NORMAL ATRIAL ACTIVATION, VENTRICULAR ACTIVATION & REPOLARIZATION

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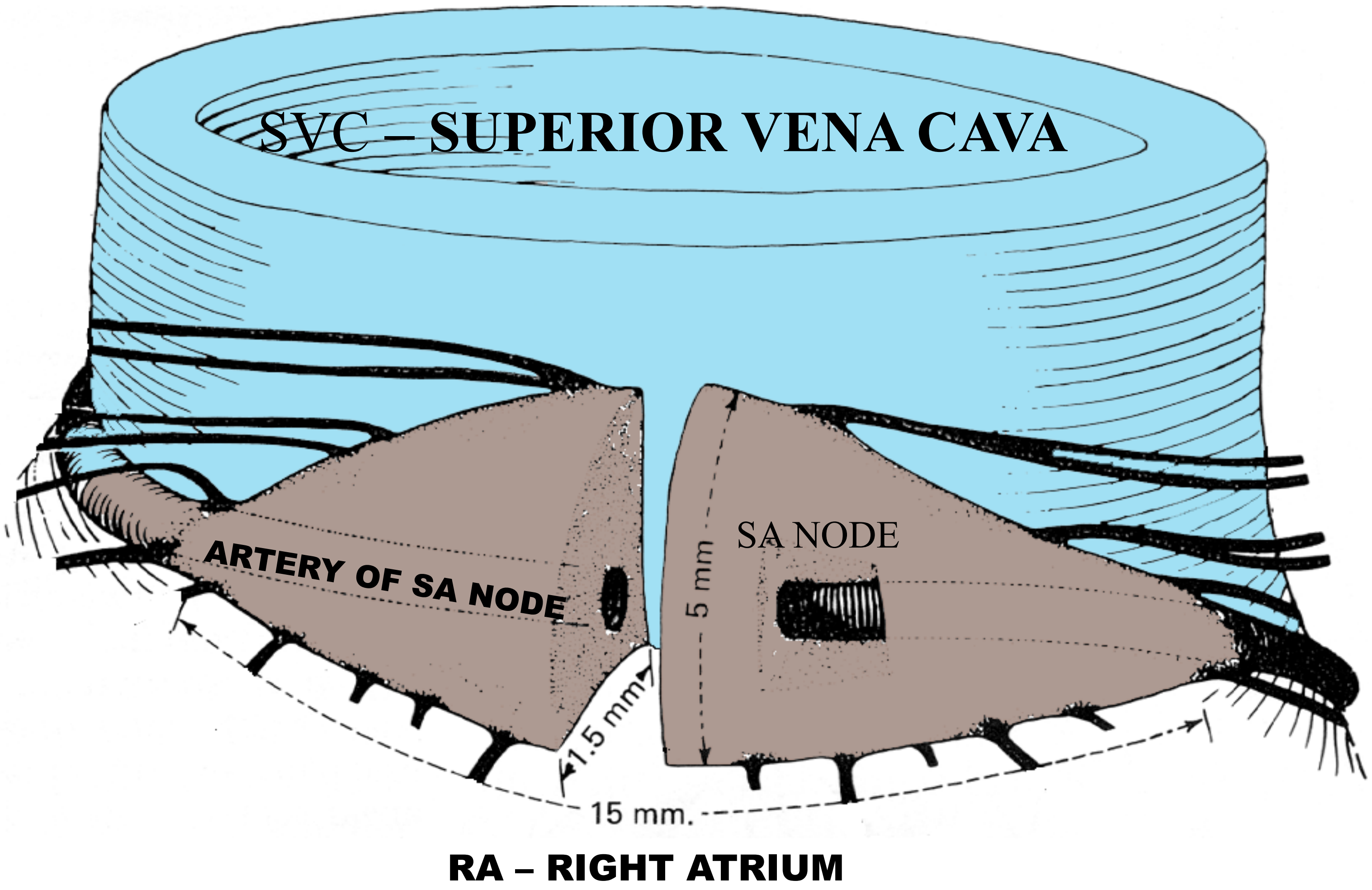
INITIAL ACTIVATION: SINOATRIAL NODE (SA NODE)



Outline of the SA node of Keith-Flack, located in the convergence of the superior vena cava with the high right atrium. Triangle morphology, longitudinally crossed by the SA node artery, the right coronary branch (60%) or the left circumflex artery. In the center of this nodule, we find pacemaker o P cells, thus called because they are pale, primitive and have the cardiac command "**p**acemakers".

