The Origin of Ventricular Arrhythmias
24 Hours Following Experimental Anterior Septal Coronary Artery Occlusion

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SUMMARY The anterior septal coronary artery was acutely ligated in 16 open-chest anesthetized dogs to produce an infarct of the septal myocardium. Twenty-four hours following occlusion complete epicardial mapping and extensive plunge electrode recording techniques were used to localize the sites of origin and patterns of activation of the ventricular tachyarrhythmias that developed during recovery. The earliest electrical activity for 13 individual rhythms was recorded from surviving septal subendocardial Purkinje fibers at the margins of the infarct, in the right or left ventricle, directly underlying the sites of earliest epicardial breakthrough. The sites of origin were verified by demonstrating unchanging activation sequences during pacing through the electrode sites which recorded the earliest activity. None of the arrhythmias arose from the His bundle or bundle branches despite the fact that these tissues course directly through the necrotic septum. The data presented supports the hypothesis that ventricular arrhythmias occurring in the 24-36 hour post acute infarction period may originate in the surviving subendocardial Purkinje system.

Our experimental model shows that in cases in which a malignant rhythm arises from a focus, whether it is due to enhanced automaticity or local re-entry, epicardial mapping alone may not identify the source of the arrhythmias. Extensive endocardial mapping may provide a more rational basis for surgical interventions designed to abolish these arrhythmias.

TWO PHASES OF VENTRICULAR ARRHYTHMIAS induced by ligation of a major branch of the left coronary circulation were originally described by Harris.1 An early phase of paroxysmal ventricular arrhythmias typically begins within two to five minutes after acute occlusion and often degenerates to ventricular fibrillation within approximately the first 20 minutes. This is followed by a quiescent period, free of arrhythmias, which usually begins 30 minutes following the coronary occlusion. The second period of ventricular arrhythmias starts within four to eight hours after ligation and persists for as long as 72 hours; spontaneous ventricular fibrillation does not usually occur during this latter phase. Harris postulated that these late ventricular rhythms originated in the peri-infarction zone or boundary zone of the infarct which, in his view, contained a subendocardial layer, a subepicardial layer, and a circumference about the infarct.

More recent electrophysiological studies, carried out on both intact animals and infarcted tissues taken from the hearts of dogs 24 hours following acute occlusion, have shown that subendocardial Purkinje fibers within the infarcted myocardium survive.2-6 In addition, transmembrane action potentials recorded from the surviving Purkinje fibers exhibit enhanced diastolic depolarizations and other specific characteristics conducive to arrhythmia genesis.2-5 These studies indicate that the ventricular arrhythmias occurring 24 hours following acute coronary artery ligation originate in the surviving subendocardial Purkinje fibers and are probably due to enhanced automaticity.2,2-6 Ventricular arrhythmias also occur following acute occlusion of the anterior septal artery and also dissociate into an acute early phase and a later chronic phase, but the characteristics of the arrhythmias associated with the later phase of this infarct have not been clearly defined.5,6

Twenty-four hours following occlusion of the left anterior descending coronary artery the infarcted tissue involves the anterior left ventricular free wall and the anterior-inferior aspect of the left side of the ventricular septum. In contrast, the extent of the infarct following anterior septal artery occlusion is restricted to the septum and extends variably to the right and left septal surfaces. The infarct includes the area underlying the bundle of His as well as the right and left bundle branch and some septal peripheral Purkinje fibers. The infarct produced by septal coronary artery occlusion therefore uniquely encompasses several types of ventricular specialized conducting tissues. The arrhythmias which appear 24 hours following anterior septal artery occlusion, therefore, may originate in any or several of these tissues (i.e., necrotic muscle, proximal His-bundle branch, or distal Purkinje fibers). The present studies were undertaken to define the origin of the ventricular arrhythmias occurring 24 hours following acute anterior septal artery (ASA) occlusion and to determine the characteristics of the resulting ventricular activation.

