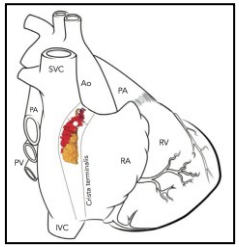
SA node and sinus node dysfunction



Anatomy (Arrhy Electrophys Rev. 2015;4:28)

- The SA node (sinoatrial node, historically 'sino-auricular' node; Keith, 1907) is the primary pacemaker of the heart.
- A 1-2 cm, crescent-shape of special conduction cells located at the superior-posterior of the RA (SVC-RA junction). In some people, it is extended along crista terminalis down to IVC-RA junction.
- SA node is supplied by RCA in 60% of people. The others from LCX. Dual blood supply is also common.
- Directly innervate by sympathetic and parasympathetic.

Physiology of SA node (PACE 2010; 33:1392)

- SA node is capable of repetitively impulse generation resulting in regular sinus rhythm.
- Rate of SA node is regulated by changing in the slope of phase 4 or depolarization threshold in phase 0.
- Action potential of SA node is markedly different from myocardium. (Physiology 2013;28:74)
  - Phase 0: The upstroke is slower due to lack of Na current and depended only on Ca2+ inward current via L-type voltage-gated Ca2+ ($I_{Ca(L)}$). The depolarization threshold is around -30 to -40mV.
  - Phase 4: There is a gradual increased in resting potential so-called "diastolic depolarization" due to 2 main mechanism

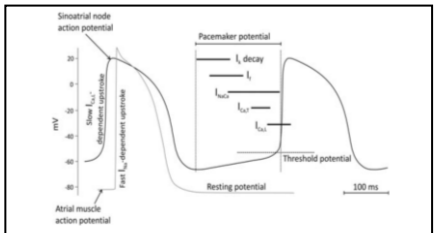


Figure 5. *Typical action potentials recorded from atrial muscle (light gray) and the center of the SAN (black). The temporal contributions of the main ionic currents to the pacemaker potential are shown by the black bars. Adapted from Boyett.*[115]

1. "Membrane clock" - I_{Kr}, I_f, lack of $I_{K,1}$: Start with decay of inward K (I_{Kr}) which responsible for repolarization. Then Na+ and K+ Inward current via funny channel (I_f). Diastolic depolarization can happen because of absence of the inward rectifier K+ current ($I_{K,1}$) which responsible for maintaining negativity of resting membrane potential in others myocytes by outward K current.
2. "Ca2+ clock" - RYR2, $I_{Ca(T)}$, NCX: Ca2+ released from the sarcoplasmic reticulum into the cytoplasm via ryanodine receptor (RYR) which initiate Ca induced Ca release via $I_{Ca(T)}$, Then one Ca2+ was exchange out for three Na+ via a Na+–Ca2+ exchanger resulted in a net positive charge

"Normal-looking" sinus P wave on ECG

- The SA node's depolarization cannot be visible on the 12-lead ECG due to its small mass. The behavior of the SA node, therefore, is observed by a conduction of the atrial depolarization in response to SA node (P wave).
- Normal-sinus P wave on 12-lead ECG
  - Positive in I, II, aVF. The P wave axis is around 60°.
  - In lead II, duration < 120 ms (3 small boxes in width), amplitude < 0.2mV (2 small boxes in height)
  - In chest leads, positive or biphasic in V1, V2 and positive in V3-V6.
  - In V1, terminal negative part is less than 40 ms (1mm) and 0.1 mv (1mm) deep.
  - Identical P wave morphology from beat to beat.

Normal sinus rhythm

- Identical (same morphology of P wave), regular, "normal-looking" sinus P wave rate 60-100 bpm.

