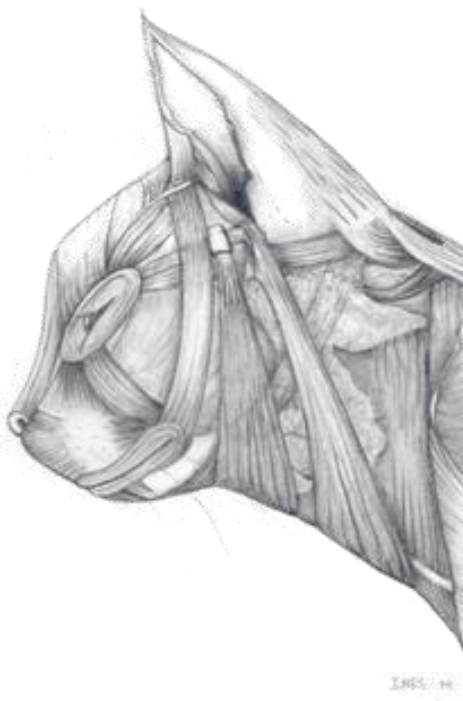
FIZIOLOGIJA ŽIVALI

Laboratorijske vaje

FIZIOLOGIJA SRCA



dr. Katja Adam

UP FAMNIT

KRČENJE SRCA, AKCIJSKI POTENCIALI (AP) CELIC V RITMOVNIKIH (PEACEMAKER) IN CELICAH SRČNEGA MIŠIČJA

- OSNOVE SPREMINJANJA MEMBRANSKIH POTENCIALOV V RITMOVNIKIH IN TKIVU SRČNE MIŠICE:

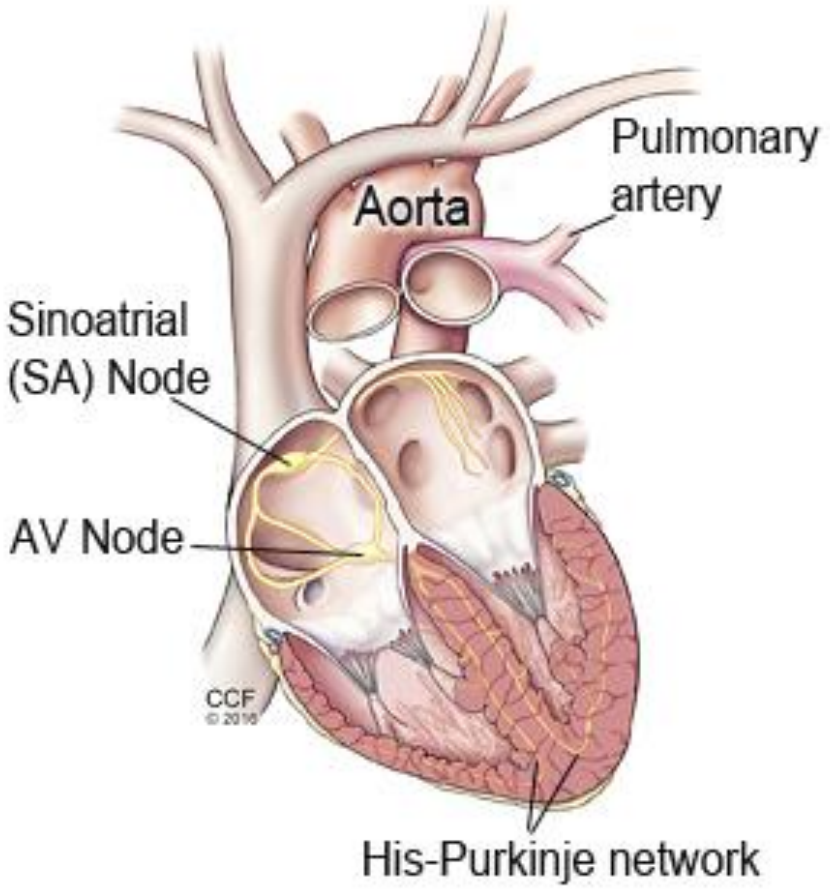
https://www.youtube.com/watch?v=v7Q9BrNfIpQ

SLOVARČEK

- AP – akcijski potencial
- MMP – mirovni membranski potencial
- SA node – sinoatrialni vozel (ritmovnik v desnem atriju)
- AV node – atrioventrikularni vozel
- SAR –sarkoplazemski retikulum

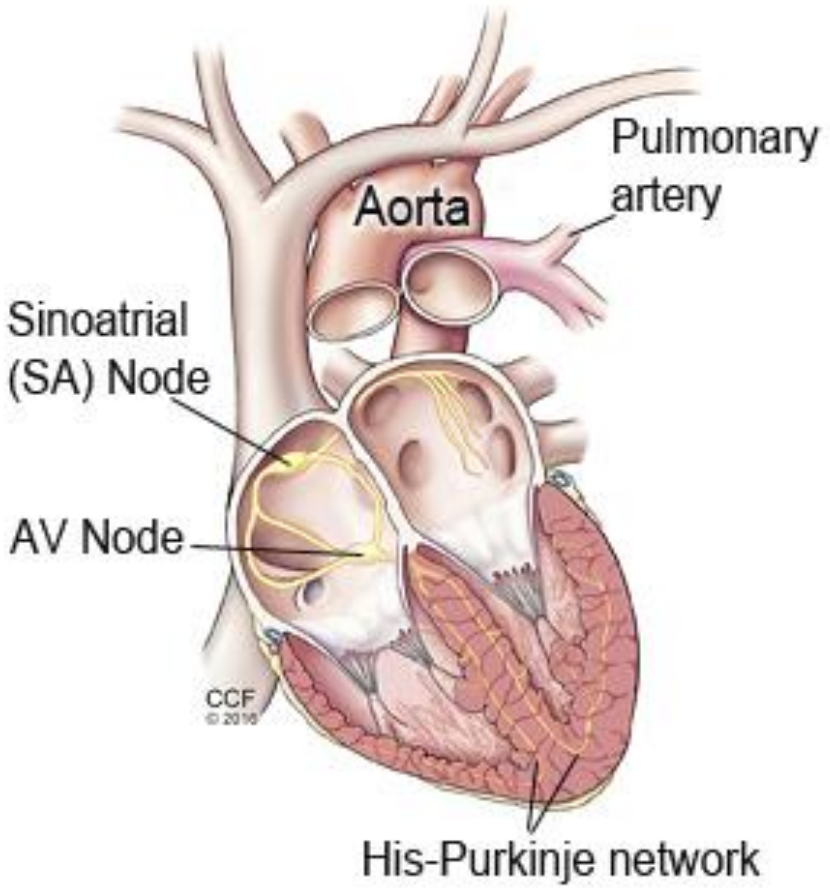
FIZIOLOGIJA SRČNE MIŠICE

- SRČNA MIŠICA - avtonomne kontrakcije, niso pod vplivom živčnega sistema (avtoritmičnost)
- spontane depolarizacije-repolarizacije celic ritmovnika → akcijski potenciali v večini celic srčne mišice

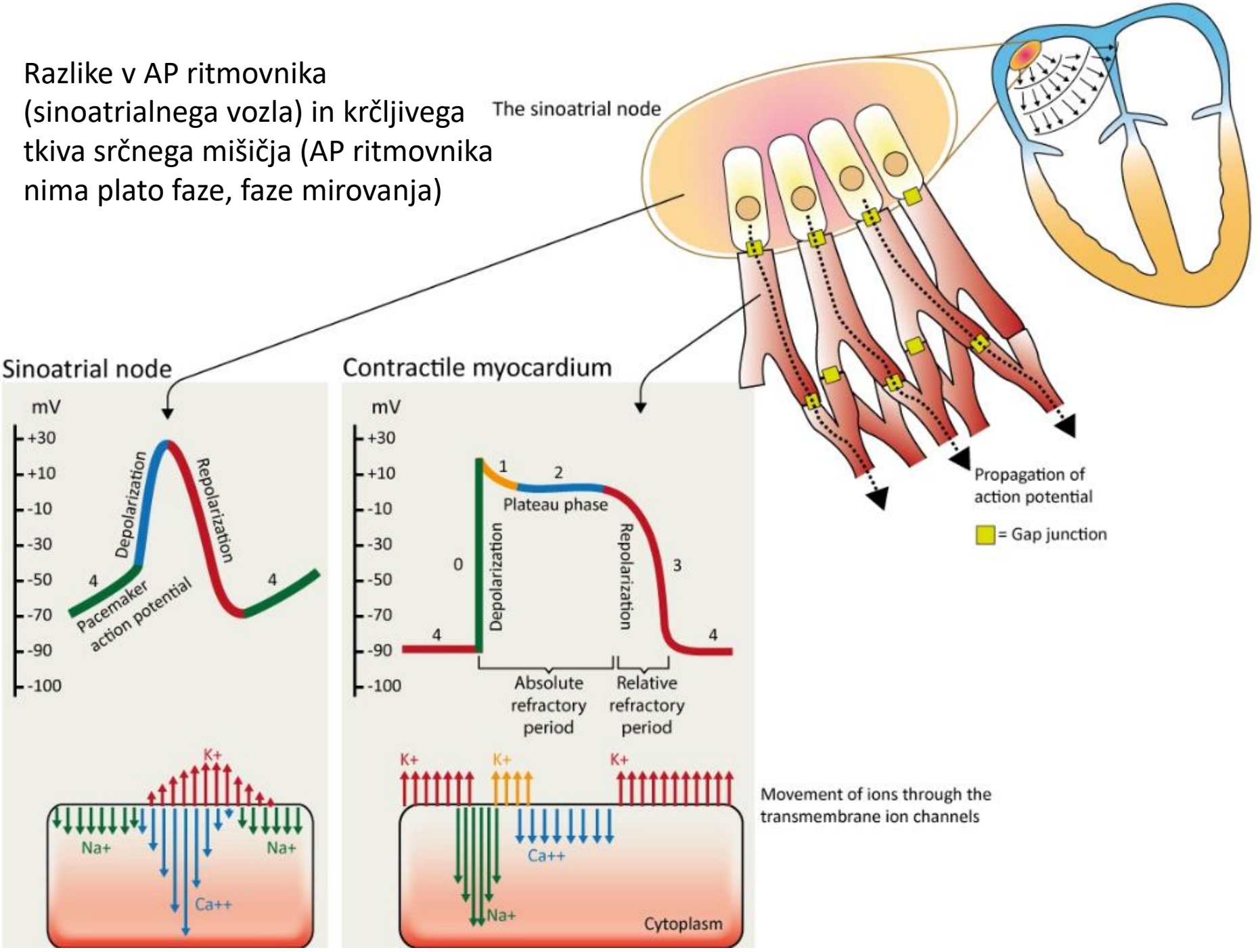


FIZIOLOGIJA SRČNE MIŠICE SESALCEV

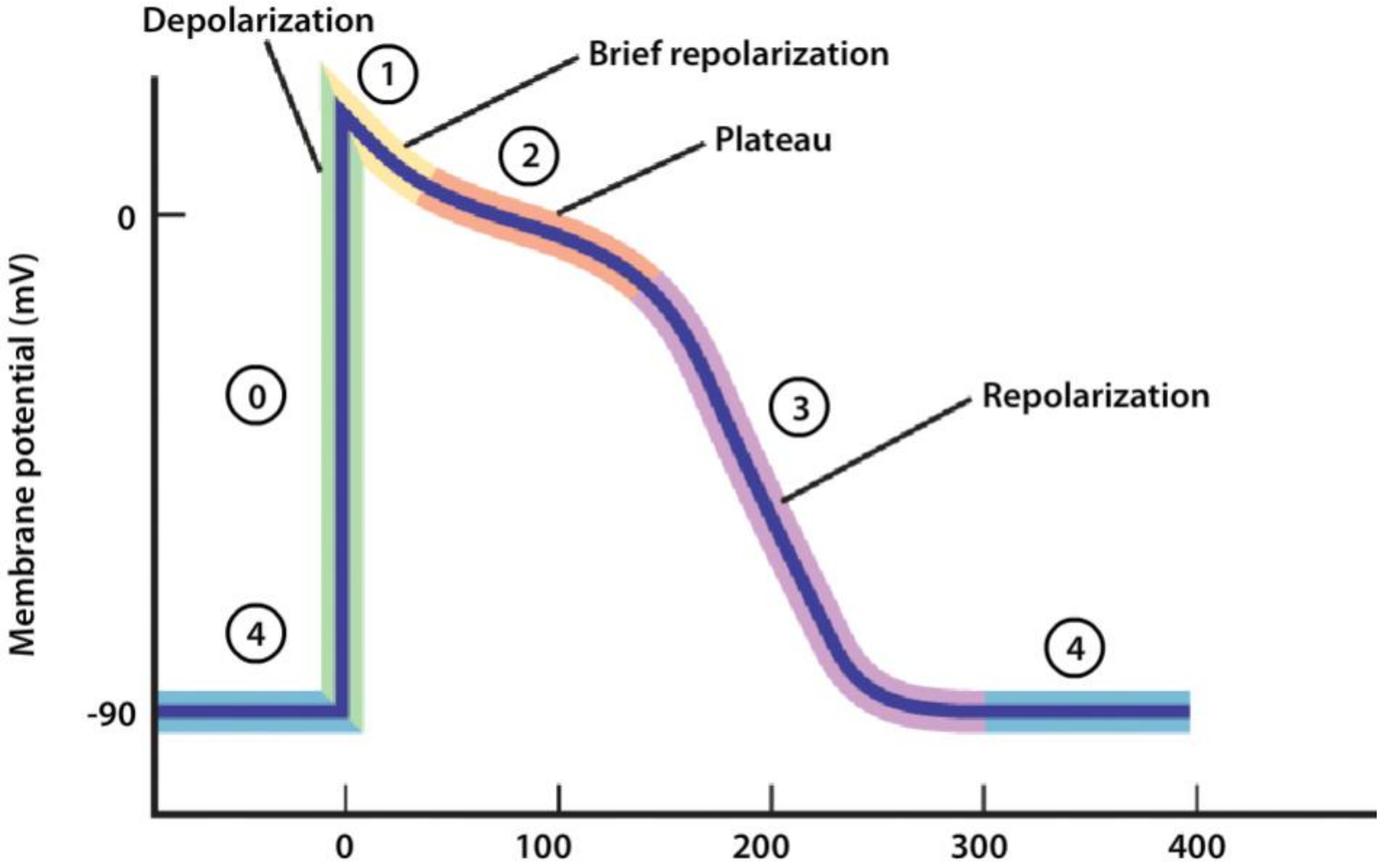
- SA vozel – ritmovnik srca, tu nastajajo akcijski potenciali, ki se preko AV vozla, Hissovega snopa in Purkinjejevih vlaken prenesejo do krčljivih celic srčnega mišičja



