A Closer Look at T Waves and Action Potentials for Introductory-Level Electrocardiographers

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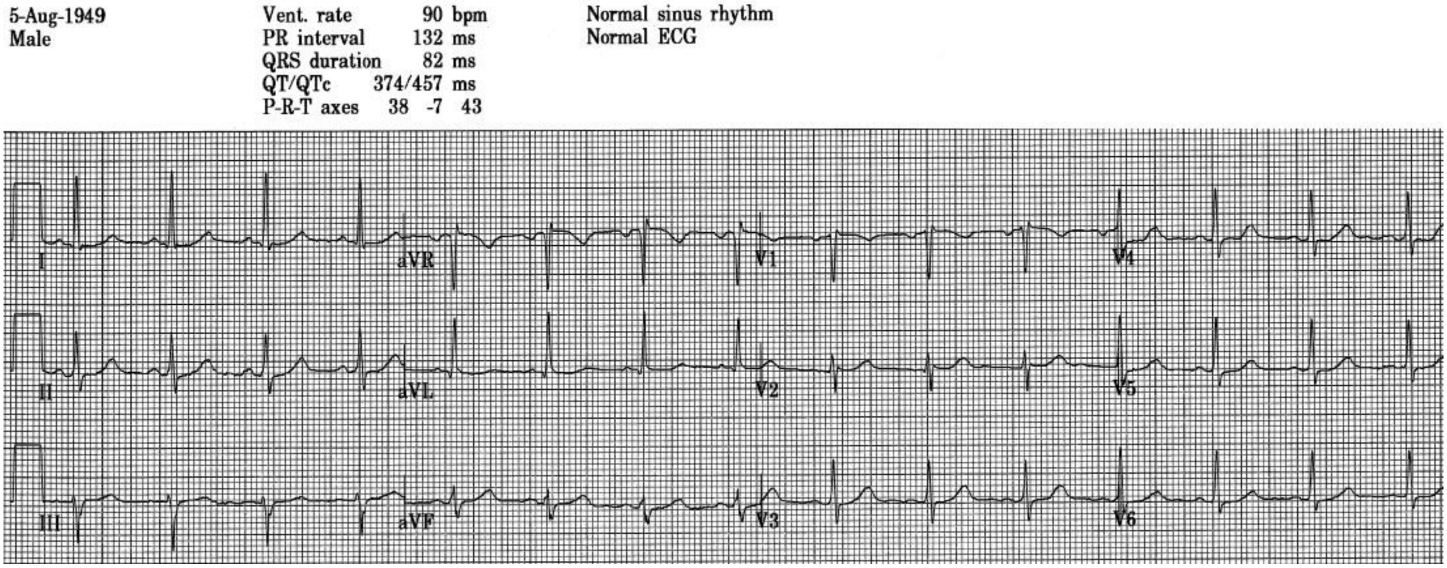

5-Aug-1949
Male

Vent. rate 90 bpm
PR interval 132 ms
QRS duration 82 ms
QT/QTc 374/457 ms
P-R-T axes 38 -7 43

Normal sinus rhythm
Normal ECG

Figure 1 12-Lead ECG

This ECG was chosen randomly from my ECG collection.

Here is the infamous “**Normal sinus rhythm**; **Normal ECG**” that we see so frequently. Today, we are going to concentrate on looking at T waves with a more discerning and critical eye.

You are just as apt to miss a significant finding when the machine interpretation says “**Normal sinus rhythm**; **Normal ECG**” as when it says “**Acute MI**” or “**Ventricular Tachycardia**” if you don’t take the time to inspect the ECG yourself.

