Mechanisms of Ventricular Parasystole

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SUMMARY Eight cases of ventricular parasystole are reported. In all these cases, regardless of whether parasystole seems intermittent or "continuous," the presence of second degree entrance block of the Mobitz type I was suggested. Parasystole alternated with concealed extrasystolic bigeminy showing occasional reentrant extrasystoles. Such intermittent parasystole appears to originate in the reentrant path of extrasystoles. Reentrant extrasystolic bigeminy was seen in a comparatively rapid sinus rhythm, whereas parasystolic bigeminy was seen in a comparatively slow sinus rhythm. The difference between the interectopic intervals during parasystolic bigeminy and during (manifest or concealed) extrasystolic bigeminy was comparatively small so that occasionally the difference was not distinct; on such an occasion the case showed a seemingly "continuous" parasystole. These observations strongly suggest the possibility that most cases of parasystole, whether intermittent or "continuous," may be governed by incomplete entrance block of the second degree.

THE PRESENCE of a second degree entrance block of the Mobitz type I in two cases of intermittent ventricular parasystole, in which the ventricular-ectopic conduction time was often markedly prolonged, was recently demonstrated. In one of these cases, it was shown that when a sinus impulse fell shortly after the absolute refractory period of the region surrounding the ectopic focus, it reached the ectopic focus after a marked delay in conduction, and thereafter it occasionally became a reentrant extrasystole. On the basis of these findings, Kinoshita suggested the possibility that not only these cases but most cases of parasystole, whether intermittent or "continuous," might be governed by such a second degree entrance block.

In the present paper, eight cases of ventricular parasystole are analyzed in order to ascertain the possibility that even in seemingly continuous parasystole, such a second degree entrance block is present.

Materials and Methods

The clinical material in this study was obtained from eight patients with ventricular parasystole. With the exception of four previously reported cases of intermittent parasystole, these eight patients are all the cases of parasystole that have been previously analyzed, regardless of whether intermittent or continuous. All eight cases showed sinus rhythm with ventricular ectopic beats of the same configuration and an otherwise normal heart.

The diagnosis of parasystole was made in accordance with the usual criteria: 1) varying coupling intervals, 2) frequent appearance of fusion beats, and 3) temporary or "continuous" independence of the ectopic rhythm from the basic rhythm.

In the electrocardiograms obtained from these patients with parasystole, the following intervals were measured: 1) interectopic intervals (E₁-E₂) containing one sinus beat (S₁), 2) those containing more than one sinus beat, and 3) intervals from the first ectopic beat in the interectopic interval to the first intervening sinus beat (E₁-S₁). In order to find the effect of sinus impulses on the ectopic rhythm, the relationships between intervals 1) and 2), and between intervals 1) and 3), were examined. In addition, the number of intervening sinus beats in the intervals 2) were analyzed.

Results

The results obtained are summarized in table 1. In cases 1–6, when a sinus beat occurred within a certain critical period after an ectopic beat, the sinus beat was usually followed by another ectopic beat and the interval between these two ectopic beats was almost invariable. In table 1, such interectopic intervals containing one sinus beat are represented by "long E₁-E₂," and intervals between the former ectopic beat and the intervening sinus beat are represented by "E₁-S₁ in long E₁-E₂." These findings suggest the presence of the parasystolic rhythm. However, these cases do not appear to show continuous parasystole, as mentioned below.

On the other hand, when a sinus beat occurred much beyond the above-mentioned critical period after an ectopic beat, the sinus beat was not followed by an ectopic beat; i.e., the interval between the ectopic beat preceding this sinus beat and the next ectopic beat contained more than one sinus beat (cases 1–6). This interectopic interval containing more than one sinus beat was usually different than any multiple of the manifest ectopic cycle length mentioned above (i.e., "long E₁-E₂" in table 1). This suggests that in this interectopic interval, the first intervening sinus impulse conducted to the ventricles discharged the ectopic focus and reset the parasystolic rhythm. In other words, the presence of intermittent parasystole due to second degree entrance block 1–3 is suggested. A typical example of such intermittent parasystole is shown in the first two strips of figure 1 (case 1).

