A Study of Ventricular Arrhythmias Associated with Acute Myocardial Infarction in the Canine Heart

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SUMMARY
A study was designed to correlate changes in bipolar epicardial electrograms recorded from normal and acutely infarcted myocardium with the onset of ventricular arrhythmias. Electrodes were sewn to selected sites on the left ventricle, and after control electrograms and ECG's were recorded, the left anterior descending coronary artery was doubly ligated close to its origin. Electrograms recorded from within the infarct initially manifested diminished amplitude and increased duration of the deflection which reflected depolarization. The appearance of ventricular arrhythmias during phase 1 of Harris was associated with the appearance in electrograms recorded from within the infarct of continuous electrical activity which extended beyond the T wave of the preceding beat and preceded the onset of the arrhythmia. During the continuous electrical activity, it was not possible to delineate which deflections of the electrogram reflected depolarization or repolarization and it was suggested that the continuous electrical activity was localized fibrillation. For three experiments in which no arrhythmias occurred during phase 1 of Harris and for all animals which survived into phase 2 of Harris, the absence of ventricular arrhythmias was correlated with the absence of continuous electrical activity or localized fibrillation recorded from within the area of the infarct.

Additional Indexing Words:
Acute myocardial infarction
Localized fibrillation
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It is well known that ventricular arrhythmias are associated with myocardial infarction. Wilson's group was the first to study experimentally produced myocardial infarction by recording epicardial electrograms and to correlate changes in the local electrogram with changes in the ECG which occurred during the experimentally produced infarction. Since then, there have been numerous studies which have contributed to the understanding of the nature of arrhythmias associated with myocardial infarction. In 1943, Harris and Rojas used a string galvanometer to record epicardial electrograms from ischemic areas of the canine heart following acute occlusion of the left anterior descending coronary artery. They reported that as the ischemia developed, electrograms recorded from within the area of the infarct demonstrated a progressive loss of amplitude and increase in duration, until in many cases, no electrogram could be recorded. Recent studies using more sophisticated electronic recording techniques have demonstrated that bipolar electrograms could be recorded from areas of ischemic myocardium. The present study was designed to reexamine the observations of Harris and Rojas by recording bipolar electrograms from acutely infarcted regions of the canine myocardium and correlating the electrical activity thereby recorded with the occurrence arrhythmias involving the remainder of the ventricles.

Methods
Twenty-five mongrel dogs weighing 15-25 kg were anesthetized with intravenously administered pentobarbital, 30 mg/kg. For each animal, a tracheostomy was performed, a cannula was inserted into the trachea, and the animal was mechanically ventilated using a Harvard respirator. A left thoracotomy was performed in the fifth intercostal space, the pericardium widely incised, and a pericardial cradle created.

An acute infarct was created by doubly ligating the left anterior descending coronary artery at its origin. In some experiments, branches of the circumflex artery...
were also ligated. Prior to creation of the infarct, acrylic plaques, 1 cm x 3 cm, each containing five silver electrodes, were sewn to selected epicardial sites on the left ventricle and used to record bipolar electrograms before, during, and after creation of the acute infarct. The interelectrode distance was 2-3 mm. One electrode plaque was always sewn to a left ventricular site not supplied by the left anterior descending coronary artery, i.e., a ventricular site distant from the infarct. The other electrode plaques (four to six in number) were sewn within the area of the left ventricle nourished by the left anterior descending coronary artery. An electrocardiogram was monitored simultaneously with the electrograms on a DB-12 Electronics-for-Medicine switched-beam oscilloscope and recorded on photographic paper moving at 50-100 mm/sec. Electrocardiograms were recorded with the preamplifier filters set for frequencies of 0.1-200 cycles/sec and bipolar electrograms were recorded with the preamplifier filters set for either 12-200 cycles/sec or 0.1-200 cycles/sec.

**Results**

In 22 animal studies in which ventricular arrhythmias resulted after coronary artery ligation, a consistent pattern appeared in the bipolar electrograms recorded from within the area of the infarct.

Illustrated in figure 1 are the control records and records obtained 1 and 2 min after ligation of the left anterior descending coronary artery. The first seven traces in each panel are bipolar electrograms and the bottom trace is ECG lead II. The seventh trace is recorded from the plaque electrode outside the area of the infarct. In each electrogram, for each ventricular beat, deflections which reflect local ventricular depolarization (i.e., a QRS complex) are clearly delineated. Note also, that local repolarization (i.e., a T wave) is evident in most electrograms. Note that 1 min after coronary artery ligation, electrograms recorded from within the area of the infarct demonstrate, to varying degrees, diminished amplitude and increased duration when compared with the control records. Also, note that the Q-T interval in the ECG has shortened. Two min after coronary artery ligation, the changes in the electrograms are still more pronounced. These data confirm previous observations.4-8

