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Role of Atrial Fibrillation and Atrioventricular Conduction (Including Wolff-Parkinson-White Syndrome) in Sudden Death

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A short refractory period of the accessory pathway is considered a major threat for sudden death in patients with Wolff-Parkinson-White syndrome and atrial fibrillation. RR interval and QRS signal analysis together with signal analysis of a bipolar high right atrial electrogram were obtained in six patients with Wolff-Parkinson-White syndrome and either induced or spontaneous atrial fibrillation. A record of a sufficiently long episode of atrioventricular (AV) conduction by way of the bypass tract that could be used for satisfactory RR interval sequence and QRS analysis was obtained from only one patient.

The results were compared with those of a representative patient with atrial fibrillation and normal AV nodal-His conduction. In a patient with Wolff-Parkinson-White syndrome, atrial fibrillation and AV conduction by way of the bypass tract may exhibit high ventricular rates (median RR intervals of about 300 ms) and long/short RR interval ratios of just over 1 (RR intervals not exceeding 400 ms). The right atrial electrogram showed a noiselike excitation pattern. This study suggests that rather than a short refractory period of the bypass tract, it is lack of concealed conduction, responsible for the presence of long RR intervals, that allows the ventricles to reach very high ventricular rates and at times to fibrillate. The normal AV nodal-His system seems to protect the heart against high ventricular rates and ventricular fibrillation during atrial fibrillation by its relatively long refractory period and capacity to induce long RR intervals by means of concealed conduction.

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During atrial arrhythmias, as for example atrial fibrillation, the atrioventricular (AV) nodal-His conduction system protects the heart against excessively high ventricular rates as well as against ventricular fibrillation (1–3). Because ventricular fibrillation is considered to be the most frequent cause of sudden death (4–7), a normal functioning AV conduction system is a crucial safeguard against sudden death in the presence of rapid ectopic atrial rhythms. The question is how does the AV nodal-His system achieve this ability for protection?

The unique feature of death in a patient with the Wolff-Parkinson-White syndrome is the presence of an accessory AV pathway with a short refractory period (8). Patients with the Wolff-Parkinson-White syndrome and atrial fibrillation are particularly, although rarely, at risk for sudden death (1,9,10). The short refractory period of the bypass tract has been held primarily responsible for allowing high ventricular rates and, on rare occasions, ventricular fibrillation.

Spontaneous atrial fibrillation is a common occurrence in dogs (11). Despite the fact that the functional refractory period of the canine AV nodal-His system is only seldom longer and is, in fact, often shorter (12) than that of the majority of bypass tracts in patients with the Wolff-Parkinson-White syndrome, atrial fibrillation does not seem to be a major cause for sudden death in these animals. Conduction velocity in the His bundle and its branches and the ventricular activation pattern in the dog heart do not differ significantly from those in the human heart (13,14). Therefore, the threat of ventricular fibrillation in patients with the Wolff-Parkinson-White syndrome and atrial fibrillation may be due not solely to the short refractory period of the accessory pathway, but also to lack of other properties that lengthen the RR interval.

This report deals with RR interval- and QRS signal analysis in patients with the Wolff-Parkinson-White syndrome during atrial fibrillation and conduction by way of the bypass tract. This may provide additional and different information

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about the electrophysiologic properties of the accessory pathways than can be obtained by programmed stimulation alone. As a consequence, the protective function of the normal AV nodal-His system against sudden death in case of atrial arrthymias may be better appreciated.

Methods

In 11 patients with the Wolff-Parkinson-White syndrome and atrial fibrillation, the histogram and serial autocorrelogram of RR intervals for ventricular rhythm analysis as described in previous studies (15–17) was used. The electrocardiogram was recorded on magnetic tape using the limb lead or one of the precordial leads with the tallest R wave for QRS detection and computation of the RR intervals.