The above observations suggest that the sinus impulse occasionally reset the parasystolic rhythm. However, the interval from this sinus beat to the next ectopic beat was often considerably longer than the expected multiple of the parasystolic cycle length. An
**TABLE 1. Electrocardiographic Data in Eight Patients with Ventricular Parasyxyle**

<table>
<thead>
<tr>
<th>Age/Sex</th>
<th>Long E₁-E₂ (sec)</th>
<th>Short E₁-E₂ (sec)</th>
<th>Mean difference</th>
<th>E₂-S in long E₁-E₂</th>
<th>E₁-E₂ containing more than one S: the numbers of S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>60/M</td>
<td>1.46-1.47</td>
<td>1.36-1.38</td>
<td>0.10</td>
<td>&lt; 0.85 even</td>
</tr>
<tr>
<td>Case 2</td>
<td>47/M</td>
<td>1.41-1.45</td>
<td>1.27-1.31</td>
<td>0.14</td>
<td>&lt; 0.85 even</td>
</tr>
<tr>
<td>Case 3</td>
<td>45/M</td>
<td>1.65</td>
<td>1.55</td>
<td>0.10</td>
<td>&lt; 1.00 even</td>
</tr>
<tr>
<td>Case 4</td>
<td>19/M</td>
<td>1.62-1.63</td>
<td>1.56-1.57</td>
<td>0.06</td>
<td>&lt; 1.05 even</td>
</tr>
<tr>
<td>Case 5</td>
<td>33/F</td>
<td>1.12-1.14</td>
<td>not found</td>
<td>(1.11)†</td>
<td>&lt; 0.71 even</td>
</tr>
<tr>
<td>Case 6</td>
<td>19/M</td>
<td>1.42-1.44</td>
<td>not found</td>
<td>(0.08)†</td>
<td>&lt; 0.96 even</td>
</tr>
<tr>
<td>Case 7</td>
<td>34/M</td>
<td>not found</td>
<td>1.58-1.59</td>
<td>(0.13)†</td>
<td>— even</td>
</tr>
<tr>
<td>Case 8</td>
<td>43/M</td>
<td>not found</td>
<td>1.58-1.59</td>
<td>(0.04)†</td>
<td>mostly even</td>
</tr>
</tbody>
</table>

*Length of the pure parasyxyle cycle containing no intervening sinus beat.
†Calculated short interectopic interval containing one sinus beat, in which the latter ectopic beat (E₂) was a concealed reentrant extrasystole.
‡Difference between the long E₁-E₂ and the calculated short interectopic interval, or between the pure parasyxyle cycle length and the short E₁-E₂.

Abbreviations: E₁-E₂ = interectopic interval; S = intervening sinus beats.
example is shown in the third strip of figure 1. This suggests that after a considerable delay in ventricular-ectopic (V-E) conduction, this sinus impulse reached the ectopic focus and reset the parasystolic rhythm. In cases 1-4, when a sinus beat occurred a little beyond the critical period after an ectopic beat, this sinus beat was occasionally followed by another ectopic beat, but the interval between these ectopic beats was distinctly shorter than the parasystolic cycle length. In table 1, such short interectopic intervals containing one sinus beat are represented by “short E₁-E₄.” These findings suggest that the sinus impulse

**Figure 1.** (case 1) Intermittent parasystole alternating with a form of concealed extrasystolic bigeminy showing occasional (manifest) reentrant extrasystoles. These strips are portions of a continuous 30-minute recording. The third and fourth strips are continuous. The last two strips are also continuous. It is suggested that the ectopic beats E₄ in the third strip and E₅ and E₆ in the last two strips are reentrant extrasystoles, whereas the other manifest ectopic beats are parasystolic beats. The mechanism is illustrated by the diagrams below the strips. All time intervals in this and in subsequent figures are expressed in hundredths of a second. Coupling intervals of ectopic beats to the preceding sinus beats are indicated by numbers within parentheses in the strips. Intervals from ectopic beats to their following sinus beats are indicated by numbers without parentheses in the strips. Shaded areas represent the absolute refractory period of the ventricular-ectopic junction. S = sinus beat (or impulse); E = ectopic beat (or impulse giving rise to it); (E) = parasystolic impulse that fails to become manifest; V = ventricles; RP = reentrant path containing the ventricular-ectopic junction, the ectopic focus, and the ectopic-ventricular junction. The beats labeled E + S represent fusion beats. Intraventricular conduction of the sinus (or ectopic) impulse leading to the ventricular-ectopic junction is indicated by dashed lines.

