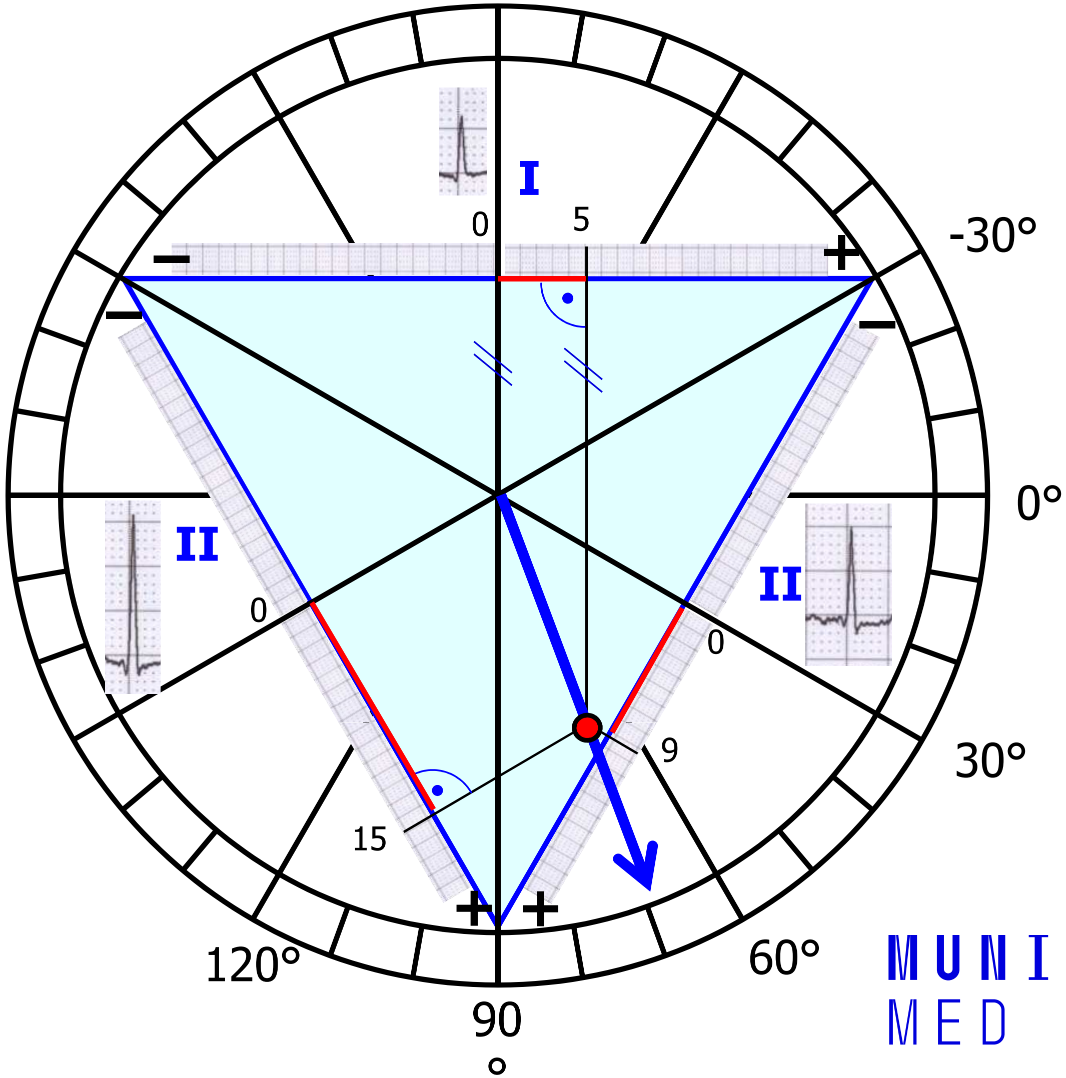
Electrical heart axis – calculation

- Lead III:
  - The same way, draw the line for $QRS_{III} = 9$
- Draw an arrow that starts at the center of the triangle and passes the cross of the drawn lines
- This arrow shows the direction of the cardiac electrical axis in the frontal plane
- Note: logically, even lines from just two leads are sufficient

The cardiac electrical axis for ventricular depolarization in the frontal plane is 70 °