The electrocardiograms were always recorded with the patient in the supine position under steady state conditions in a temperature-controlled room. The records had to be long enough to obtain a sufficient number of RR intervals for acceptable data analysis. In 6 of the 11 patients, intracardiac recordings were obtained during clinical electrophysiologic studies. Some were obtained before and some after drug therapy (Table 1). During these procedures, atrial fibrillation occurred either spontaneously or was induced by programmed atrial stimulation. A high right atrial bipolar electrogram was recorded on magnetic tape and subjected to off-line signal analysis as described previously for ventricular fibrillation (18). Basically, 10 ms samples of the recorded signal were taken and the obtained values subjected to serial autocorrelation analysis. Signal analysis was also used for the study of the electrocardiogram during atrial fibrillation and conduction by way of the bypass tract and compared with QRS signal analysis during atrial fibrillation and normal AV nodal-His conduction.

Results

It was difficult to obtain sufficiently long records of stable and pure pre-excitation during atrial fibrillation for adequate analysis. Because the electrophysiologic properties of the bypass may vary (19), the episodes of pre-excitation were frequently interrupted by normal AV nodal-His conduction, resulting in fusion complexes or ventricular activation with normal QRS configurations. Therefore, the record of only one patient (Table 1, Patient 1a) with a sufficiently long episode of AV conduction by way of the bypass tract could be used for satisfactory RR interval and signal analysis.

Figure 1 shows the electrocardiogram (lead V_1) and the bipolar atrial electrogram of Patient 1a without medication. Early QRS complexes, probably extrasystoles, originating in or near the bypass tract, are indicated by arrows. In Figure 2, the signal analysis of the atrial electrogram of the same patient is shown. The serial autocorrelogram of the successive samples demonstrates that, with the exception of the first coefficients, all further coefficients do not differ from zero. Figure 3 shows RR interval duration as a function of RR interval sequence number. Of the 284 intervals, 261 are longer than 250 ms and 23 are shorter. In this case, the functional refractory period of the accessory pathway appears to be about 250 ms. The RR intervals shorter than 250 ms are almost certainly caused by the extrasystoles (arrows in Fig. 1) and the QRS complexes directly following them. The absence of RR intervals over 375 ms should be noted. The long/short RR interval ratio of the pre-excitation complexes is less than 1.5.

In Figure 4, the same presentation of data is constructed from RR intervals recorded in a dog with atrial fibrillation, normal AV conduction and without medication. The functional refractory period appears to be no more than 200 ms. Nevertheless, the long RR intervals reach values of about

Table 1. Data for Six Patients With the Wolff-Parkinson-White Syndrome and Atrial Fibrillation

Patient	Localization	Medication	ERP (ms)		During AF	
			Bypass	Atrium	Minimal RR (ms)	Mean RR (ms)
1a	Left posterior	—	—	—	170	305
1b	Left posterior	Amiodarone	≤250*	250	210	360
2	Septal	—	270†	200	200	250
3	Left lateral	—	260[2]	220	290	—
4	Left lateral	Amiodarone	—	—	260	390
5	Septal	Quinidine, amiodarone	290*	<300	210	270
6a	Left lateral	—	<305†	250	215	300
6b	Left lateral	Amiodarone	≤270†	270	230	375

*During cycle length of 500 ms; †during cycle length of 600 ms. AF = atrial fibrillation; ERP = effective refractory period.