THE FIVE CELLULAR TYPES OF THE HEART

CARDIOMYOCYTES OR MYOCARDIOCYTEAL MUSCLE CELLS

Cardiac muscle tissue occurs only in the heart. Its cells are joined end to end. The resulting fibers are branched and interconnected in complex networks. Each cell has a single nucleus. At its end, where it touches another cell, there is a specialized intercellular junction called an "intercalated disc," which occurs only in cardiac tissue. Cardiac muscle is controlled involuntarily and, in fact, can continue to function without being stimulated by nerve impulses. This tissue makes up the bulk of the heart and is responsible for pumping blood through the heart chambers into the blood vessels.

P CELLS OR PACEMAKER CELLS: Pale (poor in glycogen), Pacemaker, Primitive (the most primitive ones)
TRANSITION CELLS: A & B are located within the boundaries of the SA-node
PURKINJE CELLS: They are found in the intraventricular conduction system and in the internodal bundles.
CONTRACTILE CELLS:

1) Atrial
2) Ventricular: SUBEPICARDIAL;
MID-MYOCARDIUM: M CELLS;
SUBENDOCARDIAL.

We show here the five types of cells existing: **P, transitional, Purkinje, contractile, and M cells**. They are histologically indistinguishable from contractile cells; however, with an action potential similar to Purkinje cells (in another slide of the first class this was explained).

CHARACTERISTICS OF P CELLS OR PACEMAKER CELLS

P cells are the cells that create the rhythmical impulses, also are pacemaker cells, and they directly control the heart rate. These cells are modified cardiomyocyte. They possess rudimentary contractile filaments, but contract relatively weakly. Cells in the SA node spontaneously depolarize resulting in contraction, approximately 60 to 100 times per minute. This native rate is constantly modified by the activity of sympathetic and parasympathetic nerve fibers, so that the average resting cardiac rate in adult humans is about 70 beats per minute. Because the SA node is responsible for the rest of the heart's electrical activity, it is sometimes called the *primary pacemaker*.

The SA-node is normally the most rapid pacemaker. However, what we call the SA node is actually the integrated activity of pacemaker cells in a compact region of the right atrium. (1;2) These several thousand cells depolarize and produce action potentials almost synchronously. They seem to be influencing each other through cell-to-cell coupling, a process that has been called mutual entrainment (3). The location of the primary pacemaker may move among groups of cells within the region of the SA node. Only about 1 % of the cells in the SA node act as the leading pacemaker.(4)

1. Bleeker WK, Mackaay AJ, Masson-Pévet M, Bouman LN, Becker AE Functional and morphological organization of the rabbit sinus node.Circ Res. 1980;46:11-22.
2. Boyett MR, Honjo H, Kodama The sinoatrial node, a heterogeneous pacemaker structure. Cardiovasc Res. 2000;47:658
3. Jalife JMutual entrainment and electrical coupling as mechanisms for synchronous firing of rabbit sino-atrial pace-maker cells. J Physiol. 1984;356:221.
4. Boyett MR, Dobrzynski H, Lancaster MK, Jones SA, Honjo H, Kodama I
5. Sophisticated architecture is required for the sinoatrial node to perform its normal pacemaker function.J Cardiovasc Electrophysiol. 2003;14(1):104.

The heterogeneity is considered in terms of the gradient model of the SA node, in which there is gradual change in the intrinsic properties of SA node cells from periphery to center, and the alternative mosaic model, in which there is a variable mix of atrial and SA node cells from periphery to centre. The heterogeneity is important for the dependable functioning of the SA node as the pacemaker for the heart, because: (1)

(i) Via multiple mechanisms, it allows the SA node to drive the surrounding atrial muscle without being suppressed electrotonically;
(ii) Via an action potential duration gradient and a conduction block zone, it promotes antegrade propagation of excitation from the SA node to the right atrium and prevents reentry of excitation; and
(iii) Via pacemaker shift, it allows pacemaking to continue under diverse pathophysiological circumstances.

P CELLS O PACEMAKER CELLS

LOCATION: central portion of the SA node;
DIAMETER: 5 to 10 μ;
SARCOLEMMA: scant intercalated disks: slow conduction;
SARCOPLASMIC RETICULUM (SR): little developed;
MITOCHONDRIA: scant;
SARCOMERES: scant, without contractile function;
CYTOPLASMIC GLYCOGEN: scant: pale cytoplasm;
NUCLEUS: central;
AUTOMATIC: those of greater automatism or diastolic depolarization command the heart;
10) ELECTROPHYSIOLOGICAL FEATURES: cell with slow response with Ca2+ dependent zero phase.