**Figure 2.** (case 2) Parasystolic bigeminal rhythm alternating with a concealed extrasystolic bigeminal rhythm showing occasional reentrant extrasystoles. All the strips are continuous. The ectopic beats E₅, E₆ and E₇ appear to be reentrant extrasystoles. Shaded areas represent the absolute refractory period of the ventricular-ectopic junction. S = sinus beat (or impulse); E = ectopic beat (or impulse giving rise to it); V = ventricles; RP = reentrant path containing the ventricular-ectopic junction, the ectopic focus, and the ectopic-ventricular junction. The beats labeled E + S represent fusion beats. Intraventricular conduction of the sinus (or ectopic) impulse leading to the ventricular-ectopic junction is indicated by dashed lines.
reached the ectopic focus after a marked delay in conduction and thereafter became a reentrant extrasystole; that is, the latter ectopic beat in this short interectopic interval appears to be a reentrant extrasystole. In figures 1–4 (cases 1–4, respectively), such short interectopic intervals containing one sinus beat are seen, suggesting the presence of reentrant extrasystoles. Usually, the interectopic interval containing more than one sinus beat was about equal to or somewhat longer than the short interectopic interval containing one sinus beat, as shown in figures 1 and 2. In cases 5 and 6, such reentrant extrasystoles were not found.

When the first (or second) sinus beat after an ectopic beat occurred shortly before termination of the parasystolic cycle, the parasystolic rhythm was occasionally not disturbed by this sinus impulse, probably because of interference of the sinus and parasystolic impulses within the V-E junction. An example is shown in figure 3 (case 3).

In all the cases, the numbers of intervening sinus beats in the interectopic interval containing more than one sinus beat were almost all even. This indicates the presence of a form of concealed bigeminy* due to 2:1 entrance block. When the sinus rate was slightly faster than twice the parasystolic rate, no ectopic beats were found because of repeated 2:1 discharge of the ectopic focus, as shown in the initial part of the top strip in figure 1. When, on the other hand, the sinus rate was slightly slower than twice the parasystolic rate, parasystolic bigeminy was maintained for a while, as shown in the top strip of figure 1 (case 1) and in the third and fourth strips of figure 2 (case 2).

Distinct differences in length between the long interectopic interval containing one sinus beat (showing the parasystolic cycle length) and the short one (in which the latter ectopic beat shows a reentrant extrasystole) were found in cases 1–4, although these differences were comparatively small. Figure 4 shows part of a long recording in case 4. In this figure the
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FIGURE 4. (case 4) Intermittent parasystole alternating with a concealed extrasystolic bigeminy showing occasional reentrant extrasystoles. These continuous four strips are part of a continuous 40-minute recording. S = sinus beat (or impulse); E = ectopic beat (or impulse giving rise to it); V = ventricles; RF = reentrant path containing the ventricular-ectopic junction, the ectopic focus, and the ectopic-ventricular junction. The beats labeled E + S represent fusion beats. Intraventricular conduction of the sinus (or ectopic) impulse leading to the ventricular-ectopic junction is indicated by dashed lines.

difference is only 0.06 seconds, on the average. In some other parts of this recording, the ranges of interectopic intervals of these two forms were somewhat wider than those observed in figure 4, and a distinct difference between them was not found. As a result, the ectopic rhythm in such parts showed a seemingly "continuous" parasystole. In cases 5 and 6, because manifest reentrant extrasystoles were not found, all interectopic intervals containing one sinus beat were of the long form. However, calculated interectopic intervals of the short form were obtained where the latter ectopic beat was a concealed reentrant extrasystole instead of the manifest one. Such calculated intervals of the short form were distinctly shorter than those of the long form, although the differences between them were also comparatively small.

