Direction Of Normal Repolarization in ATRIA and Ventricles - An Analysis Based on their Pumping action

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Abstract :

Ta and T waves of the ECG indicate that depolarization and repolarization in atria progress in a similar direction while in ventricles tend to be opposite which has been assumed due to pressure and temperature gradients between the epicardium and endocardium. In this paper an analysis of this phenomena is presented based on the pumping action of atria and ventricles. In atria inlet and outlet valves are located on opposite sides while in ventricles they are on the same side. During filling and ejection there is no change in the direction of blood flow in atria while in ventricles there is a change. Therefore sequence of contraction ie depolarization and relaxation ie repolarization should take place in the same direction in atria and in opposite direction in ventricles. As such Ta wave should be opposite to P wave and T wave same as QRS in polarity. And this is seen in the ECG.

Introduction :

It has not been possible to successfully trace the pathways of atrial and ventricular replarization in mammalian hearts because the injury potentials produced by extracellular electrodes obscure the potentials caused by repolarization. Intracellular electrodes although they work effectively with surface cells, cannot be used for this purpose since they cannot easily give information about the repolarization of deeper myocardial cells. Besides, any type of experimental intervention like opening the chest etc. will change the repolarization potentials. Therefore the only way to get any hint of the direction of normal repolarization, is to use whatever information is available from the body surface electrocardiogram[4].

There is an isoelectric period beween end of atrial depolarization and beginning of ventricular depolarization. This is because the much larger potentials of the ventricles conceal the potentials due to atrial repolarization. However, some times the ventricular potentials do not conceal the atrial repolarization potentials which may be seen as a wave called the Ta or Tp wave having opposite polarity to the P wave of the ECG. This indicates that the repolarization of artium progress in a direction similar to that followed by depolarization.

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In most ECG leads the T wave representing ventricular repolarization has the same polarity as the QRS complex. The main direction of the T and QRS loops of VCG is also more or less the same. This suggests that the sequence of repolarization in ventricles does not follow the same pathway as depolarization and indeed that the pathways tend to be opposite. It is assumed that this sequence of repolarization is due to pressure and temperature gradients between the epicardium and the endocardium. No theory has so far completely explained the normal pathway of ventricular repolarization.[4] In this paper an attempt is being made to understand this rather complicated phenomena and as to why such difference exists between the repolarization of the **atria** and ventricles.

Method of Analysis:

If **atria** and ventricles act as pumps, then why should there be this difference in the sequence of repolarization betwean the two ?. Although it may not have been possible to successfully trace these events experimentally, there ought to be a reason for this. The heart is the most efficient pump and nature must have designed both the mechanical and electrical systems of the heart for achieving this function.

Normally, the conventional ECG is drawn and then the mechanical changes during the various phases of the cycle are deduced. Analysing the reverse way, we may try to deduce the general sequence of depolarization and repolarization which is required for the efficient function of the **atria** and ventricles as pumps ie filling and ejection.

In **atria** the inlet and outlet valve are located on opposite side. Blood enters through the inlet valves in one direction and is pumped out through outlet valves in the same direction ie there is no change in the direction of blood flow during filling and ejection. In the ventricles inlet and outlet valves are located on the same side. Blood enters through the inlet valves in one direction and is pumped out through the outlet valve in the opposite direction ie in flow during filling is opposite in direction to out flow during ejection. Thus there is a basic difference in the pumping characteristics of the **atria** and ventricles. The **atria** pump in such a manner that there is no change in the direction of blood flow while the ventricles pump in such manner that there is a change in the direction of blood flow. For such a flow characteristics to take place, nature has located the inlet and outlet valves in the **atria** on opposite sides while for the ventricles on the same side. The electrical system of the heart must also be so designed by nature so that both the **atria** and ventricles pump the blood in a manner as they do.

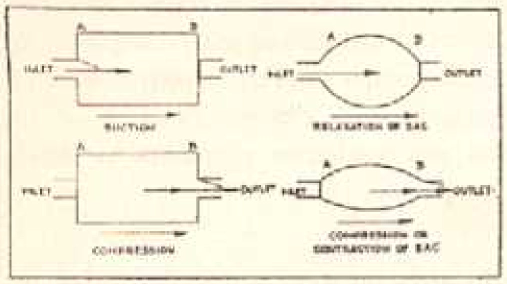

Fig. 1

Fig. 1 shows the operation of a simple pump. Inlet and outlet valves are located on the opposite side of the cylindrical pump. Fluid enters at A and is pumped out through the outlet valve on the opposite side at B. In this suction and compression must take place in the same direction. Instead of a cylinder if the pump is made out of an elastic sac, suction caused by relaxation of the sac and compression caused by the contraction of the sac must take place in the same direction.

