The Mechanism of Synchronization in Isorhythmic A-V Dissociation

Some Observations on the Morphology and Polarity of the P Wave During Retrograde Capture of the Atria

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SUMMARY
We studied 11 patients with spontaneous isorhythmic atrioventricular (A-V) dissociation occurring during cardiac surgery. The period of synchronization or accrochage was shown to result from retrograde capture of the atria by an A-V junctional rhythm. The P wave in leads II, III, and aVF was biphasic (−, +) during the period of synchronization, with the initial negative portion of the P wave or the entire P wave often buried within the QRS complex. It was concluded that isorhythmic A-V dissociation occurs only during the period when the rhythm alternates between an atrial rhythm and an A-V junctional rhythm and results when either the dominant pacemaker slows or the latent pacemaker accelerates.

Additional Indexing Words: Accrochage Retrograde P waves A-V junctional rhythm Arrhythmia

isorhythmic A-V dissociation\(^2\) on the basis of experiments that Segers had made on isolated frog hearts\(^3\). He recorded electrical activity from each of two isolated hearts, or parts thereof, and showed that although their intrinsic rates were different, when the hearts were juxtaposed there was apparent synchronization of the two pacemakers. When the period of synchronization was brief, he described it by the term "accrochage"; when the two independent rhythms maintained the same rate for longer periods, he used the term "synchronization." He assumed that a similar, but undefined, interaction caused a synchronous discharge of impulses by the atrial and ventricular pacemakers in isorhythmic A-V dissociation.

Although many cardiologists apparently have accepted Seger's experiments and conclusions\(^4-9\), Brumlik\(^10\) recognized that the records he obtained do not provide an exact

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analogue of the electrocardiogram in isorhythmic A-V dissociation. In Seger's experiments, prior to and after apparent synchronization, there was a continuous change in the phase shift between the two electrical impulses such that one electrogram first preceded the other by progressively shorter intervals and then, after the end of the period of synchronization or accrochage, followed it by progressively longer intervals. In isorhythmic A-V dissociation, in contrast, the electrocardiogram reveals a limited range of P-R and R-P intervals. Prior to synchronization the P-R interval decreases progressively; after the end of synchronization the P-R interval increases again. Typically, the P wave never moves through the S-T segment and T wave toward the subsequent QRS complex. This characteristic, as well as the mechanism responsible for synchronization, requires explanation.

Several other theories have been advanced in an attempt to provide a mechanism by which ventricular activity might influence atrial rate in A-V dissociation and block. On the basis of the suggestion made by van der Pol and van der Mark that the cardiac pacemaker might be thought of as a relaxation oscillator, Grant, Nadeau and James, and Roberge and co-workers have emphasized similarities between the interaction of sinus and A-V junctional pacemakers and a system of coupled relaxation oscillators. Recently, James has suggested that the pressure pulse in the sinus node artery might cause entrainment of the sinus by the ventricles. Rosenberg and Lepeschkin, although discussing A-V block rather than A-V dissociation, considered mechanical interaction between the ventricles and the atria as well as reflex mechanisms which would influence the rhythm of either chamber with respect to the other. None of these studies has provided a sufficient explanation for all of the electrocardiographic characteristics of isorhythmic A-V dissociation.

In this paper, we will present the results of studies on episodes of isorhythmic A-V dissociation which occurred during cardiac surgery. In these studies we have employed atrial and ventricular electrograms and direct electrical stimulation of the heart in an attempt to demonstrate the mechanisms responsible for synchronization and for the limited range of P-R and R-P intervals. Our results show that true A-V dissociation occurs only transiently during this arrhythmia and that the predominant rhythm is in fact an A-V junctional rhythm* with retrograde capture of the atria. A-V dissociation occurs only during the period when the rhythm alternates between an atrial rhythm and an A-V junctional rhythm and results when either the dominant pacemaker slows or the latent pacemaker accelerates.

**Methods**

Thirty patients were studied during cardiac surgical procedures. A summary of pertinent clinical data for 11 patients in whom isorhythmic A-V dissociation appeared is provided in table 1. The studies were initiated as part of an attempt to better understand the nature of arrythrias seen both during surgery and in the postoperative period. The protocol varied somewhat for each patient since the conduct of the study was determined by the nature and requirements of the surgical procedure.

