

Atrial Rhythm during Ventricular Fibrillation in the Dog

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ABSTRACT Depolarization of the atrioventricular junctional tissues and of the atrial septum was examined in the perfused dog heart before and during ventricular fibrillation by (1) recording the potentials from the junctional tissues in the regions of the interatrial and interventricular septum and examining the relationship of activity at these sites to atrial depolarization, (2) computing histograms and autocorrelograms of atrial firing intervals to study atrial rhythmicity, and (3) plotting the sequence of atrial septal depolarization. The junctional tissue was generally randomly depolarized by the fibrillating ventricles. The histograms and autocorrelograms indicate that during ventricular fibrillation the atrial depolarization intervals do not remain constant, but vary widely. This seems to be due to the retrograde excitation from the junctional tissues. Plots of the depolarization sequences of the interatrial septum also indicate that retrograde depolarization takes place. The junctional tissues decrease the number of impulses that can pass from ventricle to atrium, and they similarly decrease the number of impulses that pass in an antegrade direction during atrial fibrillation.

LITTLE IS known about the function of the atrioventricular (AV) conduction system during ventricular fibrillation, although it is known that during atrial fibrillation the ventricular rhythm is random because the AV junction is depolarized by atrial impulses that are inconstant in temporal sequence, direction, and magnitude.^{1, 2}

During ventricular fibrillation the atria perhaps beat normally, depolarizing the AV conduction system in a normal fashion or, alternatively, the Purkinje fibers and the AV junction perhaps are driven by the fibrillating ventricular myocardium, causing the atria to depolarize in a retrograde direction with an irregular rhythm.³

During an earlier study of the depolarization of the AV conduction system we found, using extracellular electrodes,⁴ that at times these hearts fibrillated unexpectedly. In these experiments the potentials from the AV conduction system seemed to follow atrial depolarization, indicating that retrograde (ventricular-atrial) conduction did not take place. However, it could be assumed that during ventricular fibrillation the AV junction is bombarded by impulses from below, just as it is bombarded from above during atrial fibrillation. Our present work was undertaken to study the atrial response and the transmission characteristics of the AV junction during ventricular fibrillation.

If the AV conduction system is depolarized by the atria during ventricular fibrillation, we would expect the atrial rate to remain normal. If, on the other hand, the conduction system is irregularly depolarized by the fibrillating ventricular muscle, and if such depolarization is conducted

retrograde to the atria, we could expect a change in the rhythm of the atria (analogous to the irregular depolarization of the AV junction by the atria during atrial fibrillation). To study these questions we recorded extracellular potentials from the AV conduction system and examined histograms and autocorrelograms of atrial firing intervals during induced ventricular fibrillation.* Finally, we plotted the sequence of depolarization of the interatrial septum, using multiple electrodes during normal beats and during ventricular fibrillation.

Methods

Study of the AV Conduction System

We studied the activity of the AV bundles in 15 isolated dog hearts perfused by a donor animal according to the Langendorff procedure.⁵ After perfusion had been established, the right atrium was opened widely to permit visualization of the region of the AV junction, common bundle, and basal right bundle. Multipolar electrodes (interelectrode distance, 1 mm), of the type used in several laboratories to study atrial and ventricular depolarization,^{6, 7} were inserted into selected regions of the atrial and ventricular septum and records obtained through them were examined for potentials from the branches of the AV conduction system. When such potentials were identified, records were made with a conventional amplifier and Visicorder and, in addition, potentials were stored on magnetic tape. The data recorded included an atrial poten-

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*The histogram of interatrial firing intervals graphically demonstrates the interval distribution. When the interval is constant there will be a single peak in the histogram, and as the interval varies more widely the histogram will become broader, with beats at widely varying intervals. Even when the interval varies widely there may be an inherent rhythmicity (bigeminy, trigeminy, respiratory variations, etc.). Such rhythmicity is disclosed by an autocorrelogram. In calculating an autocorrelogram, a table of beat intervals is correlated with itself, the correlation is repeated as the table of intervals is moved one rank, etc. If there is rhythmicity, the shifted table becomes a close replica of the original table at the proper shift, and correlation increases.

tial, usually from the region of the sinus node, and one or more potentials from regions of the AV conduction system. After control records had been taken for several hundred heart beats, ventricular fibrillation was induced by rapid ventricular stimulation at threshold voltage, and the recording was then repeated while the heart was fibrillating. The taped records, which included at least 400 atrial beats, were used for averaging (see below).