Razlike v AP ritmovnika (sinoatrialnega vozla) in krčljivega tkiva srčnega mišičja (AP ritmovnika nima plato faze, faze mirovanja)

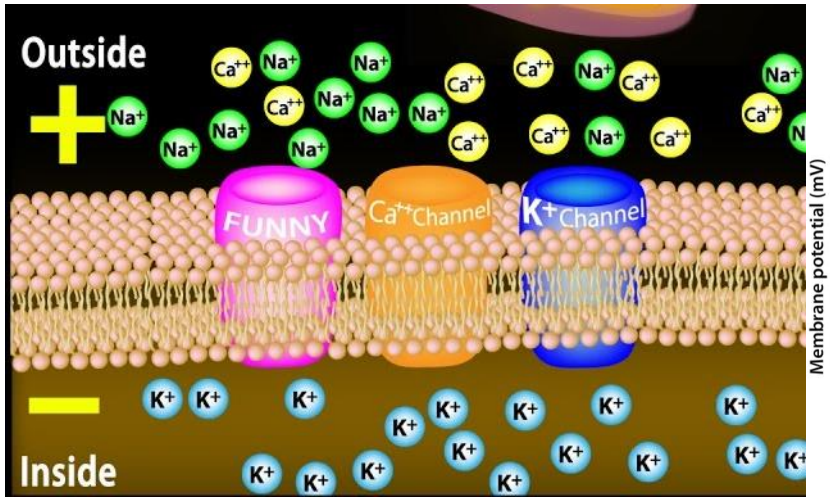


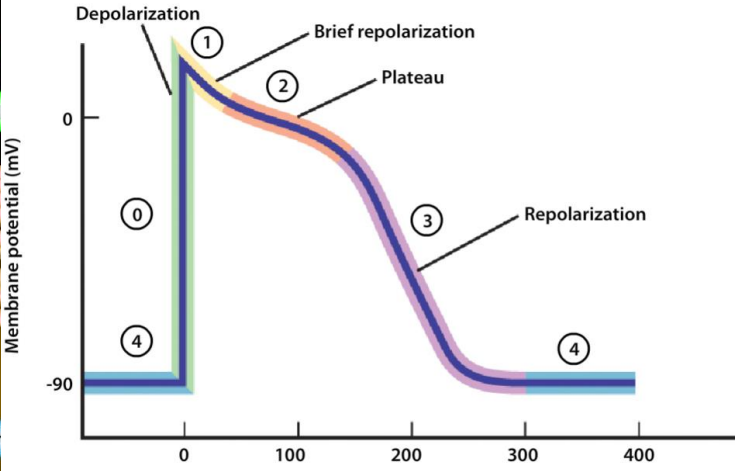
AKCIJSKI POTENCIAL SRČNE MIŠICE



AKCIJSKI POTENCIAL MIŠIČNIH CELIC V SRCU

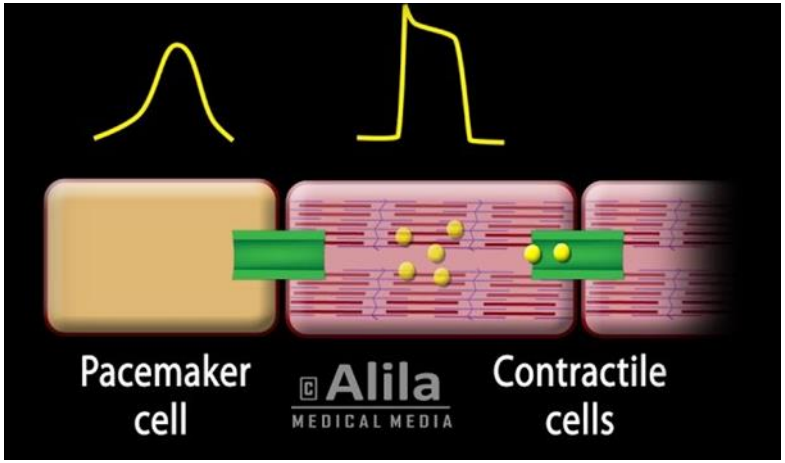
- **4 – MIROVANJE – MIROVNI MEMBRANSKI POTENCIAL – RESTING PHASE**
- več Na in Ca zunaj, več K not
- ta razporeditev ionov določa MMP, ki je v mirovanju -90 mV

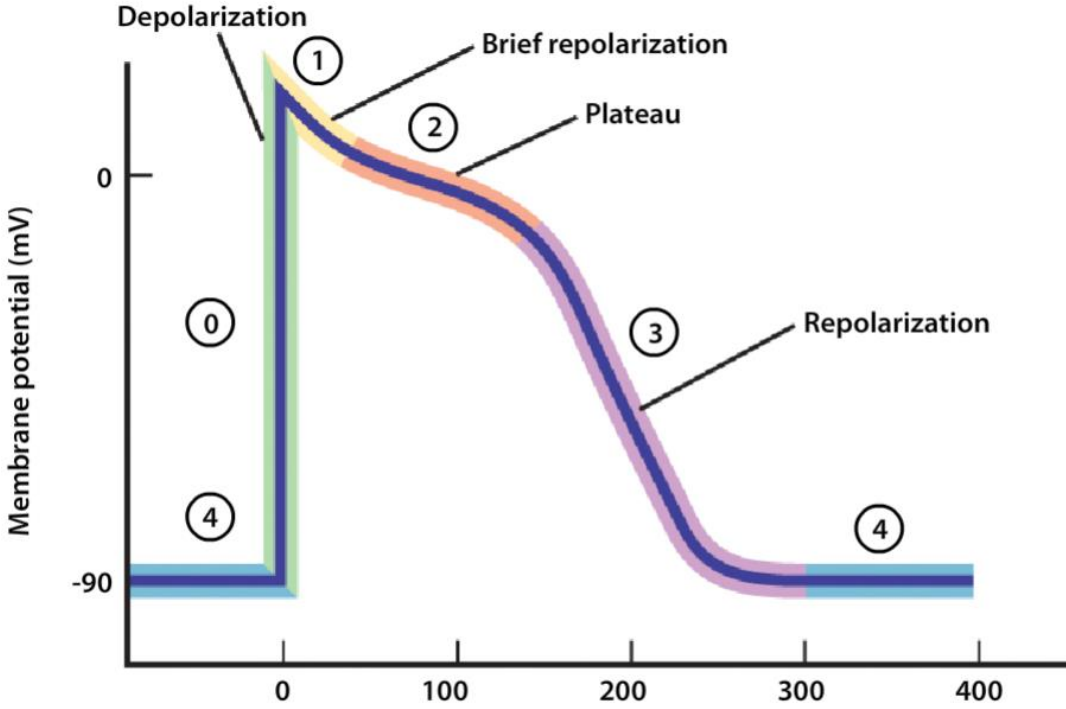




AKCIJSKI POTENCIAL MIŠIČNIH CELIC V SRCU

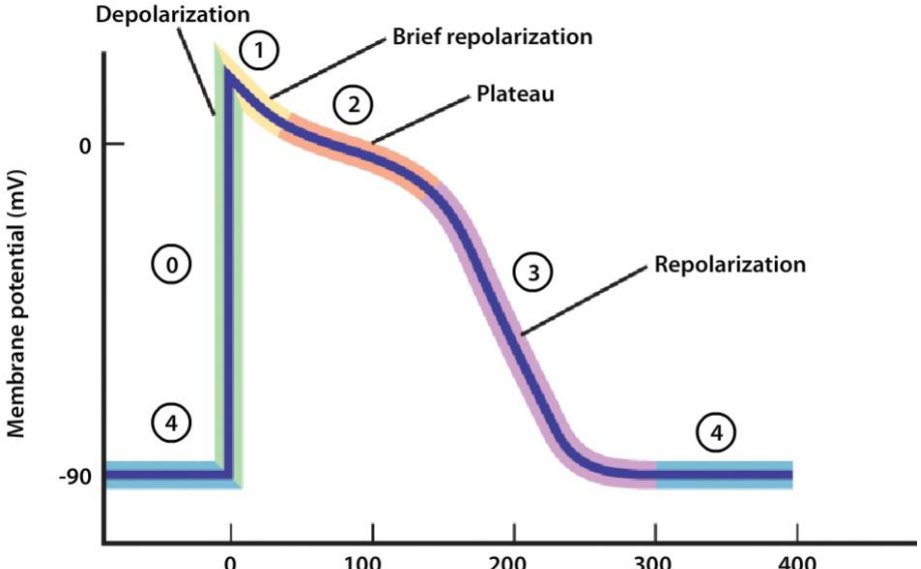
- 0 – DEPOLARIZACIJA
  - zaradi vdora ionov, ki prehajajo iz sosednje celice se membranski potencial malo dvigne (na -70mV) – pražni dražljaj, threshold
  - to povzroči odprtje hitrih Na kanalčkov → VDOR Na^+ v celico → membranski potencial se zviša, celica se depolarizira
  - pri -40mV se odprejo še počasni Ca kanalčki, kar povzroči vdor Ca v celico (počasen)





AKCIJSKI POTENCIAL SRČNE MIŠICE

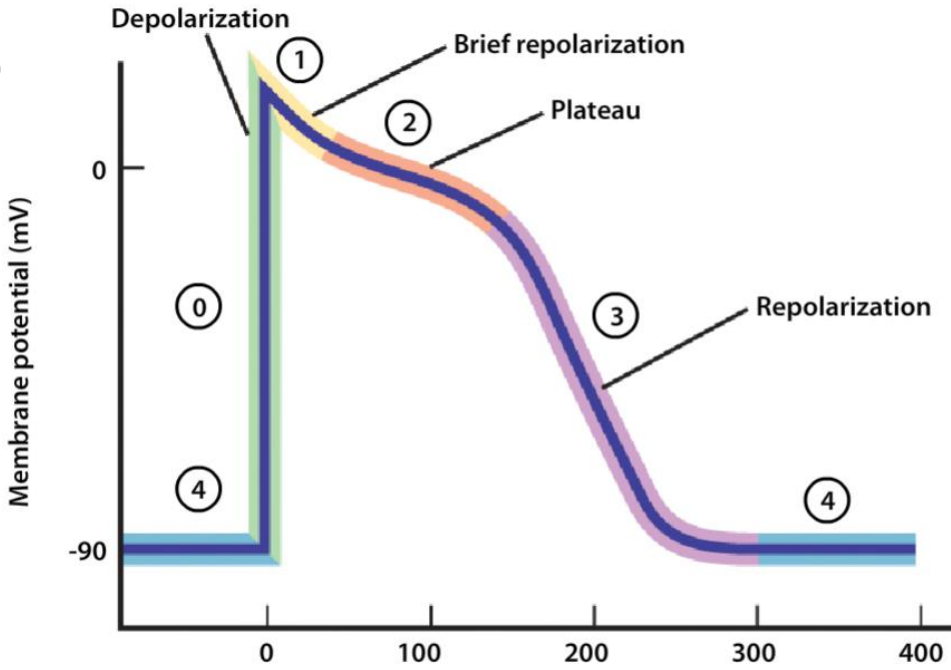
- 1 – ZGODNJA REPOLARIZACIJA
  - napetostno odvisni Na kanalčki se HITRO ZAPREJO (Na^+ ostane v celici) → memb potencial malo pade zaradi manjšega vnosa Na^+ v celico
  - napetostno odvisno K kanalčki se odprejo – MALO K ven iz celice
  - skozi počasne Ca^{2+} kanalčke gre Ca^{2+} v celico – iz ekstracelularne tekočine, zaloge v SAR