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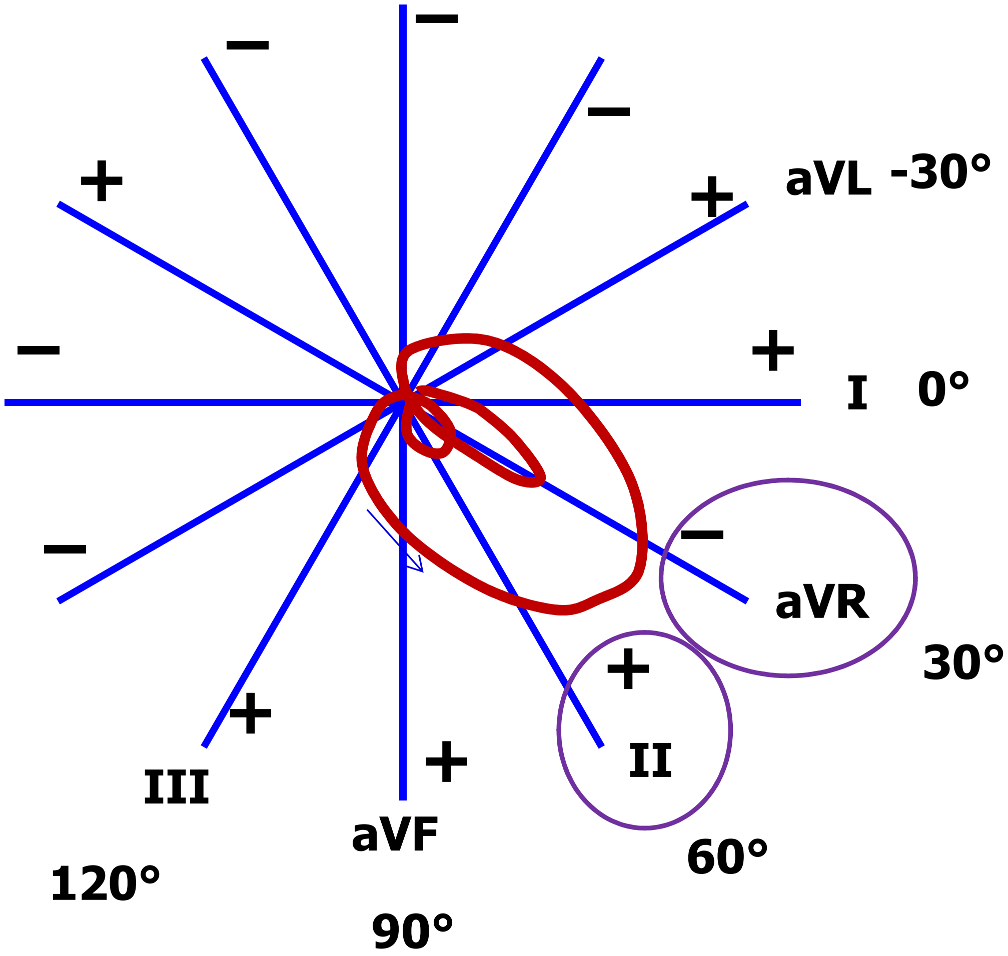
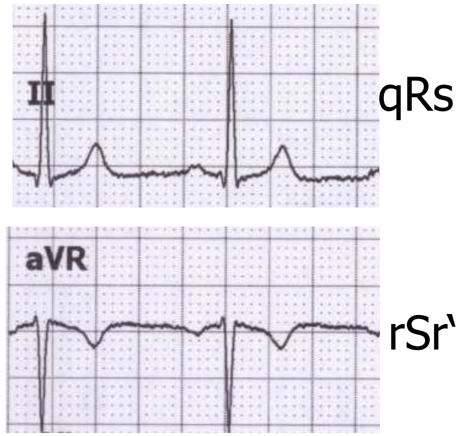
Leads II and aVR



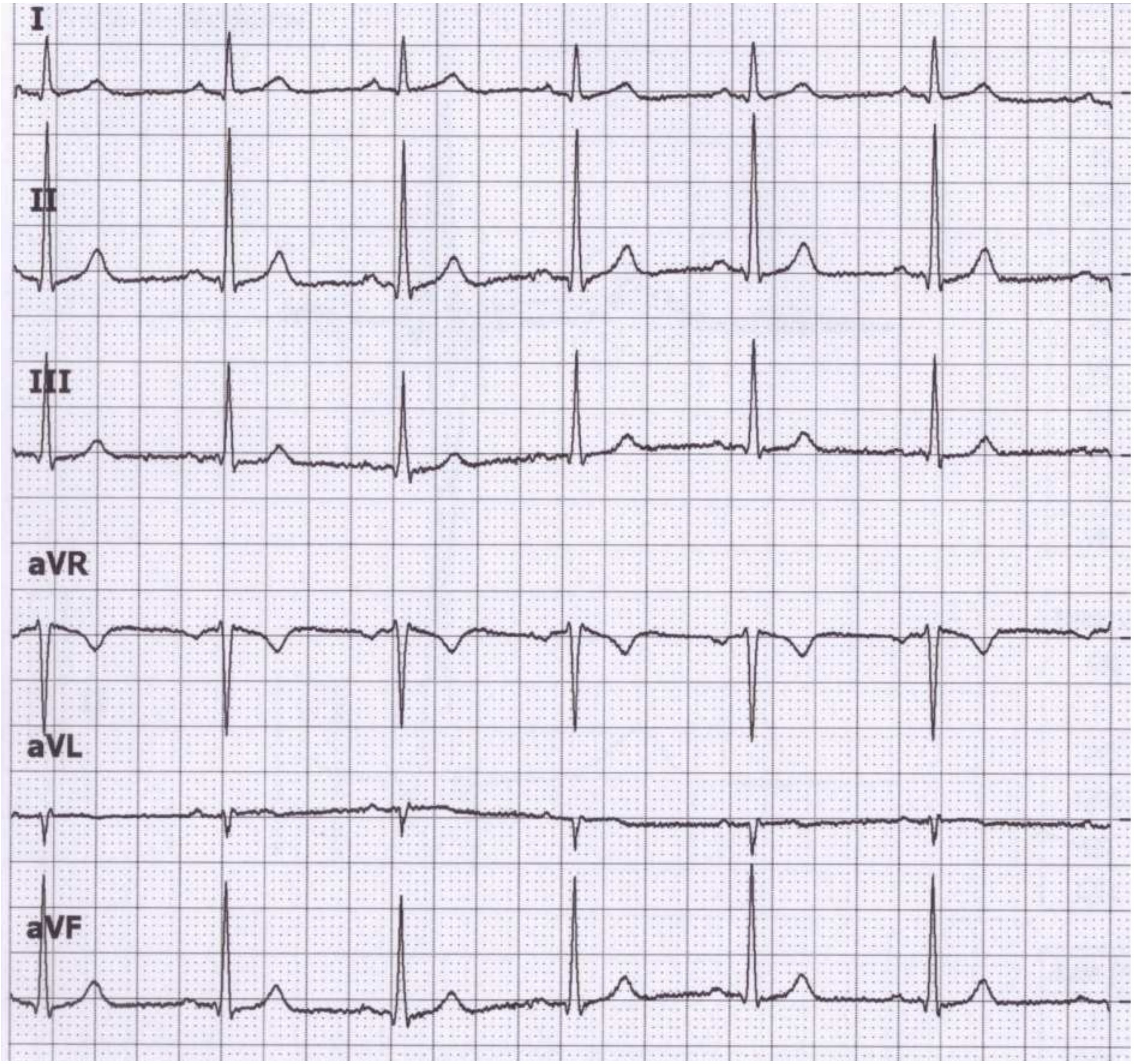
Note the appearance of the ECG in the lead II and aVR. Both leads look at electrical cardiac activity from a similar angle (deviation only 30 °), but the aVR has the opposite polarity (it looks at the heart upside down compared to II). Therefore, leads II and aVR are similar, only mirror-inverted.