The heart was defibrillated with countershock, then fibrillation was reinduced and a second set of records was made. The records obtained during fibrillation were considered usable only when the potentials from the AV conduction system seen prior to defibrillation were also present after fibrillation was reinduced.

While the heart was fibrillating, we cut the terminal branches of the Purkinje system by incising the ventricular septal surfaces bilaterally, and again repeated the recordings. Finally, the heart was again defibrillated so that we could ascertain whether the expected complete AV block had resulted from bilateral interruption of the bundles.

Magnetic tape records of the experimental data were averaged with a computer of average transients (CAT) triggered from atrial depolarization. We used this procedure to determine whether AV conduction system potentials (which were at times not clearly visible during fibrillation) followed or preceded atrial depolarization at a fixed time interval. It was possible to trigger the CAT from the atrial electrogram and then, for several hundred heart beats, average the next 100 to 250 msec of the record to see if AV conduction system potentials (obscured by the large potentials of ventricular fibrillation) followed atrial firing. In addition, we ran the tape backward with the same triggering and averaging; had the AV conduction system potentials occurred before atrial depolarization in a constant fashion, they would have appeared following atrial depolarization in a reversed record of this type.

Analysis of Atrial Depolarization Intervals

During cardiopulmonary bypass we recorded atrial electrograms from 20 dogs on magnetic tape through bipolar electrodes stitched to the right and left atrial appendages. Throughout the experiments, pH, blood gases, electrolytes, temperature, and arterial blood pressure were carefully controlled. Ventricular fibrillation was initiated by a short d.c. current applied to the ventricular myocardium, and it was terminated by conventional countershock. The atrial electrograms were recorded on magnetic tape. Five-minute recordings were made before, during, and after the period of ventricular fibrillation. We produced histograms and autocorrelograms of the P-P intervals of 400 or more consecutive atrial depolarizations (P waves), using a digital computer and the techniques described in an earlier paper.¹

Atrial Depolarization Sequence

In six experiments we attached 10–14 hooklike electrodes to the surface of the interatrial septum and, using the time of activity determined from these, plotted the pathway of atrial depolarization before and during ventricular fibrillation. In these studies the instant of local activity was deter-

mined from the most rapid portion of the "intrinsic" deflection in unipolar recordings.

Results

Potentials from the AV Conduction System

Unipolar and bipolar potentials were recorded from the right bundle and from the common bundle in all hearts studied. These potentials consisted of biphasic or triphasic waves of short duration which followed the P wave. Potentials recorded from the common bundle followed the P waves by a shorter interval; potentials from the right bundle preceded the R waves by a shorter interval. When potentials were recorded from the common bundle, the electrodes usually showed potentials from adjacent atrial fibers as well; electrodes near the right bundle recorded large potentials from neighboring ventricular fibers. In two cases, insertion of the electrodes near the common bundle resulted in a prolongation of the P-R interval, apparently as a result of damage to the specialized fibers.

Effects of Ventricular Fibrillation

During ventricular fibrillation, potentials from the AV conduction system (Fig. 1) apparently could be identified by eye in approximately 30 per cent of the recordings. This was so, more often when the electrode was near the common bundle in the atrium. Identification was at times uncertain because the potentials could differ in shape from those seen during normal conduction and, more importantly, because