Records obtained from the same experiment as figure 1 are illustrated in figure 2. The panel on the left demonstrates the evolution of the changes in the electrograms recorded 3 min after creation of the infarct. Note that the electrograms recorded from within the infarct in the top four traces are now markedly flat and broad. However, the
electrogram recorded from the noninfarcted myocardial (bottom trace) remains unchanged when compared to control. Marked S-T-segment elevation is apparent in the ECG. In the panel on the right, recorded 10 sec after that on the left, the recording amplification has been increased for the top four traces to better see the electrical events. Several important observations can now be made. First, during sinus rhythm, the configuration of the electrogram recorded from normal myocardium remains unchanged, but electrograms recorded from some of the electrodes within the infarct (traces 1–4) demonstrate bizarre-looking complexes whose configurations may vary from beat to beat (compare the first, second, fifth, and sixth beats of the first and third traces) and complexes in which clear delineation between deflections which reflect local depolarization and repolarization can no longer be made. We have chosen, for these and other records, to refer only to the electrical activity recorded in these electrograms because it is not possible with the limits of the recording technic to identify which deflections reflect local depolarization or repolarization. However, it seems a reasonable assumption that these deflections reflect more than one local depolarization. This becomes especially important because the appearance of ventricular arrhythmias was associated with electrical activity recorded from within the infarct which extended beyond the T wave of the preceding beat in the ECG and preceded the onset of premature beat(s). The implication is that this depolarization may propagate to the repolarized normal myocardium, thereby producing a reentrant arrhythmia. Thus, note that the appearance of ventricular extrasystoles (third and fourth beats in the ECG) is associated with electrical activity recorded within the infarct (second, third, and fourth traces) that extends beyond the T wave of the preceding sinus beat, i.e., precedes the extrasystole. In fact, this electrical activity appears to be continuous during the two ventricular extrasystoles (third and fourth beats), until it stops spontaneously. With cessation of this electrical activity recorded from the ischemic area, the ventricular arrhythmia of the heart stops and a sinus rhythm resumes. The onset and cessation of arrhythmias in this manner was a common event in our studies, occurring many times in every dog heart which manifested arrhythmias.

Figure 3 illustrates records obtained from the same experiment as figures 1 and 2, recorded several minutes after those in figure 2. Notice again how from some sites within the infarct, the configuration of the electrogram changes from beat to beat (traces 1 and 2, first four beats of the left panel). With the fifth beat in the left panel, a run of ventricular tachycardia begins. Note how it is associated with continuous electrical activity in the

![Figure 3](image-url)
first, second, fourth, and probably third traces. The right panel shows the spontaneous cessation of the ventricular tachycardia 3 sec later. Note that, as illustrated in figure 2, the cessation of the ventricular tachycardia is associated with cessation of recorded electrical activity from within the area of the infarct. Electrical activity recorded from the ventricular electrodes reappears with the next sinus beat. However, the sinus rhythm lasts just one beat, for ventricular extrasystoles reappear, associated, as in the previous example, with electrical activity recorded in the infarct which extends beyond the T wave of the preceding sinus beat. And again, this electrical activity recorded from the area of the infarct appears continuous until it ceases spontaneously, at which time the ventricular arrhythmia of the heart also ceases.

Illustrated in figure 4 are records obtained from another experiment after creation of the infarct. All traces are bipolar electrograms except for ECG lead II, the second trace from the bottom. The trace immediately above the ECG trace is the electrogram recorded from normal myocardium. The recording amplification for all other electrograms has been increased from that of the control (as in figure 2) to better see the electrical events.

The rhythm, as seen in the ECG, changes over several beats from sinus rhythm to ventricular tachycardia to ventricular fibrillation. Note the appearance of continuous electrical activity in the bottom trace associated with the onset of ventricular tachycardia. However, this example differs from those shown previously, for there is no spontaneous cessation of this electrical activity, but rather continuous electrical activity appears several beats later in other electrograms and the ventricular tachycardia becomes ventricular fibrillation. Note that continuous electrical activity appears last in the electrogram recorded from noninfarcted myocardium. In every experiment in which ventricular fibrillation occurred, it was always preceded by a similar pattern of electrical activity recorded from the electrodes within the area of the infarct: continuous electrical activity is first recorded from one or more electrodes within the area of the infarct; the continuous electrical activity spreads to all the electrodes within the infarct, and then to the noninfarcted myocardium.

Examination of the electrograms recorded during ventricular fibrillation from both normal and infarcted myocardium, as in figure 4, demonstrates striking similarity between them, i.e., continuous electrical activity with absence of clear delineation between depolarization and repolarization. It is tempting, therefore, to suggest that electrograms, recorded from within an infarct, which demonstrate continuous electrical activity are in fact demonstrating localized ventricular fibrillation, i.e., fibrillation confined to an area within the infarct. Moe, Harris, and Wiggers were the first to use the term “localized fibrillation.” They recorded epicardial bipolar ventricular electrograms from several sites and demonstrated that when ventricular fibrillation was initiated by a premature ventricular stimulus, it was initially confined to the immediate region of the stimulating electrodes. And of further interest, the electrograms they recorded during localized and generalized fibrillation were similar to those recorded in our studies demonstrating continuous electrical activity.