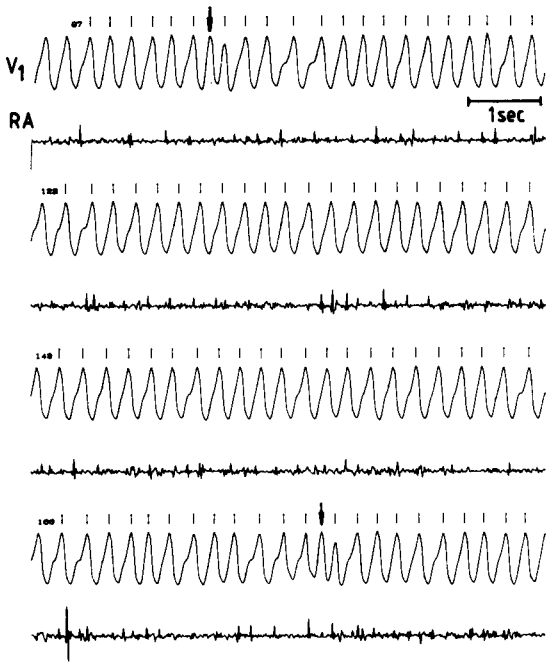


Figure 1. Patient 1. Lead V_1 and bipolar atrial electrogram during induced atrial fibrillation and AV conduction by way of the bypass tract. The extrasystoles are marked with an **arrow**. The **vertical bars** indicate the R wave selection by the computer. RA = right atrium.

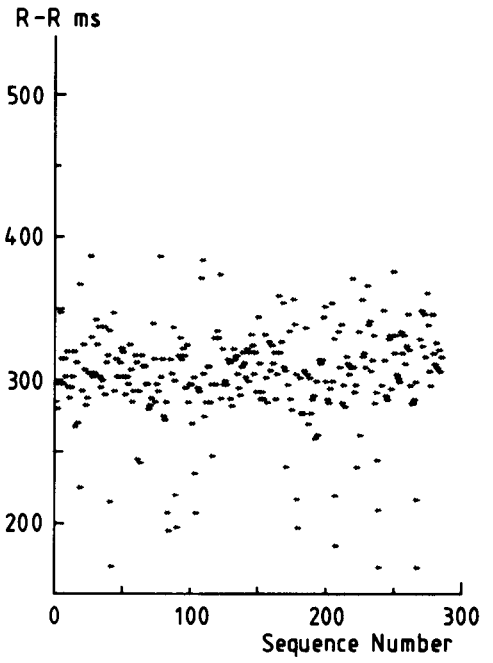


Figure 3. Patient 1. RR interval duration as a function of RR sequence number of the ventricular rhythm shown in Figure 1. The intervals below the 250 ms level are probably due to the extrasystoles and the QRS complexes directly following the extrasystoles. For further details, see text.

500 ms and the long/short RR interval ratio is close to 2.5. The median RR intervals in the dog and our patient with the Wolff-Parkinson-White syndrome are almost equal (about 300 ms). Figure 5 shows the histogram and serial autocorrelogram of the RR intervals of Patient 1 during atrial fibrillation and conduction by way of the bypass tract. It can

Figure 2. Patient 1. Serial autocorrelogram (SAC) of the atrial electrogram during atrial fibrillation and AV conduction as shown in Figure 1. With the exception of the first coefficient, the correlation coefficients do not differ from zero. The signal has noise-like characteristics. The **lines horizontal to the X axis** are the 95% confidence limits. Sampling interval = 10 ms.

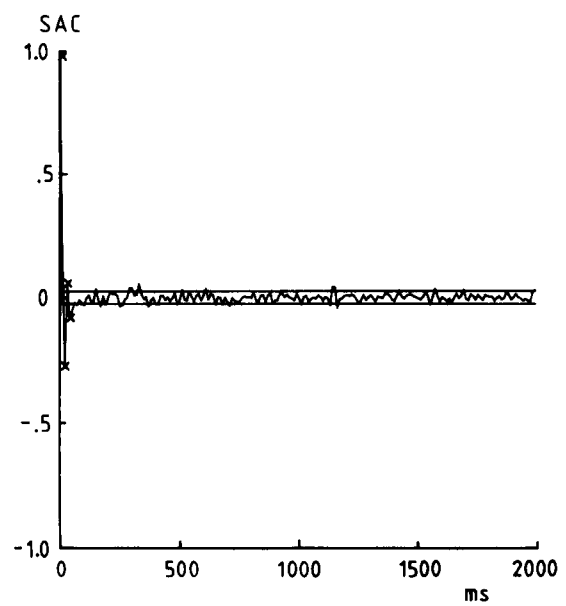
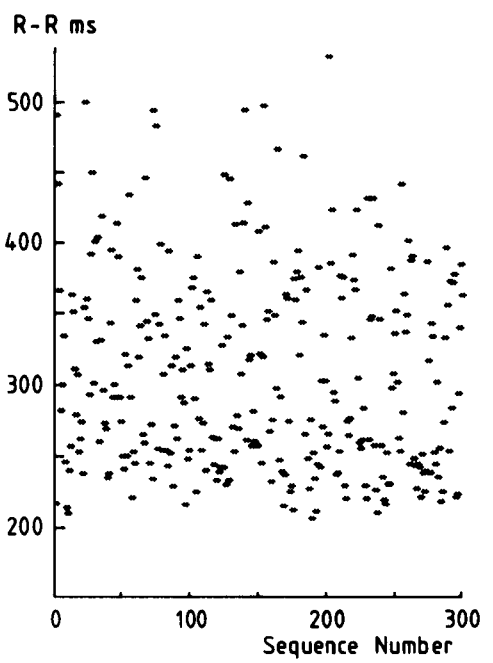