Methods

Studies were performed on 16 healthy mongrel dogs weighing between 10 and 15 kg. The animals were anesthetized with 30 mg/kg i.v. sodium pentobarbital, then ventilated with room air through a pharyngeotracheal tube using a volume cycled positive pressure respirator. Body temperature was maintained using a thermal mattress. The heart was exposed through a left thoracotomy at the fifth intercostal space. The pericardium was opened and the left atrial appendage retracted. Blunt dissection was utilized to expose the anterior septal coronary artery. In the majority of animals, this artery originated either as the first branch of

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the left anterior descending artery or at the bifurcation of the left anterior descending and left circumflex arteries. Following acute one stage ligation of the anterior septal artery (ASA), the lead II electrocardiogram exhibited ST-segment and T wave changes, indicating an acute occlusion. The electrocardiogram was continuously monitored while the thoracotomy was closed and during the recovery period until the animal was extubated. This varied between 1 and 3 hours. During this period of time, occasional arrhythmias were observed and acute heart block occurred as previously described by other investigators.\textsuperscript{9} However we did not observe spontaneous ventricular fibrillation in any of our animals.

Twenty-four hours following the initial procedure, the animals were reanesthetized with 10 mg/kg sodium pentobarbital and 1.0 mg/kg diazepam, each intravenously. For the electrophysiological studies the chests were opened at the right fifth intercostal space and the hearts were suspended in a pericardial sling. In order to allow the ventricular ectopic rhythms to establish themselves without competition from supraventricular beats, the sinus node was mechanically crushed. In some animals, vagal stimulation was also applied. The electrophysiological studies were performed only during stable monofocal ventricular rhythms.

Complete epicardial mapping was performed as previously described.\textsuperscript{4,10,11} The technique involves inserting a close bipolar plunge wire electrode into the free wall of the right ventricle to be used as the epicardial reference electrode. The activation sequences of both right and left ventricular surfaces were determined by moving a hand-held roving bipolar electrode along predetermined points. The time of activation of these epicardial points relative to the fixed reference allows us to construct isochronic maps which define the sequence and timing of epicardial activation. The reproducibility of the measurements at each location is within \( \pm 2 \) msec.

Plunge type bipolar electrodes were also used to record from the His bundle, right and left bundle branches, and other (generally 10–15) sites within the peripheral Purkinje system and the septal myocardium. These electrodes were inserted via a 23 gauge needle in the tissues located by surface landmarks and by palpation through the atrial and ventricular free walls. The exact position of each electrode was verified at postmortem examination. In addition, multipolar, ten lead transmural plunge electrodes allowed intramural recordings at 1 mm intervals in selected experiments.

Following the electrophysiological studies, the animals were sacrificed and their hearts removed. The plunge wire electrodes were left in place so that their location could be determined relative to the region of septal infarction and the bundle branch-Purkinje network. The bundle branch-Purkinje system was delineated on the septal surfaces by staining with a 2\% tincture of iodine solution. The extent of infarction was not always apparent on the septal endocardial surfaces. In order to more clearly define the area of infarction, the vital stain nitroblue tetrazolium was used. The interventricular septum was sectioned producing slices 2 to 4 mm thick. The cuts were made perpendicular to the septal endocardial surface and extended from base to apex. These sections were incubated at 37° in a solution of nitroblue tetrazolium according to the technique of Nachlas and Schnitka.\textsuperscript{12} This technique made it possible to reconstruct the extent of the entire septal infarction and to establish its relationship to the septal recording electrodes and septal bundle branch-Purkinje system.

### Results

All animals in these studies were initially in normal sinus rhythm. At 24 hours following the occlusion of the anterior septal artery, the animals had developed spontaneous ventricular ectopic rhythms competing with normal sinus rhythm. Following re-anesthesia and crushing of the sinus node, the animals exhibited stable ventricular rhythms which by electrocardiographic criteria appeared to be originating in one or two competing foci. Complete electrophysiological studies were accomplished on 13 stable rhythms occurring in ten animals. Two of the remaining six animals served as sham-operated controls. In another animal the left anterior descending coronary artery was inadvertently occluded as well as the anterior septal artery and was not included in this series. One animal was excluded because of heart worms. Complete electrophysiological studies could not be performed on the remaining dogs for technical reasons.

The spontaneous ventricular rate for the 13 rhythms associated with the anterior septal occlusion averaged 133 ± 35.9 s\(^{-1}\) beats/min. This rate is slightly slower than the 196 ± 19.5 s\(^{-1}\) beats/min which was the spontaneous ventricular rate following left anterior descending coronary artery occlusion described in a previous publication from our laboratory.\textsuperscript{6} These ventricular rates are considerably faster than those idioventricular rhythms which spontaneously occur in anesthetized dogs during atrio-ventricular dissociation following His bundle ablation. In a previous study\textsuperscript{13} the spontaneous ventricular rate during experimental atrioventricular (A-V) dissociation was only 49.2 ± 8.4 s\(^{-1}\) beats/min.