For each patient an acrylic plaque containing five silver electrodes was sutured to the right atrium to provide a clear record of atrial activity during the surgical procedure and to permit atrial pacing at any time that control of atrial rate appeared desirable. In 10 cases this electrode plaque was located near the sino-atrial node; in one (patient 2), it was placed near the lower end of the sulcus terminalis. One pair of electrodes in the plaque was used only to record a bipolar atrial electrogram; another pair was used either to record a second electrogram or to stimulate. The fifth electrode contact served as a spare. A probe electrode, containing three silver contacts, was used primarily either to stimulate the ventricles or to record bipolar venricular electrograms; at times it also was employed to stimulate or record from other areas. Use of such an electrode to locate the bundle of His and other parts of the specialized conducting system has been described previously.

Stimuli were provided by a Medtronic pacemaker and delivered through an isolation transformer to provide effective isolation of the cardiac

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*A rhythm initiated by a pacemaker located somewhere between the NH region of the A-V node and the bifurcation of the bundle of His.
Table 1
Clinical and Therapeutic Information for 11 Patients Studied during Cardiac Surgery

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<th>Case</th>
<th>Age (yr)</th>
<th>Sex</th>
<th>Lesion</th>
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Abbreviations: VSD—ventricular septal defect; ASD—atrial septal defect; LVA—left ventricular aneurysm.
electrodes from ground. Bipolar electrograms and simultaneous standard and augmented ECG leads were monitored on an eight-channel Electronics for Medicine oscilloscope and recorded on photographic paper moving at either 25 or 50 mm/sec. ECGs were recorded with the preamplifier filters set for frequencies of 0.1 to 200 Hz (cycles/sec) and bipolar electrograms were recorded with the preamplifier filters set for frequencies of 12 to 200 Hz. Measurement of all intervals in the records was made with a vernier measuring device which had an accuracy of ±0.1 mm.

Results

In all cases, an atrial rhythm was present prior to the onset of isorhythmic A-V dissociation, whether the latter appeared with the chest opened or closed. During the arrhythmia, by recording the atrial electrograms, we demonstrated that after the P wave had merged with the QRS complex, the atrial electrogram configuration changed, the atrial

Figure 1

The records in A, B, and C are a continuous rhythm strip demonstrating A-V junctional rhythm with retrograde atrial capture, A-V dissociation, and atrial rhythm. The records in D show one cycle of the rhythm present immediately prior to the rhythm strip and those in E show one cycle of rhythm recorded immediately following that in C. SA identifies the bipolar electrograms recorded from the region of the sino-atrial node. In A-C, only lead I is shown with the SA electrograms. In D and E, leads I, II, III, aVR and aVL are shown simultaneously with the SA electrograms. Paper speed was 50 mm/sec and time lines indicate intervals of 1 sec. All numbers are in milliseconds. Circled numbers indicate the interval from the beginning of the QRS complex to the SA electrogram (Q-a). Other numbers indicate atrial cycle length (a-a) and ventricular cycle length (R-R).
cycle length became identical to the ventricular cycle length, and the atrial electrogram followed the ventricular complex at a fixed interval, that is, there was strong indication that an A-V junctional rhythm with retrograde atrial activation was present. When a P wave could be seen in the limb leads during this A-V junctional rhythm, that is, during the period of isorhythmic A-V dissociation thought to represent synchronization or accrochage, the P wave in leads II, III, and aVF was either biphasic (−, +) or positive.

**Observations in Case 1**

The first patient to be described was a 6-year-old girl undergoing surgery for correction of a ventricular septal defect. The rhythm seen in figure 1 was recorded after the chest had been opened and the heart exposed, but prior to heart bypass and cooling. In this and all other figures, all numbers are in milliseconds: the circled numbers represent the time interval between the beginning of the ventricular complex and the atrial electrogram (Q-a interval), and the other numbers represent atrial and ventricular cycle lengths measured from electrogram to electrogram (a-a cycle length) and from QRS to QRS (R-R cycle length). Panels A, B, and C are a continuous rhythm strip. The top two traces of each panel are atrial electrograms recorded from two electrode pairs in the acrylic plaque sewn near the sinoatrial (SA) node. The third trace is lead I. Panel D shows one cycle length of the rhythm recorded immediately prior to that in panel A. Panel E shows one cycle length of the rhythm recorded immediately after that in panel C. In addition to the atrial electrograms and lead I, panels D and E also show leads II, III, aVR, and aVL.

