The conduction system of the heart physiology

The heart functions as a dual pump, rhythmically contracting to maintain effective circulation. This rhythmic contraction is orchestrated by a specialized conduction system composed of nodes and conductive cardiac muscle fibers that **generate and propagate electrical impulses** , ensuring synchronized contraction of atrial and ventricular chambers.

This intrinsic conduction system enables the heart to beat **automatically and rhythmically** without external neural stimulation. Efficient cardiac pumping depends on precise timing: the **atria contract slightly before the ventricles** , allowing ventricular filling, and the **ventricles contract simultaneously** to maximize cardiac output.

Overview of Cardiac Conduction System Components

1. **Sinoatrial (SA) Node**
2. **Internodal and Intra-atrial Pathways (including Bachmann's bundle)**
3. **Atrioventricular (AV) Node**
4. **Bundle of His (AV Bundle)**
5. **Right and Left Bundle Branches**
6. **Purkinje Fibers**

Each component ensures the stepwise and time-optimized conduction of action potentials across cardiac tissue.

Sequential Events in the Cardiac Cycle

1. **Impulse Generation** : The SA node initiates an action potential.
2. **Atrial Conduction** : Impulse spreads across the atria ? **Atrial systole** .
3. **AV Node Delay** : Conduction slows at the AV node, allowing full ventricular filling.
4. **Ventricular Conduction** : Impulse travels via the Bundle of His ? bundle branches ? Purkinje fibers ? **Ventricular systole** .

Detailed Components of the Conduction System

1. Sinoatrial (SA) Node

- **Location** : Upper wall of right atrium, near the entrance of the **superior vena cava** .
- **Structure** : Elliptical strip of specialized pacemaker cells (~2–3 mm wide, ~10–15 mm long).
- **Function** :
    - Primary pacemaker of the heart (**60–100 bpm**).
    - Generates spontaneous depolarizations due to **unstable resting membrane potential** (phase 4 automaticity).
    - Impulses spread through **gap junctions** across atrial muscle fibers.
- **Autonomic Regulation** :

    - **Sympathetic stimulation** (?? receptors) ? ? heart rate.
    - **Parasympathetic stimulation** (M? receptors via vagus nerve) ? ? heart rate.
- **Blood Supply** :
    - Typically from the **right coronary artery (RCA)** ; in some individuals, from the **left circumflex artery (LCx)** .
- **Special Feature** : Rich in **?? and M? receptors** , giving it high sensitivity to autonomic input.

2. Internodal and Intra-atrial Pathways

- **Function** : Transmit impulses from SA node to AV node.
- **Major Tracts** :
    - **Anterior internodal pathway** : Includes **Bachmann's bundle** , which transmits impulse from **right to left atrium** .
    - **Middle (Wenckebach) and Posterior (Thorel) internodal tracts** .
- **Conduction Velocity** : ~0.5–1.0 m/s, faster than surrounding atrial myocardium (~0.3 m/s).
- **Timing** : Takes ~ **0.03 seconds** for impulse to travel from SA node to AV node.

3. Atrioventricular (AV) Node

- **Location** : Posteroinferior part of interatrial septum, near opening of **coronary sinus** , at the base of the **right atrium** .
- **Function** :
    - Delays conduction (**~0.09 sec**) to allow full ventricular filling before contraction.
    - Acts as a **secondary pacemaker** (intrinsic rate: **40–60 bpm**).
- **Conduction Delay Mechanism** :
    - Fewer **gap junctions** and narrow fibers ? slower impulse propagation.
    - Additional delay (~0.04 sec) occurs as impulse enters the **Bundle of His** .
- **Blood Supply** : Typically from a branch of the **right coronary artery** or **left circumflex artery** .
- **Clinical Relevance** :
    - A common site for **heart blocks** and **re-entrant arrhythmias** .
    - AV nodal delay ensures **atrial contraction precedes ventricular contraction** .

4. Bundle of His (AV Bundle)

- **Anatomy** : Continuation of AV node, penetrating the **fibrous skeleton** of the heart into the **interventricular septum** .
- **Function** :
    - The only **electrical connection** between atria and ventricles.
    - Allows **unidirectional impulse propagation** (atria ? ventricles).
- **Structure** :
    - Divides into **right and left bundle branches** .
    - Cells exhibit fast conduction properties and some pacemaker activity.
- **Clinical Note** :
    - Preserved conduction in this region is critical. Damage here causes **bundle branch blocks** or **complete heart block** .

5. Right and Left Bundle Branches

- **Course** :
  - **Right bundle branch** (RBB): Travels along the right side of the septum to the apex of the right ventricle.
  - **Left bundle branch** (LBB): Divides into **anterior and posterior fascicles** supplying the left ventricle.
- **Location** : Beneath the **endocardium** on respective sides of the septum.
- **Function** : Conduct impulses rapidly to Purkinje fibers.
- **Blood Supply** :
  - Supplied by septal branches of **left anterior descending (LAD)** artery.

6. Purkinje Fibers

- **Structure** :
  - Large, specialized cardiac fibers with abundant glycogen and few myofibrils.
  - High density of gap junctions ? **rapid conduction velocity (~4 m/s)** .
- **Location** : Subendocardial layer of both ventricles.
- **Function** :
  - Final conduit of the conduction system.
  - Ensures **simultaneous depolarization** of both ventricles for powerful ejection of blood.
- **Intrinsic Rate** : **15–40 bpm** if upstream pacemakers fail.

Summary of Conduction Times

Pathway	Approximate Time (sec)
SA node to AV node	0.03
AV node delay	0.09
AV bundle delay	0.04
Total atrial to ventricular delay	~0.16
Purkinje system ? Myocardium	~0.03–0.06

Clinical Correlation

- **Arrhythmias** arise when there's disruption in impulse generation or conduction.
  - *SA node dysfunction* ? sinus bradycardia or arrest.
  - *AV block* ? first-, second-, or third-degree heart blocks.
  - *Bundle branch blocks* affect synchronization of ventricular contraction.
- **Pacemakers** may be required for sustained bradyarrhythmias.
- **Electrocardiogram (ECG)** findings correlate with specific conduction defects (e.g., prolonged PR interval in AV block).

High-Yield Points

- SA node = **primary pacemaker** (60–100 bpm).

- AV node = **gatekeeper** ; delays conduction (40–60 bpm).
- Only **Bundle of His** bridges atria and ventricles.
- **Purkinje fibers** = fastest conduction velocity (~4 m/s).
- Total delay between atrial and ventricular contraction ? **0.16 seconds** .
- **Autonomic regulation** alters rate of SA node firing.
- Ischemia of the AV node or Bundle of His ? **conduction blocks** .
- **Bachmann's bundle** = primary path to the **left atrium** .