1. **Boyett MR, Honjo H, Kodama I. The sinoatrial node, a heterogeneous pacemaker structure. Cardiovasc Res. 2000 Sep;47:658-687.**

PERINODAL CELLS OR TRANSITIONAL CELLS

There is a gradual transition in cell type over several millimeters from the center in all directions to the periphery of the SA-node.
Perinodal cells, sometimes called transitional or (T) cells, transmit the electrical impulse from the SA node to the right atrium. SA nodal dysfunction may result from abnormalities in impulse generation by the P cells or in conduction across the T cells. The conduction velocity within the sinus node is very slow compared to non-nodal atrial tissue. This is a result of poor electrical coupling arising from the relative paucity of gap junctions in the center of the node compared to the periphery. These gap junctions may result in preferential conduction pathways for the propagation of the action potential from the center to the atrial muscle and might provide the structural substrate for the transitional zone, enabling the sinus node to drive the surrounding atrial muscle without being suppressed by this tissue .(1)

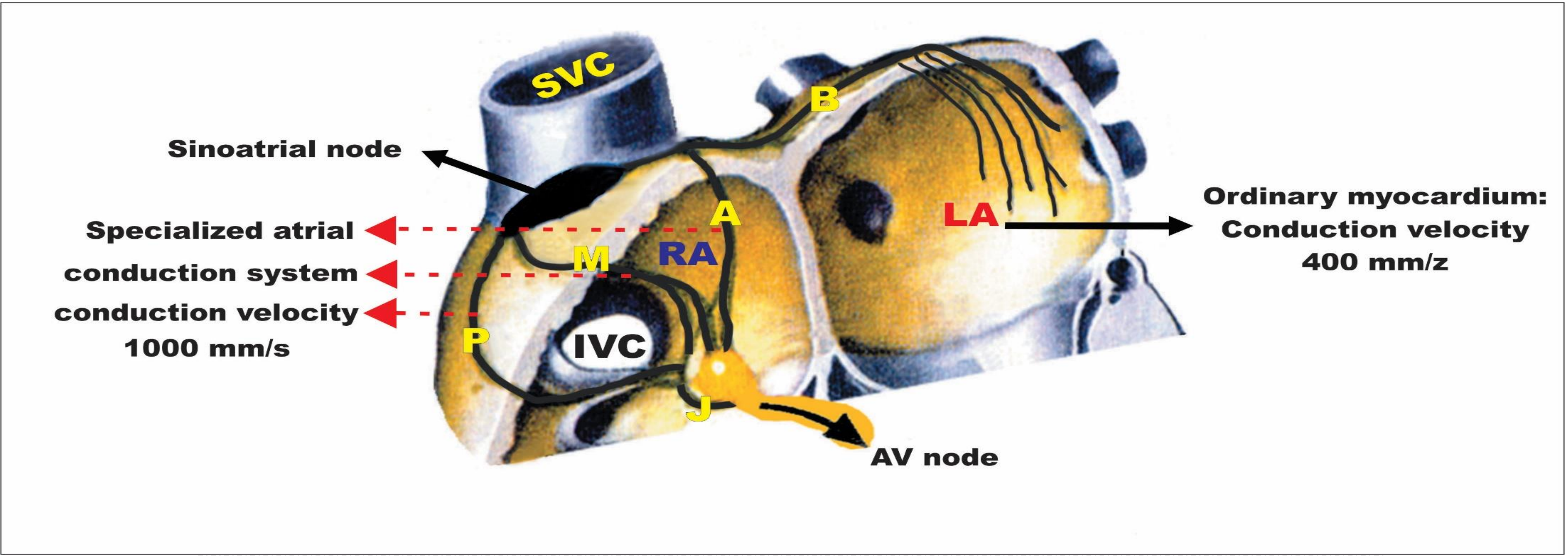
PERINODAL CELLS OR TRANSITIONALCHARACTERISTICS

1) **LOCATION:** SA node, AV node & His bundle;
2) **FUNCTION:** bridge between P cells and the rest of the atrial myocardium;
3) **MORPHOLOGY:** narrow and long. Longer in the His bundle;
4) **SARCOLEMMA:** it may or may not have intercalated disks;
5) **SARCOMERES:** arranged in a parallel way as in contractile fibers; however, the quantity is lower.