Utilizing ventricular mapping techniques, we defined the earliest area of epicardial activation as the right ventricle in eight of 13 rhythms and on the left ventricle in five of 13 rhythms. These early epicardial activation sites all occurred near the interventricular septum. In animals showing early right sided "breakthrough," right ventricular activation tended to occur early in the total epicardial activation sequence; similarly left ventricular breakthrough was accompanied by early left ventricular activation. In addition, it was observed that the total of left and right ventricular epicardial activation did not usually encompass the entire duration of the QRS complex during ventricular rhythms. Following the epicardial mapping procedure, plunge electrodes were inserted to define the sequence of activation of the specialized ventricular conducting tissues as well as local septal muscle activation, with a view to finding the earliest ventricular activity.

Figure 1 presents selected analog records recorded during supraventricular pacing and during spontaneous ventricular tachycardia in one experimental animal. At the top of the figure, the epicardial and septal surfaces of the heart are shown schematically. Each septal recording site is indicated with its approximate relationship to the specialized ventricular conducting system as well as the area of myocardial infarction, which is that bounded by the dotted lines. The analog records present only selected data from the multiple
records obtained. A total of 15 septal recordings was made in this particular experiment. Recording site S1 was located in the bundle of His; this record includes both the His bundle spike (h) and the high ventricular septal spike (s). Left septal Purkinje spikes (p) are indicated in recordings S3, S4, and S5. During supraventricular pacing, the normal sequence of activation for these recording sites can be observed. This animal, which was typical of all of our experimental preparations, showed normal atrioventricular conduction intervals during overdrive pacing of the ventricular arrhythmia. The low atrial septal to His conduction time in the bundle of His electrogram was 38 msec, and the His to left Purkinje spike interval was 30 msec. The electrograms shown at the lower part of figure 1 demonstrate the normal sequence of activation during spontaneous ventricular tachycardia. The corresponding epicardial activation map indicated an early left anterior breakthrough during this spontaneous rhythm. The Purkinje fiber spike recorded by the S5 plunge electrode was obtained in the left ventricular septum directly underlying the early area of epicardial breakthrough. Note that the early septal activation precedes retrograde His bundle activation by 25 msec. In all of our studies during spontaneous ventricular rhythms earliest recordable peripheral Purkinje fiber activation preceded proximal His-bundle branch activation by 25 to 51 msec.

Figure 2 presents similar data from another experiment. The upper analog records exhibit six septal recordings during a spontaneous ventricular tachycardia which produced early right ventricular epicardial breakthrough. In this case, electrodes S3 and S4 were the sites of earliest recordable ventricular activation. These sites (as revealed at postmortem examination) occurred 5 to 7 mm apart, each at the base of the right anterior papillary muscle as shown in the schematic diagrams above. After multiple plunge recordings had located the sites of early activation during the ventricular rhythms, we verified that we had in fact located the earliest site by electrical pacing through the electrode at the site of earliest recordable activity. The lower left records of figure 2
were obtained during pacing through the electrode located at S4. During S6 pacing, the activation sequence through the septum was essentially unchanged from the spontaneous activation sequence, as shown by the similar time relationships among the electrograms. In addition the morphological patterns of the individual electrograms are strikingly similar for the S1, S2, S5, and S6 electrodes as well as for the surface electrocardiogram exhibited above. This is in contrast to the results with pacing from site S4 (at the lower right in the figure). Small, but perceptible differences from the spontaneous activation sequence are apparent. This is most evident at sites S2 and S6 where it is also noted that the polarity of the local electrograms is reversed. Small changes are also recognizable in the surface electrocardiogram.

Table 1 presents the relative conduction intervals among the various septal recording sites in figure 2 during spontaneous rhythm as well as during pacing from S1 and S6. Notice that the relative activation times among the septal sites during pacing from S1 were very similar to those during the spontaneous rhythm. The maximum difference was 11 msec between the site S4 and septal site S6. During pacing from electrode site S4, which was approximately 5 to 7 mm away from site S1, the activation times among the various septal sites were changed to a greater degree. There was a difference of 11 msec between sites S4 and S5, 16 msec between septal sites S1 and S5, and 23 msec between site S1 and the stimulus artifact of pacing site S6. Using both multiple recording and pacing techniques, we were able to locate the earliest site of activation to within 1 cm. In all of our experiments, the earliest ventricular activation was found to occur on either the right or left septal surfaces.