In case 7 (fig. 5), interectopic intervals of the long form (containing one sinus beat and showing the parasystolic cycle length) were not found, though pure parasystolic cycles containing no intervening sinus beat were seen. Accordingly, all interectopic intervals containing one sinus beat were of the short form. In a comparatively rapid sinus rhythm, in which twice the sinus cycle length was slightly shorter than the interectopic interval of the short form, manifest reentrant extrasystolic bigeminy was maintained for a while, as shown in the bottom strip of figure 5. In case 8 (fig. 6), similar findings were observed. However, the difference between the parasystolic cycle length and the interectopic interval of the short form was not enough. Therefore, at first glance this case seemed to be continuous parasystole.

In conclusion, the possibility of the presence of a second degree entrance block cannot be ruled out in any of the cases in the present report, even in cases of seemingly continuous parasystole.

Discussion

It has been maintained that in continuous parasystole, the ectopic focus is protected by entrance block during all phases of the ectopic cycle.\textsuperscript{7,8} However, the observations in the present report strongly suggest that even in seemingly continuous parasystole, incomplete entrance block of the second degree may be present. In fact, features similar to those in our cases showing second degree entrance block appear to be found in many cases which have been reported as continuous parasystole. Examples of these are case 79 of Schamroth,\textsuperscript{8} and cases 1 and 2 of Watanabe (his figs. 1 and 2).\textsuperscript{9} Mechanisms of parasystole are discussed below.

Mechanism of "Continuous" Parasystole

Diagrams in figure 7 illustrate mechanisms of parasystole which are suggested on the basis of the findings in the present report. Shaded areas in the diagrams represent the absolute refractory period of the ventricular-ectopic (V-E) junction. In diagrams A and B, the absolute V-E refractory period is longer than half the parasystolic cycle length, but much shorter than the parasystolic cycle length. The initial part of diagram A shows that when the sinus rate is slightly faster than twice the parasystolic rate, alternate sinus impulses (S\textsubscript{1} and S\textsubscript{2}) discharge the ectopic focus, and
no ectopic beats are seen. The subsequent part of diagram A shows that when the sinus rate becomes slightly slower than twice the parasystolic rate, parasystolic bigeminy (E₁–E₂) is maintained for a while until a sinus impulse, S₁₀, falls after the absolute V-E refractory period. The sinus impulse S₁₀ falls shortly after the absolute V-E refractory period and discharges the ectopic focus after a marked delay in V-E conduction. Thereafter, it becomes a reentrant extrasystole, E₄. The interectopic interval E₃–E₄ is shorter than the parasystolic cycle length (E₁–E₂ or E₂–E₃).

Diagram B shows that in a comparatively rapid sinus rhythm in which twice the sinus cycle length is slightly shorter than the above short interectopic interval (E₃–E₄ in diagram A), manifest reentrant bigeminy (E₁–E₃, diagram B) is maintained for a while until a sinus impulse (S₁₁, diagram B) is blocked at the V-E junction.

In diagrams A and B, the difference between the parasystolic cycle length and the interectopic interval during extrasystolic bigeminy (regardless of whether manifest or concealed) is comparatively small. If a distinct difference between them is not found, the ectopic rhythm in this case will show a seemingly continuous parasystole, despite the presence of incomplete entrance block of the second degree.

In a recent study by Moe et al. on a mathematical model programmed to simulate parasystole, two principal features were postulated on the basis of the results of their experiments using a bundle of dog Purkinje fibers. One was that when a supraventricular beat occurs late in the parasystolic cycle, it
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Figure 6. (case 8) Seemingly continuous but probably intermittent parasystole. These strips are portions of a continuous 40-minute recording. The upper three strips are continuous. In the bottom strip a pure parasystolic cycle is seen. Bigeminy in the third strip may probably be reentrant. \( S \) = sinus beat (or impulse); \( E \) = ectopic beat (or impulse giving rise to it); \( V \) = ventricles; \( RP \) = reentrant path containing the ventricular-ectopic junction, the ectopic focus, and the ectopic-ventricular junction. Intraventricular conduction of the sinus (or ectopic) impulse leading to the ventricular-ectopic junction is indicated by dashed lines.