1. Joyner RW, van Capelle FJ Propagation through electrically coupled cells. How a small SA node drives a large atrium .Biophys J. 1986;50:1157-1154

Mode of atrial depolarization

Hypothesis A: Preferential pathways(1)



Representation of the currently accepted mode of atrial activation. The stimulus originates in the SA node and is conducted up to the AV node through three preferential pathways: anterior, middle and posterior. The left atrium activates by a branch of the Bachman's anterior internodal bundle. These preferential pathways are formed by Purkinje cells, which make conduction velocity be greater (1 m/sec) in relation to the ordinary atrial muscle (400 mm/sec). In the Thorell's posterior internodal bundle a branch originates, which ends directly in the proximal area of the His bundle: James' bypass bundle.

1. James TN, Sherf L. Specialized tissues and preferential conduction in the atria of the heart. Am J Cardiol. 1971 Oct;28:414-427.

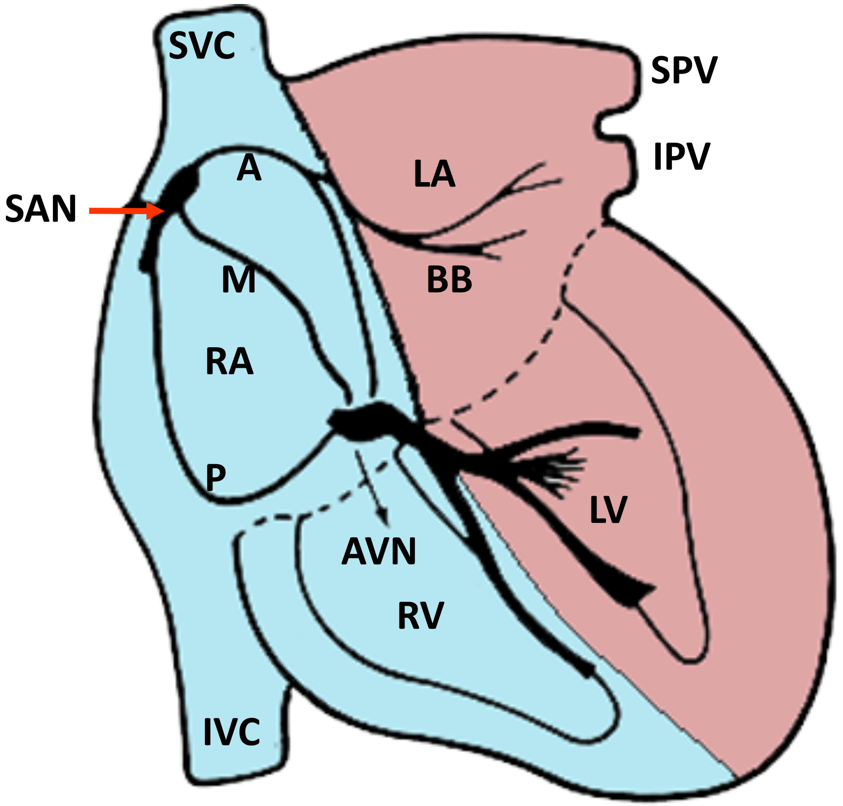
CONDUCTION VELOCITY IN THE DIFFERENT REGIONS OF THE HEART

Central region of SA node	2 to 5 mm/s
Peripheral region of SA node	7 to 11 mm/s
Internodal bundles	1000 mm/s (because have Purkinje fibers)
Atrial ordinary muscle	400 mm/s
AN region of AV node	100 mm/s
N region of AV node	20 mm/s
NH region of AV node	800 mm/s
His, branches & Purkinje arborizations	4000 mm/s
Ventricular ordinary muscle	400 mm/s