For the first four beats in figure 1A, the atrial electrogram follows the ventricular complex at a fixed interval of 67 msec over a range of ventricular cycle lengths from 549 to 560 msec. Because of this, and because the a-a cycle length equals the R-R cycle length, this rhythm is thought to represent an A-V junctional rhythm with retrograde atrial capture. Further support for this conclusion is provided by changes in the record which begin with the fifth beat. At this time the atrial cycle length decreased and A-V dissociation resulted. Also, during this period, the shape of both atrial electrograms changed (arrows), suggesting a different sequence of atrial activation. In fact, the atrial electrogram of the fourth beat, although it occurred at the expected interval for retrograde atrial activation from an A-V junctional pacemaker, appears to be a fusion beat. As the Q-a interval shortens and the ventricular cycle length remains longer than the atrial cycle length, the atrial electrogram passes through the QRS complex. With the seventeenth beat (arrow in fig. 1C), the ventricular complex begins to follow the atrial electrogram by a constant interval and the length of each ventricular cycle is the same as the length of the atrial cycle, that is, the atrial rhythm has captured the ventricles. The only period of isorhythmic A-V dissociation in the record is the brief period during which the faster atrial rhythm and the slower ventricular rhythm are dissociated. The records in figure 1D, obtained during A-V junctional rhythm with retrograde atrial capture, demonstrate no obvious P wave in any of the ECG leads. However, when the QRS complexes of figure 1D are compared with those of figure 1E, in which the P wave clearly precedes each QRS complex, there is a suggestion of a P wave at the end of each QRS complex in figure 1D.

Figure 2 shows the same sequence of events recorded from the same patient a few minutes later. The initial sequence (fig. 2A) demonstrates an A-V junctional rhythm with retrograde capture of the atria. The paper speed was then slowed to 25 mm/sec. A continuous record of 22 beats of A-V junctional rhythm with retrograde atrial capture, which occurred between figure 2A and B, is not shown. In figure 2B, beginning with the fifth beat, A-V dissociation occurs (arrow). A continuous record of eight beats of A-V dissociation between B and C (fig. 2)
is not shown, but C and D (fig. 2) are continuous. With the fourth beat in figure 2D, the atrial rhythm captures the ventricles, and A-V dissociation ends. Importantly, although the amplitude of each atrial electrogram has been reduced, with respect to that employed for figure 1, to make a clearer record, the configuration of these deflections during each of the three rhythm sequences (A-V junctional rhythm, A-V dissociation, and atrial rhythm) is the same as in figure 1.

The records in figure 3 from the same patient show that the ventricles have been captured by pacing the right atrium in the

![Figure 2](http://circ.ahajournals.org/)

*Figure 2*

These records are rhythm strips demonstrating A-V junctional rhythm with retrograde atrial capture (A and B), A-V dissociation (B, C, and D), and atrial rhythm (D). Only C and D are continuous. All numbers are in milliseconds. Circled numbers indicate Q-a interval. Other numbers indicate a-a or R-R cycle lengths. Paper speed is 50 mm/sec except for B where paper speed is 25 mm/sec. Time lines at intervals of 1 sec.
Figure 3

These records show a spontaneous A-V junctional rhythm with retrograde atrial capture which follows cessation of a driven atrial rhythm. The drive stimulus was delivered to the SA nodal region. S indicates the stimulus artifact in lead I. All numbers have the same significance as in figure 1. Time lines are at intervals of 1 sec; paper speed is 50 mm/sec.

Figure 4

This figure shows a rhythm produced from the bundle of His by driving through a probe electrode located over the common bundle. The top trace shows the stimulus artifact. S indicates the stimulus artifact in the ECG recordings. The number in parentheses is the interval between the drive stimulus and the SA electrogram. Time lines are at intervals of 1 sec; paper speed is 50 mm/sec.

region of the SA node through one of the electrode pairs of the electrode plaque. Prior to this, an A-V junctional rhythm had been present. The top trace records the stimulus delivered through one of the electrode pairs. The second trace is the atrial electrogram.
ISORHYTHMIC A-V DISSOCIATION

Figure 5

The records in A show a driven ventricular rhythm without retrograde atrial capture while those in B show a driven ventricular rhythm with atrial capture. The latter is followed by a spontaneous A-V junctional rhythm with retrograde atrial capture when, at the fifth complex, the ventricular drive ends. S identifies the stimulus artifact in the ECG. Time lines are at intervals of 1 sec. Paper speed is 50 mm/sec.

