The Heart Centre
Cardiac Monitoring: ECG Interpreta-
tion and Analysis
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Read pages 1-20 in *ECGs Made Easy*, Anatomy and Physiology, for a review of basic cardiac structure and function prior to beginning this course as a solid understanding is needed to be successful.

**The Heart’s Conduction System**

Cardiac cells have four primary characteristics:

- **automaticity** – the ability of the pacemaker cells to generate their own electrical impulses spontaneously
- **excitability** - the ability of the cells to respond to an electrical impulse
- **conductivity** – the ability of cells to conduct an electrical impulse
- **contractility** – the ability of cells to cause muscle contraction

There are two kinds of cardiac cells – myocardial cells and pacemaker cells. Myocardial cells, or “worker” cells, are found in the muscular layer of the walls of the atria and ventricles. These cells are permeated by contractile filaments which when stimulated electrically produce muscle contraction. The primary job of myocardial cells is muscle contraction and relaxation.

The heart is a pump driven by electrical signals generated by all the cardiac muscle cells but certain groups of cells are given the responsibility of “running the show”. These are called the pacemaker cells and they can set the pace of the heart rhythm. The pacemaker cells generate the electrical signal that gets sent in turn to every other cell in the heart and ultimately leads to cardiac muscle contraction. They are able to generate this signal without any external force or stimulation; a unique ability of cardiac cells that is called automaticity.
Action Potential, Depolarization and Repolarization

An **Action potential** is a five phase cycle that reflects the difference in the concentration of ions across the cell membrane at any given time. Cardiac cells are filled with ions (electrically charged molecules). Potassium (K\(^+\)) is the main ion inside cells and sodium (Na\(^+\)) is the main ion outside cells. Calcium, bicarbonate, and chloride are also present but we will focus on K\(^+\) and Na\(^+\).

A membrane separates the inside of the cells from the outside of the cell. Ions are constantly moving across this membrane through membrane channels. The difference in the concentration of the ions will determine the cell’s electrical charge. In the resting cell there are more negative ions inside the cell than outside. This resting state is called **polarized**. During this time no electrical activity is occurring and a straight line (isoelectric line) is recorded on the ECG.

Once a cell is stimulated the cell membrane’s permeability changes. K\(^+\) begins to leave the cell and Na\(^+\) begins to enter the cell resulting in the cell becoming more positive inside than outside. This state (more positive inside than outside) is called **depolarized** and a waveform is recorded on the ECG. Depolarization of one cell acts as a stimulus to adjacent cells causing them to depolarize. When positive and negative ions come together, energy is released, in this case an electrical impulse. This impulse causes channels to open in the next cell membrane and then the next and so on.

After depolarization the cells begin to recover, returning to their resting state. A special channel on the cell membrane, called the sodium-potassium pump, actively transports K\(^+\) into the cell and Na\(^+\) out of the cell. Once again the cells are more negative inside and more positive outside and the cells are said to be **repolarized**.

![Depolarization Diagram](image)

Propagation of the electrical impulses from cell to cell produces an electric current that can be detected by electrodes placed on the skin. This current is recorded as waves or deflections onto graph paper, called an ECG.
Refractory Periods

A refractory period is the time cells need to recovery after being discharged before they are able to respond to another impulse. This is important because during the **absolute refractory period**, myocardial cells will not respond to a stimulus no matter how strong it is. During the **relative refractory period**, some cells have repolarized and can be stimulated to respond by a strong stimulus. This is the vulnerable period of repolarization as a strong stimulus may usurp the primary pacemaker and take over pacemaker control. For example, if a premature ventricular contraction (PVC) occurred during this period, it may take over control of the heart in the form or ventricular tachycardia, a lethal arrhythmia. On the ECG this period begins at the peak of the T wave and ends at the end of the T wave.
Conduction System

The heart has specialized pathways to the atria and ventricles that conducts electricity to enable the heart to contract in a coordinated manner. Two main groups of pacemaker cells transmit the signal to large areas of the heart. The system consists of the **sinoatrial node** (SA node), the **interatrial tract** (aka Bachman’s bundle), the **internodal tracts**, the **atrioventricular node** (AV node), the **bundle of His**, the **right bundle branch**, the **left bundle branch**, and the **Purkinje fibres**.

### SA Node

The SA node is located in the upper posterior part of the right atrium. It has specialized pacemaker cells that intrinsically discharge impulses between 60-100 bpm, though is capable of discharging up to 180 bpm. It is the **primary pacemaker** of the heart. As the impulse leaves the SA node it spreads from cell to cell across the atrial muscle. As the impulse spreads it stimulates the right atrium, the interatrial septum and travels along Bachman’s bundle to stimulate the left atrium. This results in contraction of both atria.

The SA node’s blood supply comes from either the right coronary artery (60% of people) or the circumflex artery (40% of people).

### AV Node

The AV node is made up of specialized conducting cells located in the floor of the right atrium (the AV node itself has no pacemaker cells). Its blood supply is via the right coronary artery in 85-90% of people.