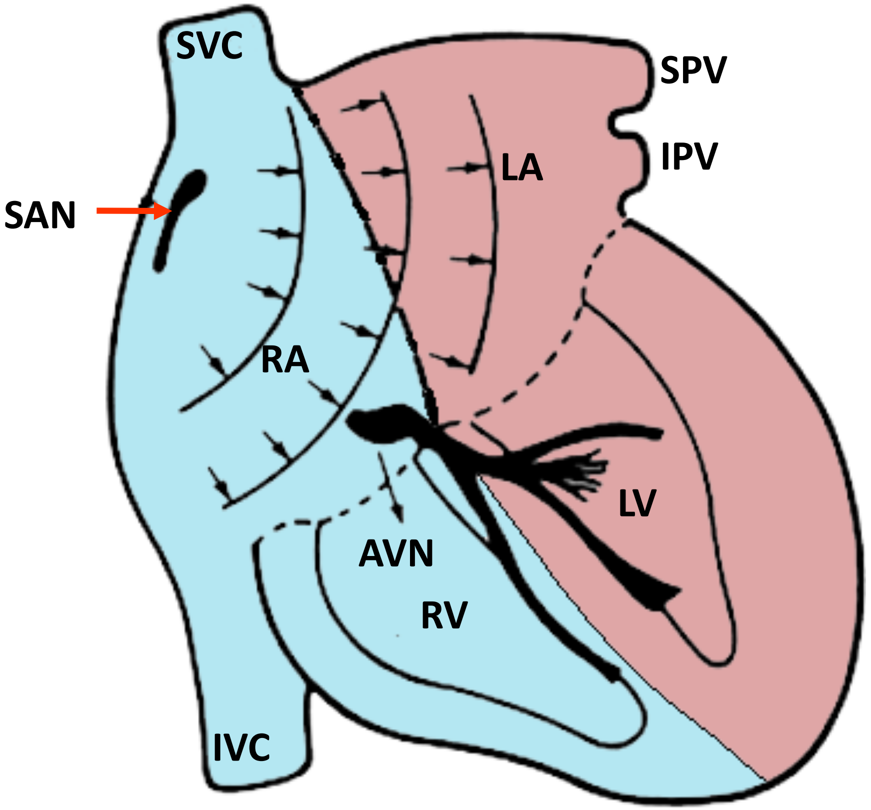
The table shows different conduction velocities of stimulation in different areas of the heart. The lowest conduction velocity is found in the central region of the SA node (2 mm/sec to 5 mm/sec) and the highest in the His-Purkinje system (4000 mm/sec).

Comparison between two theories of biatrial chamber activation

Hypothesis A



Hypothesis B



A: Anterior internodal bundle
M: Middle internodal bundle of Wenckebach

P: Posterior internodal bundle or of Thorel
BB: Bachman's bundle or fascicle

Bachman bundle Bachman fascicle, also know as the anterior interatrial band is the only track that conveys impulses to the left atrium(1)

1. Bachman G. The interauricular time interval Am J Physiol 1916; 41: 309-320.

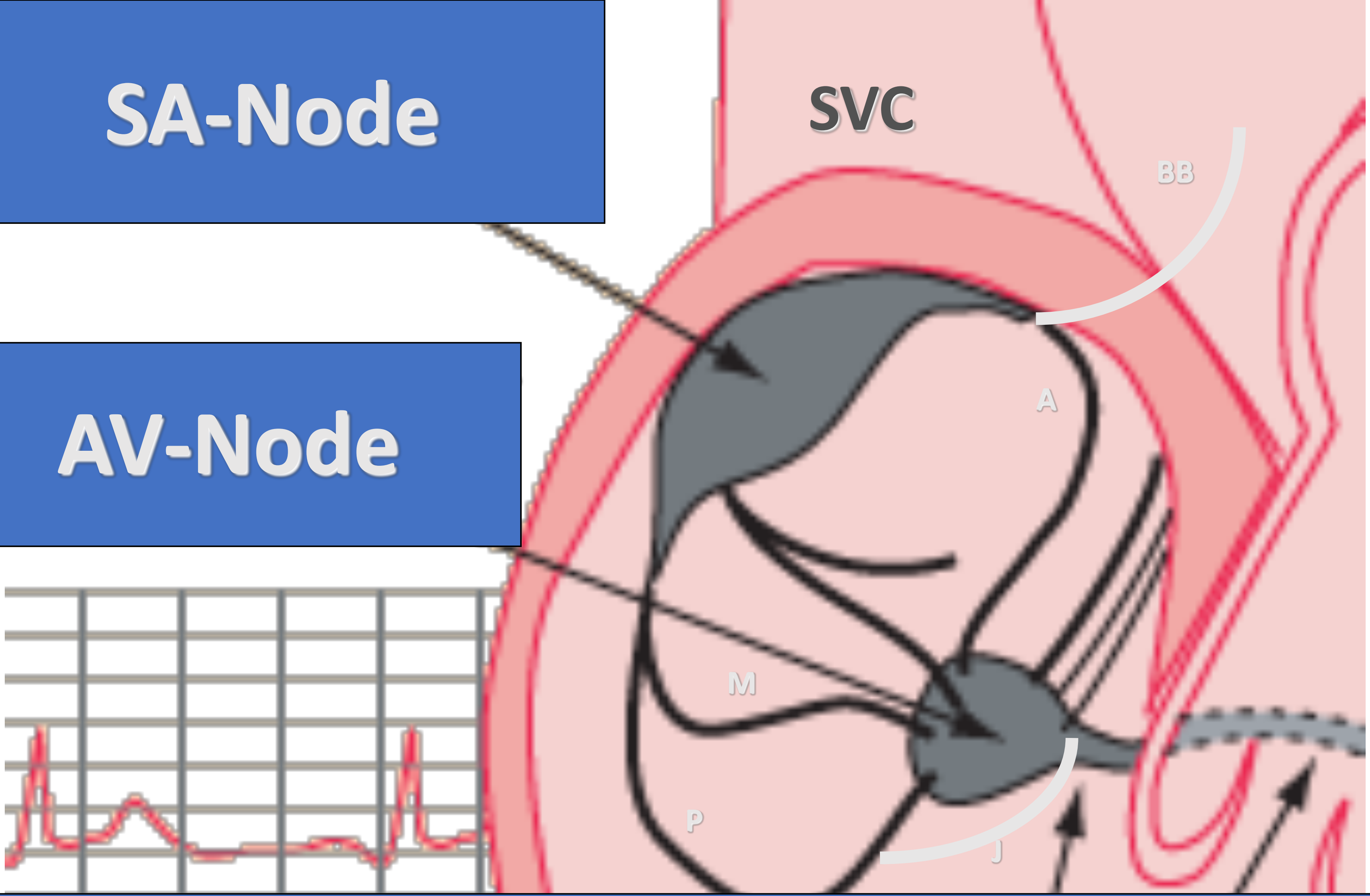
The area of the functional sinus node complex exceeds that of the anatomical sinus node; however, reasons for this discrepancy are unknown. The sinoatrial node (SAN) and atrium, including crista terminalis (CT), pectinate muscles (PM), appendages (APG), anterior or Bachmann's bundle (BB) , middle or Wenckebach's bundle and posterior or Thorel's bundle There are preferential pathways of conduction from sinus node to right atrial myocardium (1). This preferential pathways have Purkinje fibers consequently conduction velocity inside preferential pahtways is higher related to conduction velocity in ordinary atrial muscle(2)