aVR usually has negative T and P

Due to its different appearance, QRS has different description in lead aVR and II.

QRS in limb leads and axis



amplitudes of Q, R, and S	Sum of QRS	description of QRS
Q = -1 R = 6 S = 0	QRS = 5	qR
Q = -1 R = 17 S = -1	QRS = 15	qRs
Q = 0 R = 10 S = -1	QRS = 9	Rs
Q = 1 R = -11 S = 0	QRS = -10	rS
Q = 0 R = -3 S = 0	QRS = -3	q
Q = -1 R = 13 S = -1	QRS = 11	qRs

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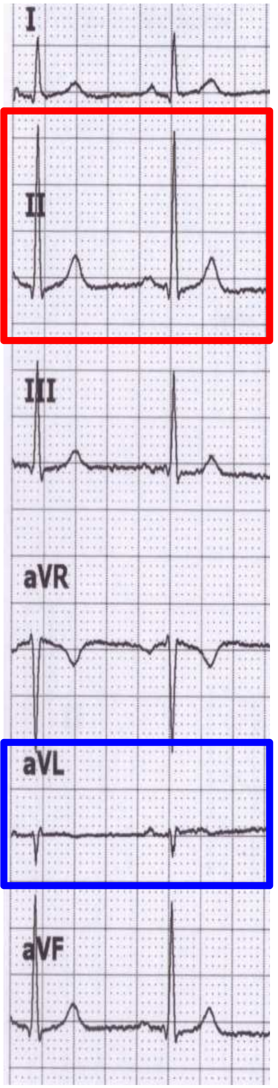
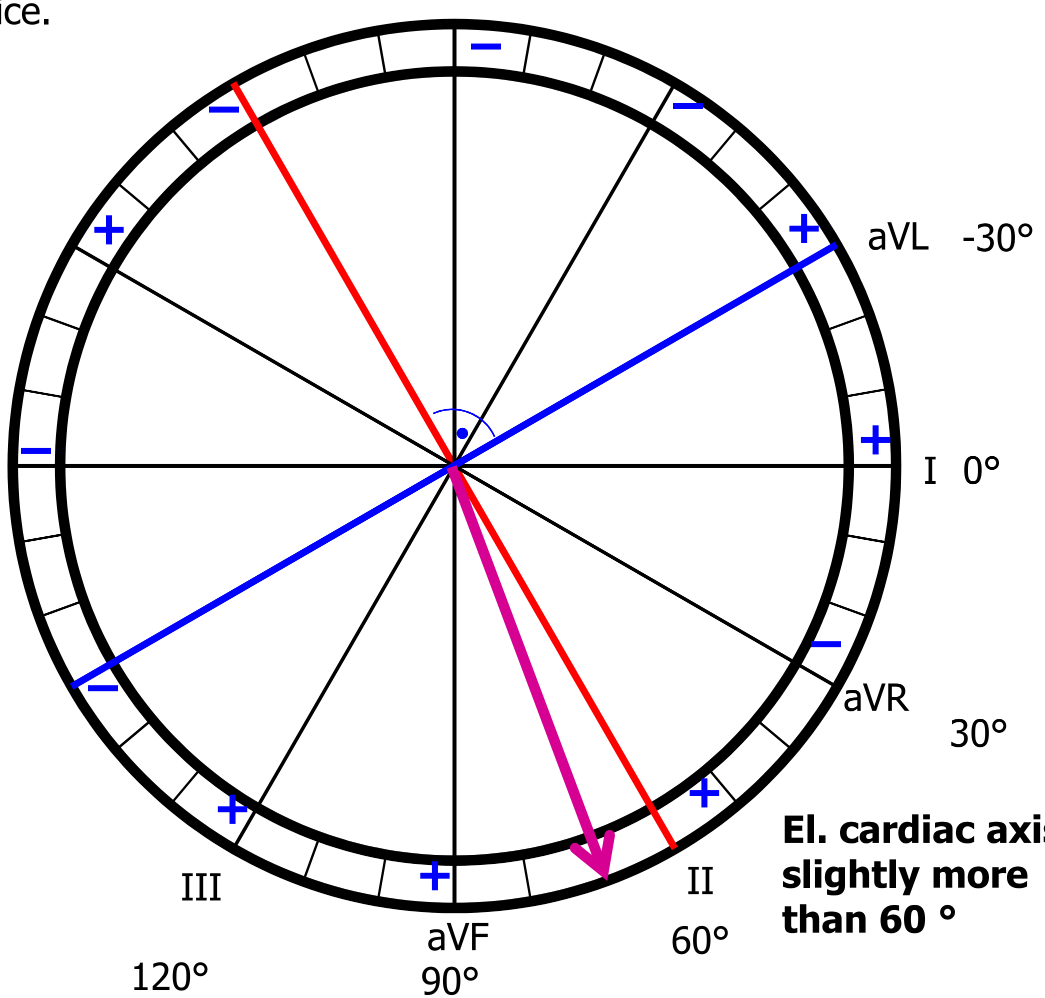
Electric axis estimation

Find the lead with the largest and smallest sum of QRS (just by eye) - those leads will be perpendicular to each other. The angle of lead with the largest sum of QRS will determine approximately el. heart axis. It is not perfectly accurate, but it is sufficient in practice.