The records in A show a driven ventricular rhythm without retrograde atrial capture while those in B show a driven ventricular rhythm with atrial capture. The latter is followed by a spontaneous A-V junctional rhythm with retrograde atrial capture when, at the fifth complex, the ventricular drive ends. S identifies the stimulus artifact in the ECG. Time lines are at intervals of 1 sec. Paper speed is 50 mm/sec.

recorded through the other electrode pair. The third trace is ECG lead 1. A stimulus artifact (S) is seen in front of the P wave during atrial pacing. The ventricular cycle length is identical to the driven atrial cycle length of 497 msec. After the fourth beat, the stimulus was turned off and the first and subsequent spontaneous beats were A-V junctional beats with retrograde capture of the atria. Also, both the configuration of the atrial electrogram and the Q-a interval during this spontaneous rhythm with retrograde capture of the atria are identical to the atrial electrogram configuration and Q-a interval in figure 2A. This provides additional evidence that synchronization in this case represents retrograde capture of the atria during A-V junctional rhythm.

During the interval between recording the traces in figures 3 and 4, complete heart bypass was initiated, temperature, measured in the retrocardiac portion of the esophagus, was lowered to 34 C, and surgical repair of the ventricular septal defect was performed. The changes in the basic configuration of the QRS complex in figures 4 through 7 are a result of ventriculotomy.

In figure 4, the records show that the heart has been captured by stimuli delivered through a probe electrode located over the bundle of His. The top trace displays the stimulus artifact. The next two traces display the atrial electrograms and the next five traces are leads I, II, III, aVR, and aVL. A stimulus artifact (S) can be seen preceding each QRS complex. Evidence that we have created an A-V junctional rhythm with retrograde capture of the atria is clear. First, atrial activation follows that of the ventricles at a fixed interval of 80 msec and at the driven rate. Second, the atrial electrograms are identical to those of figures 2 and 3 which were recorded during spontaneous A-V junctional rhythm with retrograde capture of the
These records show an atrial rhythm produced by stimulating from a point between the coronary sinus ostium and the A-V node. S represents the stimulus artifact in the ECG. The number in parentheses represents the interval from the stimulus to the SA electrogram. Time lines indicate intervals of 1 sec. Paper speed is 50 mm/sec.

These records show an atrial rhythm produced by stimulating from a point between the coronary sinus ostium and the A-V node. S represents the stimulus artifact in the ECG. The number in parentheses represents the interval from the stimulus to the SA electrogram. Time lines indicate intervals of 1 sec. Paper speed is 50 mm/sec.

The atria. Third, the stimulus artifact precedes the initial inscription of the QRS complex in the ECG by 33 msec. This is an appropriate time for conduction from the bundle of His to the ventricles. The fourth point is provided by the traces in figure 5A. For this figure the ventricles have been stimulated directly and the ventricular complexes should be compared to those seen in figure 4. Note the absence of a latent period between the stimulus artifact and the inscription of the QRS complex when the ventricles are driven directly. The QRS complexes in figure 4 are similar to the last four complexes in figure 5B, which result from a spontaneous A-V junctional rhythm, and to the ventricular complexes in figures 6 and 7 which were recorded during driven and spontaneous supraventricular rhythms, respectively. The only difference between the ventricular complexes in figure 4 and those shown in figures 6 and 7 is the presence or absence of a P wave at the end of each QRS complex. The QRS complexes in figure 4, therefore, must originate above the common bundle. It is important to compare the interval of 112 msec between the stimulus and the atrial electrogram in figure 4 with the interval of 54 msec which separates the stimulus from the atrial electrogram in figure 6. For figure 6, the atria were paced from a site between the coronary sinus ostium and the A-V node. The driven cycle length is identical for figures 4 and 6. In both instances, the propagated impulses in the atria.
atria must have traveled in a retrograde direction to reach the electrodes recording the bipolar atrial electrograms from the SA nodal region. In fact, the atrial electrograms in figures 4 and 6 are identical. Because the interval between the ventricular and atrial complexes in figure 4 exceeds that in figure 6, in the former the impulse must originate below the A-V node. In fact, the difference in the intervals between the stimulus and atrial electrogram in figures 4 and 6 results almost entirely from retrograde A-V nodal conduction time. Thus there can be no doubt that by stimulating the bundle of His we have produced an A-V junctional (His) rhythm in figure 4 and that this rhythm mimics the rhythm present during the phase of "synchronization" in figures 1, 2, 3 and 5.