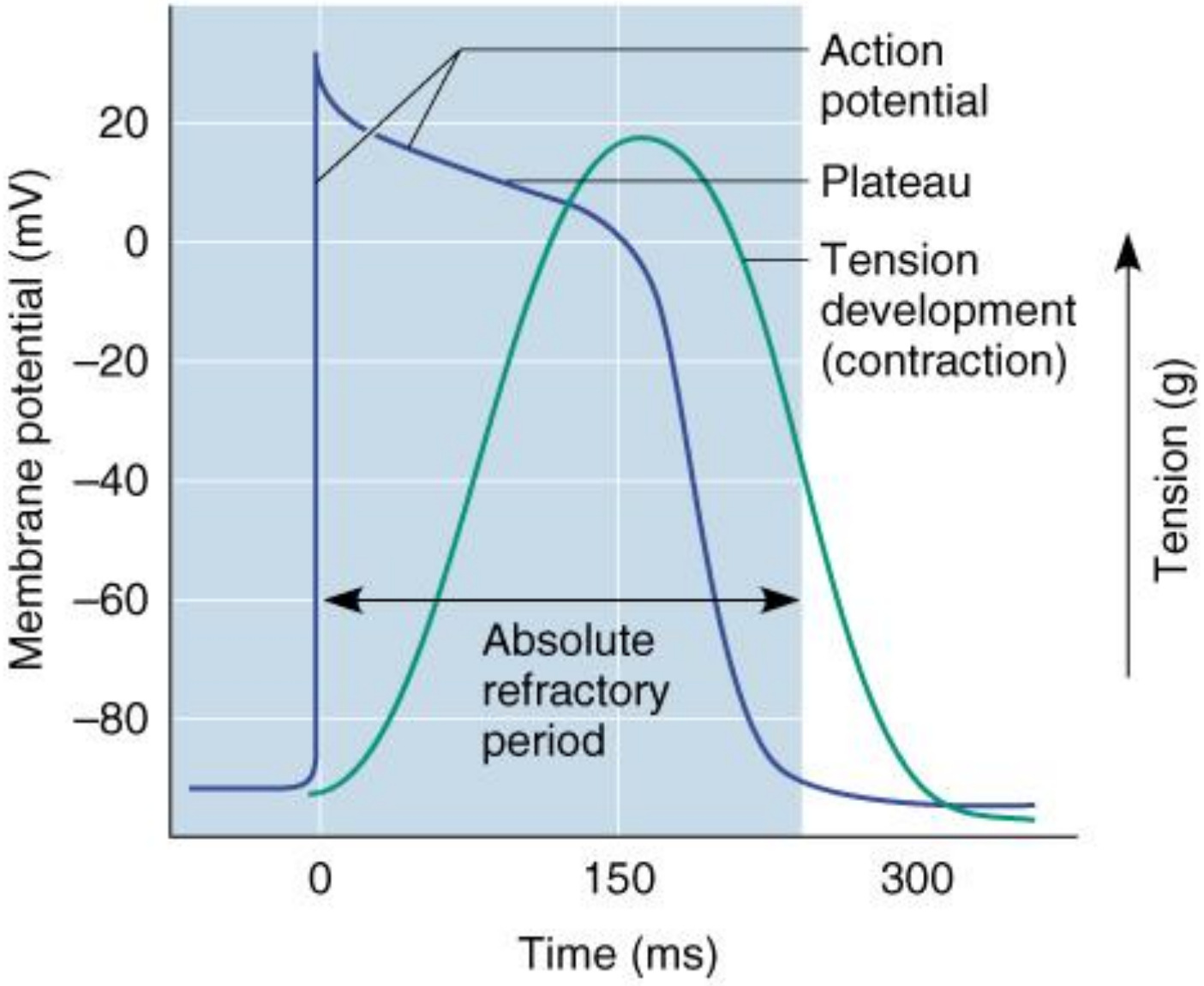


AKCIJSKI POTENCIAL SRČNE MIŠICE

- **2 - PLATO**
  - membrana je še vedno depolarizirana
  - K kanalčki odprti + odprti L-tip (long-lasting) počasni Ca kanalčki
  - vstop Ca v celico = izstop MALO K iz celice
  - Ca^{2+} vzdržuje depolarizacijo
  - 0,2 s (celoten AP 250 – 300 ms)
  - posebnost srčne mišice, nekaterih gladkih mišic

vstop Ca -> posredno povzroči krčenje mišice

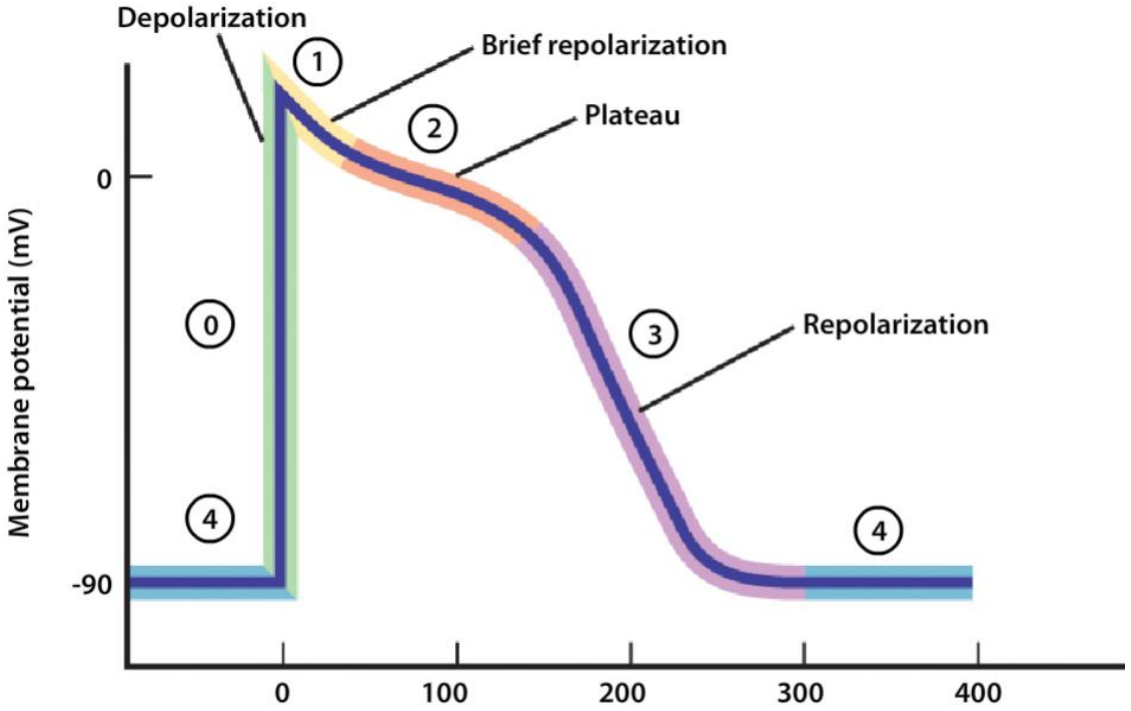




(a)

AKCIJSKI POTENCIAL SRČNE MIŠICE

- **3 - REPOLARIZACIJA**
  - Ca kanalčki se zaprejo, odprti ostanejo še K kanalčki → VELIKO K^+ gre ven iz celice
  - membrana se repolarizira (na -90mV)



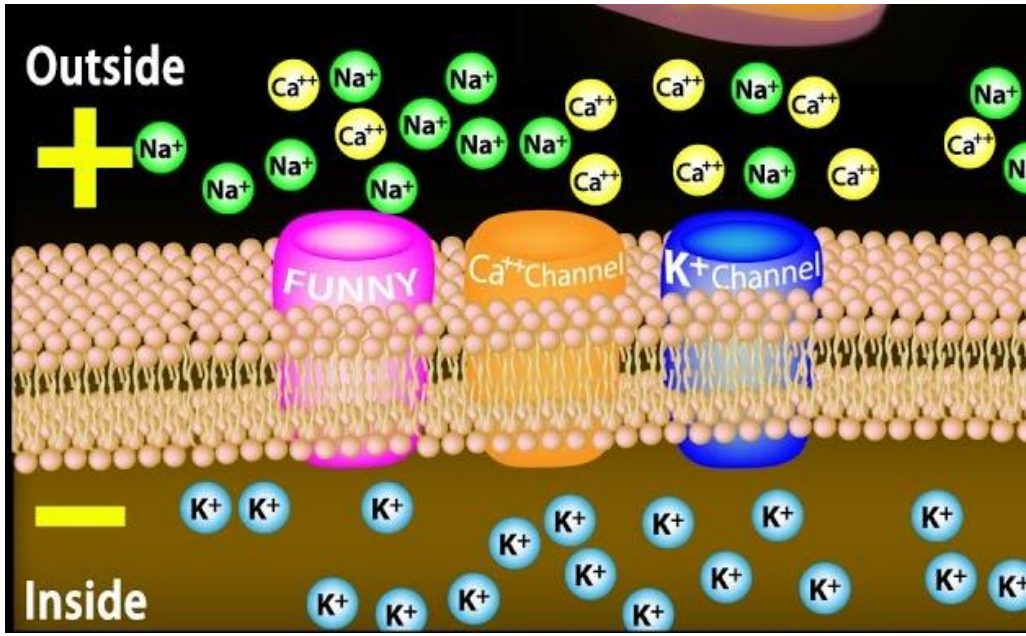
AKCIJSKI POTENCIAL SRČNE MIŠICE

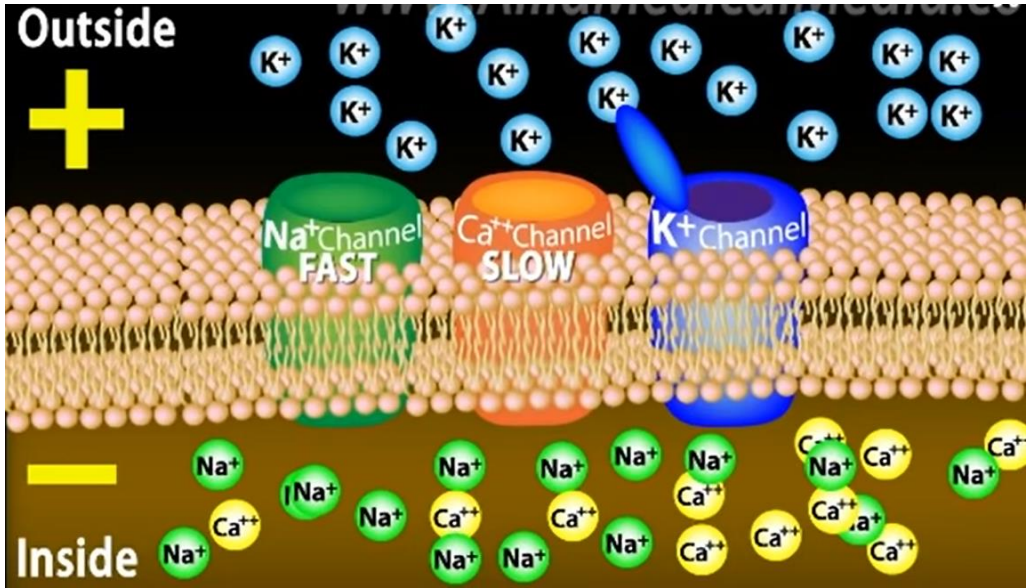
- začetno stanje:
- ZUNAJ: Na^{+}, Ca^{2+}
- NOT: K^{+}

