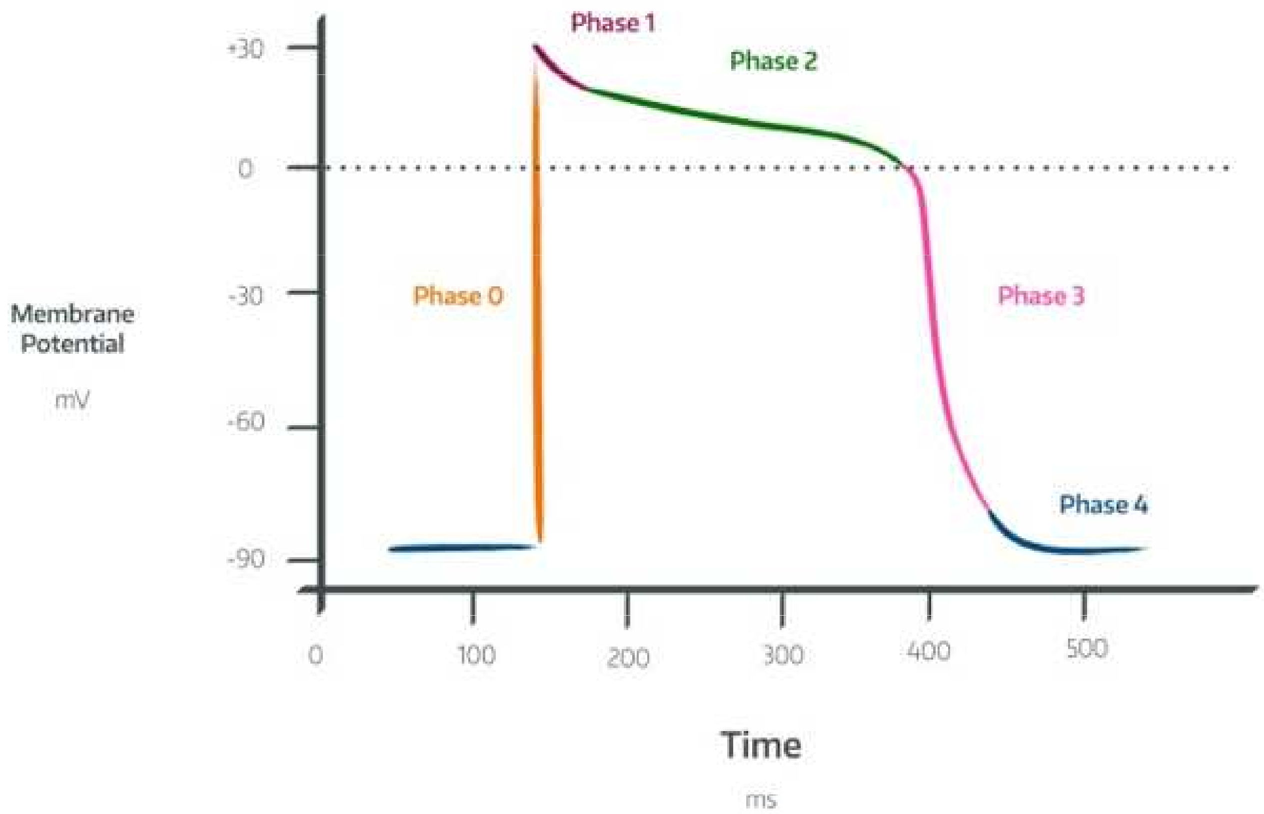
Cardiac Action Potential and Electrocardiography

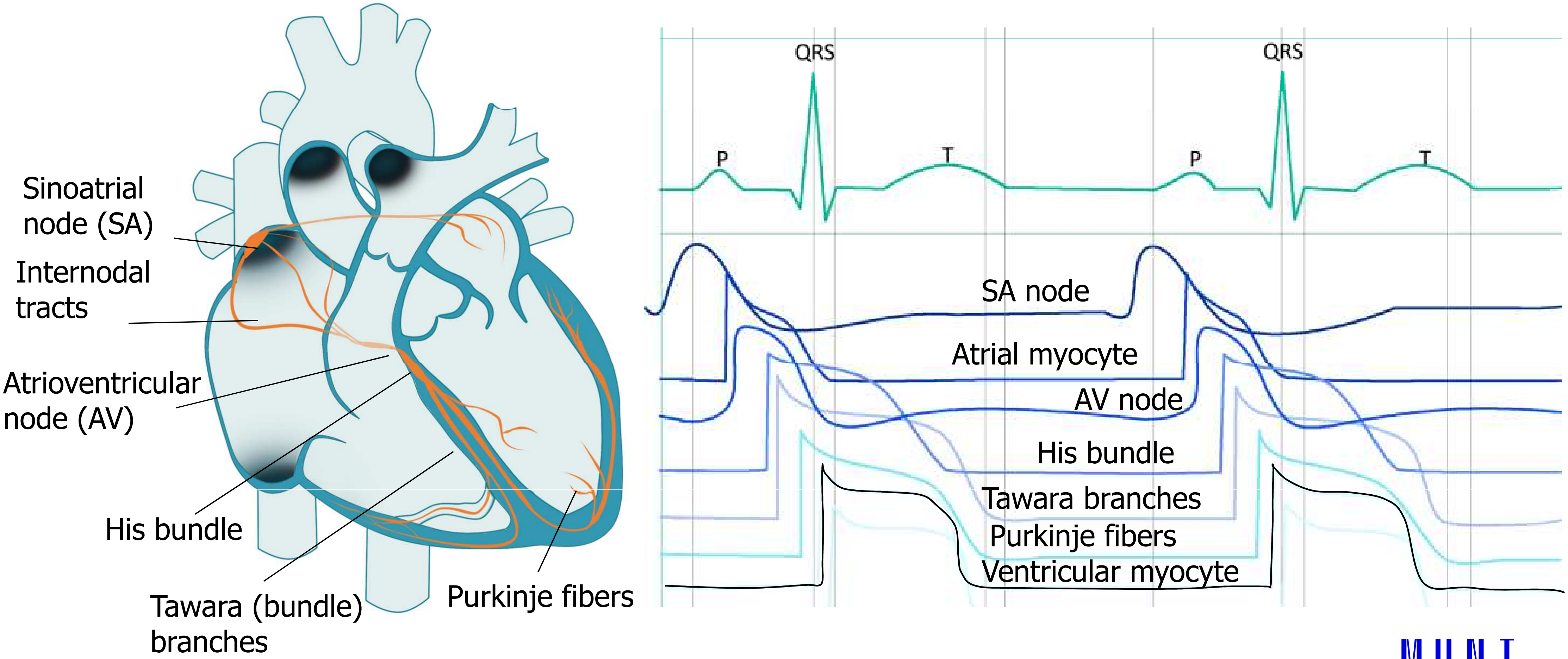
Preclinical practice 17. 4. 2024

Mgr. Martin Král

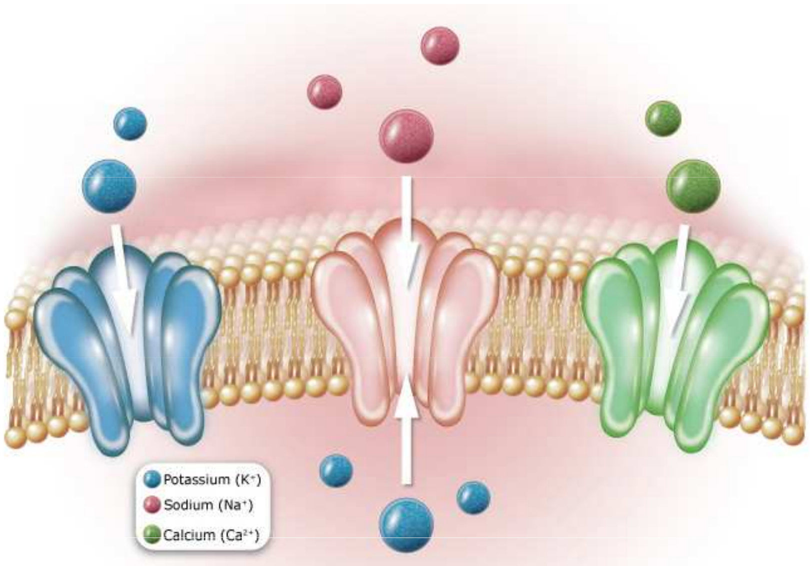
Action potential



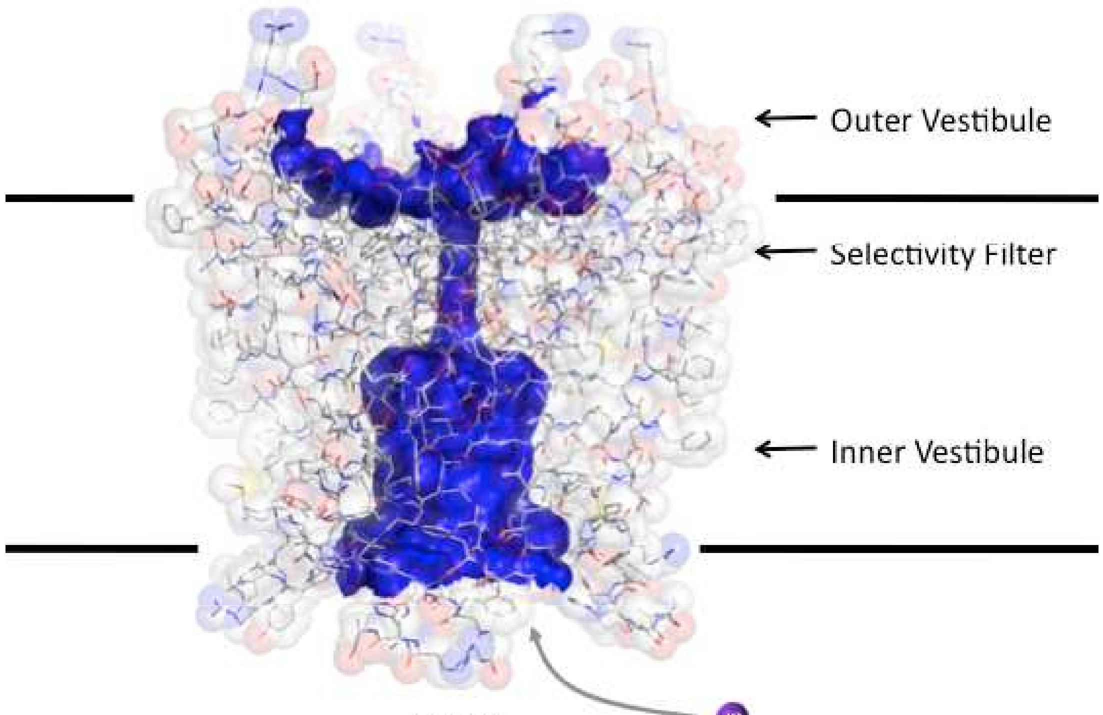
Action potential



Ion channel



Potassium (K⁺)
Sodium (Na⁺)
Calcium (Ca²⁺)



Outside
Outer Vestibule
Selectivity Filter
Inner Vestibule
Inside

Flow of ions

- electrochemical gradient
- Nernst eqation $$E_X = \frac{61}{z} \cdot \log \frac{[\mathrm{X}]_e}{[\mathrm{X}]_i}$$

- electrochemical equilibrium potential for:
  - Na^+ = +60 mV
  - K^+ = -96 mV
  - Ca^{2+} = +134