The atria pump in this fashion. It is therefore essential that the sequence of contraction and relaxation of atria muscles must be in the same direction. For muscles to contract and relax in the same sequence, it is necessary that the sequence of depolarization and repolarization must be in the same direction. Therefore the polarity of Ta wave should be opposite to that of P wave in the ECG. And this may be seen in the ECG.

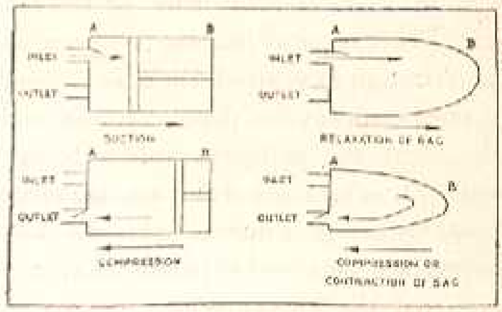

Fig. 2

Fig. 2 Shows the operation of a pump different from the previous one. Inlet and outlet valves are located on the same side of the cylindrical pump. For the fluid to enter, suction should take place in the direction A to B. Compression should take place in the opposite direction ie B to A so that the fluid is forced out in the opposite direction through the outlet valve located on the same side as the inlet valve. In this case suction and compression should take place in opposite directions. Instead of cylinder, if the pump is made out of an elastic sac suction caused by relaxation of the sac and compression caused by the contraction of the sac must take place in opposite directions.

The ventricles pump in this fashion. The sequence of contraction and relaxation of ventricular muscles must therefore be in opposite directions. For muscles to contract and relax in opposite directions it is necessary that the sequence of depolarization and repolarization should be in opposite directions. Therefore the polarity of T wave should be the same as the QRS complex in the ECG. And this is seen in a normal ECG. Before we accept these theoretical requirements let us further examine the electrical and mechanical functions of the ventricles.

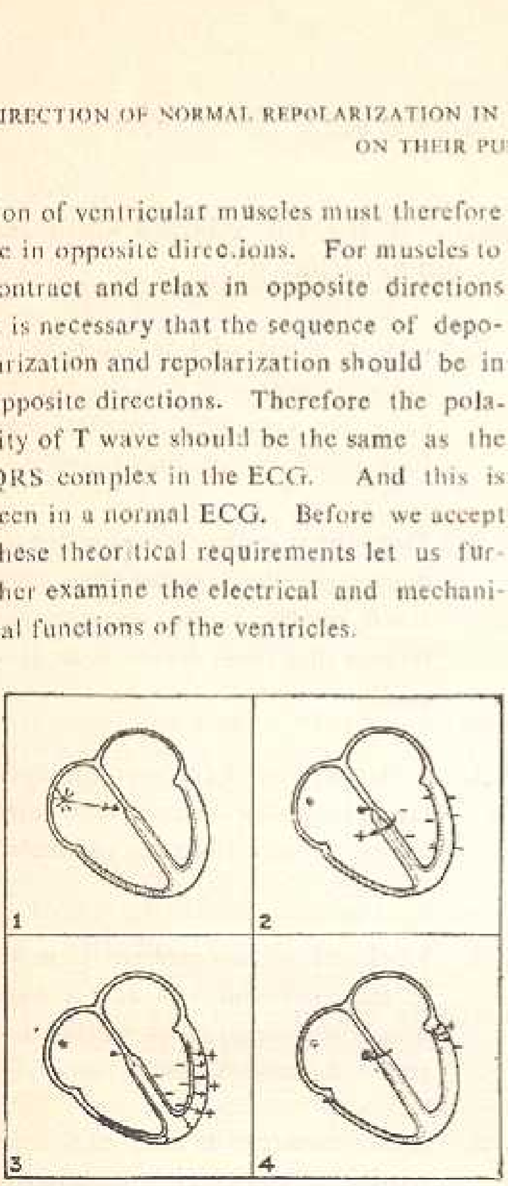

Fig. 3

Fig. 3 shows the conduction system of the heart[2]. The impulses originated at the S. A. Node spreads in a radial fashion through the muscles of both the atria. There does not seem to be a specialised pathway for atrial excitation although some workers have presented some evidence for an atrial conduction system. The impulses reach the A. V. Node where there is a delay and then the conduction proceeds through the Bundle of His. The mid portion of the I-V septum is first activated in a left to right direction. This initial activation of the septum is necessary so that the septum becomes rigid just before the contraction of the ventricles and acts like a fulcrum to increase the effectiveness of pumping action. The course of the stimulus through the free wall of the ventricle is then from apex to the base and from inside to the outside. The last regions to be activated are the posterobasal portions of the left ventricle, the pulmonary conus, and the upper most portion of the I-V septum because there is little purkinje tissue in these regions. It is interesting to note that the mid portion of the I-V septum is activated first and the basal portion last although the basal portion comes first in sequence in the pathway of the Bundle of His. This sequence of activation indicates that the contraction of the myocardium ~~dium~~ is from apex towards the base. Such a sequence of contraction is necessary so that the blood is forced out efficiently through the outlet valves of the ventricles.