In one experiment more extensive intramural multiple electrode recordings were obtained from 50 sites within the right and left ventricular free wall and interventricular septal myocardium. In addition, epicardial mapping was performed and standard 12 lead electrocardiograms were taken during spontaneous rhythm and during pacing from the earliest septal activation site. The surface electrocardiogram and the epicardial activation sequence were unchanged during pacing as compared to the spontaneous rhythm. There were no intramural myocardial activation times which occurred earlier than an early right ventricular septal site which was relatively superficial on the endocardium and exhibited an early Purkinje spike.

In one animal, a sham operation was performed 24 hours before the electrophysiological study but the isolated septal artery was not occluded. Following sinus node crush and vagal stimulation, an idioventricular rhythm occurred at a rate of 35 beats/min. This rhythm was considerably slower than the ventricular tachycardia associated with septal artery occlusion and resembled ventricular escape beats associated with normal ventricular automaticity which occurred during experimental A-V dissociation. Epicardial mapping studies and plunge electrode recordings indicated that this rhythm originated in the posterior left ventricular free wall in underlying subendocardial Purkinje fibers. This rhythm did not resemble the ventricular tachycardias that occurred postocclusion but was characteristic of the normal escape rhythm.
automaticity which is observed in animals in which higher pacemakers are suppressed.

The relationship between septal activation times and epicardial activation from a typical experiment is demonstrated in figure 3. In A, the epicardial activation map is presented. In B, the epicardial activation times and septal activation times are plotted on a common time axis with a tracing of the lead II QRS complex during a spontaneous ventricular tachycardia. In this figure, time "O" is defined as the earliest of any recordable ventricular activity. Consistently, the site of earliest septal activation as determined via plunge recordings preceded all other plunge and epicardial activity, and was always recorded in association with early Purkinje fiber activity. In this experiment the early

ventricular septal site at time O was located in the Purkinje system of the anterior right ventricular septal endocardium.

As illustrated in the epicardial activation maps above, the earliest epicardial breakthrough occurred along the interventricular septum on the right ventricular anterior surface. The ventricular activation appeared to spread uniformly from this early right ventricular site. The posterior surfaces of the heart were last to be activated. The epicardial activation times shown in B indicate that earliest right ventricular epicardial breakthrough preceded earliest left ventricular epicardial activation by 25 msec. The septal activation times superimposed on the electrocardiographic complex in B indicate that earliest septal activation preceded right ventricular breakthrough by 55 msec. Also, from this figure, it can be seen that the bundle of His was activated in a retrograde direction, 51 msec following the early right ventricular septal activation and 4 msec before earliest right ventricular epicardial activation. In addition, the bundle of His was activated 30 msec before the earliest left ventricular site on the epicardium. In our experiments, the time interval between retrograde His activation and earliest epicardial activation of the ventricle contralateral to the epicardial breakthrough ranged from 15 to 30 msec. These data suggest that activation of the ventricle contralateral to the site of earliest activation might be at least partly accomplished by retrograde conduction to the His and antegrade conduction down the contralateral bundle branch. This was in fact shown to occur in this experiment. If during spontaneous ventricular rhythm, the bundle of His was stimulated as little as 4 msec prior to its expected normal retrograde activation time, left ventricular epicardial and contralateral septal activation times were also premature by approximately the same interval, but were otherwise unchanged in patterns of activation as determined by plunge electrodes.