Conduction from the SA node spreads to the AV node via three internodal pathways which merge with the AV node. As the impulse enters the AV node conduction is slowed before the impulse reaches the ventricles. The delay allows both atrial chambers to contract and empty blood into the ventricles (atrial kick) before the next ventricular contraction. Without the delay the atria and ventricles would contract at about the same time. The AV node also blocks some of the impulses from being conducted to the ventricles when the atrial rate is rapid.

### Bundle of His

The bundle of His, also called the AV bundle, is located in the upper portion of the interventricular septum and connects the AV node with the bundle branches. The bundle of His has pacemaker cells that have an intrinsic rate of 40 to 60 bpm and serves as the back up pacemaker when the SA node fails. Its blood supply is received from the left anterior descending and posterior descending arteries. The AV...
node and the bundle of His are called the AV junction. The His-Purkinje system refers to the bundle of His, bundle branches, and the Purkinje fibres.

**Bundle Branches**
After the impulse moves through the bundle of His it proceeds through to the bundle branches. The right bundle branch conducts the electrical impulse to the right ventricle and the left bundle branch conducts to the left ventricle. The left bundle is made up of two smaller branches called fascicles that conduct the electrical signal to the anterior and posterior walls of the ventricle.

**Purkinje Fibres**
Both the right and left branches divide into a network of conduction fibres called the Purkinje fibres that spread through the interventricular septum into the papillary muscle and down to the apex of the heart. The fibres then become part of the muscle cells of the ventricles. The intrinsic rate of the Purkinje fibres pacemaker cells is 20 to 40 bpm. The electrical impulse moves from the endocardium to the myocardium to the epicardium and the ventricles contract in a twisting motion that wrings blood out of the ventricles and into arteries.
Waveforms and the Cardiac Cycle

ECG Paper

The ECG is a graphical representation of the heart’s electrical activity. ECG paper is made up of small boxes and large boxes measured in millimeters. Time (seconds) is on the horizontal axis and voltage (millivolts) is on the vertical axis. A small box is 1 mm by 1 mm or 0.04 seconds. A large box is made up of 16 small boxes. The ECG paper records at a speed of 25 mm/sec.

A cardiac cycle, or one heartbeat, is represented on the ECG as one PQRST sequence.

Key Point:
Learning ECG is like learning a new language. First you must identify the words and letters before you put them all together.

Between cycles the ECG recorder returns to the isoelectric line, the flat line in the ECG during which electrical activity is absent. Any waveform deflecting above the
isoelectric line is considered **positive** and below the line is **negative**. A waveform that deflects both above and below the isoelectric line is called **biphasic**.

This is the prototypical ECG waveform. It contains all the letters and everything is perfect and easy to identify. Don’t get use to this as you will almost never encounter this in a real patient.

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### P Wave

The first deflection in the cycle is the **P wave**. The first part of the P wave represents depolarization of the right atrium and the second part of the P wave represents left atrial depolarization. As both atria depolarize at roughly the same time we see a single waveform on the ECG.

**Normal P waves are smooth and rounded**, upright in lead II, between 0.5 and 2.5 mm high, and **0.12 sec or less** in width, and one P wave to every QRS complex.

Not all P waves are created equal however. Abnormal P waves can occur when the impulse has to travel through an enlarged atria causing abnormal depolarization of the atria and abnormal P waves. See examples below. P waves may also originate from a location other than the SA node - atria or AV junction. These P waves are called ectopic and may be positive or negative, and small, pointed, flat, wavy, or saw tooth in appearance. P waves originating from the AV junction are always negative (inverted) and may precede, following or be hidden in the QRS complex.

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<table>
<thead>
<tr>
<th>Condition</th>
<th>P Wave Morphology</th>
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<tr>
<td>Normal</td>
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<tr>
<td>Right atrial enlargement</td>
<td><img src="image" alt="Right Atrial" /></td>
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<tr>
<td>Left atrial enlargement</td>
<td><img src="image" alt="Left Atrial" /></td>
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<tr>
<td>Ectopic</td>
<td><img src="image" alt="Ectopic P Wave" /></td>
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PR Interval (PRI)
The PRI is the time from the beginning of atrial depolarization to the beginning of ventricular depolarization, or the spread of the impulse from the SA node through the atria, through the AV node, bundle of His, bundle branches and Purkinje fibres. It includes the P wave and the short isoelectric line that follows it. The PRI varies with heart rate – as heart rate increases the PRI shortens and vice versa.

An abnormal PRI can result when there are delays in conduction through the atria, AV node, or bundle of His resulting in a PRI greater than 0.20 sec. A shorter than normal PRI, less than 0.12 sec may occur if the impulse originates in an ectopic pacemaker close to the AV node or bundle of His, or travels down an abnormal conduction pathway (accessory pathway) that bypasses the AV node and depolarizes the ventricles earlier than usual. Wolff-Parkinson-White is an example of such a condition.

The PRI is measured from the point where the P wave leaves the isoelectric line to the beginning of the QRS complex. The duration of a normal PRI is 0.12 to 0.20 sec or 0.04 sec X 5 squares.