- na koncu repolarizacije:

obratno

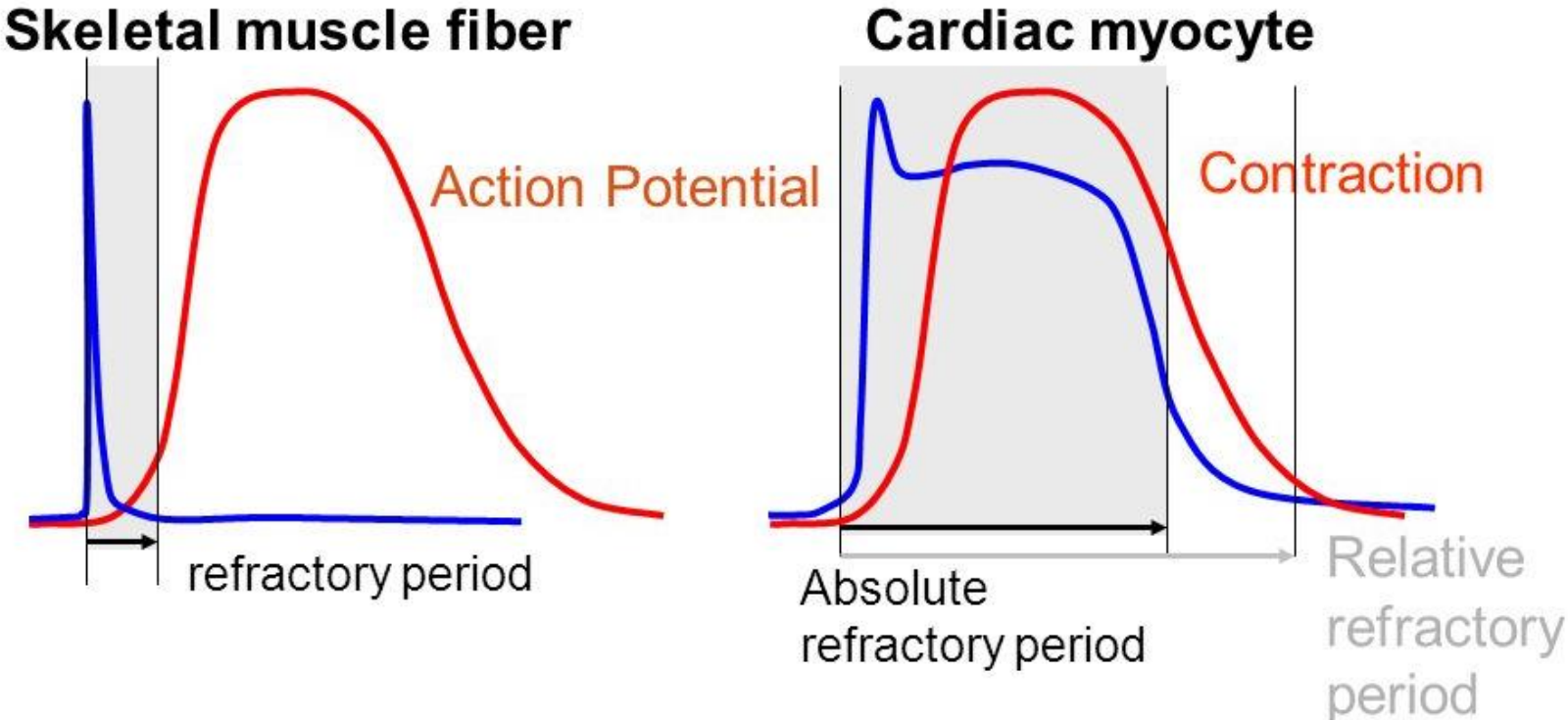
- ???





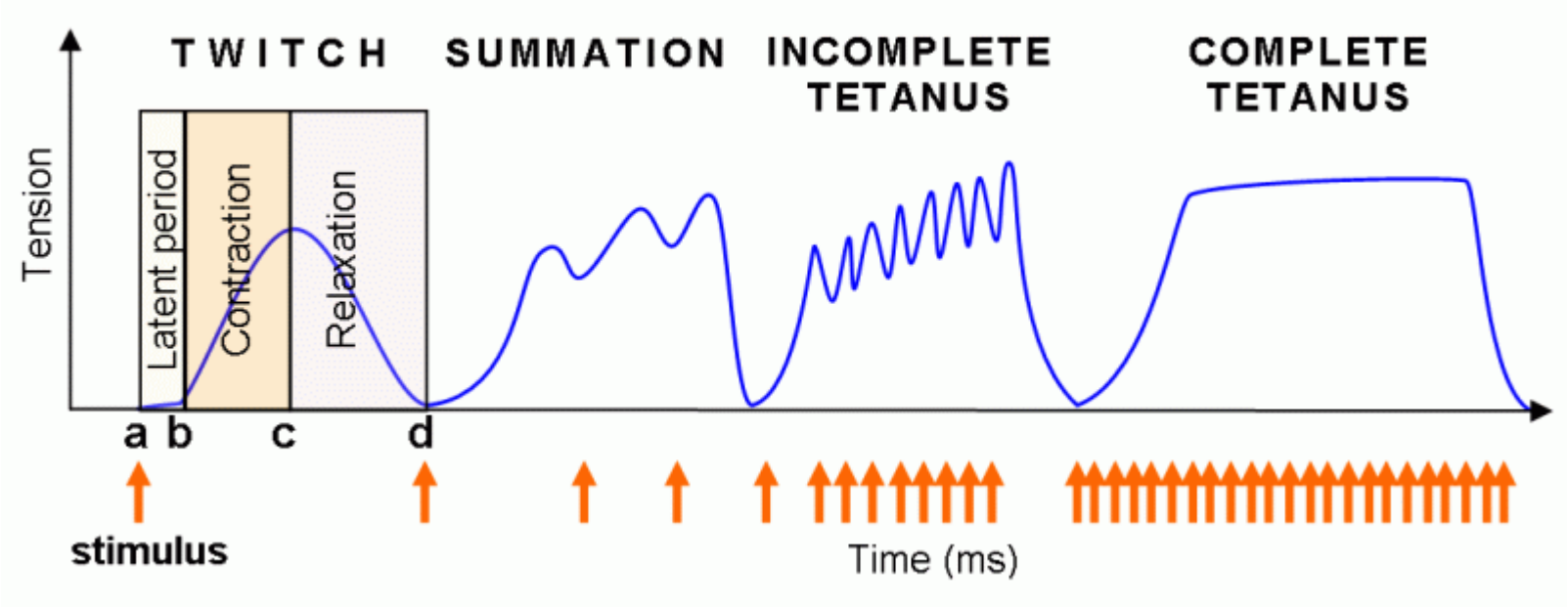
OBDOBJE REFRAKTARNOSTI

- ABSOLUTNA R. – obdobje, v katerem AP ne morejo biti generirani ne glede na moč dražljaja
- RELATIVNA R. – lahko izzovemo nov AP, vendar nadpražni dražljaj
- SRČNA M. – dolgo obdobje abs. ref. *ZAKAJ???*



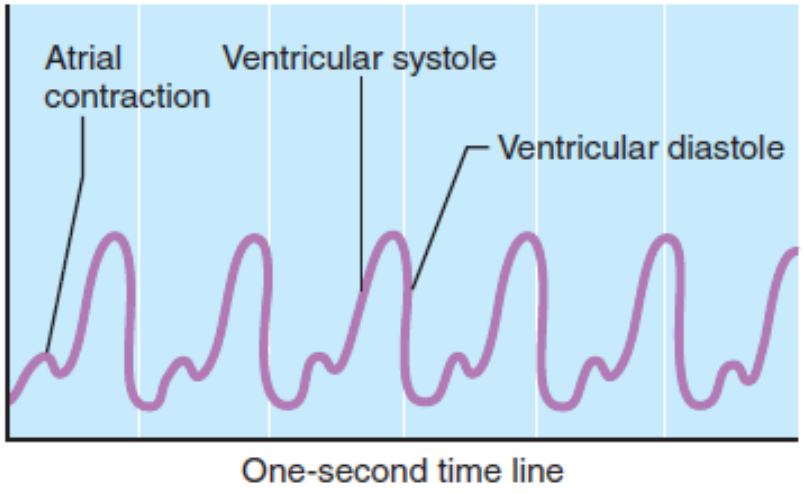
*samo za primerjavo s srčno mišico TETANIČNE KONTRAKCIJE SKELETNE MIŠICE

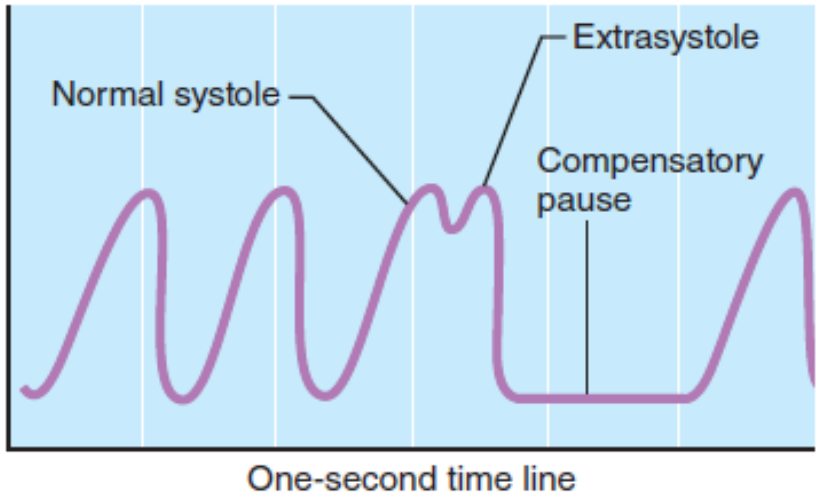
- skeletna mišica – prihaja do tetanične kontrakcije pri visoki frekvenci dražljajev (seštevanje "valov" krčenja) – motonevron oddaja AP z zelo visoko frekvenco
- močnejša kontrakcija kot pri enojnem vzdraženju
- **nepopolna tetanična kontrakcija** – m. vlakna se ne popolnoma relaksirajo med krčenji
- **popolna tetanična kontrakcija** – ne ločimo individualnih krčenj



EKSTRASISTOLE

- fiziograf – zapis krčenja (srčne) mišice
- srce se odzove s kontrakcijo v času relativne ref. dobe – po dražljaju, ki je močnejši od pražnega
- dodatna sistola – ekstrasistola – med relaksacijo ventrikla
- kompenzacijska pavza – zakaj?

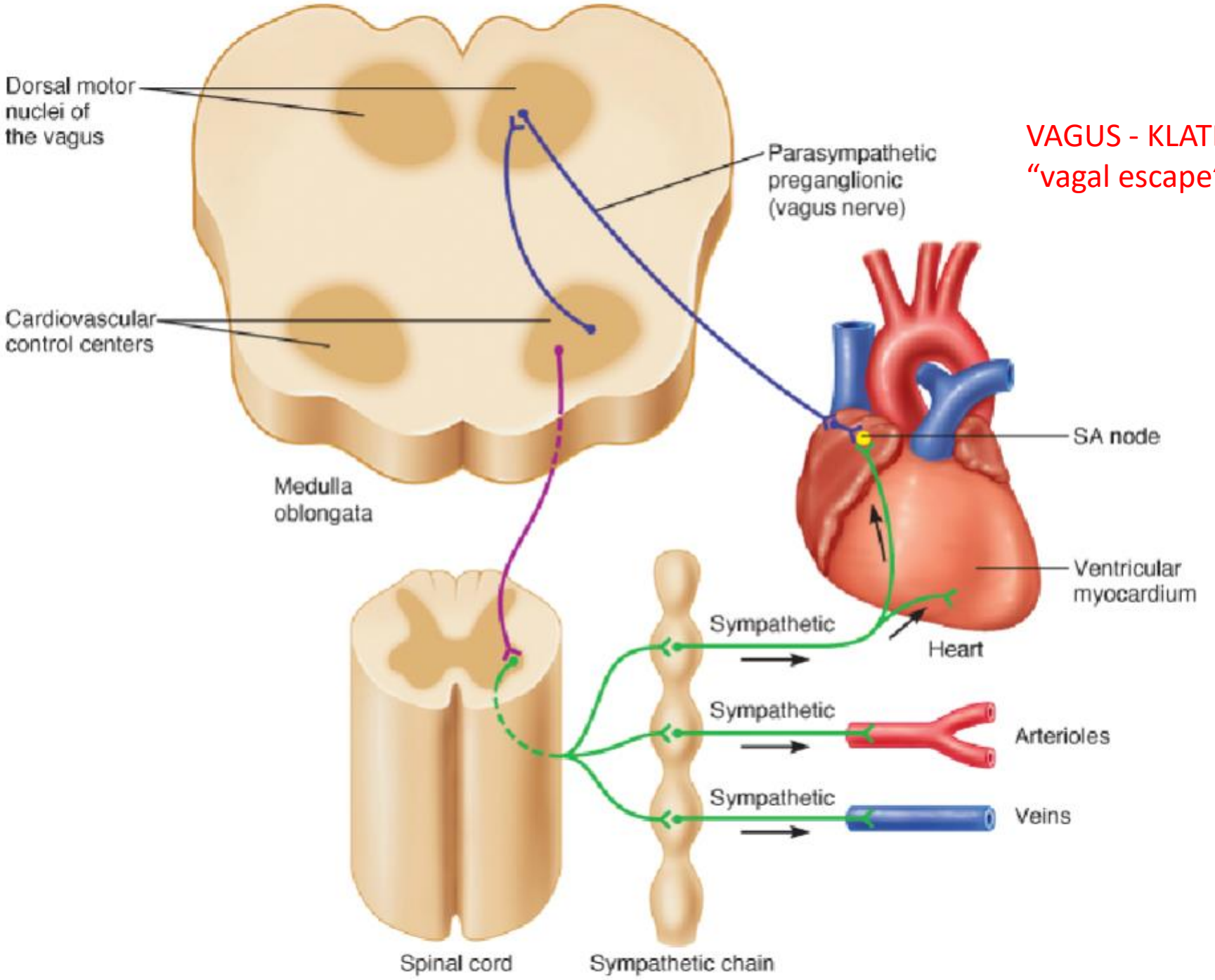




VPLIV AVTONOMNEGA Ž.S. NA DELOVANJE SRCA

- **MIROVANJE** – oba delujeta za zagotavljanje homeostaze, oba dovajata živčne impulze srcu, ampak parasimpatični je bolj aktiven
- ne vplivata na generiranje samih AP (to se zgodi spontano v ritmovnikih), temveč vplivata na moč in frekvenco krčenj srca
  - SIMPATIČNI – spodbuja
  - PARASIMPATIČNI – zavira