Figure 4 presents data from another experiment in which the ventricular tachycardia exhibited an early left ventricular breakthrough on the epicardial surface and in which the early septal activation occurred in the lower mid left ventricular septum. The epicardial activation maps in A show that earliest epicardial breakthrough was on the left ventricle primarily near the apex. The posterior surface of the left ventricle showed the earliest activation times. Right ventricular activation was delayed in comparison. The activation times for epicardium and septum plotted below show that, in contrast to figure 3, this animal exhibited left ventricular epicardial breakthrough just 7 msec after the earliest septal activation time. This brief interval was related in this case to the anatomic proximity of the early left ventricular septal site of origin to its directly overlying early epicardial site. This anatomical proximity of septum and epicardium occurs only along that part of the left ventricular septum closest to the apex. The earliest left ventricular epicardial breakthrough preceded earliest right ventricular epicardial activation time by 43 msec. The His bundle was activated in a retrograde direction 25 msec following earliest left ventricular septal activation and retrograde His activation preceded earliest right ventricular epicardial activation by 25 msec, again suggesting that contralateral ventricular activation may have been at least partially due to retrograde conduction to the His and antegrade conduction down the right bundle. The epicardial activation in A shows an island of

![Figure 3](http://circ.ahajournals.org/)

**Figure 3.** A comparison of the sequence of epicardial activation and septal activation during spontaneous ventricular tachycardia. In A anterior and posterior views of the surface of the heart are presented. The sequence of epicardial activation is indicated by the gradation in shading. The scale below in A indicates the epicardial activation time interval in msec for each of the gradations in shading. In B the epicardial activation times indicated by the circles and the septal activation times indicated by the x's are plotted on a common time axis and the electrocardiographic tracing of the lead II configuration during the tachycardia is also presented. Time O for this graph is the earliest septal activation time. The epicardial activation times in A area also referenced to the earliest septal activation site at time O. The filled circles are left ventricular epicardial sites, the unfilled circles are right ventricular epicardial sites. The arrow indicated by h defines the time of retrograde His bundle activation.
early left ventricular activation occurring on the anterior surface near the septum. This secondary site of comparatively early left ventricular epicardial activation may indicate that local conduction within the Purkinje system from the earliest septal activation site may also contribute to the activation pattern within the ventricle in which the activity originates.

Figure 5 summarizes the data obtained on all 13 ventricular rhythms. The figure presents the relationship between the early septal activation sites and their sites of early epicardial breakthrough. The schematic diagram at the left of the figure shows the anterior surface of right and left ventricles. The numbers indicate that for all 13 ventricular tachycardias studied, all originating in the left or right septal endocardial Purkinje system, early epicardial breakthrough occurred along the septum. Eight sites were of a right ventricular origin and five sites broke through on the left ventricle. In this figure the middle schematic shows the exposed right endocardial septal surface and the far right schematic shows the left septal endocardial surface. These septal schematics identify the anatomic location of the earliest sites of ventricular activation on the right or left septal endocardium for each of the rhythms. In general, there was a direct correlation between the location of the early septal activation and the corresponding epicardial breakthrough. In each experiment where epicardial breakthrough was on the right ventricular surface, the earliest ventricular activity was always recorded from the right septum (1 through 8). Likewise, earlier left sided epicardial breakthrough was always associated with earliest recordable activity from the left septal endocardial surface (9 through 13). In these same schematics the dotted lines indicate the approximate borders of the infarcted myocardium. It should be noted that the early septal activation sites for these rhythms tend to cluster about the margins of the infarct.

We also observed that in general there was a correlation between the configuration of the lead II electrocardiogram and the site of origin of the early epicardial breakthrough. This is shown in figure 6. Epicardial breakthrough on the right ventricle, occurring along the superior-anterior region, produced primarily upright lead II electrocardiographic complexes. Epicardial breakthrough occurring along the inferior and more posterior aspect of either ventricle produced primarily inverted complexes of rS type. These were primarily left ventricular sites. In this figure prominent deltoid waves are recorded on the lead II surface electrocardiogram in association with epicardial breakthrough sites 1 through 5 and site 7. These correspond to the period of septal activation as can be seen in figure 3. This was also true for the r wave of the inverted complexes of the rS configura-
It was therefore possible to predict to some degree the site of origin of the ventricular activation on the basis of the lead II QRS configuration.

Table 2 summarizes the characteristics of the ectopic ventricular rhythms which occurred 24 hours following anterior septal artery occlusion. The mean rate of the ectopic ventricular tachycardias was 133 beats/min. The total ventricular activation times from the earliest septal site to the termination of ventricular activation averaged 83 msec. Total epicardial activation time as defined by our mapping studies comprised the last 55.5 msec of this total. Total septal activation time determined by our plunge electrodes comprised the earliest 51.8 msec of the total. The data of table 2 and figure 3 demonstrate that septal activation and epicardial activation tended to occur somewhat out of phase. However, this was not always the case as can be seen in figure 4 in which septal and epicardial activation were more synchronous. Nevertheless, in each case septal activation was always earliest and always preceded earliest epicardial activity.