**Morphology and Polarity of Retrograde P Wave**

So far we have shown that, during synchronization, the atria are "locked" to the A-V junctional rhythm because the atria have been captured by the faster A-V junctional pacemaker. However, in relation to the concept and diagnosis of isorhythmic A-V dissociation, consideration of the morphology and polarity of the P wave during A-V junctional rhythm with retrograde capture of the atria is of more than passing interest. In figure 4, a P wave is seen at the end of each QRS complex. In figures 6 and 7, a P wave is seen preceding each QRS complex. If one compares the QRS complexes in figure 4 with those in figures 6 and 7, it can be seen that the retrograde P waves in figure 4 are positive in leads II and III. It should be noted that the Q-a interval of 83 msec in figure 4 is longer than the Q-a interval of 67 msec in figures 1 through 3 because of an increase in retrograde A-V conduction time. This causes the P wave to appear a little later in relation to the QRS complex. This prolongation of the Q-a interval

**Figure 7**

*Spontaneous atrial rhythm. Time lines indicate intervals of 1 sec. Paper speed is 50 mm/sec.*
resulted in part from a decrease in core temperature from 37°C to 34°C during heart bypass, and also from the faster heart rate.

In figure 5, the morphology and polarity of the retrograde P wave are better delineated. For this record, the right ventricle was stimulated through the probe electrode. The numbers in the top trace represent the stimulus cycle length, and the stimulus artifact (S) can be seen in the ECG. In figure 5A, the ventricles are captured at the driven cycle length, but retrograde atrial capture has not yet occurred. Note the appearance of the S-T segment. In figure 5B, for the first four beats, the a-a cycle length equals the R-R cycle length, the Q-a interval is fixed at 216 msec, and the configuration of the atrial electrograms is identical to that recorded during retrograde activation of the atria (figs. 2 to 4). It is clear, therefore, that in figure 5B there is retrograde capture of the atria. Because of the long retrograde conduction time, reflected by the long Q-a interval, the P wave appears in the S-T segment of the ECG. A comparison of the S-T segments in figure 5A with the S-T segments of the first four beats in figure 5B, leaves no doubt that all the P waves in the latter are biphasic and those in leads II and III are negative-positive. The ventricular drive is lost after the fourth beat in figure 5B when the stimulus strength, while being decreased to zero, becomes subthreshold. With the fifth beat, a spontaneous A-V junctional rhythm appears. Note that, again, the a-a cycle length equals the new R-R cycle length, the Q-a interval is now fixed at 102 msec, and the configuration of the atrial electrograms remains unchanged, indicating that again there is retrograde capture of the atria, this time by A-V junctional rhythm. If we compare the last four QRS complexes in figure 5B with the QRS complexes in figures 6 and 7, it is clear that in figure 5B a P wave appears at the end of each QRS complex and that in leads II and III, the visible part of the P wave is positive. However, only the terminal positive deflection of the retrograde P wave is visible.

Table 2

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*P-P cycle length = R-R cycle length.
†Q-P interval constant.
‡When atrial drive was stopped A-V dissociation occurred.
wave is seen in leads II and III. The earlier, negative deflection of the P wave is masked by the QRS complex.

A clearly positive P wave in leads II and III ordinarily suggests that the atrial rhythm is independent of the A-V junctional rhythm. However, as clearly demonstrated in this case, the apparent shape of the P wave may be misleading. In this example atrial activation results from the A-V junctional rhythm. The masked initial negative deflection of the P wave permits only the positive portion of the P wave to appear. An assumption that the P wave is truly positive suggests, in turn, that the atria are driven by an atrial pacemaker and the rhythm is A-V dissociation with synchronization or accrochage.