QRS Complex
The QRS complex represents depolarization of the left and right ventricles and is made up of the Q wave, R wave and S wave. Ventricular depolarization normally triggers contraction of the ventricles.

The QRS complex is much larger than the P wave as ventricular depolarization involves a greater muscle mass than that of the atria. Remember, the QRS represents depolarization of both ventricles, however because the left ventricle has a greater muscle mass than the right ventricle, we generally don’t see the deflection from the right ventricle as it is hidden by the larger left ventricle.

A QRS complex normally follows each P wave. Many variations exist in the configuration of the QRS complex and not every QRS complex contains a Q wave, R wave or S wave. The shape indicates what path the electrical signal took through the ventricles. Whatever the variation, it is still called the QRS complex. The Q wave is always a negative deflection. The large triangular upright waveform is the R wave and is the first positive deflection following the P wave. The S wave is the negative waveform following the R wave.
Abnormal QRS complexes may be a result of an impulse originating in an ectopic pacemaker. For example, if the impulse originates in the Purkinje fibres or the ventricular myocardium the QRS is greater than 0.11 sec (often 0.16 sec or more). Right ventricular enlargement produces an abnormally tall R wave and left ventricular enlargement produces an abnormally deep S wave. Other variations in QRS morphology may be caused by a block in the bundle branches, premature beats, conduction along an accessory pathway, or from an ectopic site in the ventricles.

The QRS is measured from the point where the complex begins to deviate from the baseline and ends where the last wave of the complex begins to level out or distinctly changes direction. The first downward deflection is the ‘Q wave’. The first upright deflection is the ‘R wave’ and the downward deflection after the ‘R wave’ is called the ‘S wave’. See image below which demonstrates the separate and distinct waves of the QRS which may help you determine where to start and end your measuring. The normal duration of the QRS complex is less than 0.11 sec or 3 boxes.
**ST Segment**

The ST segment represents early ventricular repolarization and is normally at the isoelectric line on the ECG. It begins at the point where the QRS complex and the ST segment meet. This point is also referred to as the **J point**. The ST segment may be above (elevated) or below (depressed) the isoelectric line. To determine if elevation or depression exists look at the ST segment 0.06 sec (1.5 boxes) after the J point. **Elevation or depression of 1 mm (one box) or more is considered abnormal.**

Myocardial ischemia, injury and infarction are causes of ST segment deviation.

**T Wave**

The **T wave** represents ventricular repolarization. The normal T wave begins as the deflection gradually slopes upward from the ST segment and ends when the waveform returns to baseline. **Normal T waves are rounded and slightly asymmetrical**, positive in lead II and less than 5 mm high. The T wave always follows the QRS complex. Abnormal T waves can be tall, peaked, flattened, low, biphasic or inverted. Common causes include MI, ischemia, pericarditis, hyperkalemia, bundle branch block and ventricular enlargement.
**QT Interval**

The **QT interval** is the period from the beginning of the QRS complex to the end of the T wave and represents total ventricular activity (depolarization to repolarization). The length of the QT varies according to age, gender and heart rate. **A normal QT should be half the R-R interval** when the rhythm is regular. A prolonged QT indicates a delay in ventricular repolarization which can allow more time for an ectopic focus to take control and put the ventricles at risk for ventricular dysrhythmias. Common causes include electrolyte imbalances, medications, MI, long QT syndrome.

![Various T wave morphologies](image)

**U Wave**

The **U wave** is a small waveform that follows the T wave and represents repolarization of the Purkinje fibres. It may or may not be present. **Normal U waves are small, round, asymmetric** and about 10% of the height of the T wave.
R-R and P-P Intervals

The distance from one R wave to the next R wave (and P wave to P wave) is used to determine *rhythm rate and regularity*. To determine ventricular regularity, measure the distance from one R wave to the next consecutive R wave and compare this to the other R-R intervals. Regular rhythms will have R-R intervals that measure the same. To determine atrial regularity, do the same thing with the P-P interval.

Artifact

Distortion of the ECG tracing by non-cardiac electrical activity is called *artifact*. Artifact can be caused by loose electrodes, broken cables/wires, muscle tremors, or patient movements. As it can mimic dysrhythmias it is essential to evaluate the patient.
Systematic Rhythm Interpretation

A consistent systematic approach to rhythm analysis is important in order not to miss something important. Use the following steps:

1. Calculate the **rate**. Although the atrial and ventricular rates are normally the same, they can differ in some dysrhythmias and it is important to calculate each individually. A rate of 100 bpm or more is called a **tachycardia** and a rate of 60 bpm or less is called a **bradyarrhythmia**.

   There are several methods to calculate the rate. The small box method is time consuming but is the most accurate.

**Method 1: Large Box**
For regular rhythms, the rate can be determined by counting the number of large boxes between two R waves and then dividing that number into 300.