The subsequent discharge, or “captures” the pacemaker. This is similar to that observed in our cases, and the only difference between their interpretation and ours might be a semantic one. However, the other feature postulated by Moe et al., which is that when a supraventricular beat occurs earlier in the parasystolic cycle, it delays the next discharge of the pacemaker, is quite different from our observations. In all of our cases of parasystole, when a sinus beat occurred within a certain critical period after an ectopic

Figure 7. Diagrams illustrating the mechanisms of parasystole. Shaded areas represent the absolute refractory period of the ventricular-ectopic junction. \( S \) = sinus beat (or impulse); \( E \) = ectopic beat (or impulse); \( V \) = ventricles; \( RP \) = reentrant path containing the ventricular-ectopic junction, the ectopic focus, and the ectopic-ventricular junction. Intraventricular conduction of the sinus (or ectopic) impulse leading to the ventricular-ectopic junction is indicated by dashed lines.
beat, the ectopic cycle containing this sinus beat was almost invariable in length. For example, in figure 1 of my previous report on parasystole,1 such ectopic cycles containing one sinus beat were all equal in length to the pure parasystolic cycle containing no intervening sinus beat.

**Late Protection of the Ectopic Focus**

The observations in my cases of intermittent parasystole indicated that when a sinus beat occurred shortly before termination of the parasystolic cycle, the parasystolic focus was occasionally protected from this sinus impulse. Examples of such late protection were seen in two previously reported cases1, 2 and in case 3 in the present report. It appeared that such a late sinus impulse interfered with the next parasystolic impulse within the V-E junction and failed to reach the parasystolic focus. The periods of late protection in the cases in this study were far shorter than the prolonged absolute V-E refractory period.

Cohen, Langendorf and Pick13 also reported the presence of late protection of the ectopic focus in three cases of intermittent ventricular parasystole. However, the periods of late protection in their cases were far longer than the cases in this study; namely, their late periods appeared to be nearly equal to or rather longer than the absolute V-E refractory period. These authors explained that this late protection may be due to entrance block produced by diastolic (phase 4) depolarization of the parasystolic tissue. It appears that their cases show reentrant extrasystoles alternating with parasystole. In strip A of their figure 7, showing a comparatively rapid sinus rhythm, reentrant bigeminy appears to continue until a sinus impulse is blocked at the V-E junction, in the same way as in diagram B in the present report. On the other hand, in strip B of their figure, showing a comparatively slow sinus rhythm, concealed extrasystolic bigeminy appears to continue until a parasystolic beat occurs, in a way similar to that in the present diagram A. Ectopic beats in their figure 9 also appear to be reentrant extrasystoles, but not parasystolic beats. Thus, the presence of late protection by diastolic depolarization is unlikely.

**Relationship to Reentrant Extrasystoles**

Prior to this report on reentrant extrasystoles due to second degree entrance block,2 Singer and associates13 suggested the presence of a different form of reentrant extrasystoles in a case of ventricular parasystole,4 in which the parasystolic beat was occasionally followed by a reentrant extrasystole. This feature was not seen, nor can it be explained by the mechanism suggested in the present study. In some cases of parasystole, the absolute V-E refractory period might be somewhat longer than the parasystolic cycle length, and, therefore, the interectopic interval during extrasystolic bigeminy might be somewhat longer than the parasystolic cycle length. Diagram C in figure 7 illustrates such a case. In this diagram, because of the comparatively long absolute refractory period of the V-E junction, the parasystolic impulses En, Ed and E7 are retrogradely blocked at this junction. Therefore, the parasystolic impulses anterogradely conducted to the ventricles can reenter the V-E junction and reach the parasystolic focus again, resulting in resetting of the parasystolic rhythm. After that, the reentering impulses En and Ed become manifest extrasystoles Ed and En, respectively. The case of Singer and associates may possibly be governed by such a mechanism.

Finally, I shall suggest a possible mechanism governing the genesis of parasystole itself. As mentioned above, in most cases of parasystole, including the case of Singer and associates, it is suggested that parasystole alternates with manifest or concealed reentrant extrasystoles, and that the difference between the interectopic intervals during parasystolic bigeminy and during reentrant extrasystolic bigeminy is comparatively small, so that in some cases the difference is not distinct. This suggests the possibility that parasystole itself might also be produced by a reentry mechanism, as was suggested in animal experiments by Wit, Cranefield and Hoffman.14

**References**

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