Conductivity of a muscle depends largely on the direction of the current in relation to the direction of the muscle fibre. Muscles are far more conductive along the length of the fibres than across it. The stimulus spreads in the endoepicardial direction more or less perpendicular to the direction of stimulus in the endocardial layer. So the way of excitation travels obliquely through the myocardium as shown in Fig. 4. If we consider the left

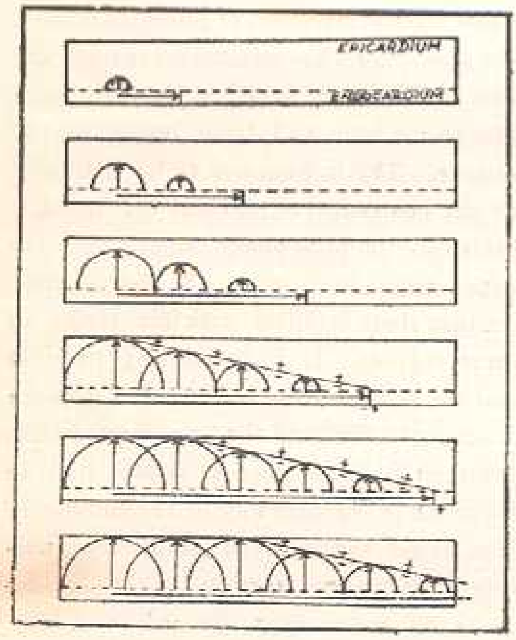

Fig. 4

of Fig. 4 as the apex region and the right side as the basal region, the contraction sequence would be such as to force the blood out from apex towards base.

Let us now, consider some mechanical details of the left ventricle which are detailed below :

1. Internal shape of left ventricle is like a cylinder with a small cone at end. The superficial muscles conform closely to spherical shape[3].

2. Therefore inner layers near endocardium especially near the apex have much smaller radius and circumference than outer layers near epicardium.

3. With the onset of contraction, inner layers must shorten more than outer layers in ejecting a particular volume[3].

4. Thickness of myocardium is more at the apex and less at the base while the internal cross section increases from apex towards base.

5. It may therefore be inferred that in general the degree of contraction is more at apex and less at the basal regions.

So far the various facets of depolarization have been discussed. From these, following prospositions and inferences are made regarding the repolarization.

1. Ventricles must also relax in a co-ordinated fashion and not in ran-

dom fashion for effective filling.

2. Since the outer layers shorten to a lesser degree than the inner layers of the myocardium, it may be proposed that they start relaxing or repolarizing first before the inner layers. That is, the direction of relaxation and therefore repolarization is opposite to the direction of contraction and hence the depolarization. This wlll therefore account for the same polarity of the T wave as the QRS complex in the ECG.

3. Since the degree of contraction, according to the shape of the left ventricle should be more at the region of the apex and less at the basal regions, it may also be proposed that the processes of repolarization in general should begin first at the basal regions and later at the apex. Such a sequence of repolarization will conform to the requirements of the pump wherein relaxation and contraction take place in opposite directions because inflow during filling is opposite in direction to outflow during ejection as shown in Fig. 2.

Summary :

The sequence of direction of depolarization and repolarization should be same for atria since inlet and outlet valves are located on opposite sides and there is no change in direction of blood flow during filling and ejection. It should be opposite for ventricles since Inlet and outlet valves are located on the same side and there is a change in direction of blood flow during filling and ejection. The sequence of depolarization in ventricles is such as to cause a sequence of contraction to force the blood out from apex to the base. Since outer layers of ventricular muscle shorten to a lesser degree than the inner layers, it can therefore be proposed that they start relaxing or repolarizing first before the inner layers. Further since the degree of contraction should be more at the region of the apex and less at the basal regions, it may also be proposed that re-polarization should begin fitst at the basal regions and later at the apex. The repolarization of atria and ventricles is thus reflected as Ta wave of opposite polarity to P wave and the T wave of the same polarity as the QRS of the ECG respectively.

Conclusion :

In this analysis certain inferences and propositions have been made based on some studies and experimental results already published by other workers.

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