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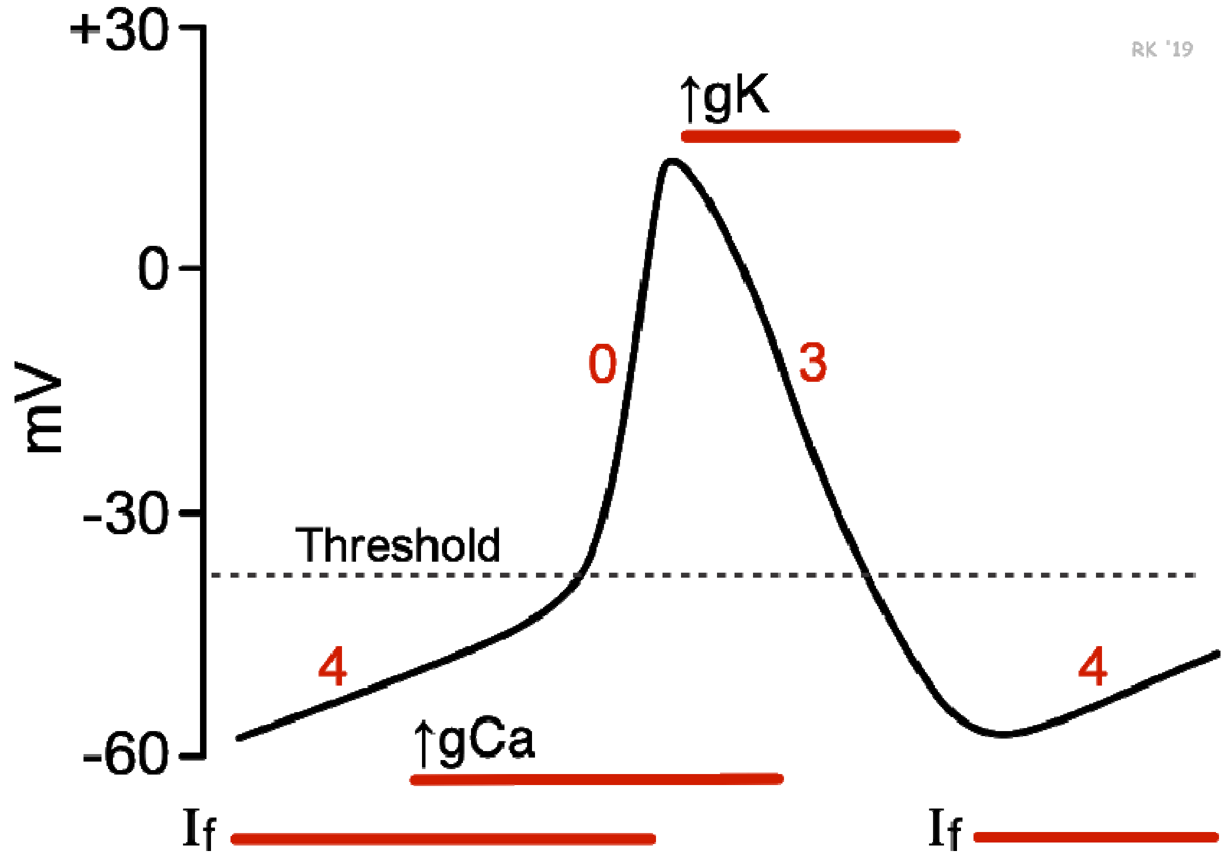
Nodal cell SA

– 100 AP per minute



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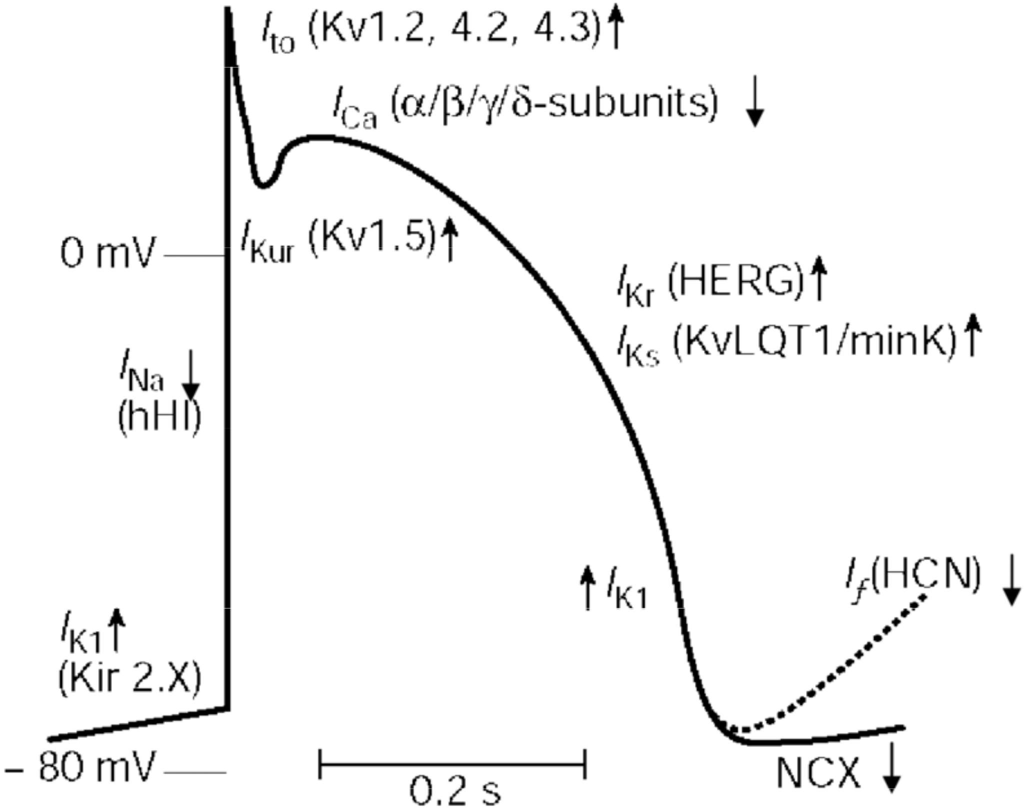
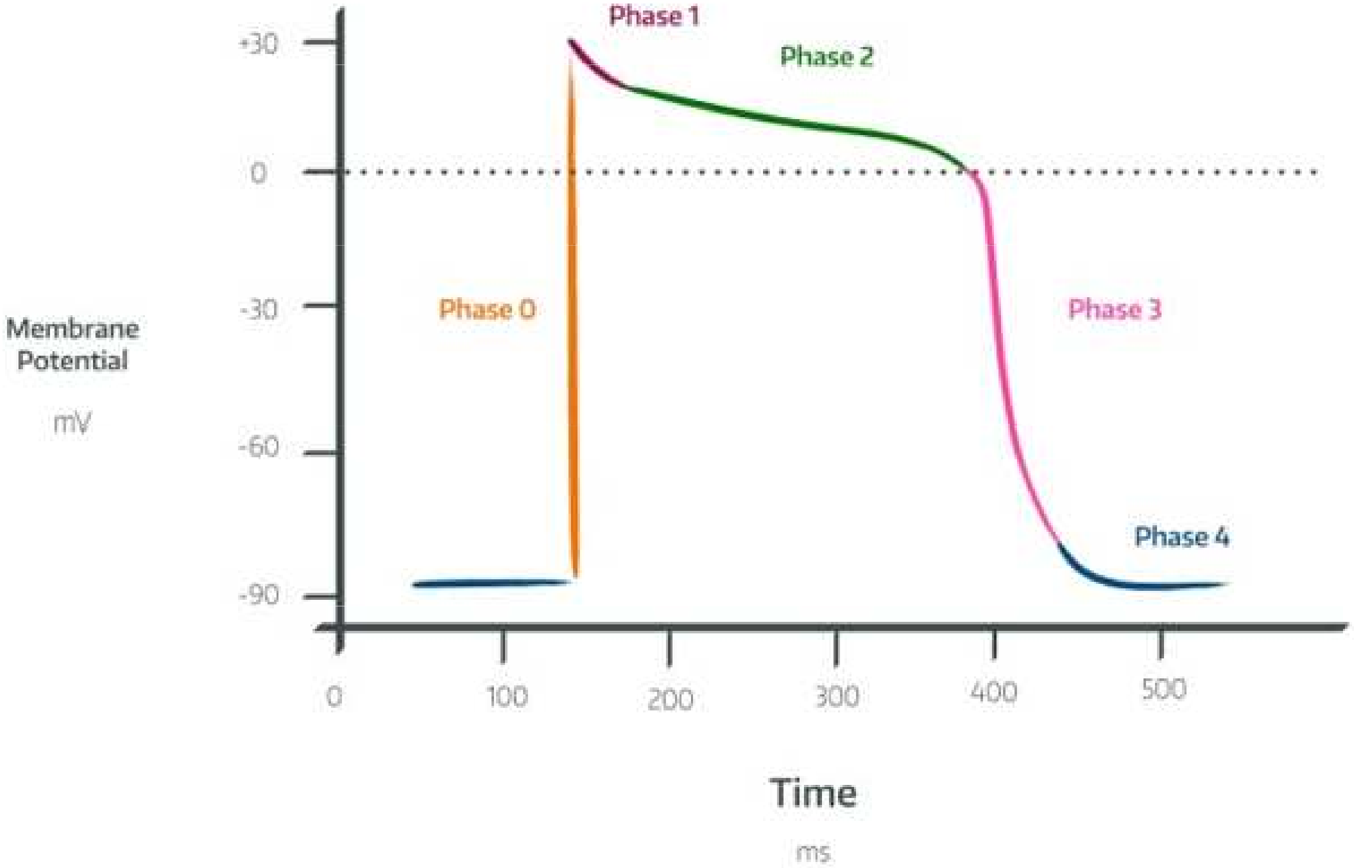
Atrial cell

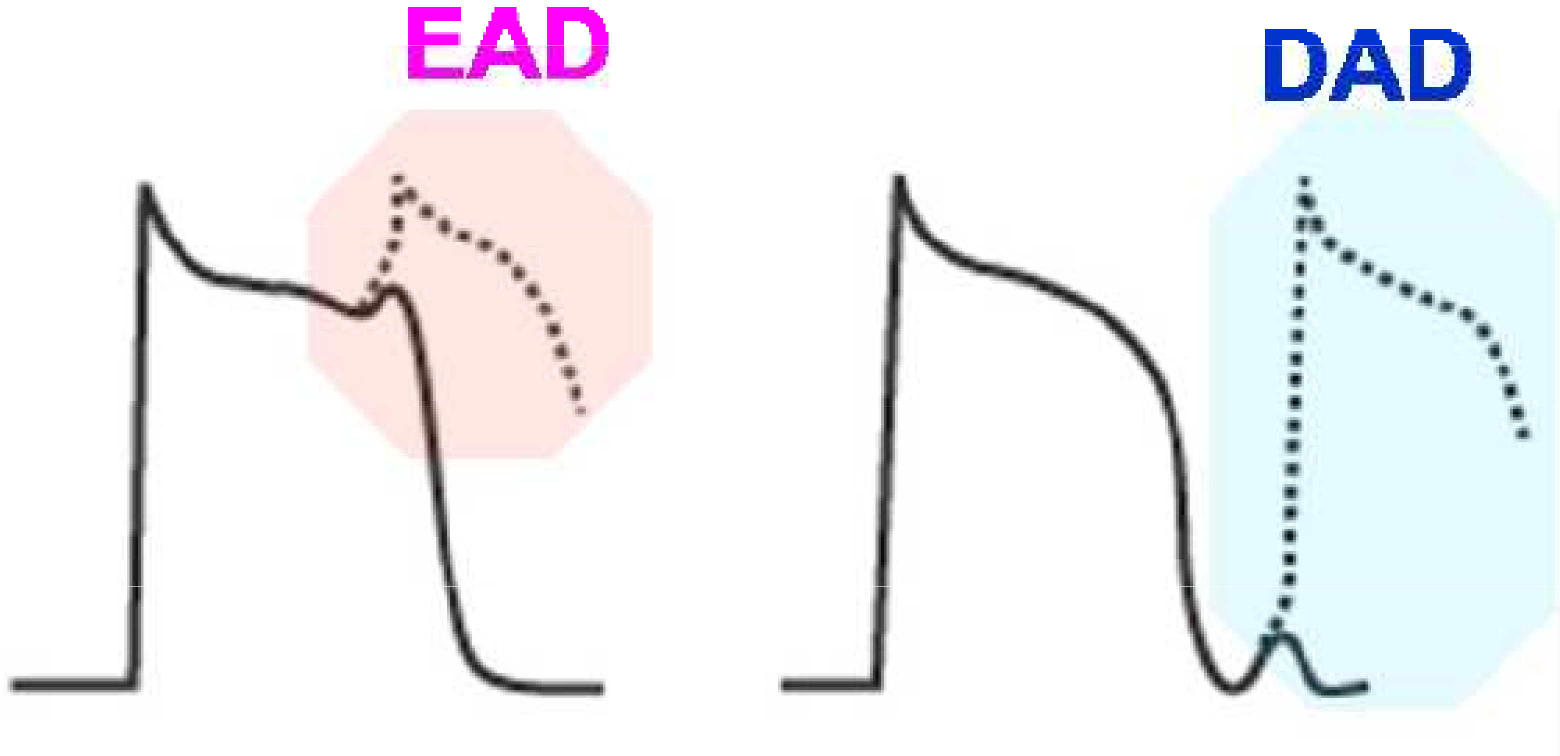


I_{to} (Kv1.2, 4.2, 4.3)↑
I_{Ca} (α/β/γ/δ-subunits) ↓
0 mV
I_{Kur} (Kv1.5)↑
I_{Kr} (HERG)↑
I_{Ks} (KvLQT1/minK)↑
I_{Na} ↓
(hHI)
↑ I_{K1}
I_f(HCN) ↓
I_{K1}↑
(Kir 2.X)
– 80 mV
0.2 s
NCX ↓