Figure 4. RR interval duration as a function of RR sequence number of the ventricular rhythm of a dog (without medication) with atrial fibrillation and normal AV conduction. For further details, see text.



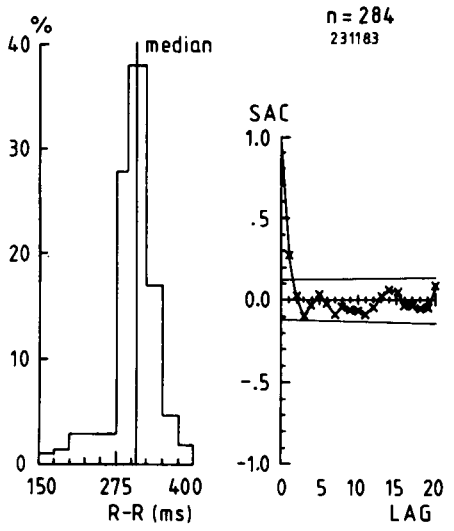


Figure 5. Patient 1. Histogram (**left**) and serial autocorrelogram (SAC) (**right**) of the ventricular rhythm shown in Figure 1. The **lines horizontal to the X axis** represent the 95% confidence limits. Within those limits, the correlation coefficients are statistically not different from zero. LAG = coefficient number. For further details, see text.

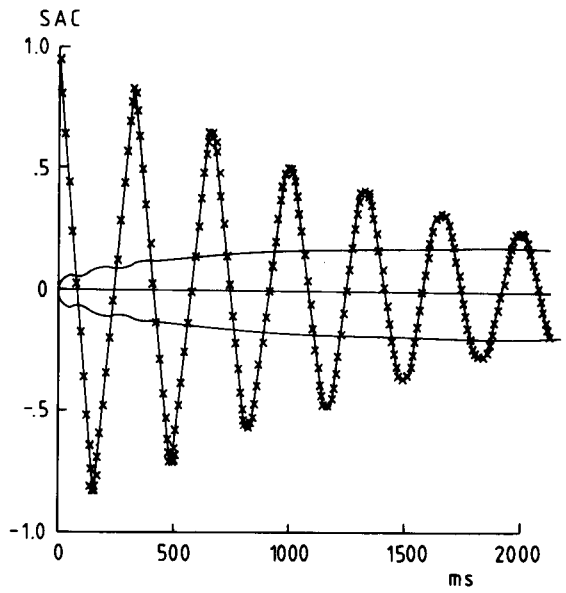


Figure 7. Patient 1. Signal analysis of the electrocardiogram shown in Figure 1. SAC = serial autocorrelogram of the successive voltage samples of the electrocardiogram. The **lines horizontal to the X axis** represent the 95% confidence limits. Sampling interval = 10 ms. For further details, see text.

be seen that the histogram is not positively skewed. The median RR interval is just greater than 300 ms.