It is important to note that continuous electrical activity or localized fibrillation recorded in an infarct is not always associated with ventricular arrhythmias. Illustrated in figure 5 are records from one experiment in which continuous electrical activity, seen in the third trace of each panel, was not always associated with ventricular arrhythmias. Note that sinus rhythm persists during these bursts of continuous electrical activity.
Electrograms (top seven traces) and electrocardiogram (bottom trace) recorded about 10 min after doubly ligating the left anterior descending coronary artery. Time lines are at 1-sec intervals and recording speed is 50 mm/sec. See text for discussion.

Figure 5

Electrograms (top seven traces) and electrocardiogram (bottom trace) recorded in the same experiment as figure 5. Time lines are at 1-sec intervals and recording speed is 50 mm/sec. See text for discussion.

Figure 6

There is some further minimal change in the electrograms, but again, no electrical activity extends beyond the QRS complex of the ECG. Again, these observations are associated with the absence of ventricular arrhythmias, and were noted in all animals surviving the acute infarct. These consistent findings are of special interest because of the scarcity of arrhythmias during phase 2 of Harris,10 i.e., the period beginning 10–20 min after creation of an infarct and lasting 4–8 hours.

In three experiments, despite the creation of a large myocardial infarct in each instance, no arrhythmias occurred. This observation is consistent with data reported by others.10–12 However, of particular importance was the fact that, for these three experiments, the absence of arrhythmias was coincident with the absence of continuous electrical activity or localized fibrillation in the electrograms recorded from within the infarct at any time.

Discussion

Our data demonstrate that, in the immediate period following acute occlusion of a coronary artery, i.e., phase 1 of Harris,4–10 transient or sustained periods of continuous electrical activity or localized fibrillation may occur within the infarcted myocardium. When this continuous electrical activity or localized fibrillation recorded within the infarct persists beyond the T wave of the preceding beat, i.e., persists until the normal myocardium has repolarized, it is almost always associated with ventricular extrasystoles. When this continuous electrical activity or localized fibrillation is sustained, it may provoke ventricular tachycardia (as in fig. 3) or fibrillation of both ventricles (as in fig. 4). The implication, of course, is that abnormal depolarization within the area of the myocardial infarction spreads to the remainder of the ventricles, with resulting arrhythmia. That this mechanism can be operative was demonstrated some time ago by Moe, Harris, and Wiggers8 in studies on noninfarcted canine hearts during the induction of ventricular fibrillation, in which fibrillation began locally at the site stimulated and from there spread to involve the rest of the ventricle, much as we are postulating.

It is not surprising that localized fibrillation within a myocardial infarct might occur spontaneously, because the conditions for fibrillation are present within the area of infarction. As demonstrated by several investigators, electrophysiologic properties of infarcted myocardium, such as enhanced threshold of excitability,13–20 shortened...
ARRHYTHMIAS IN DOGS

refractory period, 13-15, 21-26 decreased conduction velocity, 5, 6, 13-15, 27-29 and increased inhomogeneity (i.e., temporal dispersion) of the recovery of excitability 14, 15, 18-20, 23, 30-32 provide a suitable milieu for initiation and perpetuation of fibrillation. The need to have a sufficient mass of infarcted tissue to sustain localized fibrillation may be important. 21

It is of interest that Harris and Rojas 4 considered that "...after the occlusion of a coronary artery, the fibrillating process may begin in the ischemic area...", and further considered that "...the fibrillating process might spread to include the whole organ...". However, based on the data from their study and a study by Lewis, 22 they concluded that "...local electrogram [recorded] from deeply ischemic tissues never have shown activity which resembled fibrillation either before or after the onset of [ventricular] fibrillation." Moreover, they concluded that during what we now call phase 1 of Harris, the ischemic myocardium demonstrated "...reduced irritability..." and "...functional isolation..." Our study supports their conjectures, not their conclusions. The reason for their failure to record electrograms from ischemic myocardium such as we have described can only be surmised, but it is likely due to their inability to amplify the signal recorded by their string galvanometer.

Lastly, it would be of interest to know whether the phenomena we have described result from either abnormal automaticity, reentry, or a combination of the two. This question is not answered by this study. However, this study does provide important new insights into the genesis of ventricular arrhythmias in the initial period following acute myocardial infarction.

References

30. Wiggers CJ: The mechanism and nature of ventricular fibrillation. Amer Heart J 20: 399, 1940
31. Wiggers CJ, Wegrila R: Ventricular fibrillation due to single localized induction and condenser shocks applied during the vulnerable phase of ventricular systole. Amer J Physiol 128: 500, 1940
34. Lewis T: The experimental production of paroxysmal tachycardia and the effects of ligation of the coronary arteries. Heart 1: 98, 1909
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