Observation in Other Cases

Table 2 summarizes the data from all cases studied. As can be seen, the experimental protocol varied somewhat from patient to patient. However, in all patients during the period of synchronization, the R-R cycle length equaled the a-a cycle length, and the Q-a interval was constant. In all cases in which appropriate records were made, the configuration of the atrial electrogram was the same during atrial rhythm and A-V dissociation but changed during the period of synchronization. This finding clearly suggests that there was a change in the sequence of atrial depolarization. In the one exception, case 4, an electrogram was not obtained because records were made before the thorax had been opened.

In all cases in which the atria were driven during synchronization, the ventricles were captured by the faster driven atrial rhythm; this demonstrated the absence of antegrade A-V conduction block. In all but one case, when the atrial drive stopped, the first spontaneous beat was an A-V junctional beat with retrograde atrial capture. In the one exception (case 9), although the first spontaneous beat was an A-V junctional beat, the atria were captured by an atrial pacemaker, that is, there was A-V dissociation. In all cases, during “synchronization” the P wave was either biphasic or positive in leads II, III, and aV.F. In all five cases in which it was attempted, the P wave seen during synchronization was reproduced when the ventricles were driven through the probe electrode at a rate just faster than the spontaneous rate, and there was retrograde capture of the atria.

We believe that the detailed discussion of the first case and the data presented in Table 2, provide strong evidence that the period of synchronization or accrochage seen in our records represents an A-V junctional rhythm with retrograde capture of the atria. However, certain aspects of the other cases will be discussed because they illustrate additional points of importance.

Case 9 (fig. 8) illustrates in yet another way an important finding demonstrated by case 1. This record was made during the period of complete heart bypass. The atria were captured during a spontaneous A-V junctional rhythm by stimulation from the atrial endocardium very near if not immediately over the A-V node through the probe electrode. The top trace shows the stimulus artifact. The next two traces are atrial electrograms recorded from the plaque electrode in the SA nodal area. The lower three traces are leads I, II, and aVF. The numbers in parentheses represent the interval between the stimulus and the atrial electrogram. For the first three beats there was an A-V junctional rhythm with retrograde capture of the atria. Note that the R-R cycle length equals the a-a cycle length, and the Q-a interval is constant. The stimulus did not capture the atria until the fourth beat as is shown by the constant interval between the stimulus and the atrial electrogram which appears at this time. However, the ventricles were not captured for an additional two beats. During the entire record, the configuration of the atrial electrogram did not change. Only the a-a cycle length changed when the atria were captured by the stimuli delivered through the probe electrode. Since during the driven atrial rhythm, the probe electrode was stimulating the atria from the A-V nodal region,
the propagated impulse must have traveled in a retrograde direction to reach the bipolar recording electrodes in the SA nodal region. Since the configuration of the atrial electrogram was unchanged both during spontaneous A-V junctional rhythm and during the driven atrial rhythm, it can be concluded that during the A-V junctional rhythm the propagated impulse also traveled in a retrograde direction in the atria to reach the same recording electrodes in the SA nodal region. These records provide additional strong evidence for the thesis that synchronization during A-V dissociation represents retrograde atrial capture by the A-V junctional rhythm.

The next example, from case 2, is shown in figure 9. The top trace of each panel of this continuous record is a record of the stimulus delivered through one pair of electrodes of a plaque electrode sewn on the right atrium near the caudal end of the sulcus terminalis. The second trace is the atrial electrogram recorded through another electrode pair in the same plaque electrode. The third trace is lead II. In panel A, the initial rhythm is an A-V junctional rhythm. For the first four beats, the a-a cycle length equals the R-R cycle length, and the Q-a interval is constant. Beginning with the fifth beat, the atria are captured by the driving stimuli and with the ninth beat, the driven atrial rhythm captures the ventricles. In panel B, as soon as the driving stimulus is turned off, the first and subsequent beats arise in the A-V junctional region, and there is retrograde capture of the atria. At this time the a-a cycle length equals the R-R cycle length and the Q-a interval is constant. This figure demonstrates...
again that during an A-V junctional rhythm with retrograde atrial capture an atrial rhythm can be produced by driving the atria at a rate faster than the spontaneous rate and that the spontaneous rhythm seen during the period of synchronization is an A-V junctional rhythm with retrograde atrial capture. However, this record is shown also because the P wave in lead II is negative during the driven atrial rhythm. This observation is important in relation to the proposition that the morphology and polarity of the P wave need not provide an accurate indication of site of origin of the excitatory impulse.

