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# Spiral Waves and the Heart: Spatiotemporal Organization of Cardiac Rhythms

## Abstract

The heart contracts in response to electrical waves that propagate through cardiac muscle. Normally, the electrical waves propagate smoothly to effect a coordinated, effective contraction. However, in pathologic states, normal wave propagation can be disrupted, causing wave fronts to break into multiple waves. Once initiated, these multiple waves often appear as spiral waves that may be stable or, more often, destabilize by fractionating into new waves. Spiral waves repetitively excite the tissue at faster rates and following an altered activation sequence, both of which compromise the heart's ability to pump effectively. This talk will describe the current understanding of the spatiotemporal organization of electrical waves in the heart during normal rhythm and arrhythmias using state-of-theart experiments, theory, and simulations.

## Elisabeth Cherry

Heart-diseases are one of the main causes of death in industrialised country's.
In America one third of the people dies from heart-disease. The most common failure in heart-disease is coronary heart-disease. The coronary arteries cannot provide saturated blood to the heart anymore. The heart might still pump, but cannot supply enough saturated blood to other parts of the body.
Main types of heart diseases,: heart attack, - stroke, -failure and weakend pumping.
Contributing factor of heart diseases is high blood pressure.

This talk will mainly handle the electro physical properties of the hearts electro guided system.
Types of arrhythmias, our focus: tachycardia and fibrillation.
Arrhythmia's can predispose you to stroke.Arrhythmia's can occur in the upper chambres of the hart, in the ventriculars or in both. Arrhythmia can occur when the heartrate is increased or decreased. Dysfunction of the electrical system can decrease or raise the heartrate. In this talk Tachycardia has the focus; this is an increased heartrate. This in combination with an irregular heartrate.

Atrial fibrillation is the uncoordinated contraction of little groups of atrial muscle cells or muscle cells itself.  Blood clotting in this chambers might cause little embolisms to shoot in the bloodstream to the Brains causing TIA's. Atrial fibrillation is fibrillating very rapidly , the ventricles can't keep up with this frequency. And an irregular ventrical rhytm is the result. But it is not life threatening. You can live with it many years.

Ventricular fibrillation is always life threatening, contraction is no longer coordinated: The heart cannot pump. This causes thousands of deaths each year. The body cannot be supplied by enough oxygen. This condition might occur after chronic Tachycardia.
The heart is contracting in ventricular fibrillation, but not in a regular fashion. It is contracting non coordinated.

Tachycardia is a specific risk. In ventricular tachycardia we have an accelerated beat. The atria in the meanwhile might contract in the same rhythm coordinating these fast beating ventricles.
Ventricular tachycardia , caused by atrial fibrillation, seems to skip some atrial pulses which causing the heart and therefore the ventricles to beat irregular and too fast.

The Netherlands have the highest rank of cardiac arrest of all the countries in the world.

## How does electricity play a role in the heart?

Cellular electrophysiology: ions move in-and out of the cell to maintain a certain environment. The cell's membrane is largely responsible for maintaining a gradient in concentrations of ions. The cell is largely permeable through specialised protein structures. There is an electrical gradient, because of the ions (Calcium, Potassium out and Sodium stream into the cell), this give rise to where the electricity starts to happen; the action potential. The action potential triggers contraction. Distant electrical gradients cause neighbouring cellmembranes  ion channels to open for a following reaction.

Tissue of the heart is the same as all other smooth muscle fibres in your body, and these are also electric. (only not driven by acetylcholine as a neurotransmitter red.)
The structure of the heart with atria, the ventricles, the arteria''s and the veins is very complicated.
Structure of the ventricles: the Left chamber has a much thicker muscle than the other chambres.
Muscles lay in different spiral formed layers in opposite directions spread over the heart, which gives a better contraction of the heart.

Normal sinus rhythm occurs as a healthy synchronisation between atria and ventricles, first in the atria and later on (150ms) in the ventricles. You can see a smooth coordinated electrical wave through the heart, with a normal sinus.

## Flavio Fenton

When normal electric rhythms changes spiral waves occur as electromagnetic fields over the entire heart. How do spiral waves decompose and become dangerous?
We can make this visible by a nice example: When you flush a toilet you have to wait before you can flush your toilet again. The stream is not already strong enough, when you try too fast. It is just the same with an action potential in the heart. An action potential needs a refractory or restoring period. Only after this refractory period, a normal action potential can occur

Action potential → when it is too late, full wave pattern.
Action potential → too early, no potential, part of the waves are blocked.

During a heart attack, you have a premature beat, the action potential is too early, over-polarisation of the heart, part of the waves are blocked, By improper beating not all the tissue can be supplied with sufficient blood and oxygen. Spiral waves are produced after the heart-attack. This causes tachycardia and fibrillation.
There are special forms caused by heart-attack. There are linear forms which are more healthy than the spiral waves. Spiral waves can have circular courses, epicycloid trajectories like flowerpatterns and cycloid trajectories; these are like drifting spiral waves, hypercycloid trajectories, more hyper- meander trajectories or linear trajectories. Some tissue's are more excitable than others.

Why are spiral waves dangerous? Spiral waves are not stable in the heart. The rotation can be faster than the sinus. This can take over control of the heart and make it contract faster. It can break up in multiple contractions. Then there is no more pumping.

1 single spiral wave → tachycardia
Multiple spiral waves → fibrillation and cardiac death.

## How does destabilisation of spiral waves happen?

There are a few mechanisms. One is alternating Wavelenghts become to alternate in long and short wavelengths. Short wavelengths become too short and there is no time for breaks. This turns over in multiple spiral waves and the tissue gets more and more

disturbed.  Then you can have a spiral wave that is called a motor rotor. In this case you have a spiral wave that becomes shorter and breaks into short spiral waves.
Another possibility is that a  spiral wave breaks into little parts. There exists multiple short spiral waves. The only thing the heart can do is follow this short contractions.
Spiral waves go into the depth of the tissue. They move like a vortex inside. The vortex lines connect all the waves. It looks like a torus of waves. Vortex lines are very complicated dynamics. They create inside multiple electrical activity. Multiple short-lived spiral waves, multiple small contractions gives 'shivering' of the heart.

### In 3D, vortex filaments:

Ring vortex has a lot of interconnection ring creation, fusion and pinching.
Vortex lines are the centre of spiral waves, the more distorted the worse for your heart
Clean spiral waves are not very stable, 1 spiral, 1 vortexline, when distorted the more vortices occur. And finally results in Ventricle fibrillation that stops the effective pumping of the heart.

### There are different ways of resetting arrhythmias:

1) strong electrical shocks, by means of cardio-version
2) Multiple small electrical shocks Lower energy, synchronise the tissue to new rhythm
3) Anti-arrhythmic drugs, makes the rhythm more regular

When we understand how spiral waves behave, we might provide better treatments of arrhythmia's.
Instead of one big shock. We can treat the electrical patterns with little shocks and lower energy that doesn't damage the tissue. We can measure or calculate the frequency of the arrhythmia and then give 5 pulses at the rhythm of the arrhythmia or providing it a little faster to which the tissue then synchronizes, onto the offered new frequency that is. In this way you can terminate arrhythmia's with little energy and little damage.
Similarly you can restore normal patterns with chemicals. You then can make the wavelength and refractory time a little longer, so the damaged spiral waves will regulate themselves.

There are spiral waves in other systems, for example also in the brain. In the neural tissue there are also  spiral waves. Spiral waves are produced by a chemical reaction. Cells in the brain have less calcium, but a rather similar system.

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