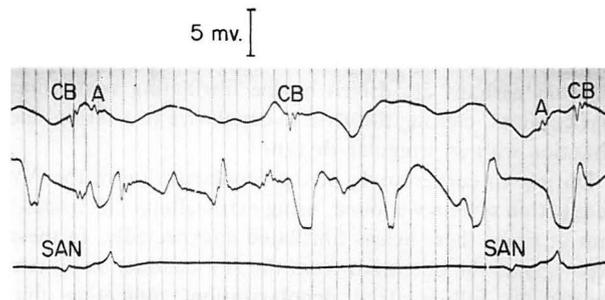


FIGURE 1. A record taken during ventricular fibrillation. In the top two traces large potential changes due to ventricular fibrillation are seen. The top trace is from the electrode in the atrium in the vicinity of the common bundle; the middle, from an electrode in the vicinity of the right bundle; and the lower, from a region of the atrium below the crista terminalis. The letters on the lines above the figure indicate the apparent firing of the various structures concerned. On the top channel the first rapid negative deflection (CB) is from the common bundle, the second (A) from the atrium, etc. In the second channel it is not possible to clearly identify the firing of the right bundle, which may be present in the various rapid deflections. The third channel shows an early (SAN) and late atrial potential; we believe that this electrode shows firing from both sides of the interatrial septum. The potentials from the common bundle are inverted from those seen in control records (not shown here), indicating retrograde conduction. Note also that the common bundle potential in the middle of the record on the top channel occurs without apparent atrial activity. The firing of the common bundle at the left of the record occurs before atrial firing, and at the right it occurs after the atrial firing. Time marks (vertical lines) denote 10-msec intervals.

the ventricular potentials due to fibrillation, particularly near the right bundle branch, were so large that identification of potentials from the AV conduction system became difficult.

For this reason the potentials from several of these hearts were averaged to determine whether a fraction of the His bundle potentials were "locked" to atrial depolarization. In the majority of such cases (whether or not records were averaged) it was clear that these potentials rarely, if ever, occurred with a fixed relationship to atrial depolarization (Fig. 2); i.e., they neither preceded nor followed atrial depolarization at a constant interval. The normal relationship between atrial firing and the firing of AV conduction system fibers was restored in all cases by electrical defibrillation.

Effects of Cutting the Bundle during Ventricular Fibrillation

After the peripheral branches of the conducting system had been cut, potentials from the bundle usually showed the same relationship to atrial potentials as in the control records (Fig. 2). In two cases in which potentials were not restored the electrode in the region of the AV fibers had been moved during attempts to cut the bundles. Defibrillation after bundle cutting left the relationship between atrial firing and firing of the AV conduction system unchanged from that shown in control records, despite the fact that there was, as might be expected, AV block.

Atrial Depolarization Intervals

Ventricular fibrillation during cardiopulmonary bypass did not always produce a change in atrial rhythm. Persistence of the sinus rhythm was observed in nine of the 20 dogs studied. Cooling the sinus node region during persisting sinus rhythm slowed the sinoatrial rhythm and resulted, in

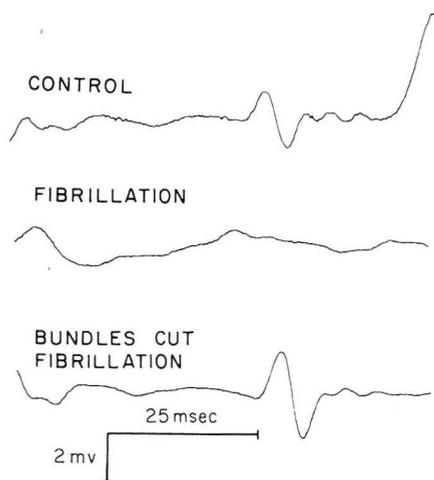


FIGURE 2. The top trace shows a control record from somewhere near the common bundle-right bundle junction. (All records were triggered from atrial firing and are averages of 300 heart beats.) During fibrillation, the averaged record shows no potentials from the atrioventricular junction tissues. When the bundles were cut during fibrillation, the firing of the junctional tissue regained its normal relationship to atrial firing. Ventricular firing occurs at the right of the control record and is not seen during fibrillation or after the bundles have been cut.

two instances, in a transient irregularity of the atrial rhythm. This suggested that there was an interference competition between the sinus rhythm and impulses originating from the AV junction (see Discussion). The effect of ventricular fibrillation on atrial rhythm in the 11 dogs which did show permanent atrial irregularity is depicted in Figure 3, which shows a histogram and an autocorrelogram of a representative observation. For comparison, a histogram and an autocorrelogram for the same dog prior to ventricular fibrillation are also shown. It can be seen that the histogram (like the histograms of R-R intervals during atrial fibrillation) is rather skewed, and that, apart from coefficient zero, all higher order coefficients (like the autocorrelograms of R-R intervals during atrial fibrillation) do not differ from zero. The mean P-P interval during ventricular fibrillation was 282 ± 70 msec. The first 10 coefficients of all 11 autocorrelograms are combined in Figure 4, showing that atrial rhythm during ventricular fibrillation can, for all practical purposes, be considered random.