Although anisotropy was documented during conduction velocity in individual cases, conduction velocity was not dependent on propagation direction at the epicardial right atrial free wall in patients with stable sinus rhythm. These findings do not exclude the presence of internodal preferential pathways as these are located sub-pericardially and a marked transmural discordance in activation has previously been documented in the vicinity of such pathways(3).

1. Stiles MK, Brooks AG, Roberts-Thomson KC, Kuklik P, John B, Young GD, Kalman JM, Sanders P.High-density mapping of the sinus node in humans: role of preferential pathways and the effect of remodeling.J Cardiovasc Electrophysiol. 2010 May;21(5):532-9.
2. Surawicz B, Knilans T.Chou's Electrocardiography in Clinical Practice: Adult and Pediatric, 6e 6th Edition 6th Edition .2008.
3. Hansson A1, Holm M, Blomström P, Johansson R, Lührs C, Brandt J, Olsson SB.Right atrial free wall conduction velocity and degree of anisotropy in patients with stable sinus rhythm studied during open heart surgery.Eur Heart J. 1998 Feb;19(2):293-300.

SA-Node

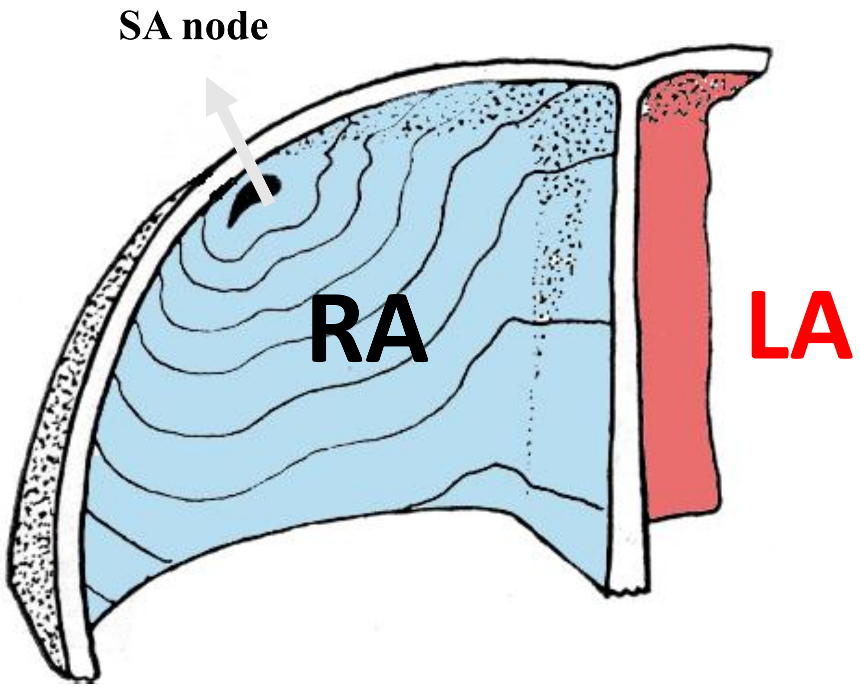
AV-Node

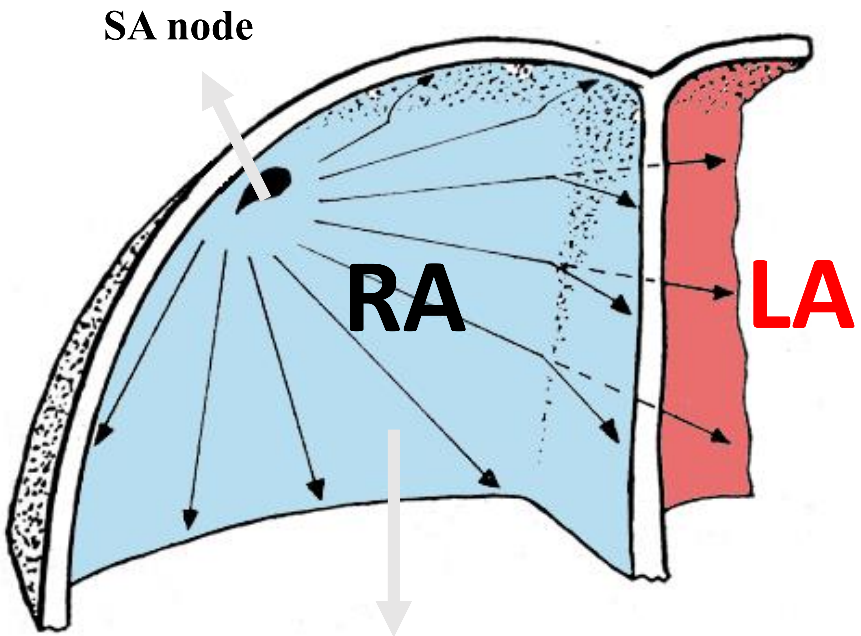


His bundle

A - Anterior internodal bundle ; M – Middle internodal bundle;
P - Posterior internodal bundle
BB – Bachman’s bundle
J - James’s tract

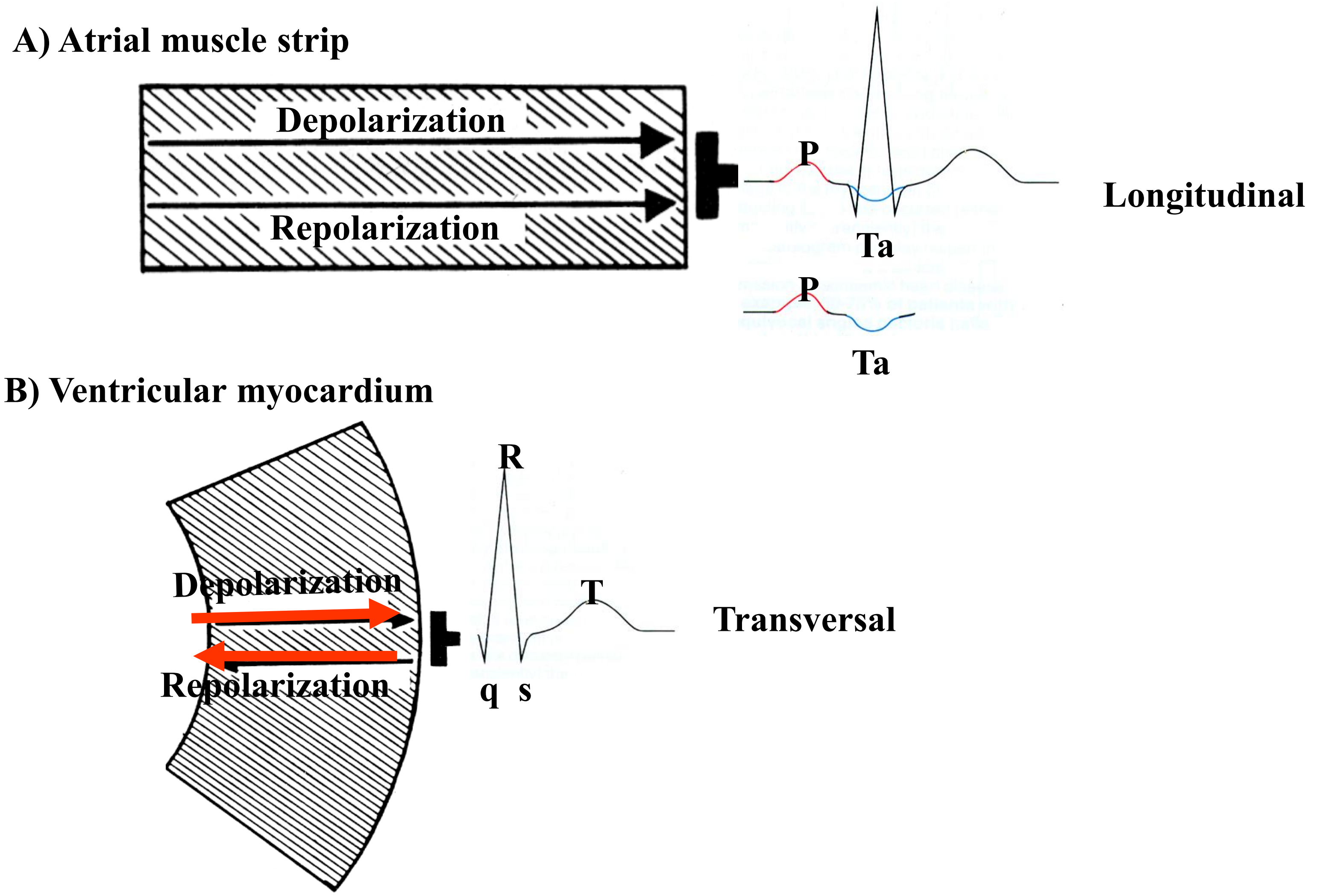
HYPOTHESIS B – The activation wave spreads in a radiated way through the atria, just as the waves in a lake when you throw a stone in it.