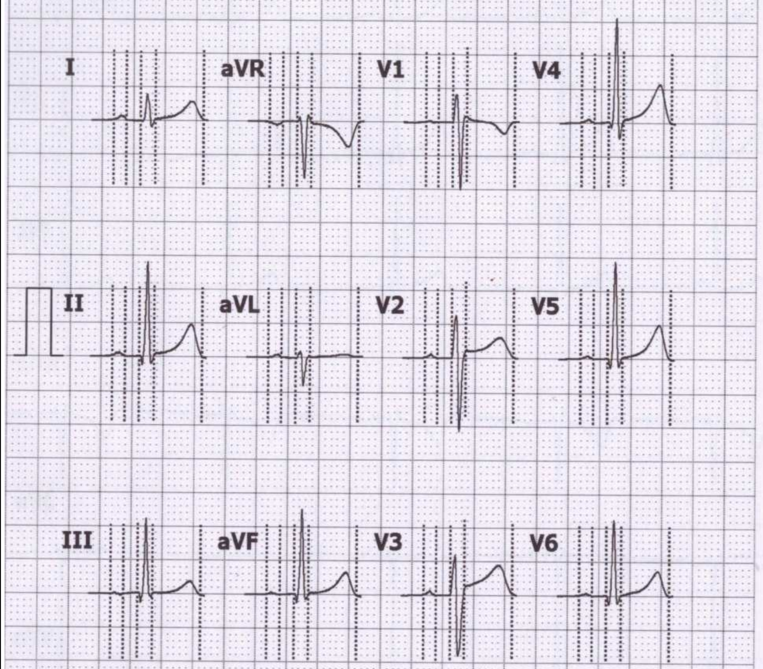
Amplitudes of Q, R, S	Sum of QRS
Q = -1 R = 6 S = 0	QRS = 5
Q = -1 R = 17 S = -1	QRS = 15
Q = 0 R = 10 S = -1	QRS = 9
Q = 1 R = -11 S = 0	QRS = -10
Q = 0 R = -3 S = 0	QRS = -3
Q = -1 R = 13 S = -1	QRS = 11



El. cardiac axis slightly more than 60 °

Electric axis calculation by software

Averaged QRS complex
25 mm/s 10 mm/mV



Amplitudes [mV]

	P+	P-	Q	R	S	R'	S'	J	ST40	T+	T-
I	0.06	-	-	0.40	-0.09	-	-	0.03	0.03	0.28	-
II	0.05	-	-0.14	1.40	-0.12	-	-	0.03	0.05	0.48	-
III	0.02	-0.03	-0.16	1.10	-0.07	-	-	0.01	0.02	0.21	-
aVR	-	-0.05	-	0.07	-0.85	0.09	-	-0.03	-0.04	-	-0.37
aVL	0.04	-	-	0.11	-0.40	0.05	-	0.01	0	0.04	-
aVF	0.03	-	-0.15	1.25	-0.09	-	-	0.02	0.03	0.34	-
V1	0.02	-0.02	-	0.41	-1.02	0.09	-	0.08	0.03	-	-0.18
V2	0.05	-	-	0.63	-1.10	-	-	0.11	0.11	0.30	-
V3	0.06	-	-	0.59	-0.92	-	-	0.09	0.15	0.42	-
V4	0.05	-	-0.09	1.55	-0.26	-	-	0.04	0.07	0.58	-
V5	0.04	-	-0.16	1.43	-0.14	-	-	0.02	0.05	0.51	-
V6	0.04	-	-0.15	1.12	-0.13	-	-	0.01	0.04	0.37	-

Intervals [ms]	
RR	1031
P	81
PQ	173
QRS	93
QT	401
QTc	395

Interpretation must be authorized by physician

Automatic marker setting
Patient's age unknown
Bradycardia

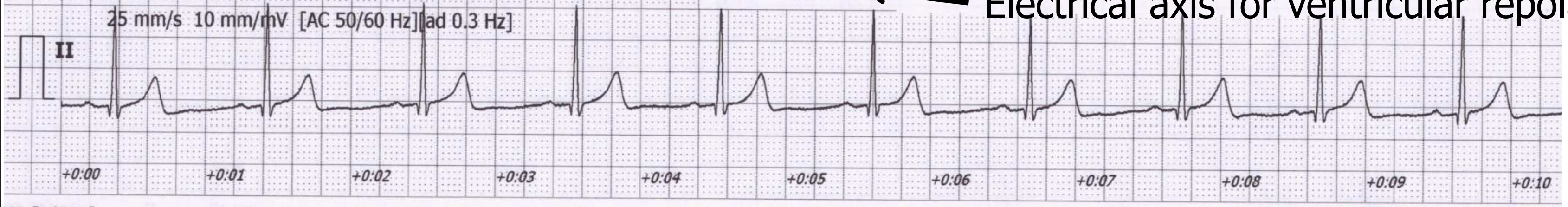
Axis [°]	
P	15
QRS	72
T	49

Electrical axis for atrial depolarization

72° Electrical axis for ventricular depolarization

Electrical axis for ventricular repolarization

25 mm/s 10 mm/mV [AC 50/60 Hz][ad 0.3 Hz]



