NATIONAL CENTER FOR CASE STUDY TEACHING IN SCIENCE

The Heart of the Matter:
Understanding the Electrical Conduction Pathway

by
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Part I – April

April, a 29-year-old pediatric nurse, was active, healthy, enjoyed yoga, and went on frequent walks with her dog and husband in the park near their apartment. One day while on a walk with their dog, April started to feel lightheaded and experienced shortness of breath. *That's strange,* she thought. *I walk this trail all the time without getting winded, and I've been drinking plenty of water.* She brushed it off, and they continued. Later that day, while walking up the stairs to her apartment, she started gasping for air and grabbed onto the railing. She felt as if she were going to collapse and immediately called Andrew her husband and told him to meet her at Dr. Allison's office.

Dr. Allie greeted April. "You look stressed, tell me what brings you in?" She took April's vitals and recorded April's symptoms of lightheadedness, shortness of breath, faster heart rate, and chest pain. Hanging her stethoscope around her neck, Dr. Allie said, "I need to send you for an ECG."

Table 1. April's results.

Vital Signs	*Normal Range*	*April*
Heart rate (HR)	60–100 bpm	180 bpm (tachycardia)
Blood pressure (BP)	120/80mmHg	160/100 mmHg
Respiratory rate (RR)	12–20 breaths per minute	25 breaths per minute (tachypnea)
Oxygen saturation (SaO_2)	95–100%	93%
Temperature	97–99 °F	Normal
Pulse rhythm	Regular	Irregular

Questions

1. Study Table 1. Based on what you find in the table, define *tachypnea* and *tachycardia*.

2. What does normal oxygen saturation indicate?

3. April presents with severe tachycardia (hear rate > 150 bpm). Stroke volume and cardiac output is affected when ventricular heart rate is greater than 160 bmp. Assuming her ventricular rate is equal to her heart rate:

   (a) How would this affect stroke volume and cardiac output? Explain. (*Hint:* SV = EDV – ESV; CO = HR × SV)

   (b) In her conversation with Dr. Allie, April described some of the symptoms she has been having. Which of those symptoms is associated with tachypnea?

   (c) Explain how April's tachypnea is related to her tachycardia.

   (d) Could April's SaO_2 influence the respiratory rate? (*Hint:* Examine an oxygen-hemoglobin dissociation graph.)

   (e) Based on your response to *(c)* and *(d)* above and information about April's vitals, which system, cardiovascular or respiratory, is under more stress?

   (f) Given your answers above, what physiological event could have caused April's blood pressure to become elevated? Why was this occurring? As a reminder, here is a patient summary:
   - heart rate (HR): 180 bpm → severe tachycardia
   - blood pressure (BP): 160/100 mmHg → hypertension
   - respiratory rate (RR): 25 bpm → mild tachypnea
   - oxygen saturation (SpO_2): 93% → mild hypoxemia

Part II – ECG and WPW

April was sent to get an ECG (results in Figure 1). An hour later, Dr. Allie told them they had found an abnormality in April's heart. Coupled with her vital tests (see Table 1), the diagnosis was Wolff-Parkinson-White syndrome (WPW). Seated next to her husband, Dr. Allie explained to the couple, "April has an abnormality within her heart; the electrical system of the heart is affected. An extra or accessory pathway interferes with the electrical isolation of the atria and ventricles. As a result, the electrical impulses bypass the AV node. It occurred during development in which clusters of cells differentiate to become the separate chambers of the heart. Errors occur, and the separation is not complete, and bits of 'wires' that should be disconnected are left connecting the upper and lower chambers. One in 1,000 individuals have this syndrome and simply do not know it and or have any symptoms. For 1–4% of individuals with this syndrome, it's life threatening. April, given your results, my immediate recommendation is to have you take procainamide (PC) and avoid strenuous activity."