The serial autocorrelogram of the RR intervals, however, demonstrates that, with the exception of coefficient 1, which is slightly positive, the coefficients do not differ from 1. The positivity of the first coefficient is due to the short RR intervals (arrows in Fig. 1). For comparison, in Figure 6 the histogram and the serial autocorrelogram of a representative patient with atrial fibrillation and normal AV nodal-His conduction are shown. The difference between this histogram and that of Patient 1 in Figure 5 should be noted. The histogram of our "normal" patient is positively skewed, with RR intervals ranging between 350 ms and 900 ms and

Figure 6. Histogram (**left**) and serial autocorrelogram (SAC) (**right**) of a patient (not included in Table 1) with atrial fibrillation and normal conduction through the AV nodal-His system. This patient did not receive any medication. The histogram and especially the median RR interval should be compared with that in Figure 5. LAG = coefficient number.

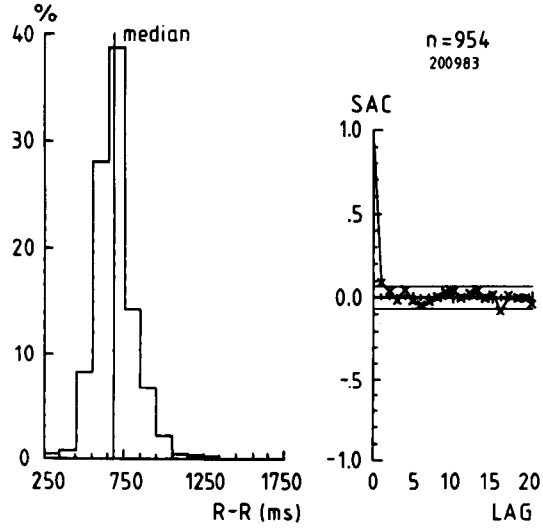
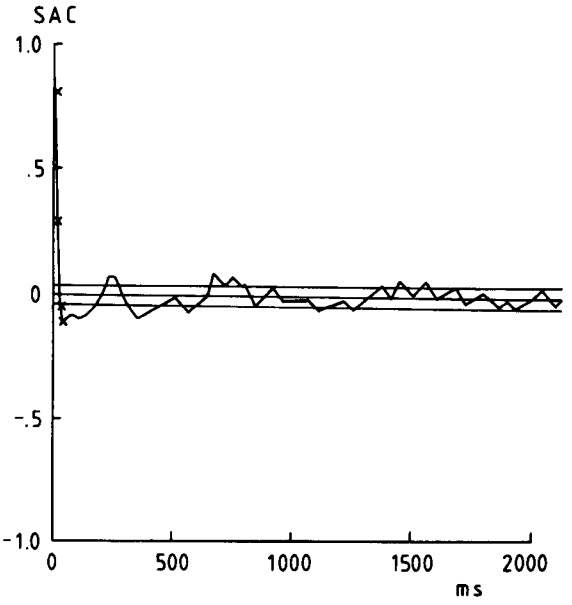


Figure 8. Signal analysis of the electrocardiogram of the patient with atrial fibrillation and normal AV conduction shown in Figure 6. This plot should be compared with the one in Figure 7. Abbreviation and format as in Figure 7.



with a median RR interval of close to 700 ms. The serial autocorrelogram demonstrates that the ventricular rhythm is random.

In Figure 7, the signal analysis of the electrocardiogram of Patient 1 with atrial fibrillation and conduction through the bypass tract is shown. It demonstrates (like the histogram) that all RR intervals have nearly the same duration and that most of the QRS complexes have a wide and almost identical form. For comparison, the signal analysis of the electrocardiogram of a patient with atrial fibrillation and normal AV nodal-His conduction is shown in Figure 8. This presentation more clearly demonstrates the greater variation in RR interval duration.