Representation of an old concept of biatrial activation. It was believed that it was processed in a radiated way, as when a stone is thrown in calm water.

Comparison of mode of atrial (A) & ventricular (B) depolarization & repolarization



Representation of longitudinal activation of the atria and transversal activation of the endocardium and epicardium in the ventricles.

The right atrium is one of the four hollow chambers of the interior of the heart. It is located in the upper right corner of the heart superior to the right ventricle. Deoxygenated blood entering the heart through veins from the tissues of the body first enters the heart through the right atrium before being pumped into the right ventricle.

The right atrium is one of the two atria of the heart, which function as receiving chambers for blood entering the heart. It is located to the right of the left atrium and superior to the much larger and more muscular right ventricle. Between the right atrium and right ventricle is a one-way valve known as the tricuspid valve The right atrium is one of the four hollow chambers of the interior of the heart. It is located in the upper right corner of the heart superior to the right ventricle. Deoxygenated blood entering the heart through veins from the tissues of the body first enters the heart through the right atrium before being pumped into the right ventricle.

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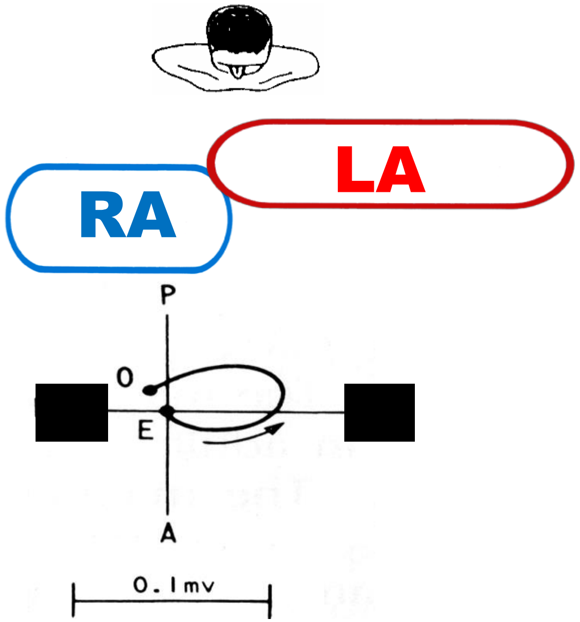
SPATIAL OUTLINE OF BIATRIAL CHAMBER

FRONTAL VIEW

SUPERIOR VIEW



RA - "DON QUIXOTE". IN THE FRONT & TO THE RIGHT.

LA - "SANCHO PANZA". IN THE BACK AND TO THE LEFT.

Representation of the spatial location of both atria. The right atrium (RA – represented in blue) located to the front and the right, and vertical. The left atrium (LA – represented in red) located backwards and to the left, and horizontally.