Let’s talk about T waves and action potentials. T waves represent the last part of repolarization. As you may recall, *depolarization* is followed by *repolarization*. After repolarization is complete, there is a short period of time – ***electrical diastole*** – during which it appears that nothing much happening. However, ions continue to move in and out of the cell, but their net movement typically results in **no *net* current**. Positive ions moving **IN** equal positive ions moving **OUT**. This entire process is represented by an **action potential**. There are three kinds of action potentials but the one we will look at today is the action potential produced by your average, hard-working *ventricular myocyte*:

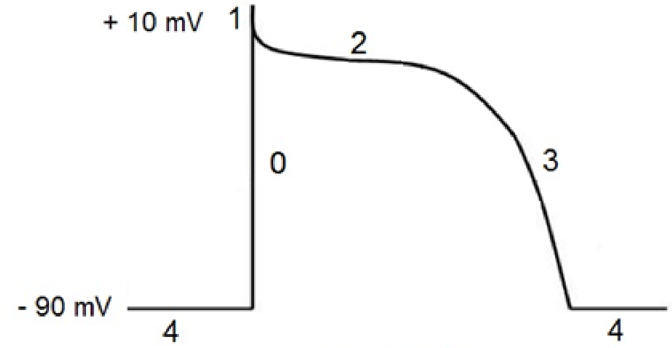

Figure 2 Ventricular Working Myocyte

Look at how much longer repolarization lasts when compared with depolarization! That vertical straight line labeled “0” represents ***depolarization*** – all of it! The entire QRS complex is represented by that one, straight, vertical line. And not just the R wave – it includes any Q waves, S waves or R′ waves. The lines representing phases 1, 2 and 3 represent ***repolarization***. Phase 2 represents the **ST segment** on the ECG and Phase 3 represents the **T wave** (there *are* reasons it doesn’t look like a T wave – don’t worry about it!). Some people think that the action potential looks like a really bad STEMI. I agree that it does, somewhat, but that is purely coincidental – there is no connection.

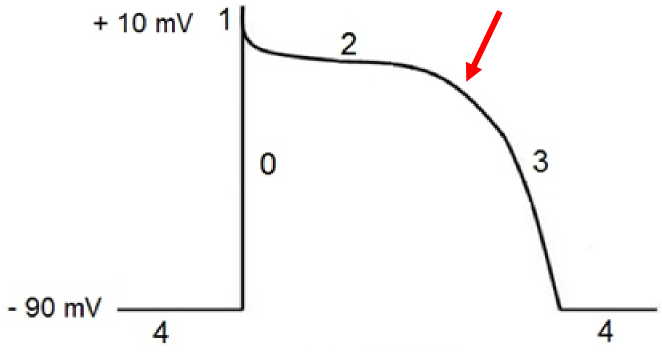

Figure 3 Ventricular Working Myocyte

During Phase 0 (depolarization), Na^+ ions rush into the cell, making the interior of the cell slightly positive (~ 10 mV). But, unfortunately, those ions can't rush back out. The door has slammed shut behind them. Although they were initially able to enter the cell by flowing down their concentration gradient, they now have to be pumped out. But that is going to take a while. In the meantime, the cell must be prevented from becoming highly positively charged. How can this be done? How about if we balance the positive ions that flowed INTO the cell (Na^+) with positive ions of the same charge (+1) flowing OUT of the cell? And, there just happens to be a huge amount of another ion with a charge of +1 located in the cell that CAN flow out through its own channels with no problem – potassium (K^+)! So, K^+ immediately begins to exit from the cell to offset the excess positive charge caused by the Na^+ influx. Shouldn't that loss of K^+ look more like a straight, downward slanting line rather than the curved line that we see, representing phases 2 and 3? Yes, it *should*. But around this time Ca^{++} starts flooding into the cell to initiate the contraction process of the myofibrils in the myocyte. Those incoming positive ions (Ca^{++} has TWO positive charges) momentarily counterbalance the exit of positive ions caused by the K^+ moving out of the cell through its own channels. But the Ca^{++} influx is short-lived. You can see on the action potential the point at which Ca^{++} stops entering the cell (red arrow) and the K^+ ions continue their exit out of the cell. At this point, there is still too much Na^+ **inside** the cell (remember: it still hasn't been removed) and too much K^+ **outside** the cell. They need to change places before there can be another normal depolarization. While K^+ can move relatively freely back and forth across the cell membrane, Na^+ cannot. There is an enzyme referred to as the Na^+/K^+ pump that facilitates the exchange of 3 Na^+ for 2 K^+ ions. The Na+/K+ pump is just one of the mechanisms used to pump Na+ out of the cell, but it is the main route of exchange.