**Method 2: Small Box**
To calculate the ventricular rate count the number of small boxes between two consecutive R waves and divide into 1500. To calculate the atrial rate count the number of small boxes between two consecutive P waves and divide into 1500. If the rhythm is irregular, give a range.

**Method 3: Ruler**
Using a commercially developed ruler place the “0” mark on a complex and the third QRS (or P for atrial rate) complex from here is the rate.
Using the small box method, the rate for the above strip would be 20 small boxes divided into 1500 for a ventricular/atrial rate of 75 bpm.

2. Assess regularity of both atria and ventricles by measuring the P-P and R-R. A regular rhythm will have P-P and R-R intervals equal. If there is a slight variation between the intervals (not all exactly the same but not more than 0.04 sec difference) the rhythm is termed essentially regular. If the difference is more than 0.04 seconds the rhythm is considered irregular. Irregular rhythms can also be regularly irregular if there is a repeated pattern of irregularity.

3. Examine the P waves. A normal P wave is smooth and round and there is one P wave associated with one QRS complex.

4. Measure the PRI. Measure from the point where the P wave leaves the baseline to the beginning of the QRS complex. A normal PRI is 0.12 to 0.20 sec. Determine if the PRIs are all the same or if they are different. If they are the same they are said to be constant. If it gets longer it is said to lengthen, and if it varies in duration and has no pattern it is said to be variable. Of course, if there is no P wave there will be no PRI.

This above PRI is 4 ½ boxes or 0.16 sec long, within normal limits and constant for this strip.
5. **Measure the QRS.** Begin measuring at the point where the first wave (Q or R wave) of the complex begins to deviate from the baseline and end where the last wave begins to level out (may be at, above, or below the baseline). The normal duration of the QRS is less than 0.11 sec. If it is greater than this it is considered wide. Note that a paced ventricle will always have a wide QRS due to artificial electrical stimulation that occurs with pacing.

The above QRS is 1 ½ boxes or 0.06 sec

6. **Examine the ST segment** for elevation or depression. Our current system is not programmed for ST segment measuring however if new ST changes are noted in more than one lead, it should be noted.

7. **Interpret and document the rhythm** based on the above information. When documenting the interpretation specify the site of origin. For example, *sinus* bradycardia or *junctional* bradycardia.

Example: The above strip is regular, rate is 75 bpm, P waves are smooth and round and there is a P wave for every QRS complex, PRI is 0.16 sec, QRS is 0.08 sec, ST is isoelectric. We would interpret this strip as *sinus rhythm*. 
Overview of the Basic Rhythms

Sinus Rhythms

Normal Sinus Rhythm (RSR)

- The name given to a normal heart rhythm.
- Sinus node is the pacemaker
- Each beat is conducted normally through to the ventricles.

![Normal Sinus Rhythm ECG](image)

**Regularity**: R-R intervals are constant - rhythm is regular.
**Rate**: atrial and ventricular rates are equal; heart rate is between 60-100 bpm.
**P Wave**: are uniform; one P wave in front of every QRS complex.
**PRI**: measures between 0.12 and 0.20 sec; constant from beat to beat
**QRS**: measures less than 0.11 sec.

Sinus Bradycardia (RSB)

- Sinus node is the pacemaker, firing regularly at a rate of less than 60 bpm
- Each impulse is conducted normally through to the ventricles.

![Sinus Bradycardia ECG](image)

**Regularity**: R-R intervals are constant - the rhythm is regular
**Rate**: atrial and ventricular rates are equal; heart rate is less than 60 bpm
**P wave**: uniform P wave, one for every QRS complex
**PRI**: measures between 0.12 and 0.20 sec; constant from beat to beat
**QRS**: measures less than 0.11 sec
Sinus Tachycardia (RST)
- Sinus node is the pacemaker.
- Firing regularly at a rate greater than 100 times per minute.
- Each impulse is conducted normally through to the ventricles.

Regularity: R-R intervals are constant - rhythm is regular.
Rate: atrial and ventricular rates are equal; heart rate is greater than 100 bpm (usually between 100 and 160 beats per minute.)
P wave: uniform P wave in front of every QRS complex.
PRI: measures between 0.12 and 0.20 sec; constant from beat to beat
QRS: measures less than 0.11 sec.

Sinus Arrhythmia
- Sinus node is the pacemaker, but impulses are initiated in an irregular pattern.
- Rate increases as the patient breathes in and decreases as the patient breathes out.
- Each beat is conducted normally through to the ventricles.

Regularity: R-R intervals vary
Rate: atrial and ventricular rates are equal; heart rate is usually in a normal range (60-100 bpm) but can be slower
P wave: uniform P wave in front of every QRS complex
PRI: measures between 0.12 and 0.20 sec; constant from beat to beat
QRS: measures less than 0.11 sec
**Sinoatrial Block**
- Pacemaker cells within the SA node initiate an impulse but it is blocked as it exits the SA node.
- Appears on the ECG as a single missed beat (a P wave, QRS complex, and T wave are missing).