- simpatični postane bolj aktiven npr. med vadbo, med izpostavitvijo nevarnosti (npr. vazokonstrikcija, širjenje zenice, pospeševanje moči in frekvence kontrakcij srčne mišice)



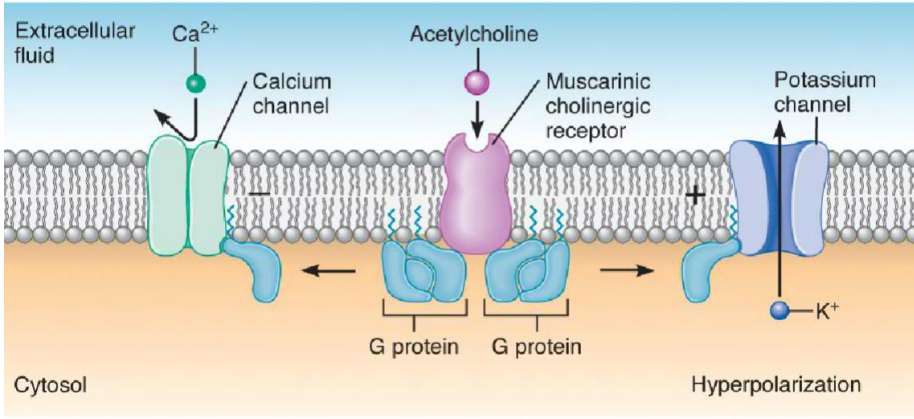
VAGUS - KLATEŽ
“vagal escape”

ŽIVEC VAGUS - KLATEŽ

- vagus= 10. možganski živec, del parasimpatičnega sistema, ki je vezan na SA vozel – zavira delovanje srca
  - sa vozel – skupek avtoritmičnih celic v steni D atrija
- če ni simpatične, parasimpatične ali hormonske stimulacije – srce utripa 100x/min
- zaradi delovanja parasimpatičnega sistema, utripa 80x/min
- če je prevelika stimulacija SA iz strani vagusa, se srce ustavi – samo začasno! zaradi refleksov simpatičnega živčevja ali spontane indukcije AP v Purkinjejevih vlaknih začne ponovno biti – temu pravimo VAGAL ESCAPE

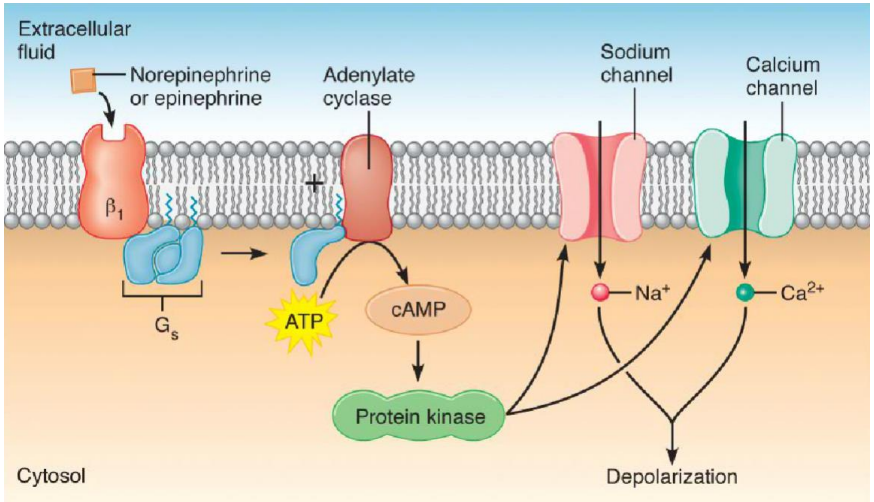
PARASIMPATIČNI Ž.S.

- “resting and digesting”
- dominira nad simpatičnim
- izloča ACETILHOLIN → veže se na **muskarinske** holinergične receptorje v membrani celic v SA vozlu
- posredno odpre K kanalčke, zapre Ca in Na kanalčke → zmanjša stopnjo depolarizacije → zmanjša frekvenco AP, utripanje srca (brez vpliva na moč kontrakcije)



SIMPATIČNI Ž.S.

- aktiviran, ko je večja potreba po energiji (stress)
- živci simpatičnega ž.s. v sinapse s srčno mišico izločajo:
  - norepinefrin (noradrenalin), epinefrin (adrenalin)
  - oba – povečata frekvenco AP, vežeta se na **β1 adrenergične receptorje** v membrani celic SA vozla → preko cAMP → odprtje Na in Ca kanalčkov → povečanje depolarizacij, zmanjšanje repolarizacij → povečanje frekvence srčnega utripa



SIMPATIČNI Ž.S.

- kemijsko sta si epinefrin in norepinefrin zelo podobna
- oba delujeta na: povečano koncentracijo sladkorjev v krvi, povečano utripanje srca, povečana kontraktilnost (kako močno se srce stisne)
  - norepinefrin lahko tudi zoži žile in s tem poveča pritisk v žilah
  - epinefrin – ti efekti zato, da telesu zagotovijo več energije → ko si pod stresom ali te je zelo strah – telo izloči val epinefrina – "**fight or flight response**"

- uporaba epinefrina – napadi astme (lahko zdravi ali preprečuje hude napade astme), zastoj srca (injekcija lahko reštarta srce pri srčnem zastoju), anestezija (dodajanje epinefrina nekaterim anestetikom jim podaljša delovanje)
- uporaba norepinefrina – v nekaterih primerih za zdravljenje septičnega šoka (huda infekcija, ki lahko vodi do odpovedi organov, void v nevarno nizke krvne tlake)

SIMPATIČNI, PARASIMPATIČNI Ž.S.

- HOLINERGIČNE SNOVI (pilokarpin ↓, atropin ↑)
- ADRENERGIČNE SNOVI (digitalis ↓, epinefrin ↑)

- **agonistične snovi** – delujejo isto kot acetilholin, epinefrin in norepinefrin (pilokarpin)
- **antagonistične snovi** – delujejo obratno kot nevrotransmiterji (atropin, digitalis)
  - DIGITALIS – upočasni srčni utrip in poveča moč kontrakcije

VPLIV RAZLIČNIH IONOV NA DELOVANJE SRCA

- celice v mirovanju: K več not, Ca in Na več zunaj; najbolj permeabilne za K

- blokatorji Ca kanalčkov – uporabljeni za zdravljenje visokega krvnega pritiska in nenormalnega utripanja srca
- manj Ca gre v celico → stopnja depolarizacije in moč kontrakcije sta zmanjšana

- modifikatorji → vplivajo na moč kontrakcije in frekvenco utripanja srca

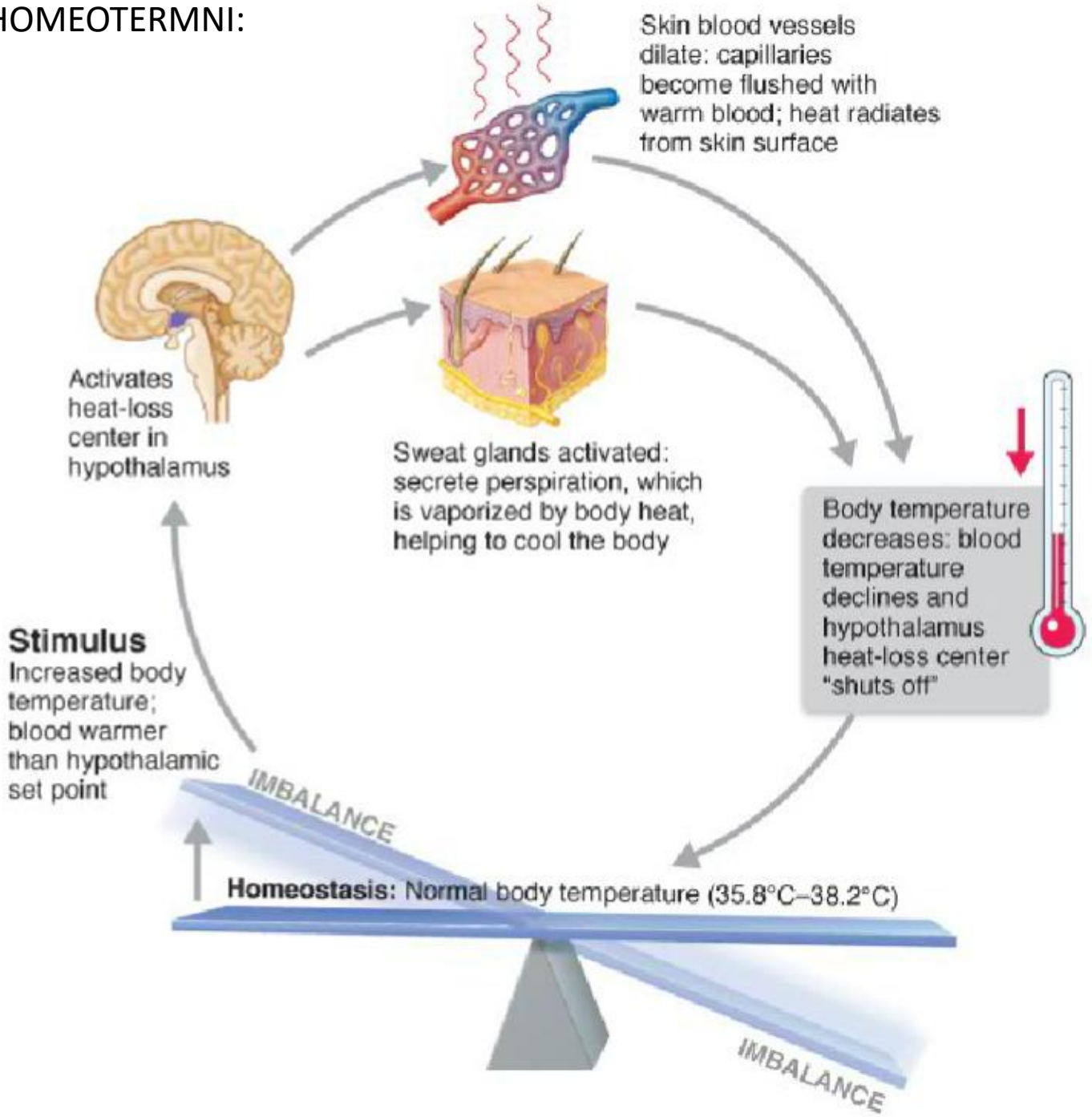
MODIFIKATORJI, KI VPLIVAJO NA SRČNI UTRIP

- kronotropni modifikatoji – vpliv na stopnjo utripanja srca
  - pozitivni - povečajo frekvenco utripanje srca
  - negativni – zmanjšajo frekvenco utripanje srca

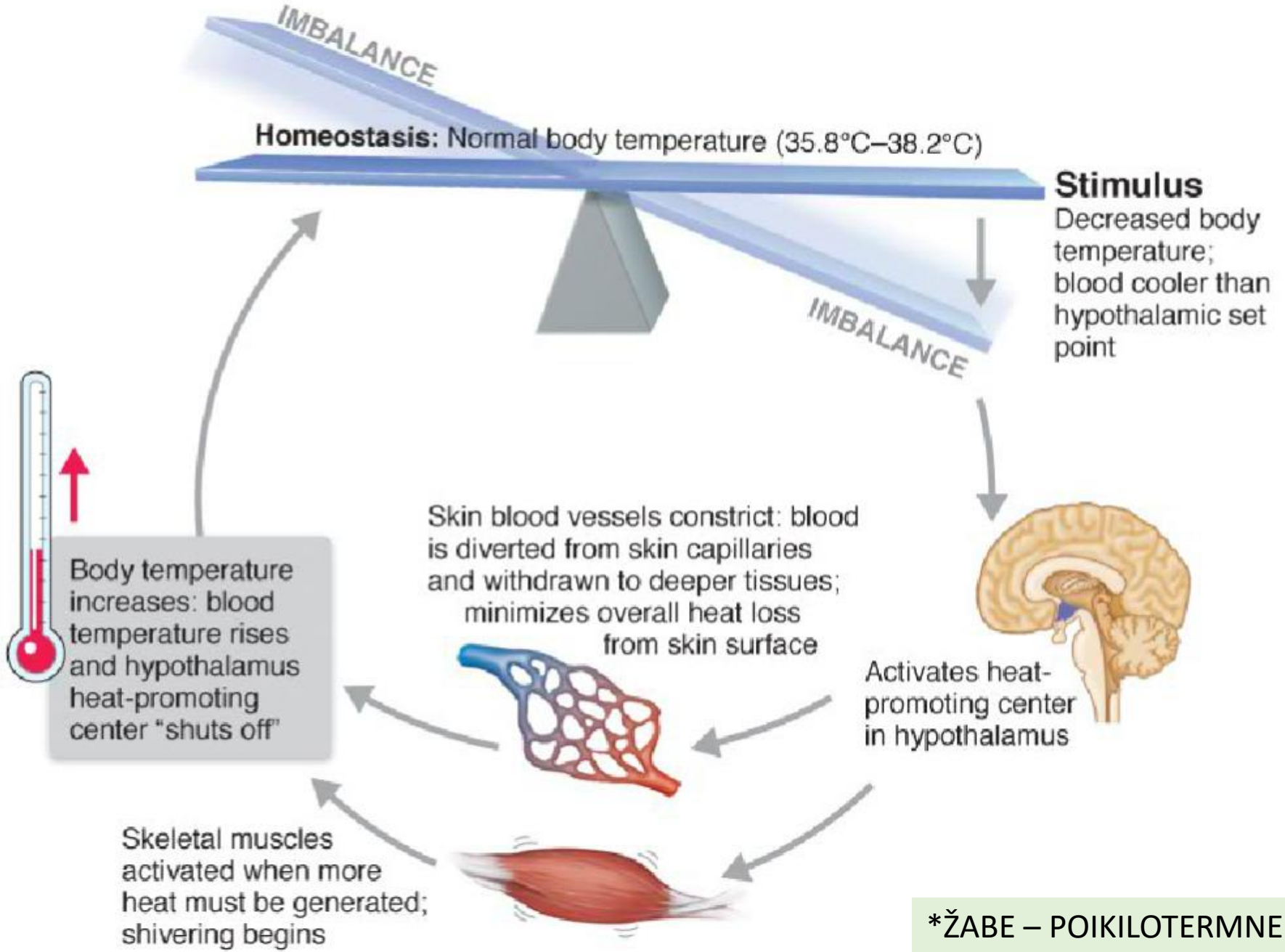
- inotropni modifikatorji – vpliv na moč kontrakcije
  - pozitivni - povečajo moč kontrakcije srca
  - negativni – zmanjšajo moč kontrakcije srca