How does the T wave fit into all this? The T wave represents the rapid phase of repolarization – the part AFTER Ca^{++} has stopped flowing into the cell and represents a rapid egress of K^+ from the cell. So whenever you look at a T wave, you are seeing that last spurt of K^+ leaving the cell in order to keep the cell from being overwhelmed with positive charges. To reinforce this concept, recall that the ECG manifestation of hypocalcemia is a prolonged ST segment with a NORMAL T wave at the end. Now do you see why the T wave remains normal while the ST segment is prolonged? It's because Ca^{++} has no effect on the T wave – only K^+ has an effect. Just think of what happens to the T wave during *hypokalemia* and *hyperkalemia*.

This normal, physiologic process creates T waves with a specific shape or morphology – a shape that we recognize as ***NORMAL!*** A *normal* upright T wave will have a slow, gradual ascent from the ST segment, a rounded peak and then a steeper, more rapid descent to the baseline. A *normal* inverted T wave will have a slow, gradual descent from the ST segment, a rounded nadir, and then a steeper, more raid ascent to the baseline. Whether a normal T wave is upright or inverted is a matter of not only physiology but also of which lead you are viewing. ***Its representation on the action potential (Phase 3) will always look the same whether it is upright or inverted***.

Now let's look at the T waves in the "Normal ECG." (*I've reproduced it for you on the next page.*)