Ventricular cell



Ventricular cell



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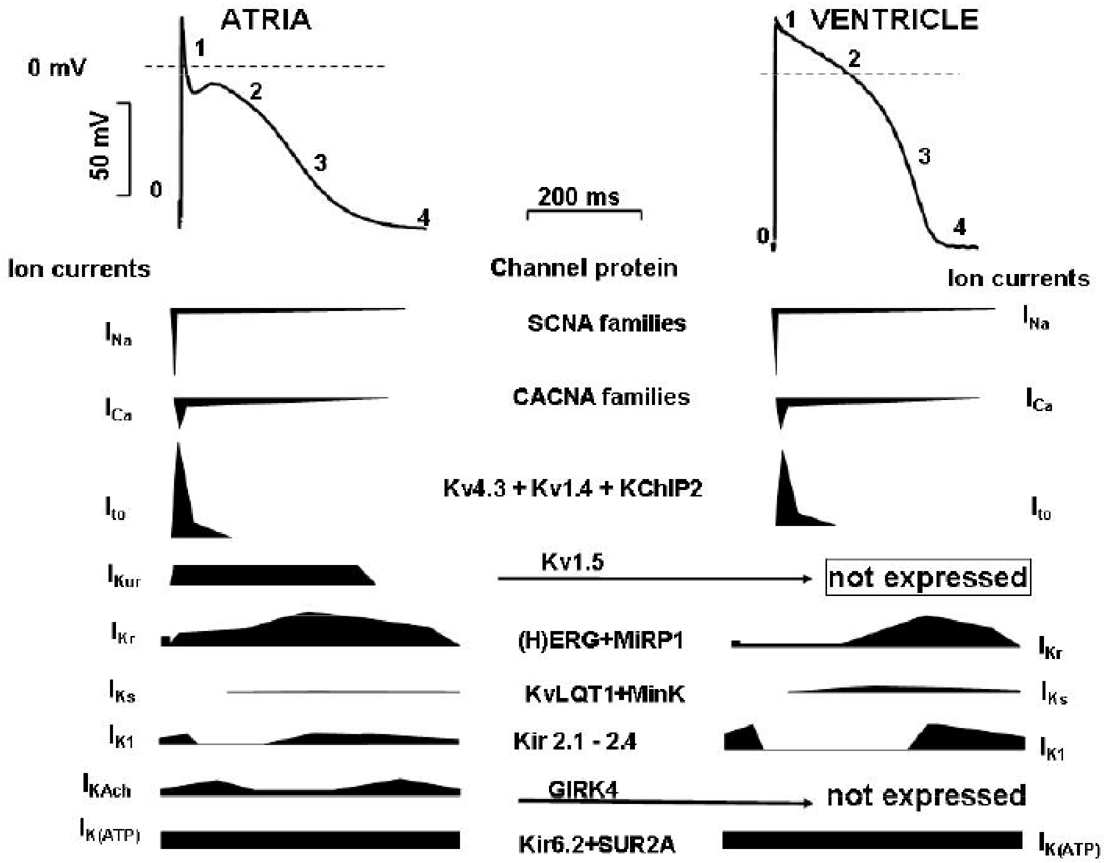
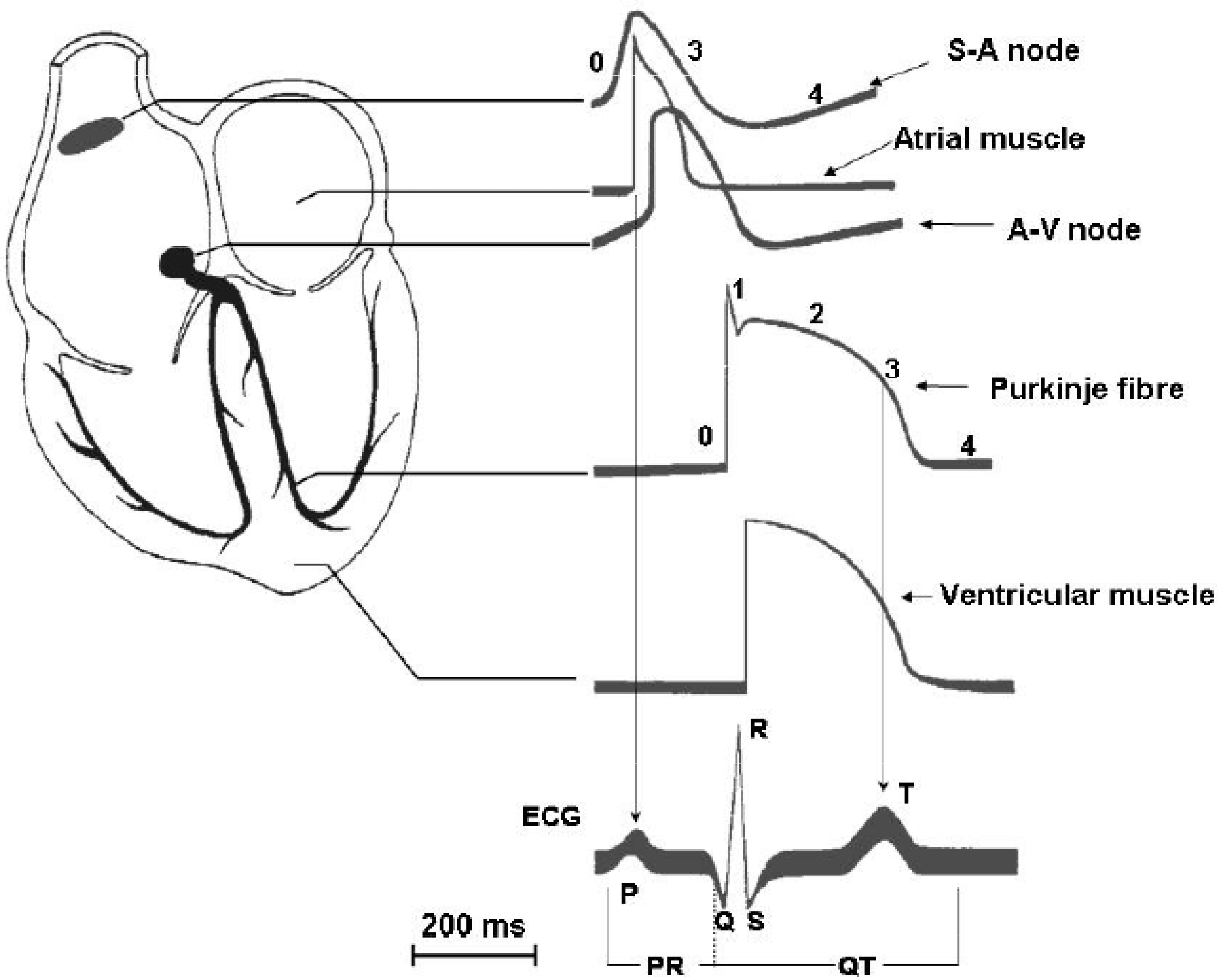
Comparison of atrial and ventricular AP



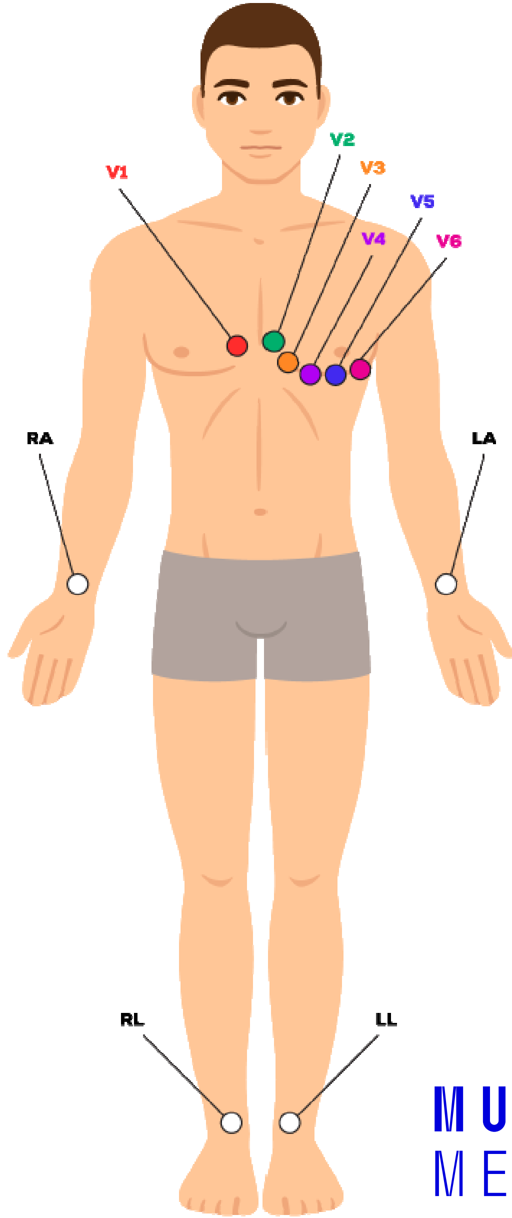
ECG



0
3
4
S-A node
Atrial muscle
A-V node
1
2
3
0
4
Purkinje fibre
Ventricular muscle
R
T
ECG
P
Q
S
200 ms
PR
QT

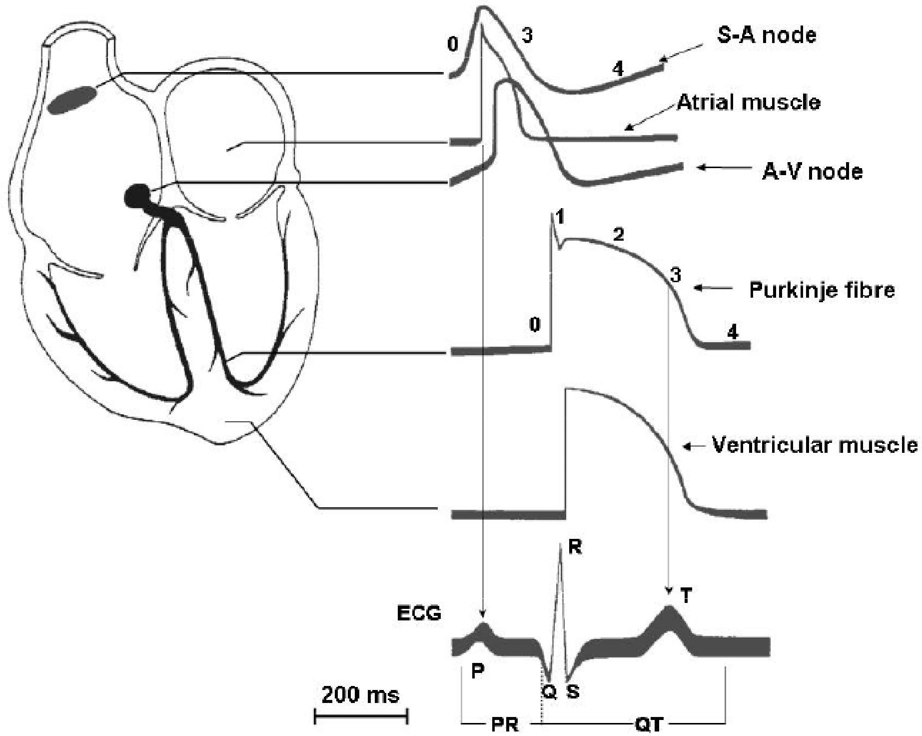
ECG

– Definition: recording of the cardiac electrical activity from the surface of the body



Spreading of the signal

- Cell to cell by gapjuctions
- By conduction system
  - Sinoatrial node (SA) – natural frequency 100 bpm (mostly under parasympathetic damping effect), conduction velocity 0.05 m/s
  - Internodal tracts – conduction velocity 1 m/s
  - Atrioventricular node – 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 3.5 m/s



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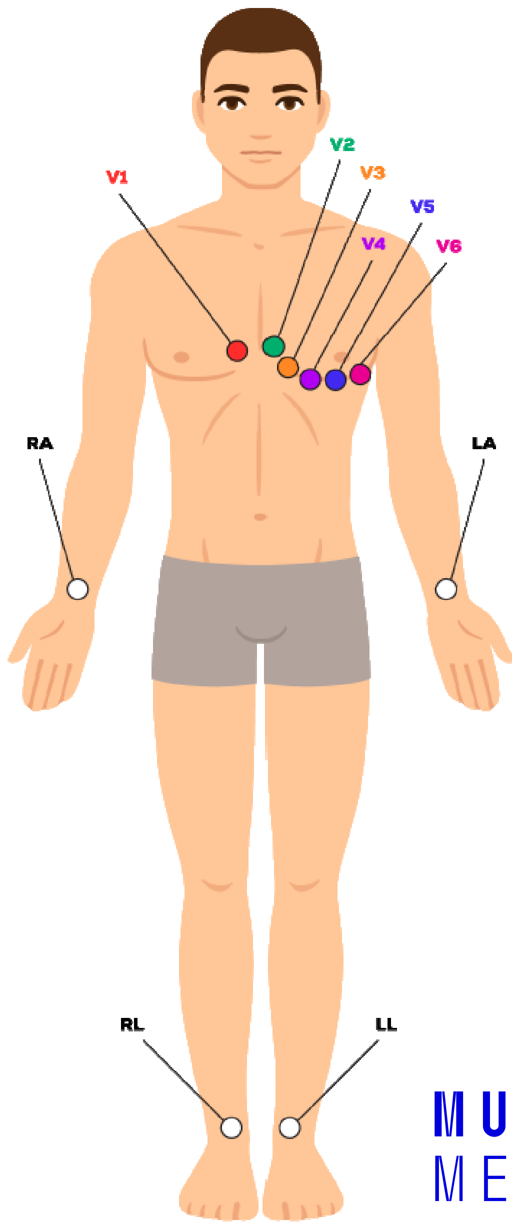
ECG