- dromotropni modifikatorji – vpliv na spremembo hitrosti prevajanja
- batmotropni modifikatorji – vpliv na spremembo vzdražnosti

LJUDJE – HOMEOTERMNI:



LJUDJE – HOMEOTERMNI:



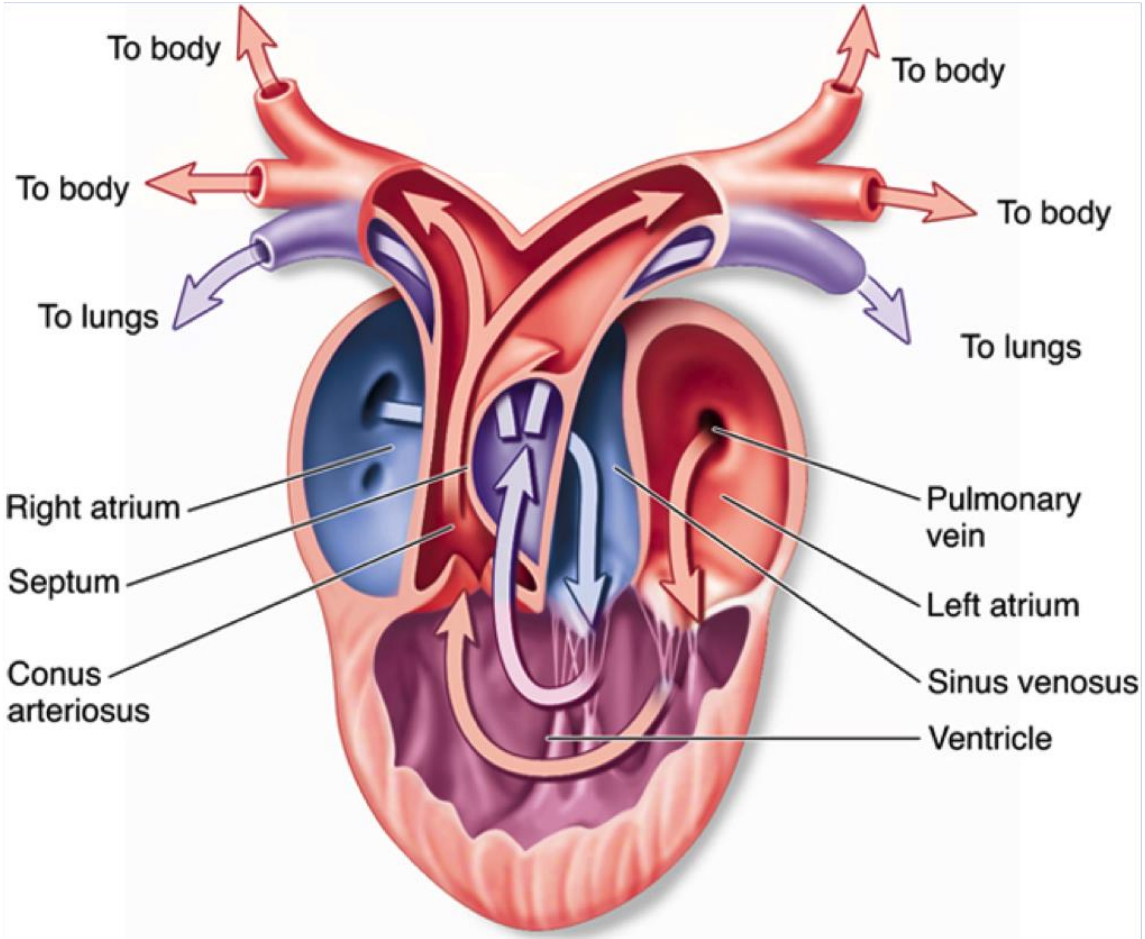
*ŽABE – POIKILOTERMNE!

VAJE – krčenje žabjega srca

KRČENJE (ŽABJEGA) SRCA

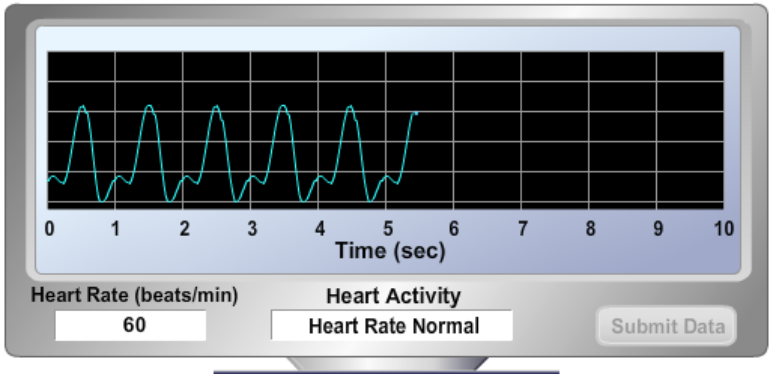
DESNO LEVO

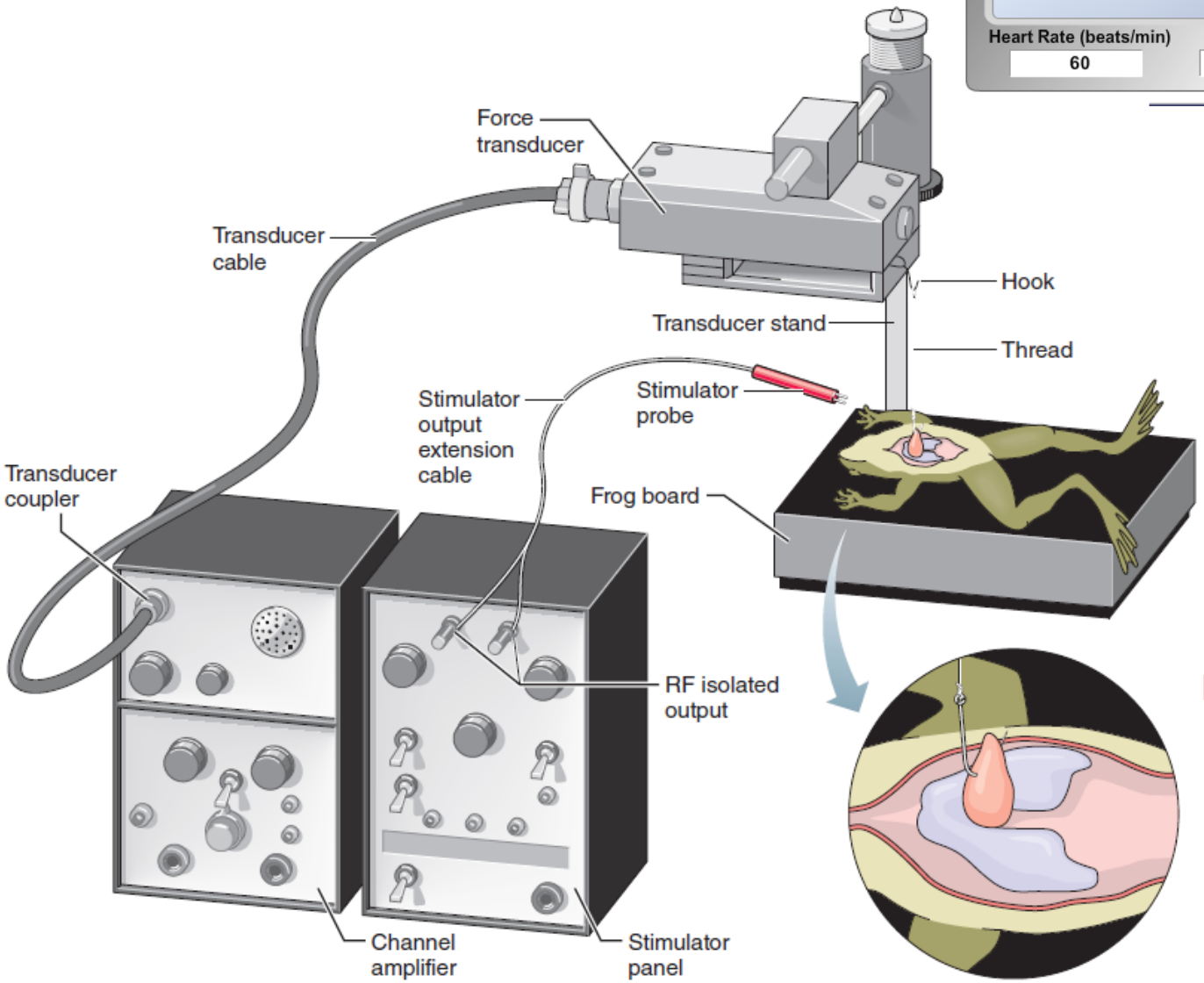
- pljučni in sistemski (telesni) krvni obtok delno ločena
- kri iz pljuč – v srce – prečrpa v organe
- trodelno srce: 2A + 1 V
- V črpa kri v pljuča in ostalo telo
- DA – deoksig. kri iz telesnih žil
- LA – oksig. kri iz pljučnih žiL
- EN ventrikel, mešanje krvi omejeno zaradi anatomskih lastnosti ventrikla