The examples of isorhythmic A-V dissociation presented so far were all recorded after thoracotomy and initiation of other surgical procedures. However, other examples were obtained prior to the initial surgical intervention, during induction of anesthesia, and thus were not influenced by the presence of an open chest. During anesthetic induction the rhythm often changed from an atrial rhythm to one in which either no obvious P wave could be seen or one in which an apparently positive P wave followed a normal QRS complex. The records in figure 10A are an example of the former. In this case (no. 3), during induction there was a long period of A-V dissociation with no obvious P waves in lead II. The continuous records in figure 10B to E were made 3 minutes later. In figure 10B, as evidenced by the increased amplitude of the R wave, the P wave is seen marching through the QRS complex during a period of A-V dissociation. A-V dissociation persists through figure 10C and D until the fourth beat in figure 10E when the atrial rhythm captures the ventricles. A suspicion that a negative P wave

Figure 9

(A) The records show a driven atrial rhythm produced during spontaneous A-V junctional rhythm with retrograde atrial capture. (B) The records show a spontaneous A-V junctional rhythm with retrograde atrial capture following cessation of atrial drive. In both A and B, the driven atrial rhythm was produced by stimulating from the caudal end of the sulcus terminalis. Circled numbers indicate either Q-a or a-Q intervals. Time lines indicate intervals of 200 msec. Paper speed is 50 mm/sec.
Figure 10
Rhythm shown in ECG lead II during induction of anesthesia. Record A precedes B by 3 min; records B through E are continuous. Time lines indicate intervals of 1 sec. Paper speed is 50 mm/sec. P-P indicates the atrial cycle length, R-R indicates the ventricular cycle length.

Figure 11
Rhythms during induction of anesthesia. The rhythm in 11A preceded that in 11B by 45 sec. P-P indicates atrial cycle length. R-R indicates ventricular cycle length. Circled numbers indicate Q-P interval. Time lines indicate intervals of 1 sec. Paper speed is 50 mm/sec.
ISORHYTHMIC A-V DISSOCIATION

(A) Unsuccessful attempt to drive atria during A-V junctional rhythm with retrograde atrial capture. Arrows point to retrograde P waves. P-P indicates atrial cycle length. R-R indicates ventricular cycle length.

(B) Successful attempt to drive atria during spontaneous A-V junctional rhythm. Arrows point to retrograde P waves. Paper speed is 50 mm/sec. Time lines indicate intervals of 100 msec.

These findings suggest that there is an A-V junctional rhythm with retrograde atrial capture. However, this positive P wave, which would be unusual in the case of retrograde atrial activation, very likely is biphasic (−, +), as has been shown in figure 5, and appears positive only because the initial negative deflection is concealed by the ventricular complex. Since a similar rhythm did not appear after thoracotomy, direct support of this suggestion is lacking. Nevertheless, we believe that the rhythm recorded from this patient during induction of anesthesia is another example of an atrial rhythm alternating with an A-V junctional rhythm during which there is retrograde atrial capture with an apparently positive P wave in lead II.

The record shown for the last case (no. 11) is a continuous rhythm strip which demonstrates positive retrograde P waves (arrows).
during A-V junctional rhythm with retrograde atrial capture (fig. 12). The top trace in both panels A and B represents the artifact of a stimulus delivered through a probe electrode to the SA nodal region. The bottom trace in both panels is lead II. In panel A, the stimulus fails to capture the atria and there is an A-V junctional rhythm with retrograde atrial capture (R-R cycle length equals P-P cycle length). In panel B, the stimulus strength has been increased and the stimulus cycle length is being decreased. Beginning with the third beat, the atria are captured. With the fourth beat, A-V dissociation clearly ends as the driven atrial rhythm captures the ventricles. If one compares the S-T segments during the driven atrial rhythm and the A-V junctional rhythm, it is clear that the P wave which appears during the latter and distorts the S-T segment is a predominantly positive retrograde P wave.