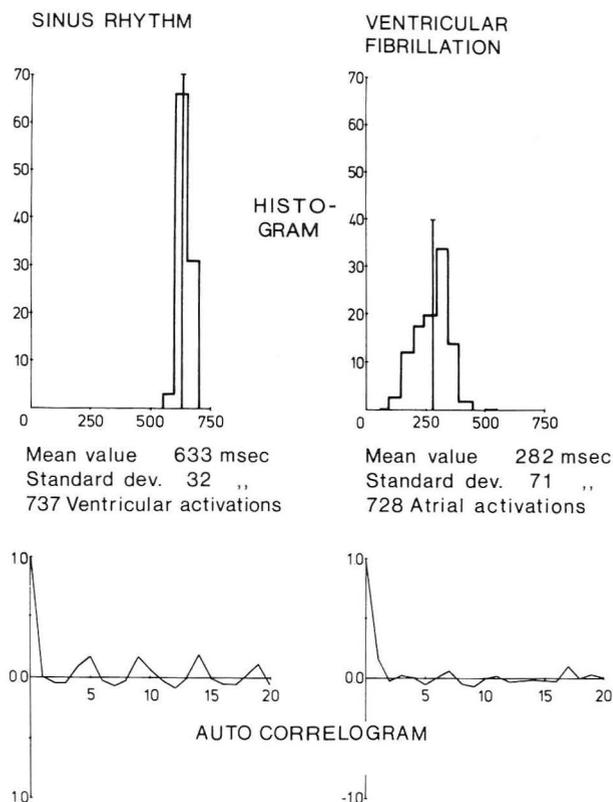


FIGURE 3. Histograms (above) and autocorrelograms (below) computed from electrograms recorded prior to (left) and during (right) ventricular fibrillation. The sinus rhythm histogram is very narrow, pointing to an almost constant rhythm. In the sinus rhythm autocorrelogram the influence of respiration can be seen (peaks at 5-beat intervals). A constant P-Q interval was present during the recording. The ventricular fibrillation histogram is rather skewed. The shortest interval probably is a measure of the refractory period of the atrioventricular conduction system during retrograde conduction. The ventricular fibrillation autocorrelograms suggest a random atrial rhythm. The similarity to histograms and autocorrelograms of R-R intervals obtained during atrial fibrillation in previously published studies^{1, 2} is striking.

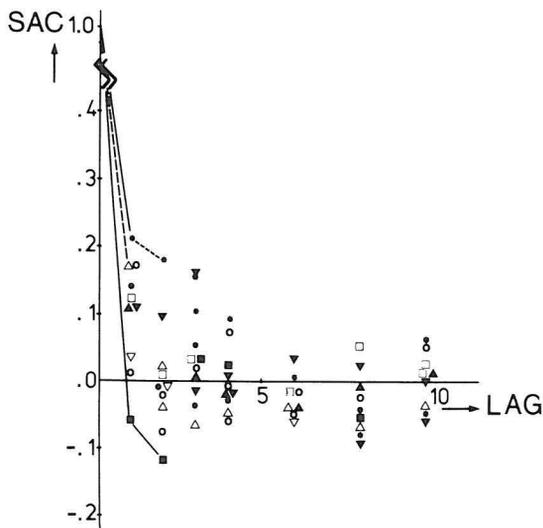


FIGURE 4. Plot of all of the autocorrelograms (SAC) from the 11 experiments in which an irregular atrial rhythm occurred during ventricular fibrillation. Symbols identify data from individual animals. Ordinate is lag in beats, abscissa is correlation. Only the first 10 correlation coefficients are shown. It can be seen that the first coefficient(s) may reach values as high as 0.2.

Atrial Septal Excitation during Ventricular Fibrillation

Plots of excitation of the interatrial septum during the control period (Fig. 5) showed the expected progression of depolarization from the region of the sinus node toward the AV junction.

During ventricular fibrillation the sequence of excitation was altered. The wave of excitation now moved generally from the region of the AV junction toward the sinus node. The sequence of excitation of the septum was not constant during fibrillation, and it appeared that excitation often proceeded simultaneously from the sinus node and the AV junction toward the central region of the interatrial septum.