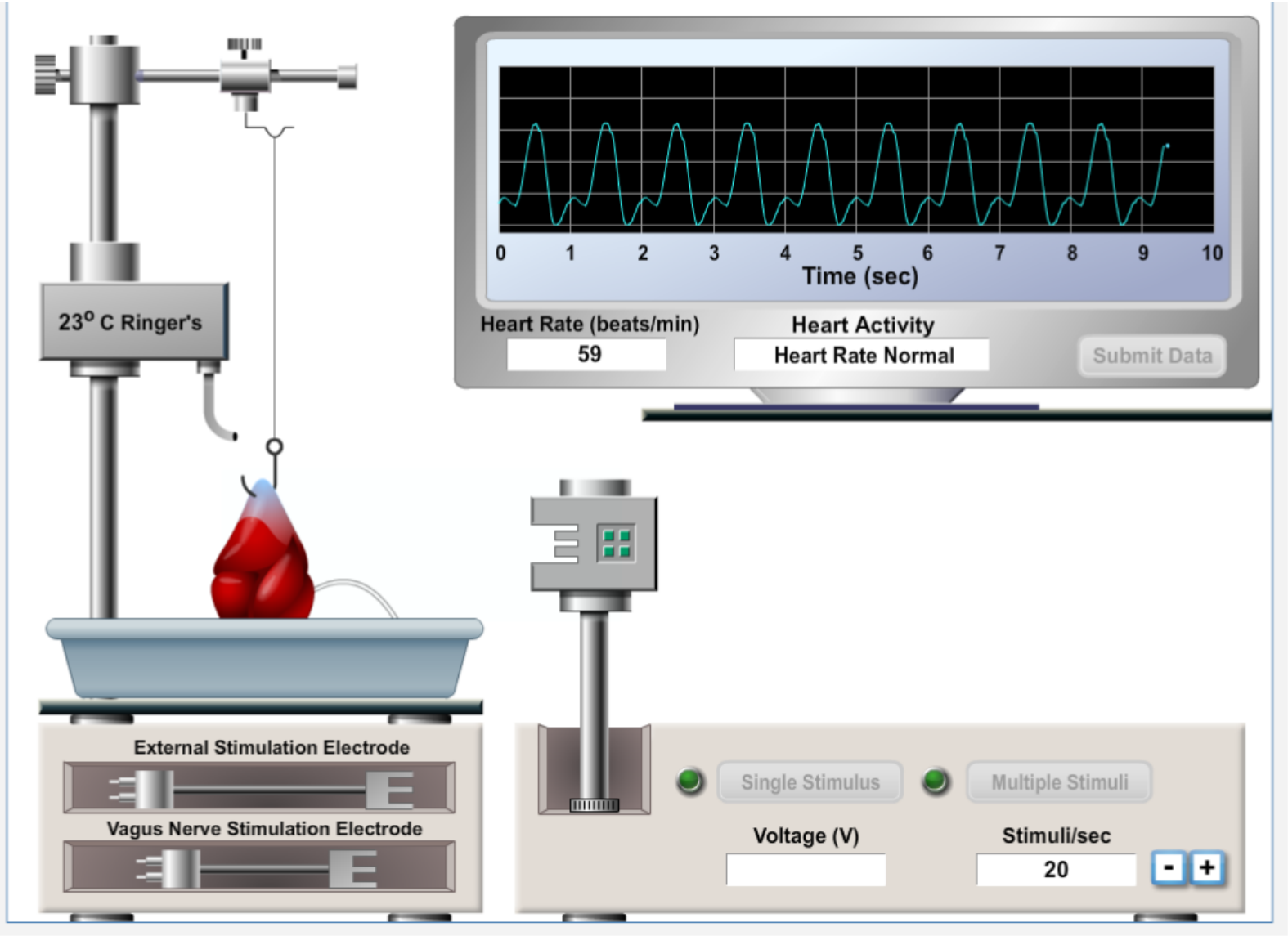
(a) Amphibian heart

OSCILOSKOP





RINGERJEVA RAZTOPINA

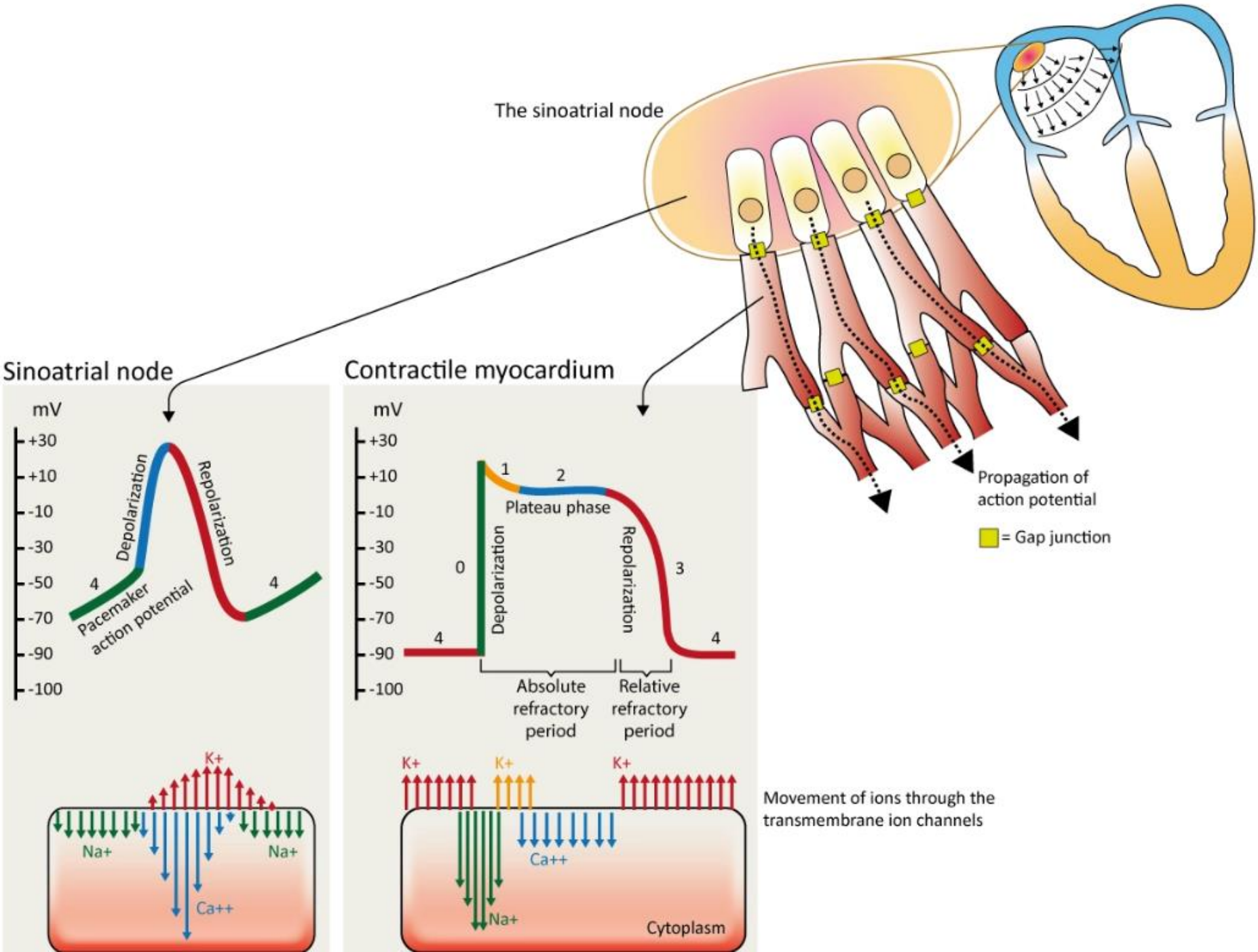


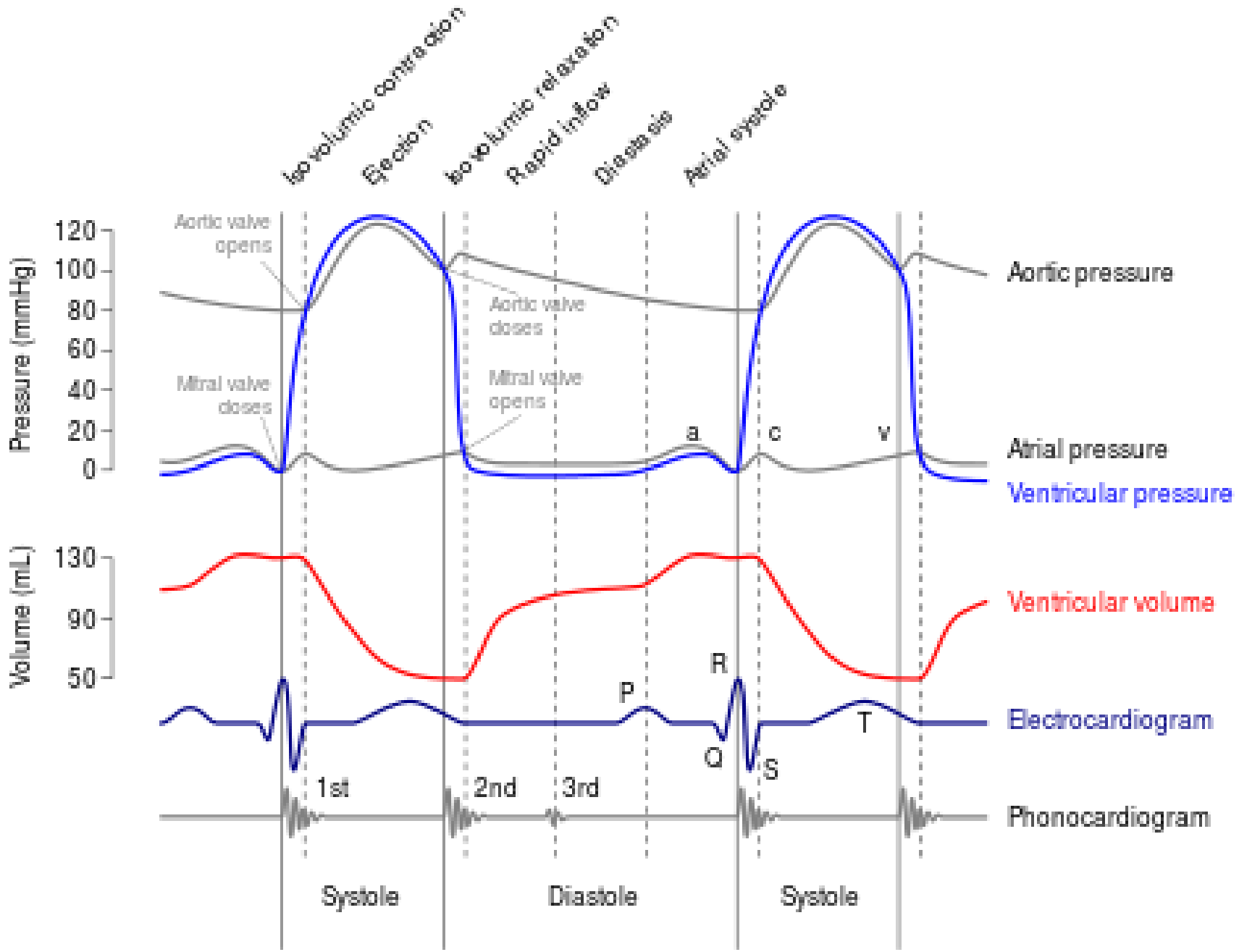
- na osciloskopu zabeleženo krčenje atrijev in ventrikla
- **NISO AP!!!**

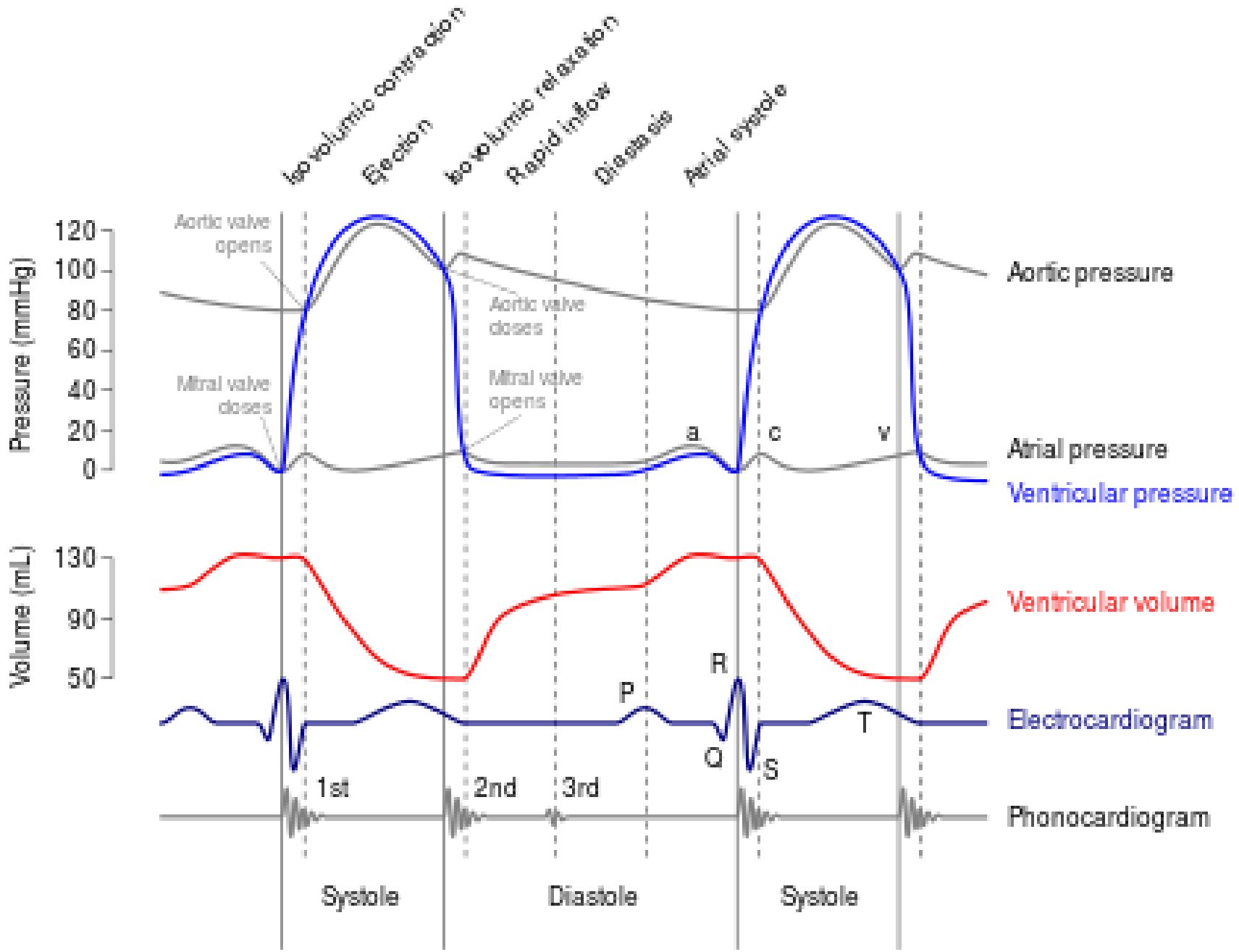
VAJE

- Exercise 6 – Cardiovascular physiology

- 6.1 OBDOBJE REFRAKTARNOSTI, EKSTRASISTOLE
- 6.2 VPLIV STIMULACIJE N. VAGUS NA KRČENJE SRCA
- 6.3 VPLIV TEMPERATURE NA KRČENJE SRCA
- 6.4 VPLIV RAZL. KEMIJSKIH SPOJIN NA DELOVANJE SRCA
- 6.5 VPLIV RAZL. IONOV NA DELOVANJE SRCA