Discussion

Of the six patients studied, we were able to obtain a sufficiently long record of pure pre-excitation during atrial fibrillation (although with a number of possible extrasystoles) in only one patient (Patient 1, episode a). Nevertheless, this single record in one patient may be representative of the nature of bypass tract conductivity in patients who may be at risk of sudden death. It stands to reason that the suppositions derived from our data need further confirmation.

Although dogs with atrial fibrillation and normal AV conduction have a refractory period of the AV nodal-His system that is shorter than that of the bypass tract in most patients with the Wolff-Parkinson-White syndrome (19), such animals with atrial fibrillation do not appear to die suddenly. It is reasonable, therefore, to hypothesize that the major protective function of the AV nodal-His conduction system is not so much its longer refractory period, but its capacity to produce long RR intervals by means of concealed conduction. RR interval sequence- and QRS signal analysis enable one to test this hypothesis.

Signal analysis of the bipolar atrial electrogram obtained during atrial fibrillation in patients with the Wolff-Parkinson-White syndrome and conduction by way of the bypass tract demonstrates that the atrial excitatory process may indeed be very close to random. Occasionally, the first coefficient or coefficients of the serial autocorrelograms of the signal samples differ slightly from zero. We do not have an explanation for this observation. If, however, these atrial electrograms are representative of atrial fibrillation in patients with normal AV nodal-His conduction, then the results of the atrial electrogram signal analysis support our former views and offer an unconstrained explanation for the random pattern of the ventricular rhythm (15–17).

There was no opportunity to record both the atrial electrogram and the ventricular rhythm during alternating episodes of normal AV conduction and conduction through the bypass tract in the same patient with atrial fibrillation. When there is a short refractory period of the bypass tract, the atrial impulses during atrial fibrillation conduct preferentially through the bypass tract rather than over the AV nodal-His system.

Protective mechanism of the normal AV node. RR interval sequence- and signal analysis of the electrocardiogram of Patient 1 with atrial fibrillation and AV conduction by way of an accessory pathway demonstrate 1) a short refractory period of the bypass tract, and 2) a long/short RR interval ratio of just over 1. This observation provides some insight into the role of the AV nodal-His system as a protective mechanism against potentially lethal ventricular arrhythmias. The protective mechanism of the normal AV nodal-His system consists of 1) a long (or longer) functional refractory period, and 2) the ability to induce long RR intervals. The opposite is probably also correct; namely, absence of the normal AV conduction properties during pre-excitation and, particularly, a lack of concealed conduction are the major factors that may be responsible for the rapid ventricular rates, ventricular fibrillation and, thus, sudden death during atrial arrhythmias such as atrial fibrillation. In addition, pre-excitation of a ventricular area that is normally activated late may make the ventricles more susceptible to ventricular fibrillation (20).

Functionally and morphologically, the normal AV node consists of nonuniform cells (21,22). This probably explains why the AV node has the capacity for concealed conduction. In 1973, Wellens and Durrer (23) studied the tissue properties of the accessory pathways and suggested that irrespective of the type of cells constituting the accessory pathways, it can be assumed that electrophysiologically these cells behave uniformly.

From the foregoing discussion, it may be assumed that in addition to introducing an appropriate delay between atrial and ventricular excitation and contraction during sinus rhythm (24), the major role of the normal AV nodal-His system appears to be the protection of the heart against potentially lethal ventricular arrhythmias in the presence of rapid atrial arrhythmias.

Conclusions

1. Because of the relatively short refractory period of the bypass tract and its limited capacity to produce long RR intervals by means of concealed conduction, patients with the Wolff-Parkinson-White syndrome and atrial fibrillation with conduction through the bypass tract may have high ventricular rates and be subject to ventricular fibrillation. This is not necessarily caused by the short refractory period itself, but may be due to the more uniform electrophysiologic properties of the bypass tract tissue.

2. The normal AV nodal-His conduction system protects against sudden death during atrial arrhythmias (such as atrial fibrillation) not only because of its long refractory period, but also and probably more importantly by its capacity for

concealed conduction, which in turn is responsible for the occurrence of long RR intervals (20).

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