HR [1/min]

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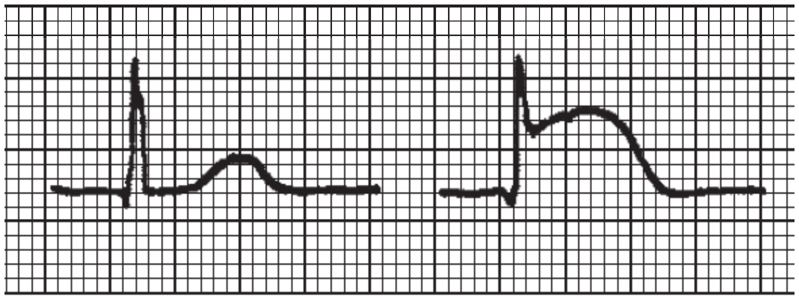
Diagnostic use of ECG

Arrhythmia: a disorder of heart rhythm, formation or conduction of the excitation

Diagnostic use of ECG

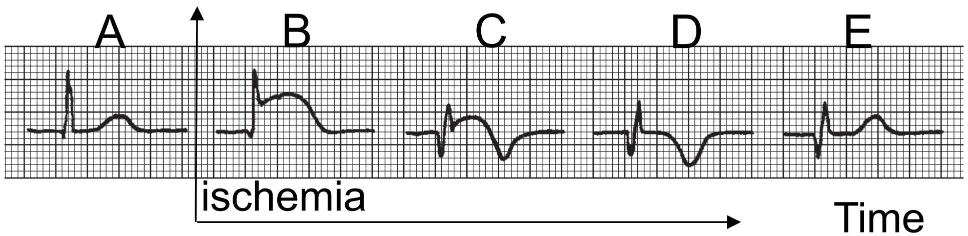
Cardiac ischemia, myocardial infarction

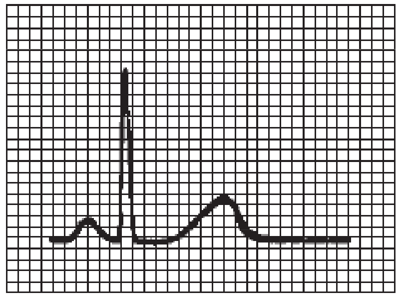
Electrolyte dysbalance - hyperkalemia



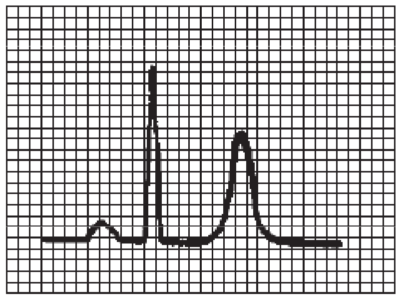
normal

ST elevation,
sign of ischemia





Normal tracing (plasma K^+ 4–5.5 meq/L).

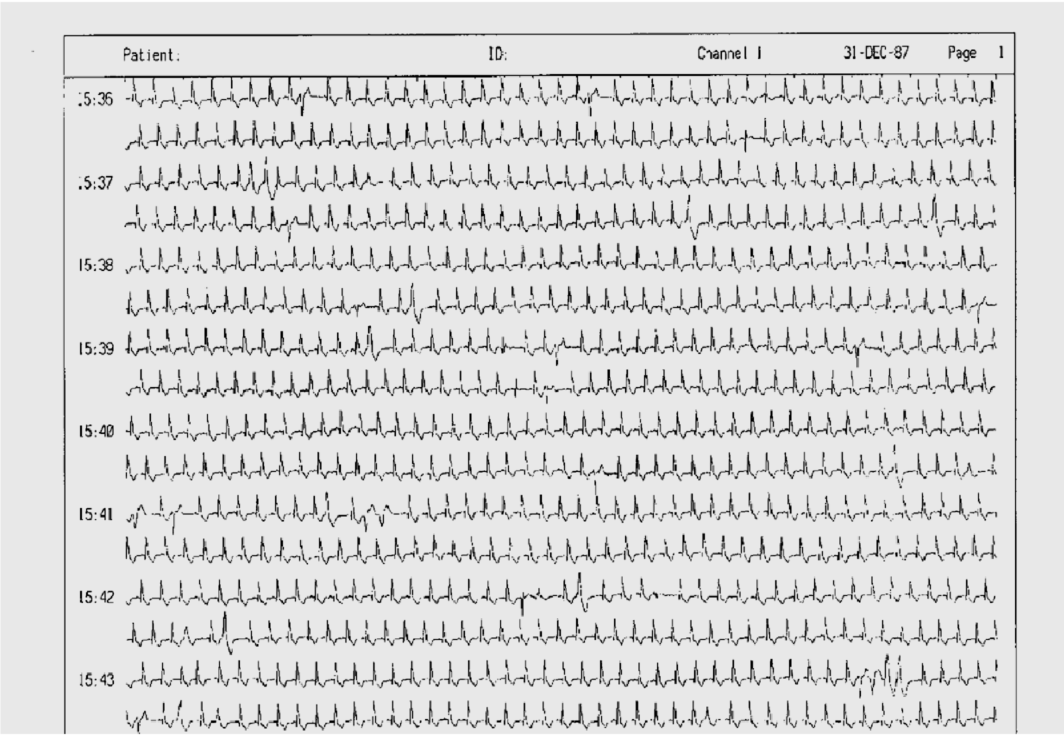


Large QRS, hight T

Hyperkalemia (plasma K^+ ±7.0 meq/L).