The sinoatrial node
Propagation of action potential
= Gap junction
Sinoatrial node
mV
+30
+10
-10
-30
-50
-70
-90
-100
Depolarization
Repolarization
4
Pacemaker action potential
4
Contractile myocardium
mV
+30
+10
-10
-30
-50
-70
-90
-100
1
2
Plateau phase
0
Depolarization
Repolarization
3
4
4
Absolute refractory period
Relative refractory period
K+
Na+
Na+
Ca++
K+
K+
K+
Ca++
Na+
Cytoplasm
Movement of ions through the transmembrane ion channels


Iso volumic contraction
Ejection
Iso volumic relaxation
Rapid inflow
Diastasis
Atrial systole
Pressure (mmHg)
120
100
80
60
40
20
0
Aortic valve opens
Mitral valve closes
Aortic valve closes
Mitral valve opens
a
c
v
Aortic pressure
Atrial pressure
Ventricular pressure
Volume (mL)
130
90
50
Ventricular volume
R
P
Q
S
T
Electrocardiogram
1st
2nd
3rd
Phonocardiogram
Systole
Diastole
Systole


Iso volumic contraction
Ejection
Iso volumic relaxation
Rapid inflow
Diastasis
Atrial systole
Pressure (mmHg)
120
100
80
60
40
20
0
Aortic valve opens
Mitral valve closes
Aortic valve closes
Mitral valve opens
a
c
v
Aortic pressure
Atrial pressure
Ventricular pressure
Volume (mL)
130
90
50
Ventricular volume
R
P
Q
S
T
Electrocardiogram
1st
2nd
3rd
Phonocardiogram
Systole
Diastole
Systole

Cardiovascular Physiology

Cardiac muscle and some types of smooth muscle contract spontaneously, without any external stimuli. Skeletal muscle is unique in that it requires depolarizing signals from the nervous system to contract. The heart's ability to trigger its own contractions is called **autorhythmicity**.

If you isolate cardiac pacemaker muscle cells, place them into cell culture, and observe them under a microscope, you can see the cells contract. Autorhythmicity occurs because the plasma membrane in cardiac pacemaker muscle cells has reduced permeability to potassium ions but still allows sodium and calcium ions to slowly leak into the cells. This leakage causes the muscle cells to slowly depolarize until the action potential threshold is reached and L-type calcium channels open, allowing Ca^{2+} entry from the extracellular fluid. Shortly thereafter, contraction of the remaining cardiac muscle occurs prior to potassium-dependent repolarization. The spontaneous depolarization-repolarization events occur in a regular and continuous manner in cardiac pacemaker muscle cells, leading to **cardiac action potentials** in the majority of cardiac muscle.

There are five main phases of membrane polarization in a cardiac action potential (view Figure 6.1).

• **Phase 0** is similar to depolarization in the neuronal action potential. Depolarization causes

Exercise Overview

voltage-gated sodium channels in the cell membrane to open, increasing the flow of sodium ions into the cell and increasing the membrane potential.

• In **phase 1**, the open sodium channels begin to inactivate, decreasing the flow of sodium ions into the cell and causing the membrane potential to fall slightly. At the same time, voltage-gated potassium channels close and voltage-gated calcium channels open. The subsequent decrease in the flow of potassium out of the cell and increase in the flow of calcium into the cell act to depolarize the membrane and curb the fall in membrane potential caused by the inactivation of sodium channels.

• In **phase 2**, known as the **plateau phase**, the membrane remains in a depolarized state. Potassium channels stay closed, and long-lasting (L-type) calcium channels stay open. This plateau lasts about 0.2 seconds, or 200 milliseconds.

• In **phase 3**, the membrane potential gradually falls to more negative values when a second set of potassium channels that began opening in phases 1 and 2 allows significant amounts of potassium to flow out of the cell. The falling membrane potential causes calcium channels to close, reducing the flow of calcium into the cell and repolarizing the membrane until the resting potential is reached.

• In **phase 4**, the resting membrane potential is again established in cardiac muscle cells and

Activities

You can also complete the following activities in this exercise.

Activity 2: Examining the Effect of Vagus Nerve Stimulation

Activity 3: Examining the Effect of Temperature on Heart Rate

Activity 4: Examining the Effects of Chemical Modifiers on Heart Rate

Activity 5: Examining the Effects of Various Ions on Heart Rate

Exercise Overview

is maintained until the next depolarization arrives from neighboring cardiac pacemaker cells.

The total cardiac action potential lasts 250-300 milliseconds.

Activities

You can also complete the following activities in this exercise.

Activity 2: Examining the Effect of Vagus Nerve Stimulation

Activity 3: Examining the Effect of Temperature on Heart Rate

Activity 4: Examining the Effects of Chemical Modifiers on Heart Rate

Activity 5: Examining the Effects of Various Ions on Heart Rate

Introduction

Recall that **wave summation** occurs when a skeletal muscle is stimulated with such frequency that muscle twitches overlap and result in a stronger contraction than a single muscle twitch. When the stimulations are frequent enough, the muscle reaches a state of fused tetanus, during which the individual muscle twitches cannot be distinguished. Tetanus occurs in skeletal muscle because skeletal muscle has a relatively short **absolute refractory period** (a period during which action potentials cannot be generated no matter how strong the stimulus).

Unlike skeletal muscle, cardiac muscle has a relatively long refractory period and is thus incapable of wave summation. In fact, cardiac muscle is incapable of reacting to *any* stimulus before approximately the middle of phase 3 and will not respond to a normal cardiac stimulus before phase 4. The period of time between the beginning of the cardiac action potential and the approximate middle of phase 3 is the **absolute refractory period**. The period of time between the absolute refractory period and phase 4 is the **relative refractory period**. The total refractory period of cardiac muscle is 200-250 milliseconds—almost as long as the contraction of the cardiac muscle.

In this activity you will use external stimulation to better understand the refractory period of cardiac muscle. You will use a frog heart, which is anatomically similar to the human heart. The frog heart has two atria and a single, incompletely divided ventricle.

Equipment Used

Introduction

- Oscilloscope display—displays the contractile activity from the frog heart
- Electrical stimulator—used to a apply electrical shocks to the frog heart
- Electrode holder— locks electrodes in place for stimulation
- External stimulation electrode
- Apparatus for sustaining an isolated frog heart—includes 23°C Ringer's solution
- Frog heart

Introduction

The autonomic nervous system has two branches: the **sympathetic** nervous system ("fight or flight") and **parasympathetic** nervous system ("resting and digesting"). At rest both the sympathetic and parasympathetic nervous systems are working but the parasympathetic branch is more active. The sympathetic nervous system becomes more active when needed, for example, during exercise and when confronting danger.

Both the parasympathetic and sympathetic nervous systems supply nerve impulses to the heart. Stimulation of the sympathetic nervous system increases the rate and force of contraction of the heart. Stimulation of the parasympathetic nervous system decreases the heart rate without directly changing the force of contraction (view Figure 6.3). The vagus nerve (cranial nerve X) carries the signal to the heart. If stimulation of the vagus nerve (vagal stimulation) is excessive, the heart will stop beating. After a short time, the ventricles will begin to beat again. The resumption of the heartbeat is referred to as **vagal escape** and can be the result of sympathetic reflexes or initiation of a rhythm by the Purkinje fibers.

The **sinoatrial node** (**SA node**) is a cluster of autorhythmic cardiac cells found in the right atrial wall in the human heart. The SA node has the fastest rate of spontaneous depolarization, and, for that reason, it determines the heart rate and is therefore referred to as the heart's "**pacemaker**." In the absence of parasympathetic stimulation, sympathetic stimulation, and hormonal controls, the SA node generates action potentials 100 times per minute.

Introduction

Equipment Used

- Oscilloscope display—displays the contractile activity from the frog heart
- Electrical stimulator—used to a apply electrical shocks to the frog heart
- Electrode holder—locks electrodes in place for stimulation
- Vagus nerve stimulation electrode
- Apparatus for sustaining an isolated, intact frog heart—includes 23°C Ringer's solution
- Frog heart with vagus nerve (thin, white strand to the right)

Introduction

Humans are **homeothermic**, which means that the human body maintains an internal body temperature within the 35.8-38.2°C range even though the external temperature is changing. When the external temperature is elevated, the hypothalamus is signaled to activate heat-releasing mechanisms, such as sweating and vasodilation, to maintain the body's internal temperature (view Figure 6.4a and Figure 6.4b) During extreme external temperature conditions, the body might not be able to maintain homeostasis and either **hyperthermia** (elevated body temperature) or **hypothermia** (low body temperature) could result. In contrast, the frog is a **poikilothermic** animal. Its internal body temperature changes depending on the temperature of its external environment because it lacks internal homeostatic regulatory mechanisms.

Ringer's solution, also known as Ringer's irrigation, consists of essential electrolytes (chloride, sodium, potassium, calcium, and magnesium) in a physiological solution and is required to keep the isolated, intact heart viable. In this activity you will explore the effect of temperature on heart rate using a Ringer's solution incubated at different temperatures.

Equipment Used

- Oscilloscope display—displays the contractile activity from the frog heart
- Electrical stimulator—used to apply electrical shocks to the frog heart
- Electrode holder— locks electrodes in place for stimulation

Introduction

- External stimulation electrode
- Apparatus for sustaining an isolated, intact frog heart—includes 5°C, 23°C, and 32°C Ringer's solution
- Frog heart

Introduction

Although the heart does not need external stimulation to beat, it can be affected by extrinsic controls, most notably, the autonomic nervous system. The sympathetic nervous system is activated in times of "fight or flight," and sympathetic nerve fibers release **norepinephrine** (also known as **noradrenaline**) and **epinephrine** (also known as **adrenaline**) at their cardiac synapses.

Norepinephrine and epinephrine increase the frequency of action potentials by binding to $ß_1$ adrenergic receptors embedded in the plasma membrane of **sinoatrial** (**SA**) **node** (pacemaker) cells. Working through a cAMP second messenger mechanism, binding of the ligand opens sodium and calcium channels, increasing the rate of depolarization and shortening the period of repolarization, thus increasing the heart rate (view Figure 6.5).

The parasympathetic nervous system, our "resting and digesting branch," usually dominates, and parasympathetic nerve fibers release **acetylcholine** at their cardiac synapses. Acetylcholine decreases the frequency of action potentials by binding to muscarinic cholinergic receptors embedded in the plasma membrane of the SA node cells. Acetylcholine indirectly opens potassium channels and closes calcium and sodium channels, decreasing the rate of depolarization and, thus, decreasing heart rate (view Figure 6.6).

Chemical modifiers that inhibit, mimic, or enhance the action of acetylcholine in the body are labeled **cholinergic**. Chemical modifiers that inhibit, mimic, or enhance the action of

Introduction

epinephrine in the body are **adrenergic**. If the modifier works in the same fashion as the neurotransmitter (acetylcholine or norepinephrine), it is an **agonist**. If the modifier works in opposition to the neurotransmitter, it is an **antagonist**. In this activity you will explore the effects of pilocarpine, atropine, epinephrine, and digitalis on heart rate.

Equipment Used

- Oscilloscope display—displays the contractile activity from the frog heart
- Apparatus for sustaining an isolated intact frog heart—includes 23°C Ringer's solution
- Pilocarpine
- Atropine
- Epinephrine
- Digitalis
- Frog heart

Introduction

In cardiac muscle cells, action potentials are caused by changes in permeability to ions due to the opening and closing of ion channels. The permeability changes that occur for the cardiac muscle cell involve potassium, sodium, and calcium ions. The concentration of potassium is greater inside the cardiac muscle cell than outside the cell. Sodium and calcium are present in larger quantities outside the cell than inside the cell.

The resting cell membrane favors the movement of potassium more than sodium or calcium. Therefore, the resting membrane potential of cardiac cells is determined mainly by the ratio of extracellular and intracellular concentrations of potassium. View Table 6.1 for a summary of the phases of the cardiac action potential and ion movement during each phase.

Calcium channel blockers are used to treat high blood pressure and abnormal heart rates. They block the movement of calcium through its channels throughout all phases of the cardiac action potentials. Consequently, because less calcium gets through, both the rate of depolarization and the force of the contraction are reduced. Modifiers that affect heart rate are **chronotropic**, and modifiers that affect the force of contraction are **inotropic**. Modifiers that lower heart rate are negative chronotropic, and modifiers that increase heart rate are positive chronotropic. The same adjectives describe inotropic modifiers. Therefore, negative inotropic drugs decrease the force of contraction of the heart and positive inotropic drugs increase the force of contraction of the heart.

Introduction

Equipment Used

- Oscilloscope display—displays the contractile activity from the frog heart
- Apparatus for sustaining frog heart—includes 23°C Ringer's solution
- Calcium ions
- Sodium ions
- Potassium ions
- Frog heart