SA node dysfunction (sick sinus syndrome)

- A spectrum of disorders of intrinsic SA node abnormality or sinu-atrial conduction e.g sinus bradycardia, sinus pauses, sinus arrest, sinoatrial nodal exit block, chronotropic incompetence, etc.
- The most common indication for pacemaker placement (30% to 50%), (JACC 2014;64:531).
- Abnormal intrinsic SA node automaticity could be from aging (fibrosis, atrophy, Δ ion channels), familial (HCN4, SCN5A, MYH6), ischemia, DM, HF, extreme physical training), trauma (e.g. heart surgery).
- Abnormalities secondary to regulation of normal functioning SA node include hypothyroidism, autonomic dysfunction, toxins, drugs, hypothermia, electrolyte abnormalities etc.
- Electrophysiology studies to investigate SA node are not routinely performed. SA node function measurements include corrected sinus node recovery time (cSNRT) and sinoatrial conduction time (SACT).

ECG finding of SA node dysfunction

- Sinus arrhythmia (Circ. 1996;94:842-847)
  - An irregular in rate of sinus rhythm with Δ P-P interval > 120ms, or >10% changes.
  - Normal, benign, phenomenon from respiratory variation causing phasic Δ autonomic tone at baroreceptor.
  - Faster when inspiration, slower when expiration. Common in young people.
- Ventriculophasic sinus arrhythmia
  - The PP interval surrounding QRS complex is shorter than PP interval without QRS complex.
  - Commonly seen in 3rd-degree AV block.
- Sinus pause or arrest
  - Transient absence of sinus P waves on ECG.
  - The duration of the pause is not necessary in the interval of the underlying sinus rate.
  - Sinus arrest imply totally disappear of SA function.
- Inappropriate sinus tachycardia (IST) (Heart Rhythm 2015;12(6):e41)
  - HR >100 bpm at rest (with mean 24-h HR >90 bpm not due to to other physiological causes).
  - Identical P wave compare to P wave during normal sinus rhythm and consistent with "normal" sinus P wave
  - Postural orthostatic tachycardia syndrome (POTS): ↑ HR > 30 bpm or a HR > 120 bpm within 10 min when from the supine to the upright position.
- Wandering pacemaker
  - A slight varied in sinus P-wave morphology and rate due to changing of the 'leading pacemaker'
  - SA node is heterogenous. The superior (near SVC-RA junction) located cells are usually faster compare to the lower ones (IVC-RA junction).
- Tachy-brady syndrome. (Circ 2016;133:1892)
  - SA node dysfunction in patient with intermittent AT or AF.
  - Sinus pauses at termination of the atrial arrhythmia.
  - Studies suggested that SA node dysfunction is a part of pathogenesis of AT or AF. (Circ J 2014;78:1272).
- Chronotropic incompetence
  - Impaired responses to physiological demands or during exercise.
  - Cannot achieve 85% of age-predicted max HR
- Sinoatrial nodal exit block
  - First degree – looks normal on 12-lead ECG.
  - Second degree type I – shorten PP interval then sinus pause (no P wave) for a beat.
  - Second degree type II – constant PP interval then sinus pause (no P wave) for a beat.
  - Third degree – looks the same as sinus arrest.

ACC/AHA 2008 (update 2013) Guidelines for Device-Based Therapy:
Indication for Permanent Pacing in SA Node Dysfunction

Recommendation	COR	LOE
1. Symptomatic brady, including due to SA pauses. 2. Symptomatic chronotropic incompetence. 3. Symptomatic sinus brady that results from required drug therapy for medical conditions.	I	C
1. HR < 40 bpm with a clear association between significant symptoms and bradycardia 2. Syncope of unexplained origin when clinically significant abnormalities of sinus node function are discovered or provoked in electrophysiological studies.	IIa	C
1. Minimally symptomatic patients with chronic HR < 40 bpm while awake.	IIb	C
1. Asymptomatic patients. 2. Symptoms but clearly documented symptoms in the absence of bradycardia. 3. Symptomatic bradycardia due to nonessential drug therapy.	III	C

Suggested Readings

The Anatomy and Physiology of the Sinoatrial Node—A Contemporary Review. PACE 2010; 33:1392–1406.