ECG Holter

24-hour monitoring of ECG



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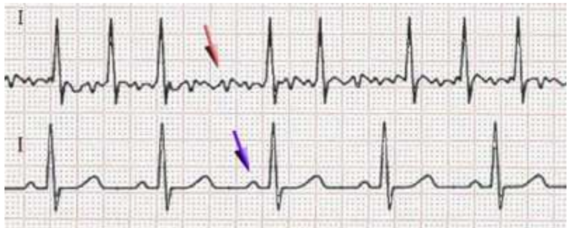
Fibrillation

Fibrillation: unsynchronized cardiomyocyte activity

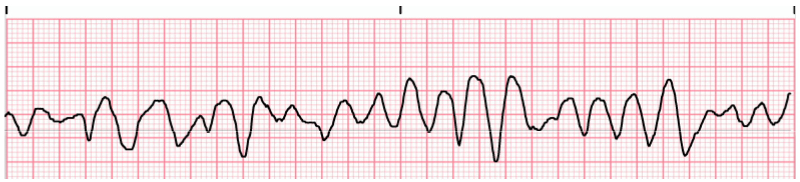
Atrial – missing P wave, slightly irregular "serrated" isoline, irregular RR (usually), frequency 80 - 180 bpm. QRS is normally shaped. It is not life-threatening. Ventricular refraction time protects ventricles from HR higher than 180 bpm, but it still exhausts the heart. Heart activity is not regulated. Risk of thromboembolia



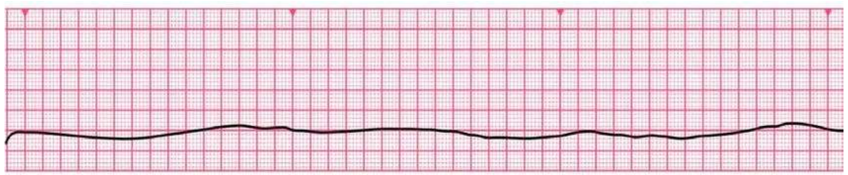
Fibrillation

Normal ECG

Ventricular – the heart does not function as a pump (cardiac arrest), zero cardiac output, brain damage after 3 - 5 minutes of fibrillation. Without early defibrillation, the cardiomyocytes become exhausted → asystole



Asystole – no electrical activity of cardiomyocytes, non-defibrillable



First aid:→ standard cardio-pulmonary resuscitation (CPR) and adrenalin

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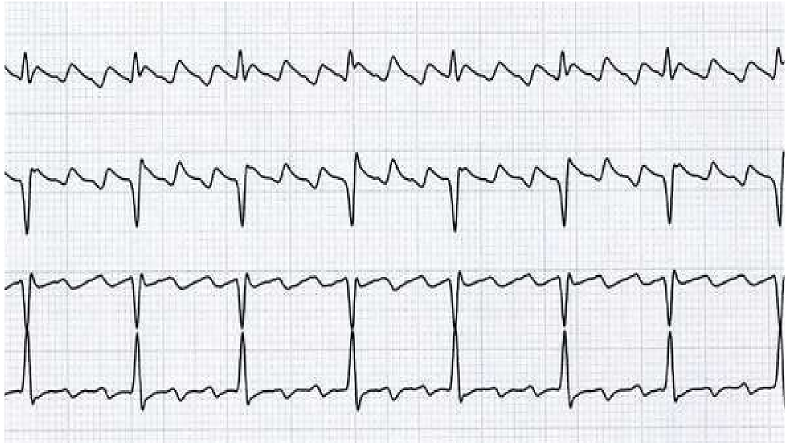
Artial flutter



- Regular “teeth“ between the QRS.
- Regular RR, tachycardia.
- The cause is atrial re-entry.
- The regularity is given by the number of "turns" of atrial depolarization per transfer to the chambers (in the picture: 3 turns per 1 transfer to the chambers, i.e. 3:1).
- If the flutter does not disappear, it changes into atrial fibrillation
- The danger of the deblocked flutter 1:1 (each atrial turn is transferred in ventricles) – exhaustion of ventricles
- Risk of thromboembolia

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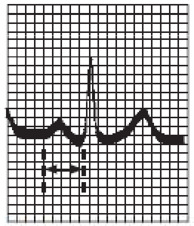
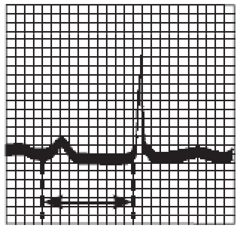
Atrioventricular block (heart block)

AV block: a disorder of the transmission of depolarization from the atria to the ventricles



PR = 0.16 s
Normal complex

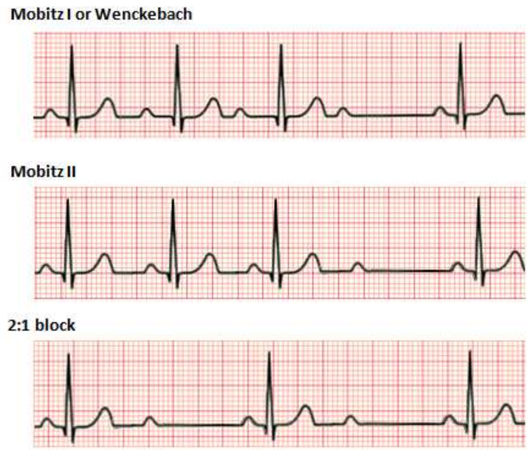
AV block 1st degree



PR = 0.38 s
First-degree heart block

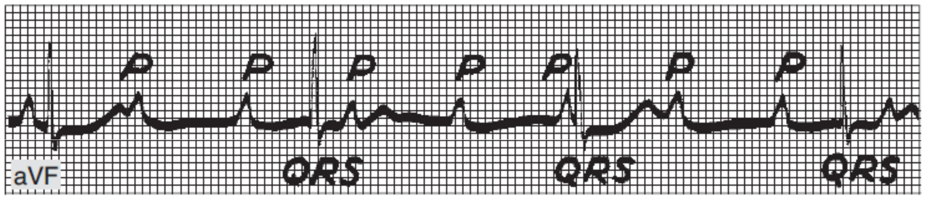
Prolongation of the transfer of depolarization from the atrium to the ventricles, prolonged PQ