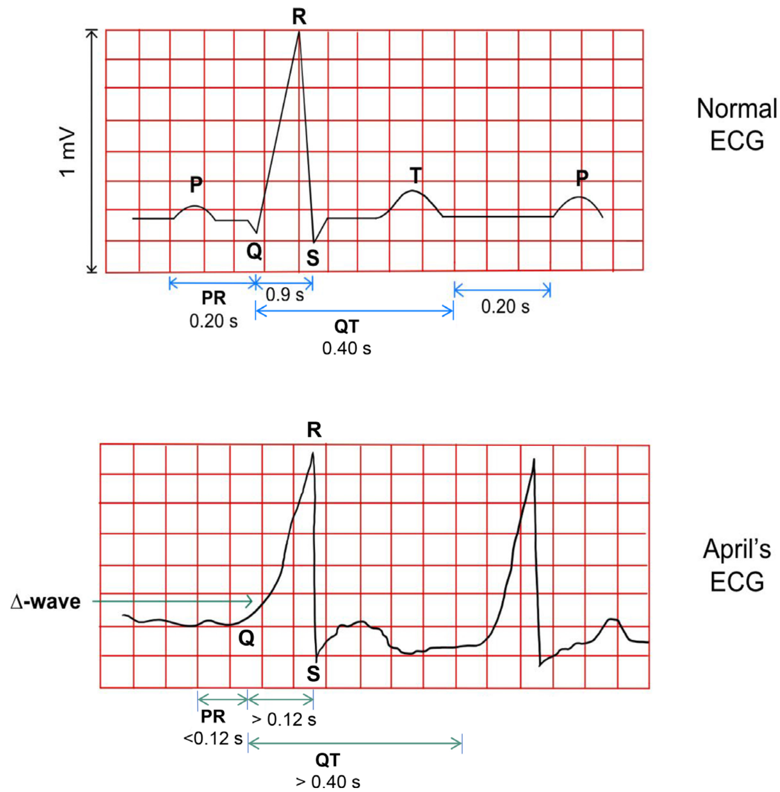

Figure 1. Normal ECG versus April's ECG.

"Isn't there a surgery option to correct this?" Andrew asked.

"Yes, I would recommend that April do the ablation procedure. I'll book the surgery, which usually takes about two months for an appointment. Procainamide will alleviate her symptoms while we wait," Dr. Allie replied.

April was relieved. She knew exactly what WPW was; her grandmother had had it and lived to 98.

Questions

1. Identify and label the parts of the internal conduction system on the heart diagram below (Figure 2).

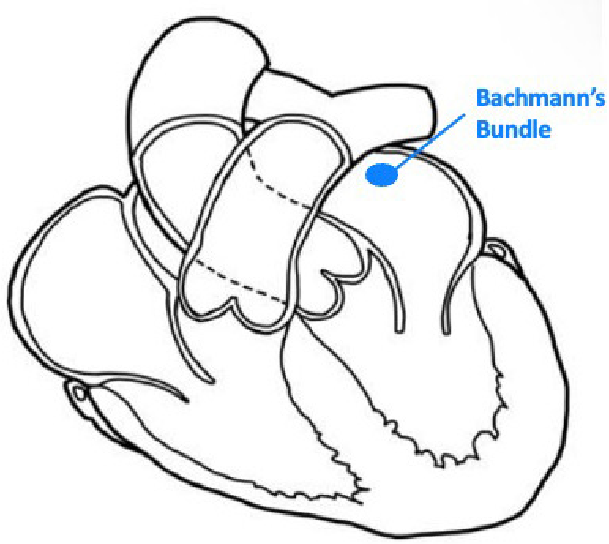

Figure 2. Normal conduction of the electrical signal.