- 1. Frequency (arrhythmias)
- 2. Conduction (blocks – SA, AV)
- 3. Rhythm
- 4. Ventricular gradient (relationship between depolarization and repolarization)



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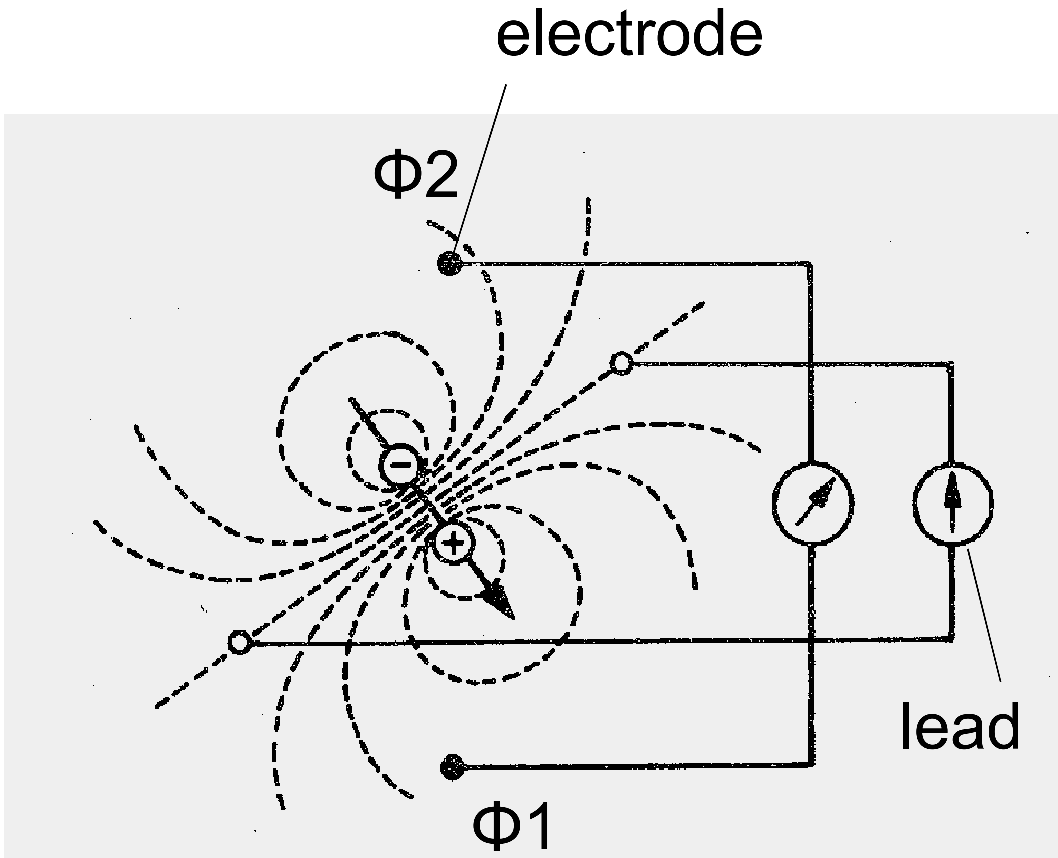
Electric dipole

- 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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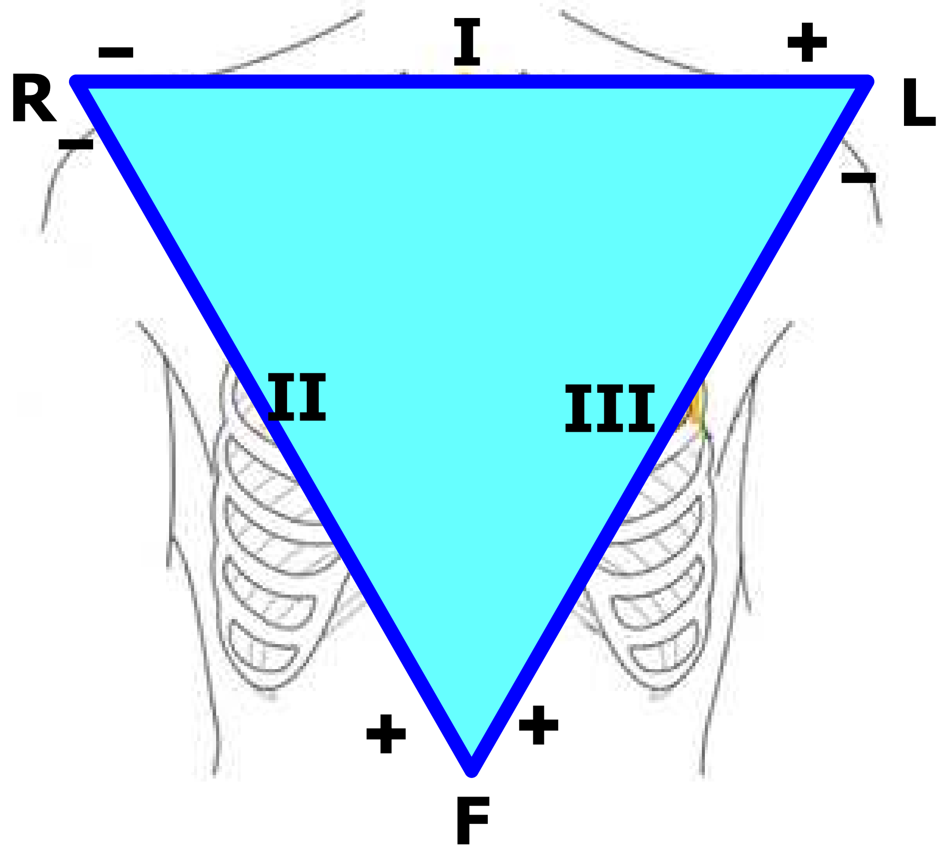
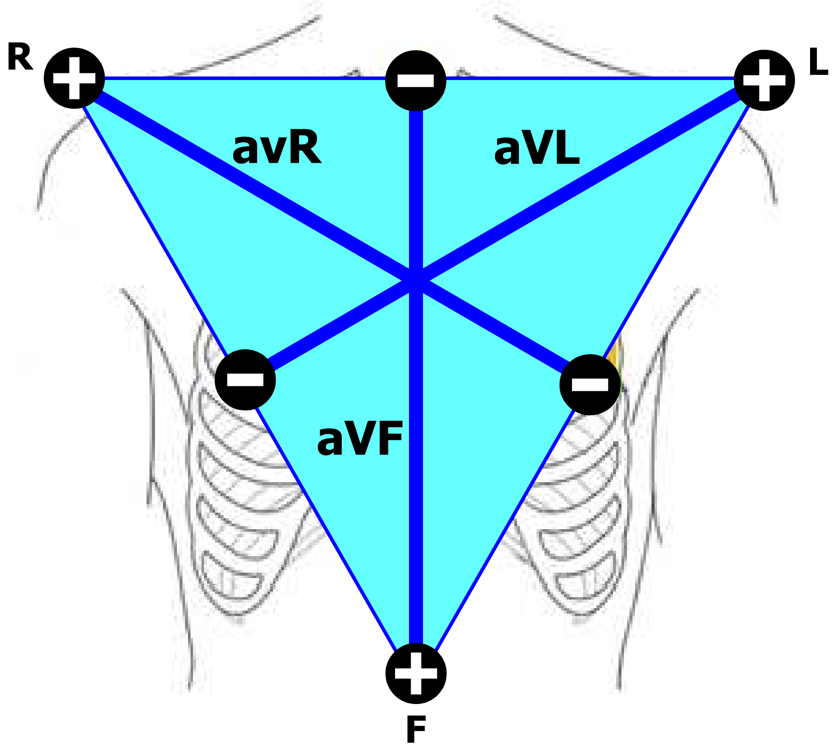
Einthoven’s triangle
(standard, limb, bipolar leads)

- 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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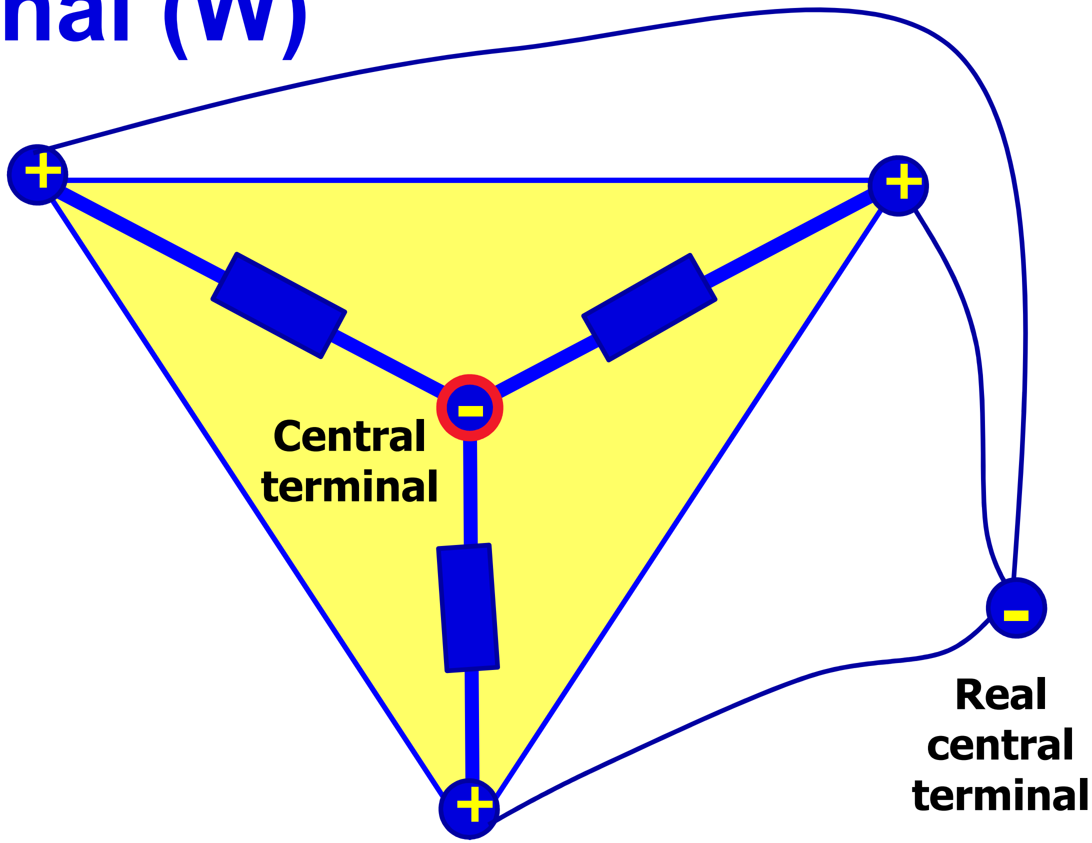
Wilson‘s central terminal (W)

- 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)