AV block 2nd degree



Some atrial depolarizations do not transfer: occurrence of P wave, which QRS does not follow

AV block 3rd degree



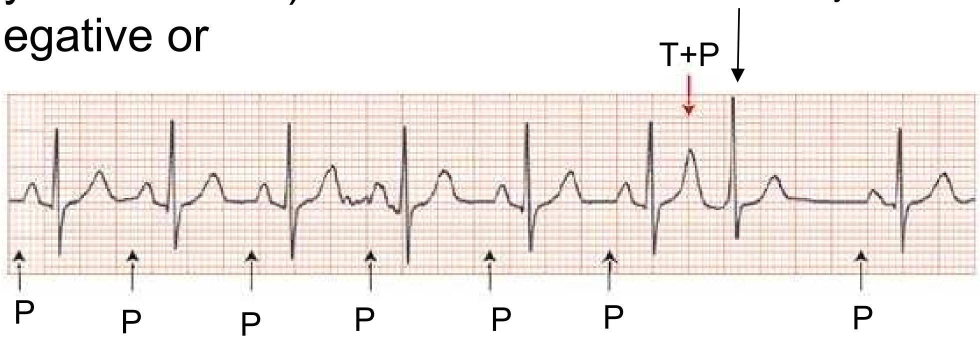
Complete heart block. Atrial rate, 107; ventricular rate, 43

A complete blockage of the transfer of depolarization from the atria to the ventricles, P and QRS are not synchronized. Pulse rate possibly very low → insufficient cardiac output

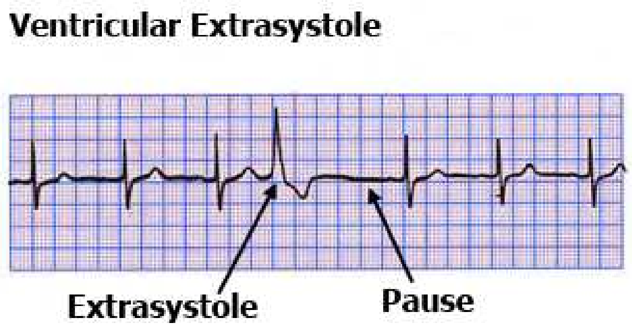
https://upload.wikimedia.org/wikipedia/commons/thumb/6/64/Afib_ecg.jpg/400px-Afib_ecg.jpg
http://www.qureshiuniversity.com/Ventricular%20Fibrillation.gif
https://ekg.academy/ekgtracings/313.gif

Extrasystoles – ectopic pacemaker

- Supraventricular – atrial or AV ectopic pacemaker
- Normal shape of QRS (depolarization spreads normally in ventricles)
  - P wave does not have a normal shape (it can be negative or covered by QRS)
  - There may be a postextrasystolic pause (re-propagation of depolarization through the atria)



- Ventricular
  - Large, abnormal shape of QRS
  - At a slow heart rate, there is no compensatory pause (extrasystole is interspersed between normal QRS)
  - Or there may be a compensating pause if the next depolarization, coming from the SA node, comes at a time when the ventricles are still refractory



https://www.stefajir.cz/supraventrikularni-extrasystola-ekg
https://www.techmed.sk/predsienova-extrasystola/
https://thoracickey.com/atrial-ectopic-beats/

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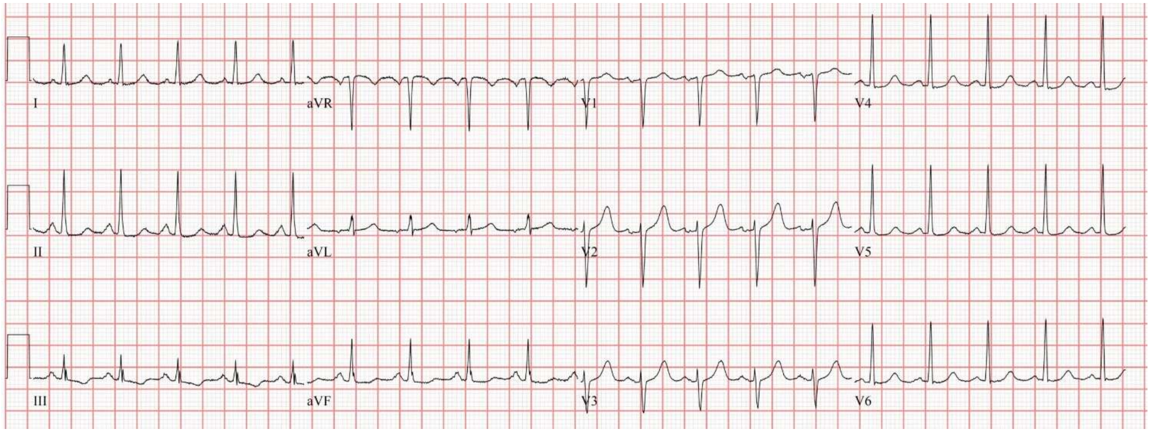
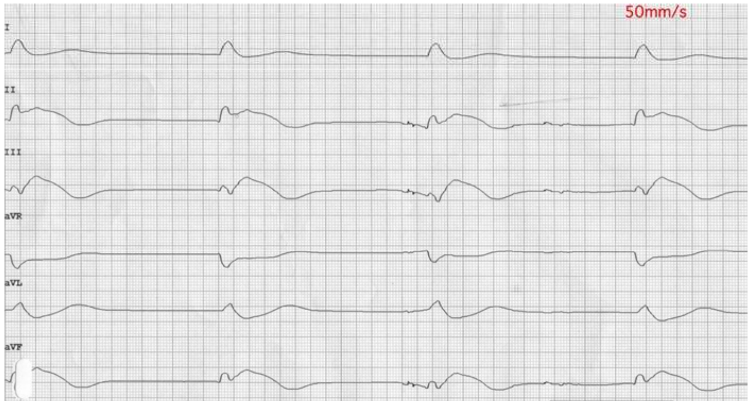
PEA – pulseless electrical activity