![ECG image]

**Regularity:** Irregular due to the pause(s) caused by the SA block – the pause is the same as (or an exact multiple of) the distance between two other P-P intervals
**Rate:** Usually normal but varies because of the pause
**P wave:** uniform P waves; when present, one precedes each QRS complex.
**PRI:** measures 0.12-0.20 sec; constant from beat to beat
**QRS:** measures 0.11 sec or less unless an intraventricular conduction delay exists.

**Sinus Arrest**
- Disorder of automaticity.
- Pacemaker cells of the SA node fail to initiate an impulse to one or more beats.
- A lower pacemaker site (the AV junction or ventricles) should assume responsibility for pacing the heart. If they do not, the PQRST complexes will be absent.
- Pause will not be a multiple of the P-P intervals as in SA Block.

![ECG image]

**Regularity:** Irregular – the pause is of undetermined length (more than one PQRST complex is missing) and is **not** the same as other P-P intervals.
**Rate:** Usually normal but varies because of the pause.
**P wave:** uniform P waves; when present, one precedes each QRS complex.
**PRI:** measures 0.12-0.20 sec; constant from beat to beat
**QRS:** measures 0.11 sec or less unless an intraventricular conduction delay exists.
Atrial Rhythms
An atrial rhythm originates somewhere in the atrial tissue. The pacemaker in this rhythm can be a single irritable focus in the atria or it can be multiple irritable foci.

You may see a P wave if the atria depolarize in an organized fashion. If the P wave does not originate in the SA Node it will look different - may be inverted, peaked or jagged.

If the atria are fibrillating, you will not see a P wave but will see a wavy baseline between irregular QRS complexes.

Once the impulse reaches the AV node, conduction will follow the normal pathway and you will see a normal looking QRS and T wave.

It is important to remember that when atrial conduction does not occur normally, 15-30% of cardiac output (atrial kick) is lost. This may have clinical implications in patients who have myocardial dysfunction and are already compromised.

Premature Atrial Complex (PAC)

- Pacemaker is an irritable focus within the atria which fires prematurely and produces a single ectopic beat.
- Conduction through to the ventricles is normal.

Regularity: single premature ectopic beat it will interrupt the regularity of the underlying rhythm.
Rate: overall heart rate will depend on the rate of the underlying rhythm
P wave: P wave of the premature beat may have a different morphology than the P waves of the rest of the strip. The ectopic beat will have a P wave, but it can be flattened, notched, or otherwise unusual. It may be hidden within the T wave of the preceding complex.
PRI: measures between 0.12 and 0.20 sec, but can be prolonged; PRI of the ectopic will probably be different from the PRI of the other complexes.
QRS: measures less than 0.11 sec
**Multiformed Atrial Rhythm (or Wandering Atrial Pacemaker)**

- Pacemaker site wanders between the sinus node, the atria, and the AV junction.
- Although each beat originates from a different focus, the rate usually remains within a normal range. However it can be slower.
- Conduction through to the ventricles is normal.

**Regularity**: R-R intervals vary slightly as the pacemaker site changes; rhythm can be slightly irregular.

**Rate**: atrial and ventricular rates are equal; heart rate is usually within a normal range (60-100 bpm) but can be slower. If the rate is greater than 100 bpm, the rhythm is termed *multifocal atrial tachycardia*.

**P wave**: morphology of the P wave changes as the pace-maker site changes. There is one P wave in front of every QRS complex, although some may be difficult to see depending on the pacemaker site.

**PRI**: measurement will vary slightly as the pacemaker site changes. All PRI should be less than 0.20 sec: some may be less than 0.12 sec.

**QRS**: measures less than 0.11 sec

**Atrial Tachycardia**

- Pacemaker is a single irritable site within the atrium which fires repetitively at a very rapid rate.
- Conduction through to the ventricles is normal.
**Regularity:** R-R intervals are constant - rhythm is regular  
**Rate:** atrial and ventricular rates are equal; heart rate is usually 150-250 bpm  
**P wave:** one P wave in front of every QRS complex. The configuration of the P wave will be different than that of sinus P waves - may be flattened, notched or hidden in the T waves of the preceding beats.  
**PRI:** measures between 0.12 and 0.20 sec; constant across the strip. The PRI may be difficult to measure if the P wave is obscured by the T wave.  
**QRS:** measures less than 0.11 sec

**Atrial Flutter**

- A single irritable focus within the atria issues an impulse that is conducted in a rapid, repetitive fashion at a rate of up to 300 bpm.  
- AV node blocks some of the impulses from being conducted through to the ventricles protect the ventricles from receiving too many impulses.

**Regularity:** atrial rhythm is regular; ventricular regular or irregular depending on AV conduction and blockade.  
**Rate:** Atrial rate is usually between 250 and 350 bpm. Ventricular rate will depend on the ratio of impulses conducted through to the ventricles.
**P wave**: No identifiable P waves; saw tooth flutter waves are present.