Following the electrophysiological studies, the plunge electrodes were left in place, the animals were sacrificed and the hearts removed. The right bundle branch appeared as a thin, darkly staining structure which terminated at the base of the anterior papillary muscle. Multiple Purkinje fibers were seen to originate from this area and spread anteriorly to the level of the right ventricular outflow tract. The left bundle branch Purkinje system showed a more extensive ramifications over the surface of the left ventricular septal endocardium. The origin of the left bundle branch was apparent at the membranous septum between the right coronary cusp and noncoronary cusp of aortic valve. However, the distinction between bundle branch and peripheral Purkinje system was not obvious anatomically. Previous studies have shown that the left bundle branch system remains electrophysiologically insulated from the underlying septal myocardium until approximately the lower one-third of the septal surface at which time peripheral Purkinje fibers feed into underlying septal myocardium.

Staining of the septal myocardium with nitroblue tetrazoleum showed that the true extent of the septal infarct may not be apparent during gross inspection of the septal endocardial surfaces. The size of the infarcted septal area varied from animal to animal but always included the His bundle, right bundle branch, and at least the proximal portions of the left conducting system. The infarcted region was restricted to the septal myocardium but extended on the right side to the base of the anterior papillary muscle. On the left endocardial septal surface, the infarcted region tended to extend more posteriorly and did include portions of the lower third of the septal endocardium.

Figure 7 presents schematic diagrams of the right and left septal surfaces showing the anatomical location of the bundle branch — Purkinje system and infarcted myocardium. This schematic emphasizes that both the right and left bundle branches occur well within the area encompassed by the infarct. In addition, portions of the right and left peripheral Purkinje system overlap with the infarcted myocardium. However it is only at the margin of the infarct in this experimental model that peripheral Purkinje fibers are present. Comparing figure 7 with figure 5, it can be seen that the early septal activation sites tended to occur in this region of overlap between the peripheral Purkinje system and the infarcted septal myocardium.

**Discussion**

From initial experiments with two stage canine LAD occlusions, Harris concluded that the late ventricular arrhythmias occurring 12 to 72 hours postocclusion originated in the boundary zones of the infarct, but he did not define specifically a tissue of origin. More recent studies, including previous experiments from this laboratory performed 24 hours following Harris-type LAD occlusions, found the origin of ectopic ventricular activity to be from subendocardial Purkinje fibers well within the infarcted area of myocardium, and clearly preceding His bundle, bundle branch, and border zone activation.

Experimental LAD occlusions, however, directly produce ischemia and death in only two sorts of tissues, muscle and Purkinje fibers. Unique to the present anterior septal artery model is the overlap of necrotic muscle with the His bundle, bundle branch, and Purkinje system, with the potential for arrhythmias directly related to the infarct to arise from any of these specialized ventricular conducting tissues or at any

<table>
<thead>
<tr>
<th>Ectopic rate (beats/min)</th>
<th>Total ventricular activation time (msec)</th>
<th>Total epicardial activation time (msec)</th>
<th>Total septal activation time (msec)</th>
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<tr>
<td>133 ± 35.9</td>
<td>83.0 ± 7.8</td>
<td>55.5 ± 18.8</td>
<td>51.8 ± 18.6</td>
</tr>
</tbody>
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Values represent mean ± SD.
interface. The data of our experiments show that the ventricular arrhythmias which occur 24 hours following acute occlusion of the anterior septal coronary artery originate in the peripheral Purkinje system of the right or left ventricular septal endocardium and cluster around the margins of the infarcted tissue. None of the arrhythmias arise from sites within the infarct that are isolated from Purkinje fibers. The unique anatomical relationship between the septal infarct and the septal peripheral Purkinje system may explain why the margins of the infarct are the sites of the ectopic rhythms in contradistinction to the previously described LAD occlusions. In the present experimental model, as revealed in figure 7, it is only at the infarct margins that there is overlap between the infarcted myocardium and the peripheral Purkinje system. There are no peripheral Purkinje fibers apparent within the mid-regions of the infarct produced by septal artery occlusion. Therefore, the ectopic activity that originates in peripheral Purkinje tissue following septal infarcts could only occur at the margins of the infarct. Other contributing factors peculiar to the infarct margin that promote such arrhythmias cannot be excluded but the previously described experience with LAD occlusions does not support such a concept.