- PEA refers to cardiac arrest in which the electrocardiogram shows a heart rhythm that should produce a pulse, but it does not. PEA can look almost like normal ECG activity. Pulseless electrical activity is found initially in about 55% of people in cardiac arrest.
- Under normal circumstances, electrical activation of muscle cells precedes mechanical contraction of the heart (known as *electromechanical coupling*). In PEA, there is electrical activity but insufficient cardiac output to generate a pulse and supply blood to the organs.
- **PEA is classified as a form of cardiac arrest.**
- **non-defibrillable, therapy: Cardio-Pulmonary Resuscitation and adrenalin**
- **Important !: Regular electrical activity on ECG does not mean maintained circulation. Always check for a central arterial pulse.**





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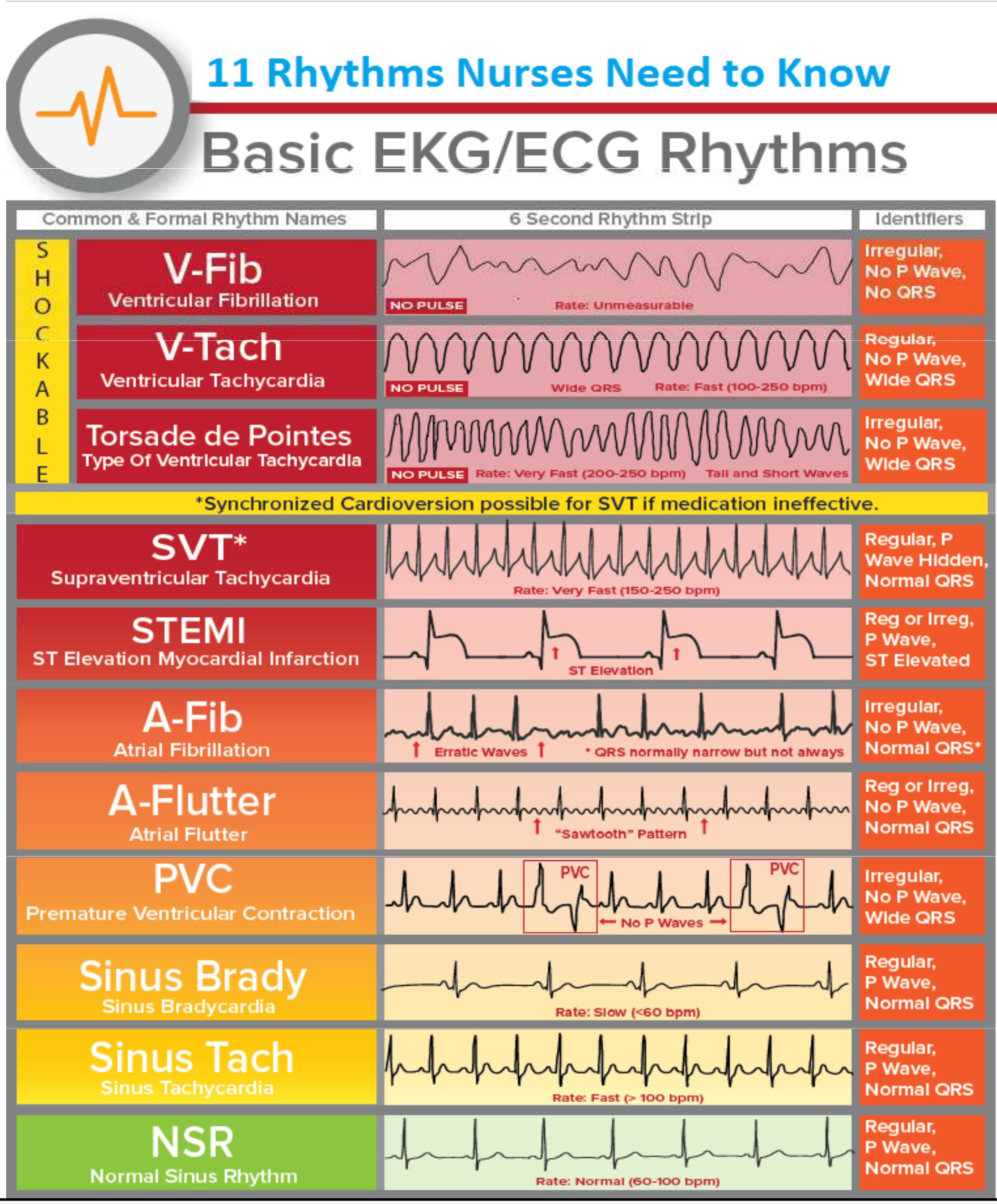

https://www.medicalestudy.com/basic-ecgekg-rhythms-nclex-cheat-sheet/