**PRI**: not measured.

**QRS**: measures less than 0.11 sec; may be wide if flutter waves are buried in the QRS complex.

### Atrial Fibrillation (A-Fib)

- altered automaticity
- multitude of foci initiate impulses causing the atria to depolarize repeatedly at a rate of 400-600 bpm
- rapid impulses cause atria to quiver or fibrillate resulting in ineffective contraction
- AV node blocks most of the impulses, allowing only a limited number through to the ventricles.

### Regularity

**Regularity**: atrial rhythm is not measurable; ventricular rhythm is grossly irregular, having no pattern to its irregularity.

**Rate**: atrial rate cannot be measured because it is so chaotic but usually 400-600 bpm. The ventricular rate is irregular and significantly slower because the AV node blocks most of the impulses. If the ventricular rate is below 100 beats per minute the rhythm is said to be "controlled"; if it is over 100 beats per minute, it is considered to have a "rapid ventricular response" or uncontrolled.

**P wave**: atria are not depolarizing in an effective way and are fibrillating; no P wave is produced. All atrial activity is depicted as "fibrillatory" waves, or grossly chaotic undulations of the baseline.

**PRI**: no P waves = no PRI

**QRS**: measures less than 0.11 sec unless an intraventricular conduction delay exists.

### Junctional Dysrhythmias

As studied with the previous rhythms, the SA node is normally the hearts primary pacemaker. The AV junction will assume responsibility of the heart as a protective mechanism. Rhythms that originate from the AV junction are called Junctional Dysrhythmias.

When the pacemaker is the AV Junction, the atria may or may not be depolarized. If they are depolarized, the electrical activity will have to travel backwards.
(retrograde) to activate the atria. This will result in an inverted P wave that may be seen after the QRS. You may not see a P wave at all if the atria are not activated.

Once conduction leaves the AV Junction and travels toward the ventricle, conduction follows the normal path. For this reason, you will see a normal looking QRS and T wave. Because of the loss of atrial synchrony in these rhythms atrial kick is lost (remember 15 - 30% of cardiac output). This can have significant clinical effect.

The AV junction may pace the heart if:
- the SA node fails to discharge (sinus arrest)
- an impulse from the SA node is blocked (SA block)
- SA node rate is slower than that of the AV Junction (e.g. Sinus bradycardia)
- SA node impulse is conducted through the atria, but not conducted to the ventricles (such as AV block)

**Premature Junctional Complexes (PJC)**

- pacemaker is an irritable focus within the AV junction which fires before the next SA node impulse and produces a single ectopic beat. The atria may be depolarized via retrograde conduction.
- Conduction through the ventricles is normal.
- PJC's may occur in patterns – couplets, bigeminy, trigeminy

![ECG waveform](image)

**Regularity**: Regular with premature beats  
**Rate**: usually within normal range but overall heart rate will depend on the rate of the underlying rhythm  
**P wave**: may occur before, during, or after the QRS complex or it can be lost entirely within the QRS complex. If visible, the P wave may be inverted.  
**PRI**: If the P wave occurs before the QRS the PRI will be less than 0.12 sec. If the P wave falls within the QRS complex or following it, there will be no PRI.  
**QRS**: measures less than 0.11 sec (unless there is a conduction delay)
Junctional Escape Beats/Rhythm

- Junctional escape beats occur when the SA node fails to pace the heart or conduction fails.
- A junctional escape rhythm is several sequential junctional escape beats. Junctional rhythm and junctional escape rhythm are the same.
- If rate is slower than 40 bpm it is called junctional bradycardia. It is bradycardia for the AV junction as it is slower than the intrinsic rate of the AV junction.

**Regularity:** Regular with late beats  
**Rate:** Usually within normal range, but depends on underlying rhythm  
**P waves:** May occur before, during, or after the QRS; if visible, the P wave is inverted in lead II  
**PRI:** If a P wave occurs before the QRS the PRI will usually be less than 0.12 sec; if no P wave occurs before the QRS, there will be no PRI.  
**QRS:** Usually 0.11 sec. or less unless aberrantly conducted or an intraventricular conduction delay exists.

Accelerated Junctional Rhythm

- Only difference between a junctional escape rhythm and an accelerated junctional rhythm is the increase in ventricular rate. This is caused by enhanced automaticity of the bundle of His.

**Regularity:** R-R intervals are constant - rhythm is regular.  
**Rate:** Atrial and ventricular rates are equal. The rate will be faster than the AV Junction’s intrinsic rate of 40-60 bpm so it is called tachycardia. Will fire at a rate of 61-100 bpm.
P waves: may occur before, during, or after the QRS complex, or it can be lost entirely within the QRS complex. If visible, the P wave will be inverted.
PRI: If the P wave precedes the QRS complex, the PRI will be less than 0.12 sec. If the P wave falls within the QRS complex or following it, there will be no PRI.
QRS: measures less than 0.11 sec, unless it is aberrantly conducted or an intraventricular conduction delay exists.

Junctional Tachycardia

- An irritable focus in the AV junction speeds up to override the SA node for control of the heart.
- Three or more PJC's occurring at a rate of more than 100 bpm
- Atria are depolarized via retrograde conduction.
- Conduction through the ventricles is normal.
- Only difference between accelerated junctional rhythm and junctional tachycardia is the increase in ventricular rate.
- Caused by enhanced automaticity.