Although Scherlag et al. have noted epicardial depolarization preceding Purkinje activation in some infarcted tissues, we were unable to record any ventricular muscle activity within the confines of the septal infarct or in the surrounding septal muscle which occurred prior to the earliest Purkinje activation. In addition, the ventricular ectopic rhythms associated with anterior septal artery occlusions always originate in peripheral Purkinje fibers although viable and normally conducting His bundle and bundle branches also lie within the infarcted septal area. The ectopic rhythms also have the characteristics of enhanced automaticity: they can be exposed by a sinus slowing; they can be abolished by overdrive pacing; they demonstrate a warm-up phase following overdrive suppression; and they can be suppressed with lidocaine. All of this suggests a primary effect of the infarct on automaticity within the septal Purkinje system but does not exclude the possibility that there is also inapparent enhancement of automaticity of other potential subsidiary pacemakers.

Since the ectopic activity originates in the septal Purkinje system during the ventricular tachycardias, the septum itself is the first to be activated in the total activation sequence (fig. 3). The depolarization wave always appears first on the ipsilateral epicardial surface. Activation of the opposing ventricle is delayed despite the fact that initial epicardial breakthrough appears along the interventricular septum (fig. 5) and that the infarct itself involved much of the interventricular septum. This may be explained by the lack of specialized conducting fibers across the septum, leaving only retrograde conduction to the His bundle, and conduction through septal muscle, as the two major means of contralateral activation. As can be seen in figures 3 and 4, retrograde conduction to the His bundle occurs and provides sufficient time for antegrade conduction down the contralateral bundle branch to contribute to a more synchronous total ventricular activation sequence. Conduction through septal muscle almost certainly occurs as well.

In their electrophysiologic characteristics, their time course of appearance and dissolution, their clinically benign consequence, and in their rate in relation to sinus rhythm, these late ventricular arrhythmias associated with anterior septal artery occlusion resemble the “benign ventricular tachycardias” or “accelerated idioventricular rhythms” that are commonly observed in the first few days following myocardial infarction in man. Direct recordings of Purkinje fiber activity responsible for arrhythmogenesis in acute human infarctions have not yet been accomplished, however, but recent microelectrode studies from this lab have demonstrated pacemaker activity in Purkinje fibers and very slow conduction in viable regions of aneuryisms, surgically removed from human hearts months following infarction.

The ventricular rhythm presented in figure 3, which shows retrograde His activity preceding epicardial activation, may have been wrongly interpreted as a fascicular tachycardia if multiple septal recordings had not been made and if the deltoid wave associated with septal activation had not been prominent in the surface electrocardiogram. It is certainly possible that some arrhythmias which appear to be fascicular in origin following human infarction may really arise from the septal Purkinje system only to go unseen on routine His records and electrocardiograms. In the particular experiment shown in figure 3, extensive endocardial mapping demonstrated early septal Purkinje activity more than 50 msec in advance of the His bundle spike.

The validity and usefulness of epicardial mapping as a guide to surgical interventions designed to terminate intractable ventricular arrhythmias is an important consideration. Our studies and others suggest that epicardial mapping alone may not be adequate for defining the area of activity for possible surgical resection. In general, there was a close correlation between the sites of earliest epicardial
breakthrough and underlying earliest septal activation (see fig. 5). Clearly, however, these rhythms originate from the septum and not from the epicardial surface where they are detected by surface mapping. Septal plunge electrode recordings have resolved earliest sites of origin for these ventricular ectopic rhythms to within a 5 mm radius, specifically with verification by pacing studies from these same sites as detailed above. Such studies reveal that there is often a delay of from 7 to 60 msec between earliest septal activation and earliest epicardial activation. Moreover, the distances between sites of septal activation and epicardial breakthrough may range from as little as 0.5 cm to as much as 4.0 cm in distance in the small heart of a 10–15 kg dog. These distances are most disparate when the rhythms arise from the left posterior septum, that area least accessible surgically to resection. On the other hand those rhythms which originate from sites near the LV apex, and which are therefore most accessible to surgical intervention are just those sites in which there is more than one area of relatively early epicardial activation because of involvement of the contiguous conduction system.

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