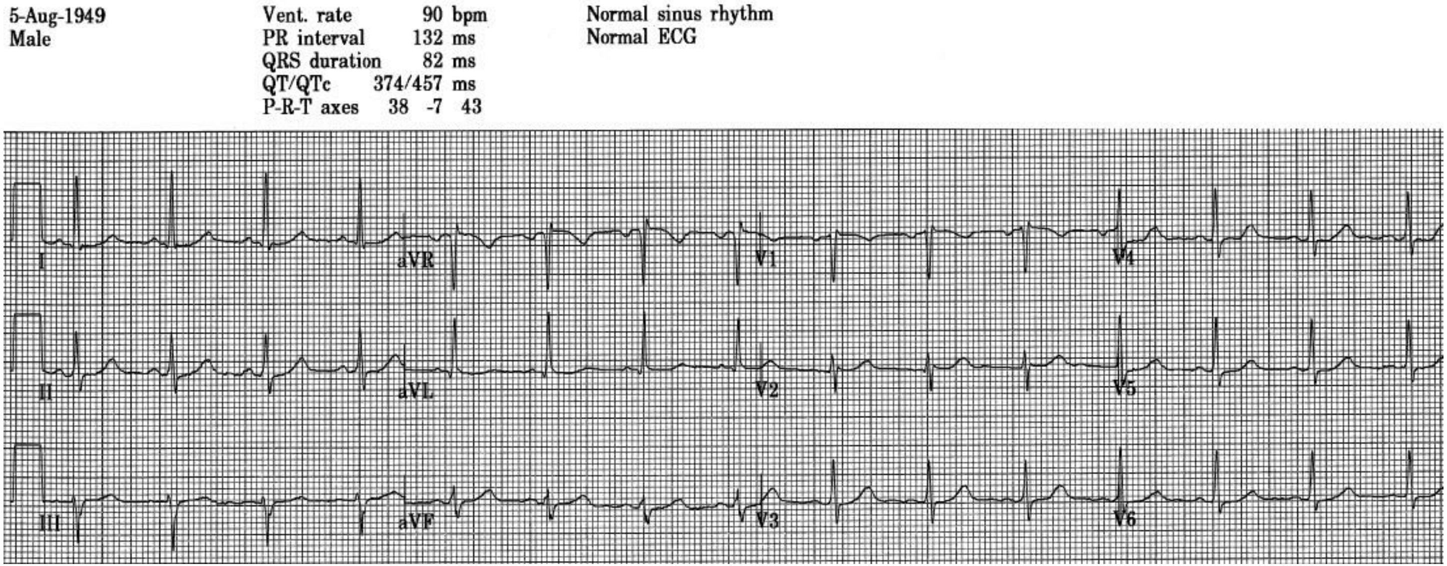

Figure 1 Repeated

Look closely. Bear in mind that this ECG was recorded in an emergency room on a 62 y/o male – we'll assume (for teaching purposes) that he presents with classic chest pain.

I don't think that many of these T waves have the normal morphology that I mentioned earlier. Here is an enlargement:

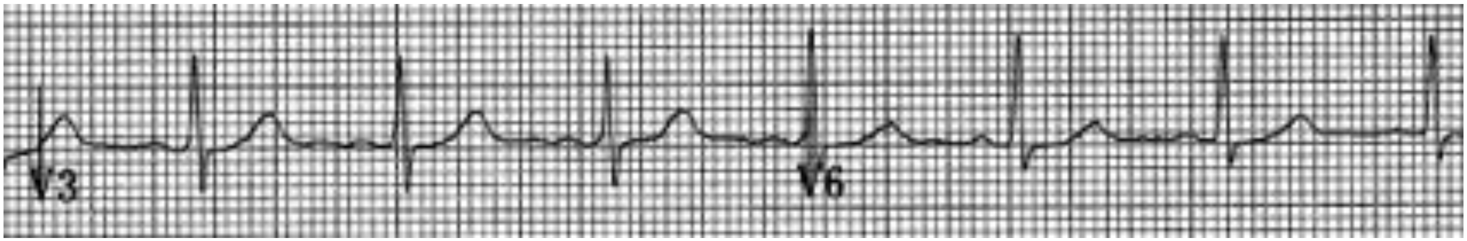

Figure 4 ECG Snippet

Do you see the abnormality that I am referring to? For your reference, here is an enlargement of what I consider to be very NORMAL T waves:

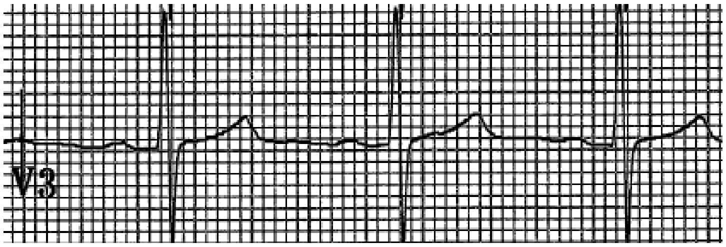

Figure 5 ECG Snippet

Do you see the difference now? Look at the symmetry of the T waves. The T waves in the original ECG appear very **SYMMETRICAL**. Now look at the T waves in the snippet above – do you see how **ASYMMETRICAL** they are? ***Symmetrical T waves are very suggestive of ischemic heart disease***. If you have a patient who has symmetrical T waves, should you send him/her directly to the ER? Well, only if the patient is having chest pain, in which case you would send him to the ER even *without* symmetrical T waves. This is usually a sign of *chronic, underlying* *disease*. Women with normal hearts may sometimes manifest symmetrical T waves. In my experience, it has been mostly young women in their late teens through early thirties.

What is there about symmetrical T waves that implies ischemic heart disease? Why are they symmetrical? When ischemia develops, the ischemic action potential shortens. This makes the downward slope of Phase 3 (representing the T wave) even steeper. ***The greater (steeper) the slope of Phase 3, the more symmetrical the T wave.***

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