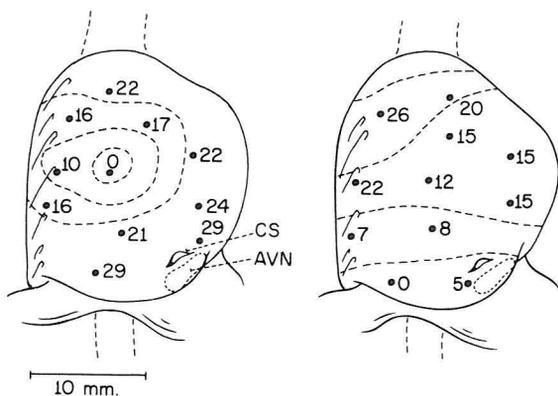


FIGURE 5. The sequence of atrial septal excitation during a control record (left), and during ventricular fibrillation (right). Dots show electrode positions. Coronary sinus (CS) and atrioventricular nodal regions (AVN) are indicated, as is the region of the superior vena cava. Figures indicate time of local depolarization in milliseconds after the earliest observed depolarization. During normal depolarization, activity spreads out from the central (probably sinus nodal) region toward the septal boundaries. During fibrillation, movement is outward from the AV nodal region.

Discussion

This study demonstrates that irregular excitation of the AV conduction system by the fibrillating ventricles results in retrograde atrial excitation. Evidence supporting this conclusion includes the following: (1) Potentials from the AV conduction system are not normally "locked" to atrial depolarization during ventricular fibrillation. (2) Plots of atrial excitation during irregular atrial rhythm demonstrate retrograde atrial excitation. (3) The irregular intervals between atrial beats in atrial interval histograms and autocorrelograms similarly indicate that the AV junction is driving the atria.

The atria do not always beat irregularly during ventricular fibrillation. When the atrial beat is regular, it apparently originates in the sinus node. Also, as demonstrated by Damato and co-workers,⁸ fusion between retrograde and sinus nodal activation of the atria may occur during ventricular fibrillation. Fusion also can explain why, in some of our 11 (out of 20) cases in which an irregular atrial rhythm was observed, the first autocorrelation coefficient differed slightly from zero (Fig. 4). Regularity or irregularity of the atrial rhythm may depend on the rate of depolarization of the sinus node. When there is rapid retrograde activation of the atria, the sinus region will be depolarized by the approaching wavefronts.⁹ When there is rapid sinus nodal depolarization, retrograde activation will be blocked and sometimes interference will occur, leading to fusion.⁸

Further, the excitation of the AV conduction system from the fibrillating ventricles is random, because impulses may enter the AV conduction system at many peripheral sites and result in a random pattern of atrial firing.

In dogs the atrial rate (200 beats/min) during ventricular fibrillation is significantly lower than the ventricular rate (300 beats/min) during atrial fibrillation.² This may show that the scaling down capability of the AV conduction system is lesser during antegrade than during retrograde conduction if one assumes that the number and strength of impulses reaching the AV junction during atrial fibrillation equal those reaching the Purkinje fibers during ventricular fibrillation. The tendency for concealed conduction to occur varies with the number and strength of impulses reaching the AV conduction system.¹ If the antegrade and retrograde scaling down capabilities of the AV conduction system do not differ substantially, then the difference in ventricular rate during atrial fibrillation and in atrial rate during ventricular fibrillation suggests that the number of impulses reaching the Purkinje fibers during ventricular fibrillation is larger than the number of impulses reaching the AV junction during atrial fibrillation. In any case, the random pattern of the ventricular rhythm during atrial fibrillation^{1, 2} and of the atrial rhythm during ventricular fibrillation suggests similar underlying processes. The depolarization rates of the common bundle during ventricular fibrillation are higher than the atrial firing rates, suggesting a blockage of impulses at the AV nodal-atrial junction.

During ventricular fibrillation the AV conduction system is depolarized by the surrounding fibrillating myocardium; this may contribute to maintenance of the ventricular fibrillatory process: a reentry mechanism¹⁰ may cause circus

movements between the conduction tissue (including the Purkinje fibers) and the surrounding myocardium.

The role of the AV conduction system during ventricular fibrillation (apart from its possible function in circus movements)⁹ is limited to scaling down the number of impulses eventually reaching the atria. The AV conduction system similarly reduces ventricular rate during atrial fibrillation.^{1,2} The irregularity of the atrial rhythm during ventricular fibrillation, as well as of the ventricular rhythm during atrial fibrillation, appears to be due to the irregularity of the fibrillatory process itself.

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