### Discussion

When an atrial rhythm with positive P waves in leads II, III, and aVF alternates with an A-V junctional rhythm which shows negative P waves following the ventricular complex at a fixed interval in the same leads, there is general agreement that retrograde atrial activation is present.6, 8, 9 Also, many published examples of A-V junctional rhythm and several of our records show no visible P wave in body surface leads because it is completely obscured by the ventricular complex. This is accepted as a standard manifestation of this arrhythmia.6, 8, 9 However, when the P waves in leads II, III, and aVF appears to be positive in the presence of an A-V junctional rhythm, the polarity of the P wave is thought to indicate that the atria are activated by an atrial pacemaker, and a constant temporal relationship between the ventricular and atrial complexes is explained on the basis of “synchronization” or “accrochage.”

For many of the published examples of isorhythmic A-V dissociation,2, 4-6, 8-11, 22-34 both the period of synchronization, or accrochage, and the P wave polarity can be explained by our findings. Since many have not realized that during retrograde atrial activation the P wave need not be purely negative in leads II, III and aVF, but can be biphasic (−, +) or largely positive, they have invoked the phenomenon of synchronization to explain a rhythm which is in fact an A-V junctional rhythm with retrograde atrial capture.

Our conclusions are supported by many observations made by others. It is of interest that Gallavardin and associates22 who published the first ECG demonstrating isorhythmic A-V dissociation, and Gallavardin and Veil37 considered the possibility that positive P waves following the QRS complex in the standard bipolar ECG leads might represent retrograde capture of the atria by the A-V junctional rhythm. Many others35-38 published examples of experimentally produced A-V junctional rhythms with positive P waves during retrograde atrial capture. Dressler and Roessler39 published an example of a human ECG which showed A-V junctional rhythm and retrograde atrial capture with positive P waves following the QRS complex in lead II. Brumlik10 has shown in experiments on the dog that retrograde depolarization of the atria can result in positive P waves in lead III. Moore and associates40 showed experimentally for both open and closed chested dogs that stimulation of the ventricles with retrograde capture of the atria produces positive P waves in II, III, and aVF. They also showed that when the atria were stimulated from a site just anterior to the dorsal lip of the coronary sinus ostium, the P wave was positive in leads II, III, and aVF. Our recent unpublished data on the sequence of atrial activation in dogs and man support these findings.

In summary, the findings reported here, and those summarized in the preceding paragraph, show that the apparent polarity and morphology of the P wave are at best an unreliable indication of the site of origin of atrial activity in A-V junctional rhythms. In such rhythms, evidence of retrograde atrial activation from the A-V junctional pacemaker
ISORHYTHMIC A-V DISSOCIATION

is afforded by the identity of P-P and R-R intervals over a range of ventricular cycle lengths and by the constant temporal relationship between the ventricular complex and the P wave.

Acknowledgment

The authors would like to express their appreciation to Dr. M. Irene Ferrer for her valuable comments and criticisms.

References

12. van der Pol, B., and van der Mark, J.: The heartbeat considered as a relaxation oscillation and an electrical model of the heart. Phil Mag 6: 763, 1928.

Circulation, Volume XXXVIII, November 1968
An Unique Pacemaker Complication

. . . The patient was seen again on June 2, 1967, several hours after the sudden onset of irregular epigastric jerking movements, occasional spasms of involuntary inspiration, and regular involuntary supinating movements of the right forearm and hand; . . . . The electrocardiogram showed failure to pace and first-degree heart block with a ventricular rate of 50 per minute.

The pacemaker twiddler’s syndrome represents a new clinical entity in which lead traction is the result of a capstan effect produced by a rotating pulse generator within a pocket which has become too capacious. Rotation can occur either spontaneously or as the result of repeated twiddling on the part of the patient, as in our case.—The Pacemaker-Twiddler’s Syndrome: A New Complication of Implantable Transvenous Pacemakers. COLIN E. BAYLISS, DONALD S. BEANLANDS, and RONALD J. BAIRD. Canad Med Ass J 99: 371, 1968.
The Mechanism of Synchronization in Isorhythmic A-V Dissociation: Some Observations on the Morphology and Polarity of the P Wave During Retrograde Capture of the Atria

ALBERT L. WALDO, KARI J. VITIKAINEN, PAUL D. HARRIS, JAMES R. MALM, BRIAN F. HOFFMAN, Bruce J. Innes and Gerard A. Kaiser

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