Supraventricular Tachycardia (SVT)

- Supraventricular arrhythmias begin above the bifurcation of the bundle of His and include rhythms that begin in the SA node, atrial tissue, or the AV junction.
- SVT is a good umbrella term when the rate is too fast to determine whether P waves are present, normal, or abnormal.
- When a rate is this fast (150-250) the AV node begins to filter some of the impulses coming to it to protect the ventricles from very rapid rates.
Regularity: R-R intervals are constant- rhythm is regular
Rate: Ventricular rhythm is regular at 150-250 bpm
P wave: Typically the P waves are hidden in the QRS complex
PRI: not measurable
QRS: 0.11 sec or less (unless an intraventricular conduction delay exists)

Ventricular Rhythms

These rhythms originate in the ventricle, the hearts least efficient pacemaker. Conduction through the ventricle does not have an organized approach and this is why a rhythm that comes from ventricular tissue does not resemble anything normal. PVC’s are often the first warning sign.

Although the ventricle is the pacemaker of these rhythms, it is possible that the SA node may continue to be stimulated. For this reason, you can often see p waves intermittently visible throughout the rhythm strip. In this case, the ventricular pacemaker has “overridden” the sinus pacemaker.

These rhythms are almost always life threatening and usually result in complete circulatory collapse. Fortunately, their bizarre looking nature also makes them easy to recognize.

It is very important to know what to do if you see one of these rhythms as you often do not have time to “look it up”. Some time will be spent reviewing the ACLS algorithms during class. Knowing the steps to take will decrease your anxiety when you need to act in an emergency.

Premature Ventricle Complex (PVC)

- A PVC is a single irritable focus within either ventricle that fires earlier than the next expected sinus beat.
- PVCs tend to appear wide and bizarre.
- can occur in patterns – couplets, bigeminy, trigeminy
- common in healthy people as well as those with heart disease
**Regularity**: essentially regular with premature beats, but depends on underlying rhythm. The PVC will interrupt the regularity of the underlying rhythm (unless the PVC is interpolated)

**Rate**: determined by underlying rhythm. PVC’s are not usually included in the rate determination because they frequently do not produce a pulse.

**P wave**: usually absent or after the QRS.

**PRI**: there will be no PRI as the PVC comes from the ventricles

**QRS**: measures at least 0.12 sec; wide and bizarre; T wave is frequently in the opposite direction from the QRS complex.
Ventricular Escape Beats/ Rhythm

- Escape beats occur late.
- Escape beats occur after the next expected sinus beat and are protective mechanisms.
- Ventricular escape rhythm (also called idioventricular rhythm) exists when three or more ventricular escape beats occur in a row at a rate of 20-40 bpm.

**Regularity:** Essentially regular with late beats that occur after the next expected sinus beat.

**Rate:** Usually within normal range, but depends on the underlying rhythm.

**P waves:** Usually absent, or with retrograde conduction to the atria, may appear after the QRS.

**PRI:** None, because the ectopic beat originates in the ventricles

**QRS:** 0.12 sec or greater; wide and bizarre; T wave frequently in opposite direction of the QRS.

**Idioventricular Rhythm (IVR)**

- In the absence of a higher pacemaker, the ventricles initiate a regular impulse at their intrinsic rate of 20-40 bpm.
- If ventricular rate slows to less than 20 bpm, it can be referred to as an agonal rhythm or “dying heart”.
**Regularity:** ventricular rhythm is essentially regular  
**Rate:** ventricular rate 20-40 bpm,  
**P waves:** Usually absent  
**PRI:** None  
**QRS:** 0.12 sec or greater; T wave frequently in opposite direction of the QRS complex.

**Accelerated Idioventricular Rhythm (AIVR)**

- exists when three or more ventricular escape beats occur in a row at a rate of 41-100 bpm.  
- usually a benign escape rhythm.

**Regularity:** Ventricular rate essentially regular  
**Rate:** 41-100 bpm  
**P waves:** Usually absent  
**PRI:** None  
**QRS:** Greater than 0.12 sec; T wave frequently in opposite direction of QRS.

**Monomorphic Ventricular Tachycardia (VT)**

- An ectopic focus in the ventricles fires regularly at a rate of 101-250 beats per minute to override higher sites for control of the heart.  
- QRS complexes are of the same shape and amplitude  
- exists when three or more sequential PVCs occur at a rate of more than 100 bpm  
- may occur as a short run of less than 30 sec (non-sustained) or persist for more than 30 sec (sustained)
Regularity: essentially regular
Rate: ventricular rate range is 150-250 beats per minute. If the rate is below 150 beats per minute it is considered a slow VT. If the rate exceeds 200 bpm it’s called Ventricular Flutter.
P waves: usually none seen; may see dissociated P waves intermittently across the strip.
PRI: None
QRS: measures 0.12 sec or greater; wide and bizarre; often difficult to differentiate between the QRS and the T wave.
**Polymorphic Ventricular Tachycardia (torsades de pointes)**
- QRS varies in shape and amplitude from beat to beat
- QRS complexes appear to twist from upright to negative or negative to upright and back.
- can occur with a normal QT or long QT