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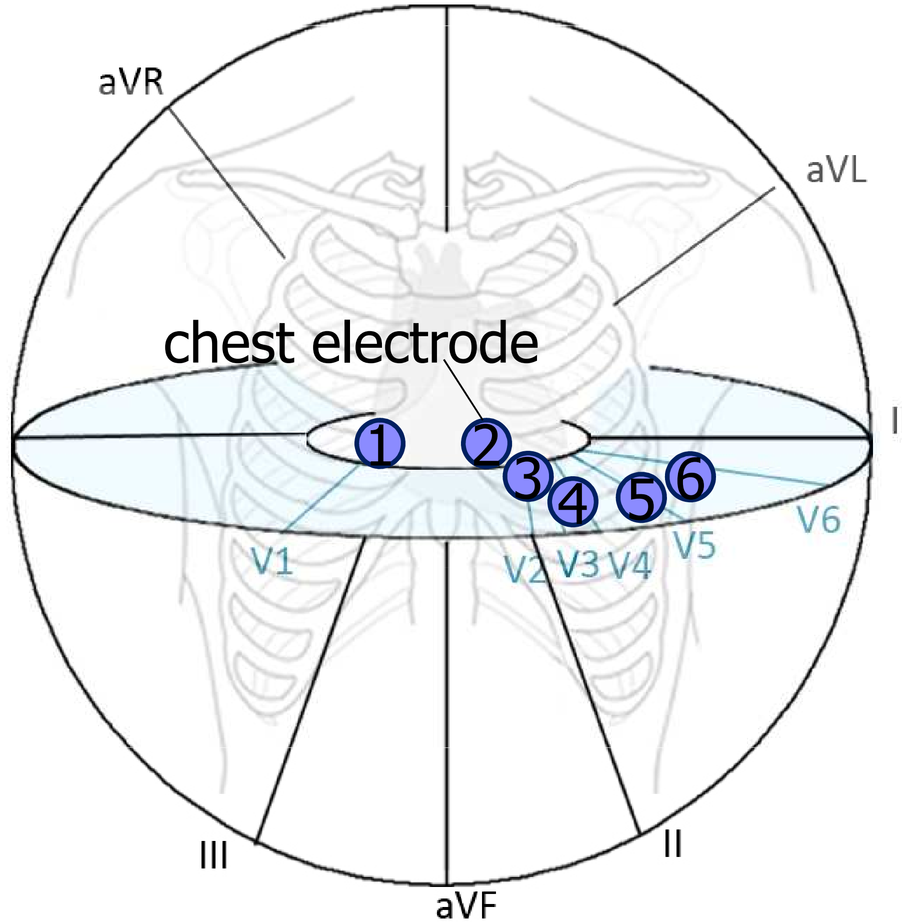
Chest leads

– 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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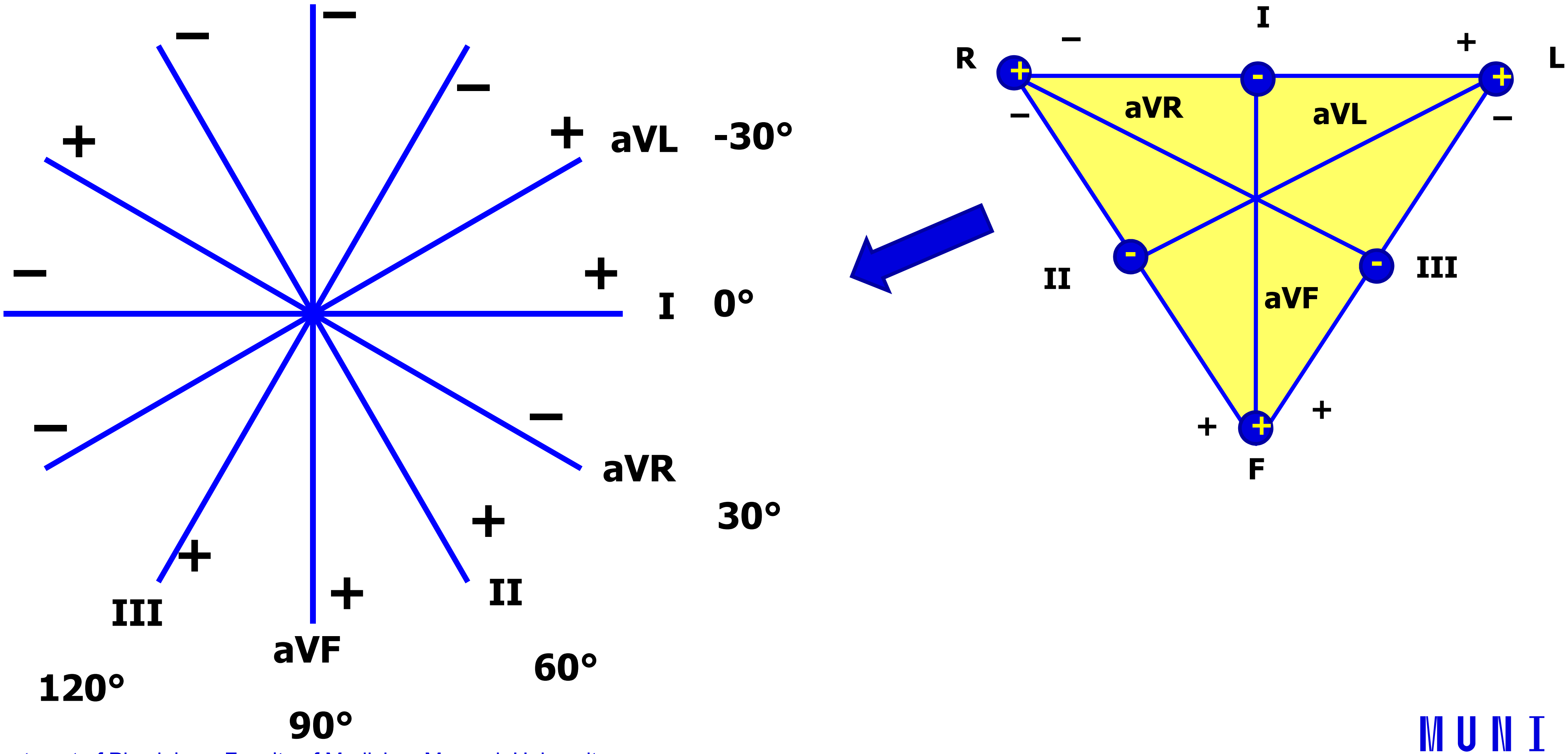
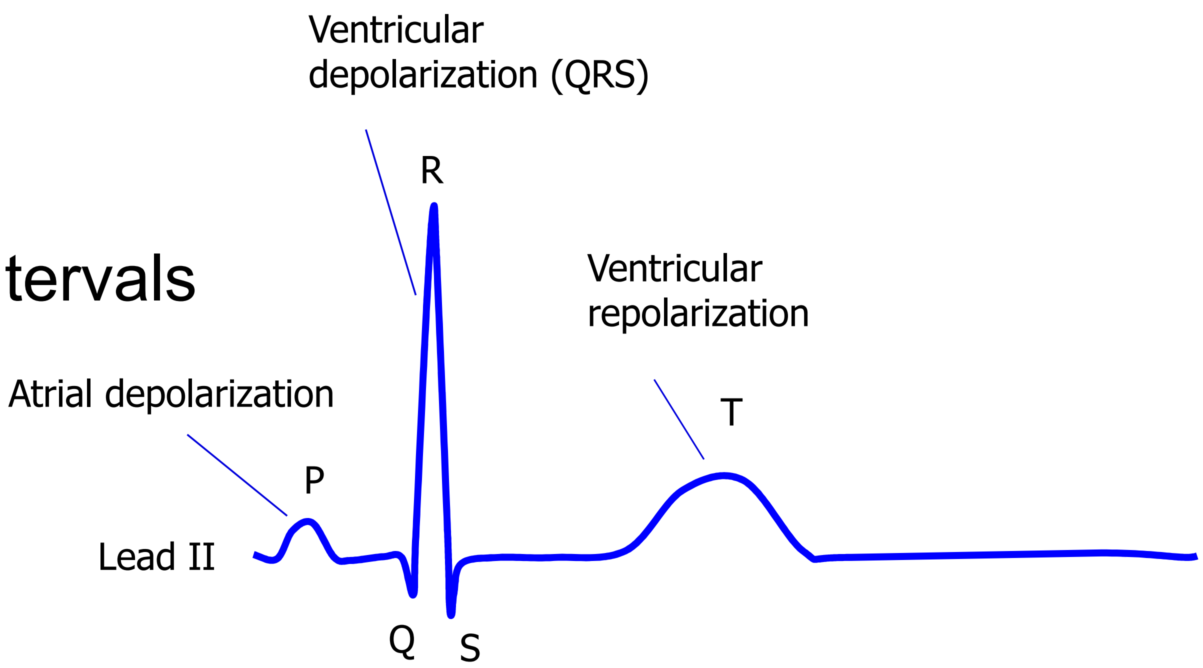
Leads according to Cabrera



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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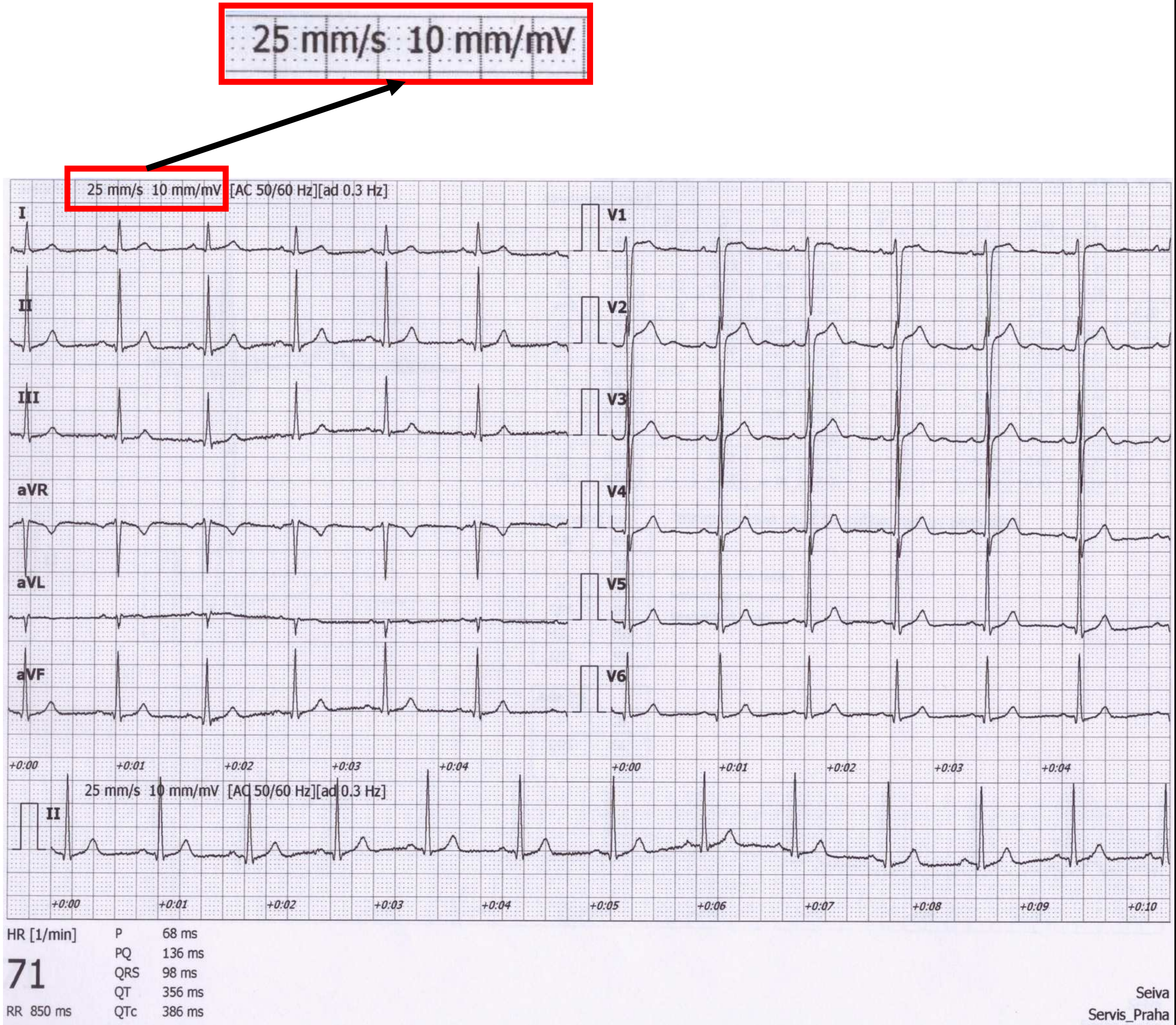
Analysis of ECG

- A millimeter grid of paper will help in fast analysis
- See the paper speed (here 25 mm/s)
  - 1 mm = 0,04 s
  - 5 mm (big square) = 0,2 s



1) Heart action

- Regularity of distances between QRS complexes - RR intervals

- 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

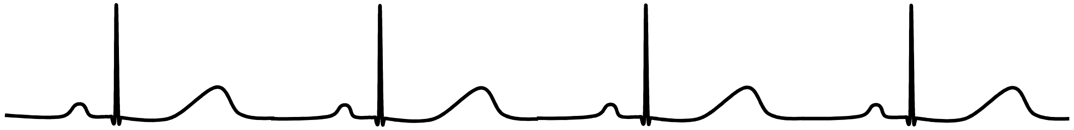
- Note: if one extrasystole is present, but otherwise the action is regular, it is called regular