2. What is the normal sequence of movement for action potentials within the heart?

3. When examining the normal ECG, identify each wave and interval.
   (a) For each wave, match the area of the heart involved, describe the corresponding electrical activity in the heart (depolarization or repolarization), and identify the associated mechanical event (contraction or relaxation).
      - P-wave (80 milliseconds):
      - QRS complex (80–100 milliseconds):
      - T-wave (160 milliseconds):

   (b) What does each interval signify?
      - PR interval (120–200 milliseconds):
      - QT interval (350–450 milliseconds):

4. A delta wave is a slurred, upward deflection at the beginning of the QRS complex. It appears immediately after the P wave, before the QRS fully develops. Examine the PR interval and QRS complex between April and that of the normal ECG. Note for April that the PR interval (<0.12 s) extends from a faint P wave to the upswing of the delta wave, whereas the QRS complex (>0.12 s) extends from the beginning of the delta wave to the end of the QRS (see Figure 1, April ECG).
   (a) What does the presence of the flat line at the end of the P-wave and the onset of the QRS complex indicate on the normal ECG?

   (b) What does the delta wave on April's ECG indicate?

5. According to Dr. Allie's explanation, Wolff-Parkinson-White (WPW) syndrome occurs due to the presence of an extra electrical pathway, known as an accessory pathway, that connects the atria and ventricles. This accessory pathway can be located anywhere along the atrioventricular ring, which includes the mitral and tricuspid valve annuli (see Figure 3 below).

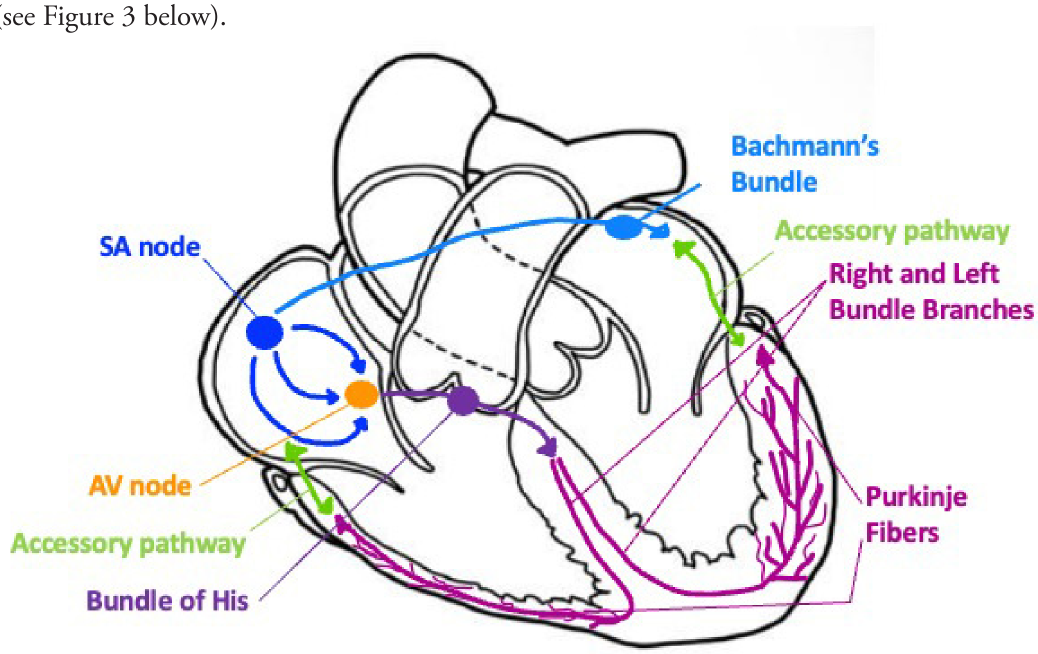

Figure 3. Conduction of the electrical signal in April's heart.

Complete Table 2 below comparing the electrical signal movement in a normal heart versus in April's heart (with WPW syndrome), based on Dr. Allie's explanation and test results.

Table 2. Electrical signal movement in normal vs. WPW syndrome afflicted heart.

Feature	*Normal Heart*	*April's Heart (WPW) Syndrome*
Path of electrical signal	SA node → AV node → Bundle of His → Bundle branches → Purkinje fibers	
AV node function		
Ventricular activation		
ECG finding	Normal PR interval and QRS complex; no delta wave.	
Signal timing and heart rate	Atria and ventricles contract in a coordinated, timely manner. Heart rate is normal.	