![ECG waveform](image)

**Regularity**: Regular or irregular
**Rate**: Ventricular rate 150-300 bpm, typically 200-250 bpm
**P waves**: None
**PRI**: None
**QRS**: 0.12 sec or greater; gradual alteration in amplitude and duration of the QRS complexes; a typical cycle consists of 5-20 QRS complexes.
Ventricular Fibrillation (V-Fib)

- Multiple foci in the ventricles become irritable and generate uncoordinated, chaotic impulses that cause the heart to fibrillate rather than contract.
- No normal looking waveforms are visible
- waves of 3mm or more in height is called **coarse**, and less than 3 mm is called **fine**
- Rhythm requires defibrillation and CPR, as it always results in full cardiac arrest.

**Regularity**: Rapid and chaotic with no pattern or regularity  
**Rate**: cannot be determined since there are no discernible waves or complexes to measure.  
**P waves**: not discernible  
**PRI**: there is no PRI  
**QRS**: no discernible QRS complexes

**Asystole (Cardiac Standstill)**

- Total absence of ventricular activity  
- No pulse, no cardiac output
Regularity: No ventricular activity, atrial rate may be discernible.
Rate: No ventricular activity, but atrial activity may be seen (“P-wave” asystole)
P waves: Usually not discernable
PRI: None
QRS: Absent

Atrioventricular Blocks

Atrioventricular (AV) blocks occur when there is a delay or interruption of conduction through the AV junction. As the name implies activity generated by the atria is not normally conducted through to the ventricle. In the most extreme case, the atria and ventricle conduct independently of each other (3rd degree AV Block).

AV Blocks are classified into 1st, 2nd or 3rd degree. First degree AV block occurs when conduction through the AV junction is delayed, not blocked, and is noted as a prolonged PRI. Second degree AV block have an intermittent disturbance in the conduction of impulses between the atria and the ventricles. Third degree heart block, also called complete heart block, is the result of a complete block of conduction between the atria and ventricles.

Second degree blocks can be progressive in nature or can be unpredictable. When the AV node is delayed in a progressive fashion, each complex will have a longer PRI than the one before until complete block forms and you will note a P wave that is not followed by a QRS complex. This is called 2nd Degree Type I AV Block. It
tends to be more predictable in nature and does not usually deteriorate to a more life threatening block.

When the AV node is unpredictably blocked, some impulses will be conducted normally and some will not be conducted at all. This is seen on the ECG strip as P waves not followed by QRS complexes. The PRI will be constant in the beats that are conducted through the AV node. This is called 2\textsuperscript{nd} Degree Type II AV Block. Because it is not predictable, it can deteriorate into a 3\textsuperscript{rd} degree block and for this reason usually requires a temporary pacemaker as back up.

In a third degree block you will see P waves and QRS complexes but there will be no relationship between them. When you interpret this rhythm you will note an atrial rate and a ventricular rate. It is important to determine whether the pacemaker is the AV junction or the ventricle (can determine this from the rate and the formation of the QRS complexes) as it will indicate how severe the block is.

**First Degree Heart Block**

- SA node impulse is delayed in the AV node or AV junction for the same period before being conducted through to the ventricles
- The AV NODE holds each sinus impulse longer than normal before conducting it through the ventricles. Once into the ventricles, conduction proceeds normally.

**Second Degree AV Block Type 1 (Wenckebach, Mobitz Type I)**

- A sinus node impulse is delayed in the AV node a little longer than the preceding one until one is eventually blocked completely. 
- Impulses that are conducted travel normally through the ventricles.

### ECG Strip

[Image of an ECG strip]

**Regularity:** regular

**Rate:** will depend on the rate of the underlying rhythm.

**P waves:** uniform; each P wave will be followed by the QRS complex

**PRI:** constant but prolonged (greater than 0.20 sec)

**QRS:** measures less than 0.11 sec
Regularity: Atrial regular (P’s plot through time); ventricular irregular
Rate: atrial rate is greater than the ventricular rate.
P waves: upright and uniform; some P waves are not followed by QRS complexes.
PRI: inconstant until one P wave is not followed by a QRS complex. After that
blocked beat, the cycle starts again.
QRS: measures less than 0.11 sec

Second Degree AV Block Type 2 (Mobitz Type 2)

- Occurs below the AV node within the His-Purkinje system
- Selectively conducts some beats while blocking others. Those that are not
  blocked are conducted through to the ventricles
- Once in the ventricles the conduction proceeds normally.
- more serious than the Type I as has greater potential to progress to third degree
  block

Regularity: Ventricular irregular, atrial regular
Rate: Atrial rate is greater than the ventricular rate; ventricular rate often slow.
P waves: upright and uniform; more P waves than QRS complexes
PRI: constant, may be longer than a normal PRI.