2) Heart rhythm

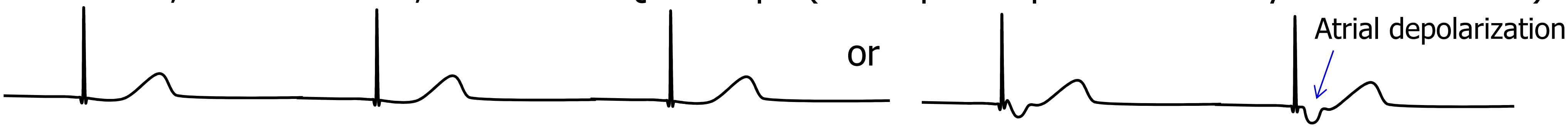
- Heart rhythm is determined by the source of action potentials that lead to ventricular depolarization
  ventricul depolarization is crucial because it determines cardiac output
- **Sinus rhythm**
  - AP begins in the SA node
  - ECG: P wave (atrial depolarization) precedes QRS complex
- **Junction 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, with a 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

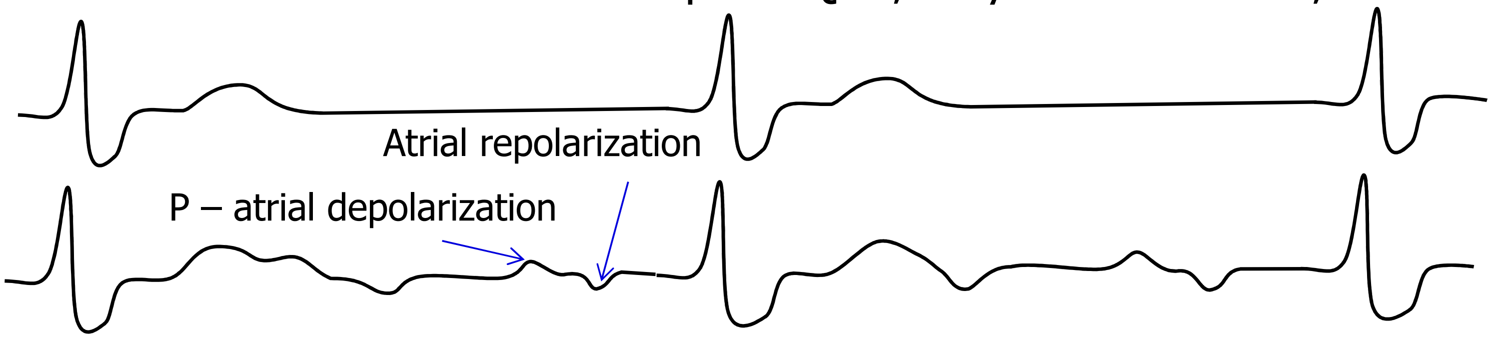
Sinus rhythm – P wave precedes each QRS complex – the impulse begins in the SA node, it is followed by the depolarization of the ventricles



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

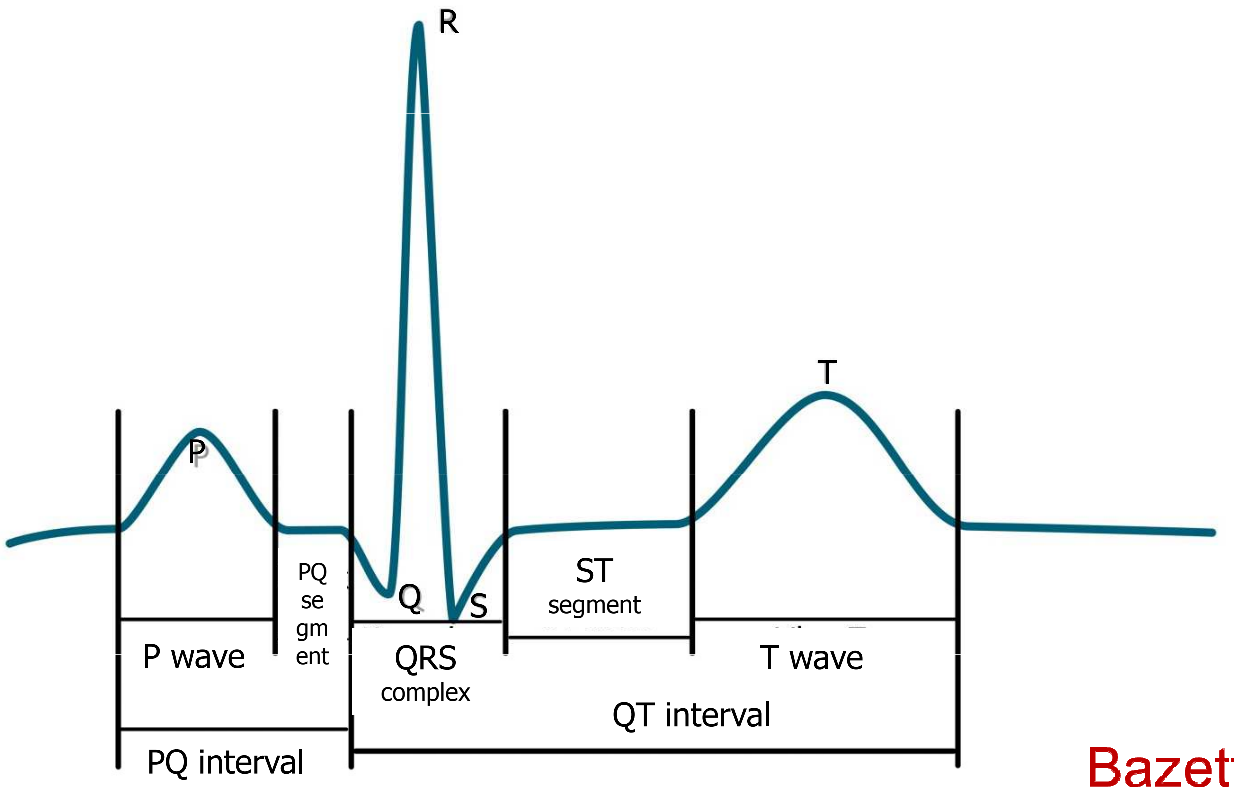
3) Heart rate (HR)

- 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

- Bradycardia: < 60 bpm

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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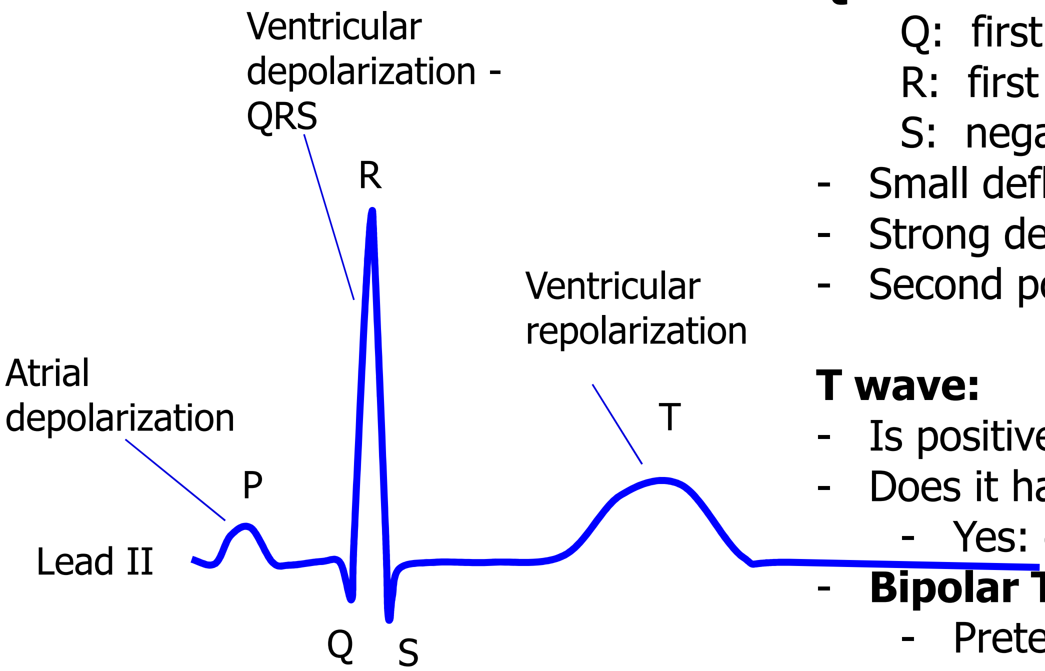
4) Waves



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

QRS:

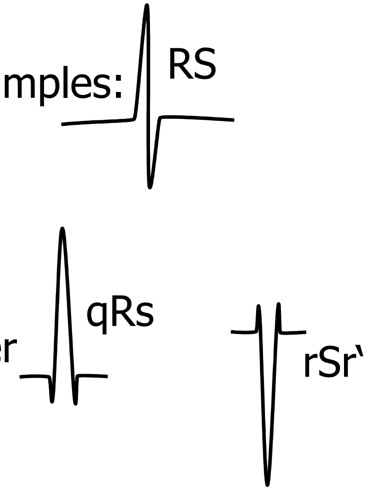
Q: first negative deflection

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 (+/-)

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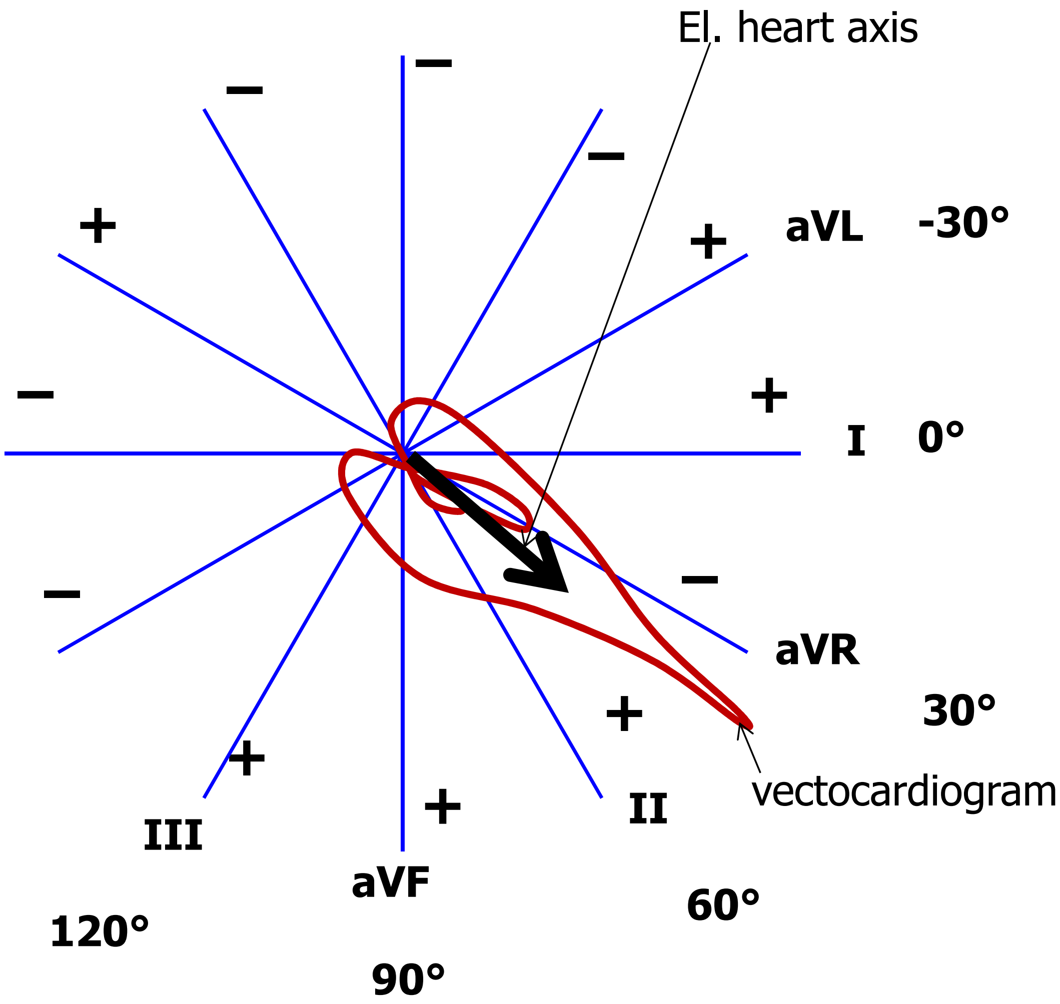
5) Electrical heart axis



Electrical heart axis: average direction of the electric heart vector during ventricular depolarization (QRS complex)

Physiological range:

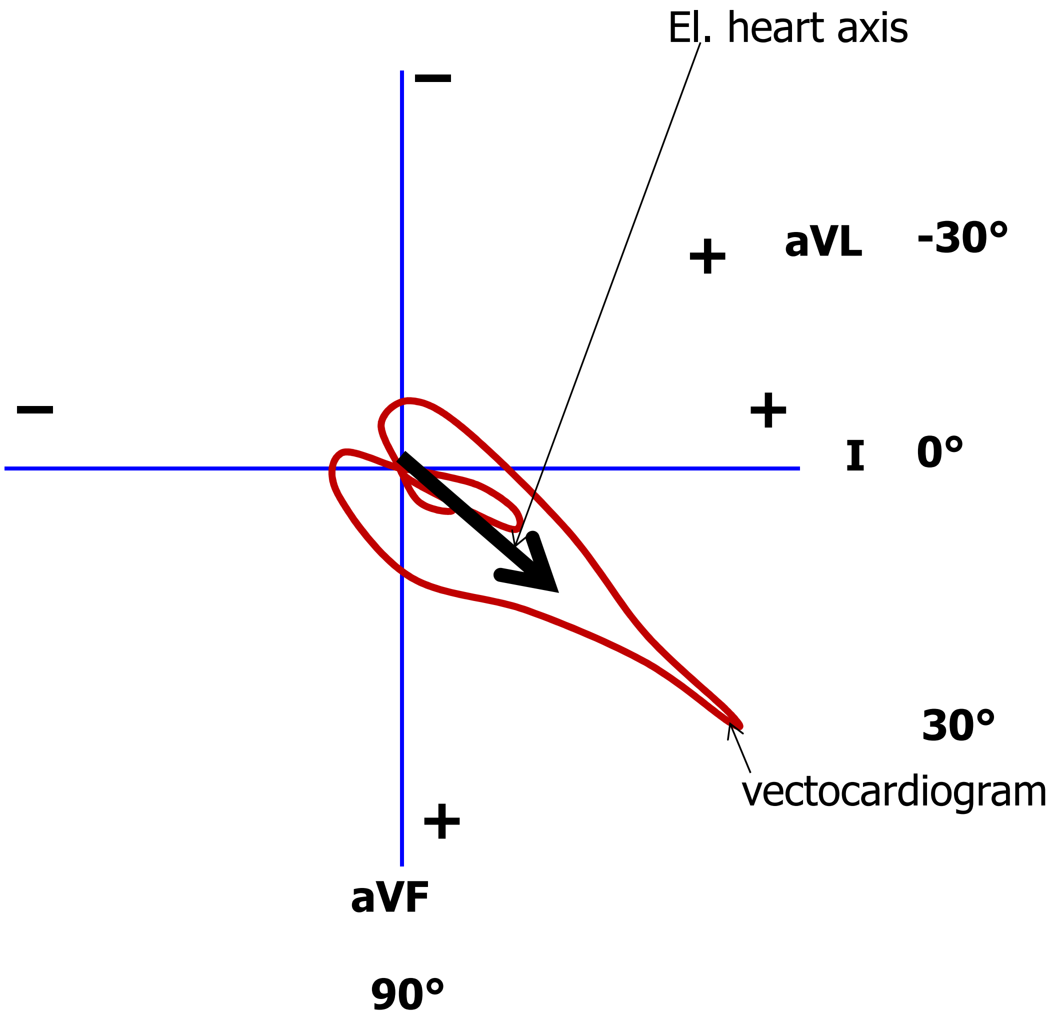
Middle type 0° – 90°
Left type -30° – 0°
Right type 90° – 120°

Pathological range:

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

5) Electrical heart axis

Electrical heart axis: average direction of the electric heart vector during ventricular depolarization (QRS complex)



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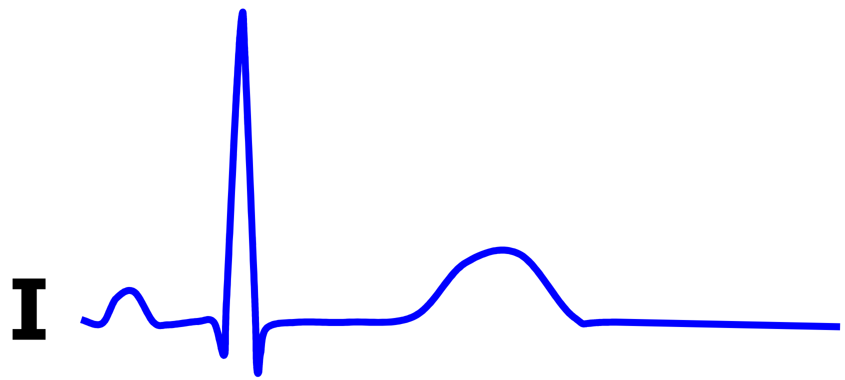

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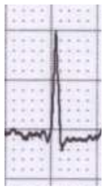
Electrical heart axis – calculation

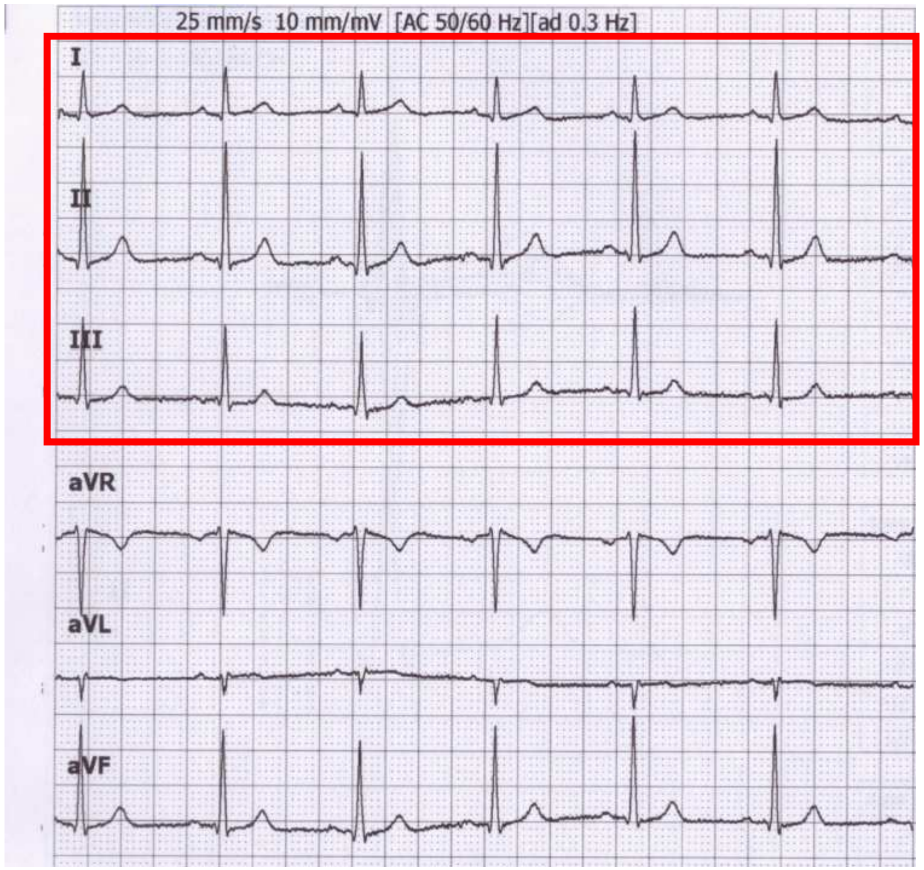
- Because the el. axis is related to ventricular depolarization in the frontal plane, for calculation, we use QRS in limb leads: I, II, III.
- Calculate the sum of QRS oscillations in leads I, II, III.
  When the oscillation goes downward, it is negative. When the oscillation is upward, it is positive.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

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

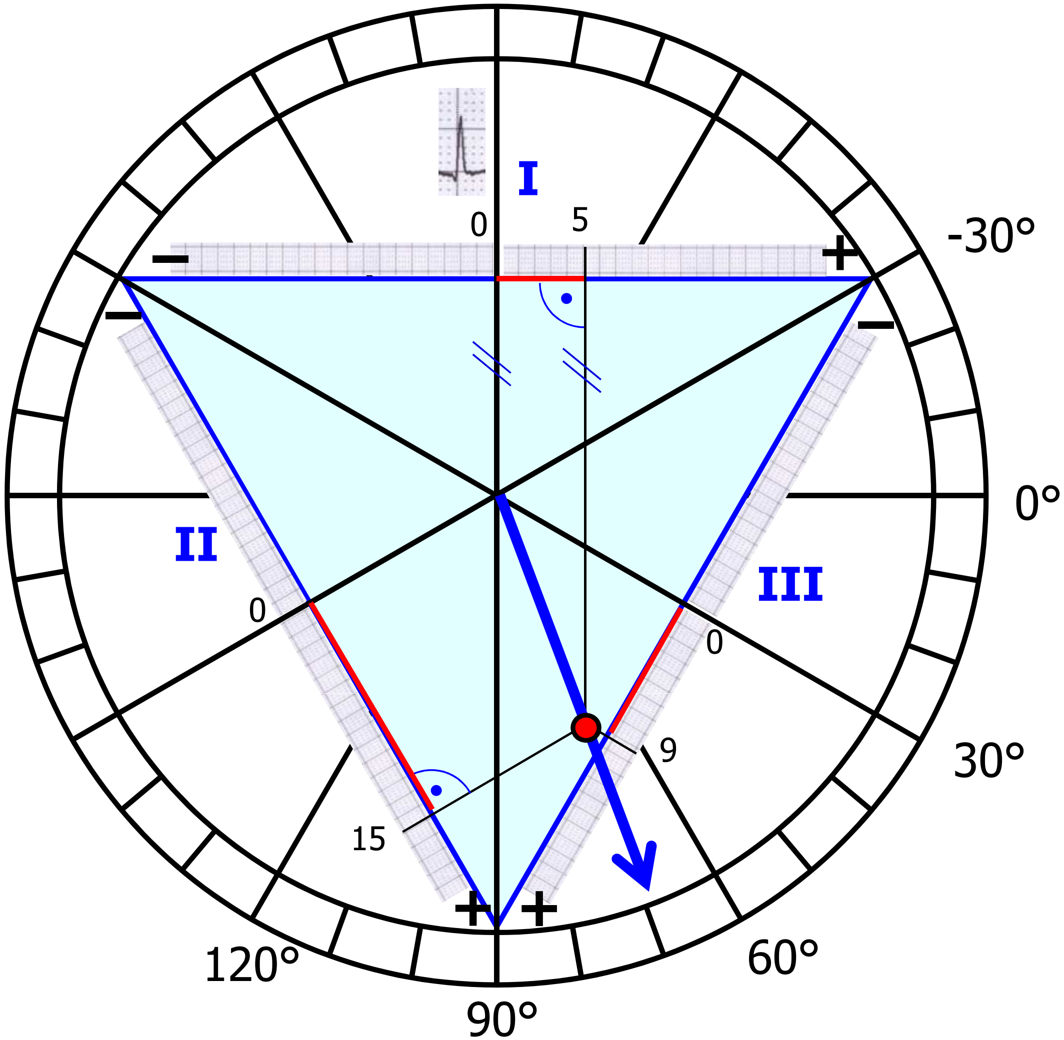
  - Lead II: Q_{II}=-1; R_{II}=17; S_{II}=-1; QRS_{II}=15

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





Electrical heart axis – calculation



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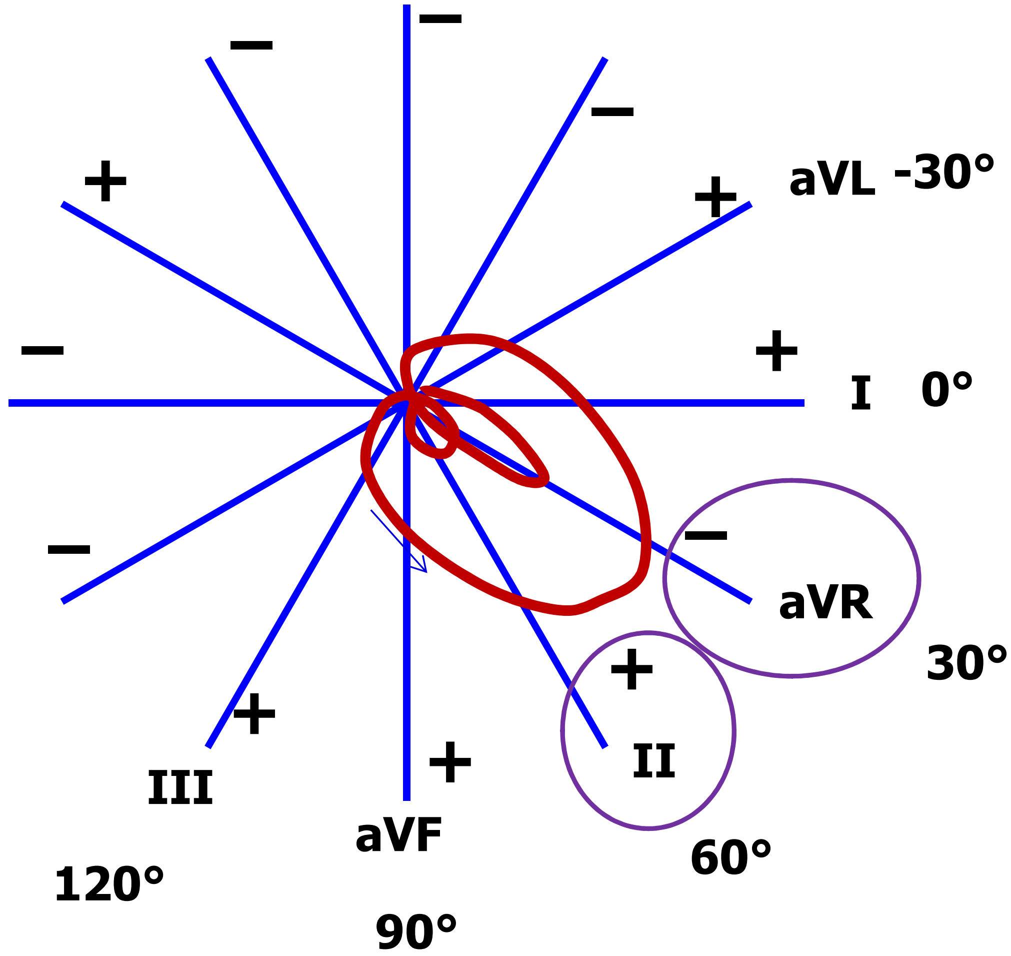
Estimation of electrical heart axis