6. How does April's increased HR affect her heart's function? (*Hint:* Table 1, cardiac cycle, preload, and diastolic filling time.)
   (a) Ventricular filling:

   (b) End diastolic volume (EDV):

   (c) Stroke volume (SV):

   (d) End systolic volume (ESV = EDV – SV):

   (e) Cardiac output (CO = HR × SV):

Part III – How the Heart Contracts

April knew that procainamide (PC), a Na^+ channel blocker, was used to treat ventricular and atrial arrhythmias and fibrillations. Was this not the same ion that gets the heart to contract? She decided to take a deeper look into how this medication would influence her heart function.

Questions

1. Using the word bank, assist April with filling in the sequence (*a–g* below) for cardiac muscle contraction.

Word bank:

K^+	ATP	troponin-tropomyosin
Na^+	power stroke	reset of the myosin head
myosin	release of the myosin head	Ca^{2+}
	crossbridges	

   (a) Influx of _______ across the sarcolemma.
   (b) Depolarization causes efflux of ________and influx of _________.
   (c) Calcium binds to the _____________________ complex that is blocking the myosin binding site on actin.
   (d) Troponin moves away from the myosin binding site, allowing formation of ______________between actin and myosin.
   (e) During the ______________the thin filament is pulled across the thick filament, decreasing sarcomere width.
   (f) ATP binds to the crossbridge causing the ________________________________ . Crossbridges are broken.
   (g) ATPase on the crossbridge splits _____, causing ______________________________.

2. Do some research on the mechanism of action of PC, then explain how it affects the action potential of cardiac myocytes.

3. How would this change in the action potential affect the contraction of the heart?

4. How would the change in excitation-contracting coupling of April's heart treated with PC affect the following? (*Hint:* cardiac cycle, preload, and diastolic filling time.)
   (a) Heart rate (HR):
   (b) Ventricular filling:

(c) End diastolic volume (EDV):

(d) Stroke volume (EDV – ESV):

(e) End systolic volume (ESV):

(f) Cardiac output (CO = HR × SV):

Optional: The Chemistry of Procainamide (PC)

[*Note:* Check with your instructor whether you are to complete the following section.]

Wishing to understand more how this molecule (Figure 4) gets into solution to reach its target and its site of action, her heart and receptor, April looked up the structure and pharmacological information of PC by using the sites below:

- DrugBank. (2024). Procainamide. [Webpage]. DrugBank Online. <https://go.drugbank.com/drugs/DB01035>
- Pritchard, B., & H. Thompson. (2023). Procainamide. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing. <https://www.ncbi.nlm.nih.gov/books/NBK557788/>

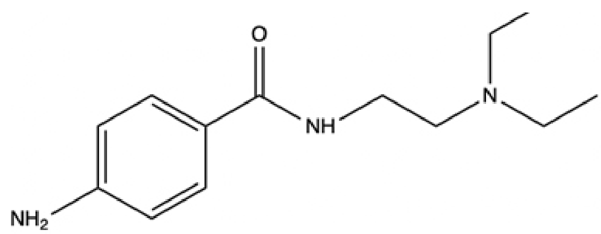

Figure 4. Chemical structure of procainamide.

Questions

1. How is PC generally administered?

2. What is its bioavailability in the body by each route?

3. Given the structure of PC, how readily will it dissolve in solution?

Part IV – Ablation Procedure

Two months later, April was evaluated and equipped with a heart monitor as she prepared for the catheter ablation procedure. On the day of the procedure, the surgeon who was performing the procedure explained to April's husband, "Catheters will be placed in the femoral vein near the groin area so that we can get to the heart. Once there, we will find the extra 'wires' that are causing WPW and get rid of them with heat."

Questions

1. What does the ablation procedure do?

2. Do some research on recovery following ablation and describe what you have learned.