– Leads II and aVR



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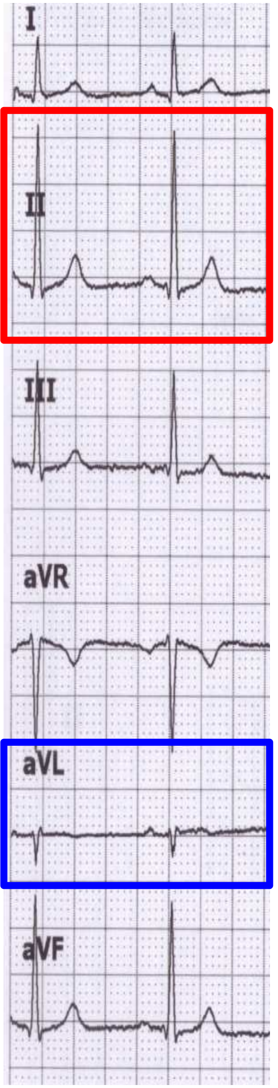
Estimation of electrical heart axis



Q = -1
R = 6 QRS = 5
S = 0

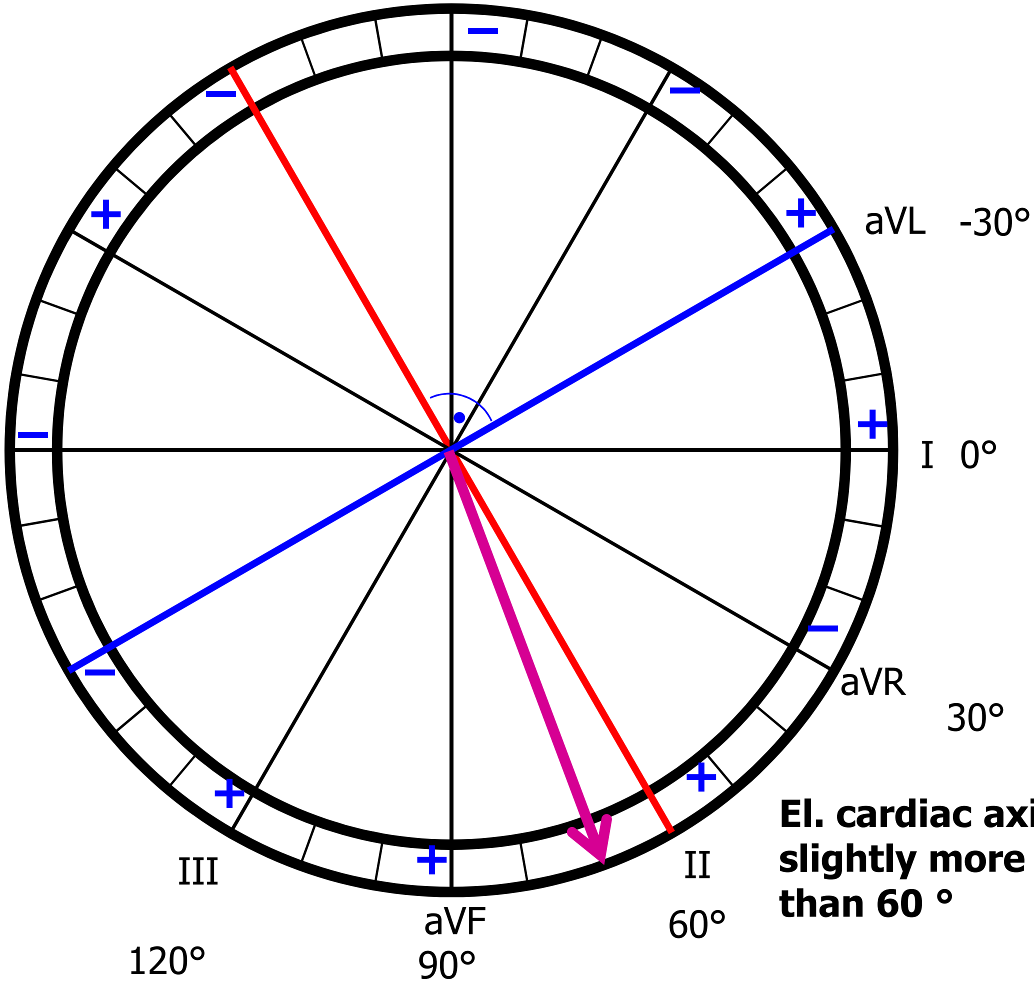
Q = -1
R = 17 QRS = 15
S = -1

Q = 0
R = 10 QRS = 9
S = -1

Q = 1
R = -11 QRS = -10
S = 0

Q = 0
R = -3 QRS = -3
S = 0

Q = -1
R = 13 QRS = 11
S = -1



El. cardiac axis slightly more than 60 °

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Estimation of electrical heart axis

Is deviation of QRS complex positive in I and aVF lead?

Yes

Physiological values between -30° to 110°

No

Is deviation of QRS complex positive in I and negative in aVF lead

Deviation to the left

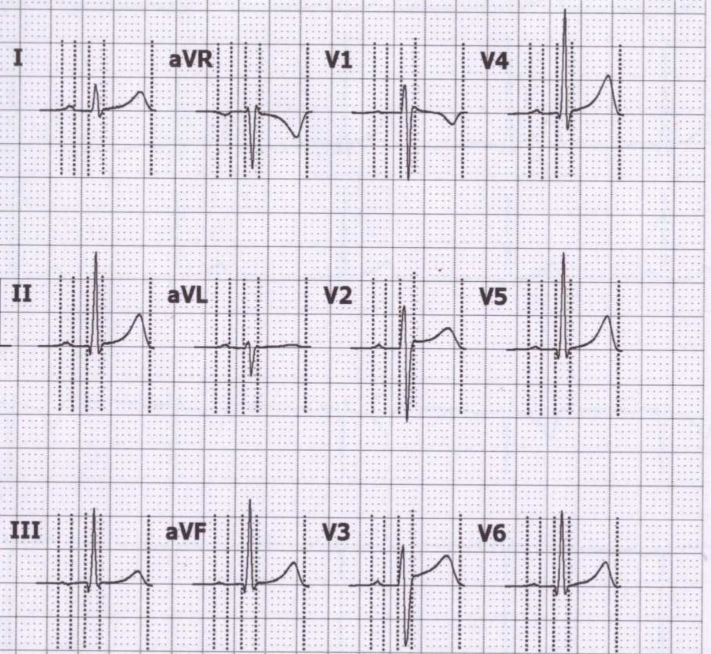
Is deviation of QRS complex negative in I and positive in aVF lead

Deviation to the right

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

HR [1/min]

58

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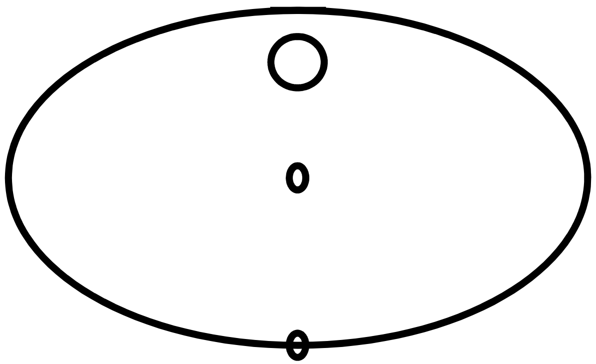
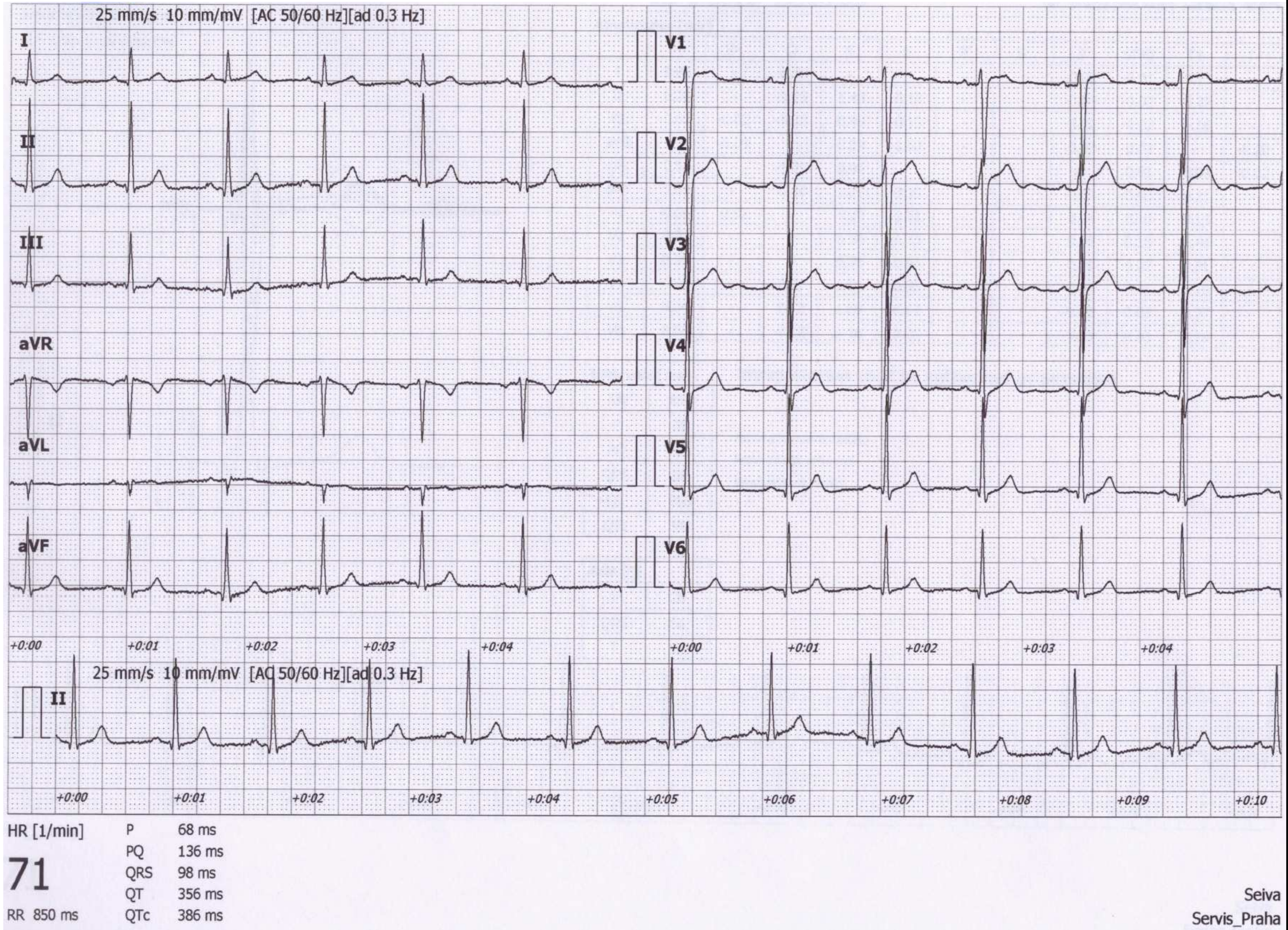
Estimation of electrical heart axis in Horizontal plane





Thank you for your attention!