Ventricular Fusion Beats

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VENTRICULAR FUSION, summation or combination beats occur when two separate pacemakers compete for control of the ventricles. The usual pair of pacemakers are the sinoatrial node and an ectopic ventricular focus; but any pair of pacemakers, whose impulses invade the ventricular myocardium more or less simultaneously but at different points, can produce fusion beats. An ectopic atrial focus or the atrioventricular node, for example, may discharge an impulse that fuses with an ectopic ventricular one. Again, two ectopic ventricular foci can compete for control of the ventricles and produce fusion beats; this is often seen in complete atrioventricular block when more than one idioventricular center is active. Theoretically the same sinus impulse may divide above the ventricles and then reunite within them to produce a fusion beat; indeed, this is precisely the mechanism of the Wolff-Parkinson-White syndrome according to the popular bundle-of-Kent theory. Malinow and Langendorf\textsuperscript{1} have compiled an exhaustive list of the possible pacemaker combinations that may produce fusion beats.

We shall confine our attention to the common form of ventricular fusion resulting from the summation of sinoatrial and ectopic ventricular impulses. Criteria for the recognition of such fusion beats, so far as we are aware, have not been precisely formulated. We have attempted to fill this gap and in the process have again been impressed with the shortcomings of the conventional bar-and-ladder diagram for depicting arrhythmias.

Time Relationships

The amount of the ventricular myocardium excited by each of the two pacemakers depends upon the relative time of excitation from the two foci. Thus, if the ventricular focus discharges when excitation of the ventricles through the normal pathways is nearly completed (B in fig. 1), the ventricular complex associated with this slightly premature beat will differ only slightly from normal complex (1 in fig. 2). If the ventricular focus discharges progressively earlier in diastole (C and D, in fig. 1), more and more of the ventricular muscle will be excited from this center, and the resulting ventricular complexes will be progressively more abnormal (3, 4, and 5 in fig. 2).

No matter where the ectopic focus is situated, its impulse should spread to the upper septum and block impulses coming downward through the special conducting pathways before activating the entire ventricular myocardium (fig. 3). The time required in the human heart for an impulse from a peripherally situated ectopic focus to reach the bifurcation of the bundle (and so block descending impulses) is important in the formulation of criteria for the diagnosis of fusion beats; but unfortunately this time is not precisely known. Direct measurements in the dog\textsuperscript{2} indicate that it requires up to 0.03 second for an ectopic impulse to reach the ipsilateral bundle branch; and indirect calculation from artificially produced fusion beats in dogs\textsuperscript{3} indicated that the time required to reach the bifurcation was 0.035 second. Somewhat longer intervals would presumably be anticipated for the human heart.

Indirect calculations from human electrocardiograms\textsuperscript{4} indicate that it requires approximately 0.04 second for an ectopic impulse to penetrate the septum and reach the contralateral bundle. This figure has recently been

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amended to 0.06 second. Others have calculated that it requires up to 0.06 second for an ectopic impulse to reach the bifurcation. No doubt the time varies slightly in different hearts; but for our purpose, and until direct measurements are available, it seems reasonable to assume that in the normal heart a minimum of 0.04 second and a maximum of 0.06 second are probably required. If we assume a maximum of 0.06 second, then it is clear that fusion can occur only if the sinus impulse arrives in the ventricles during the first 0.06 second of ectopic ventricular activation.

Criteria for Diagnosis of Ventricular Fusion Beats

In the course of our studies many criteria have emerged. For the sake of clarity we have stated them dogmatically and postponed discussion of exceptions. They may be grouped under the following headings:

1. Contour and duration of the fusion complex must be intermediate between those of the competing pacemakers (see exception below). Moreover, the width of the complex is not more than 0.06 second wider than the sinus QRS complex. For, if we assume first that it requires no more than 0.06 second for an ectopic impulse to reach the bifurcation, and, second, that the duration of the sinoatrial QRS is a measure of the time required for an impulse arriving at the bifurcation to activate the ventricles, then the maximal duration of a fusion beat must be the sum of these two intervals, i.e., 0.06 + sinoatrial QRS interval.

2. Time of appearance. The fusion beat must occur at a moment when, from the

Figure 1

Schematic representation of a normal sinoatrial beat (A); three stages or degrees of ventricular fusion (B, C, D); and an ectopic ventricular beat with retrograde conduction to the atria (E).

Figure 2

Selected strips from a 30-second tracing of lead II showing many degrees of fusion between the sinoatrial impulse and an extrasystolic ventricular impulse. The numbered complexes (1-5) show a progressively greater contribution from the ectopic impulse, which is represented in pure form by the fourth complex in the bottom strip (7). In beat 1 the only discernible deformity of the QRS complex is a loss of the diminutive S wave (indicating that the terminal vector is altered) with an associated slight lowering of the T wave. Each successively numbered beat shows progressively more deformity of the QRS-T complex, as the pattern gradually approaches that of the pure ectopic beat. Note that the initial vector is unaltered in beat 1 compared with the sinoatrial beat, whereas it is altered in all the other fusion beats (2-5); on the other hand the terminal vector is altered in all the fusion beats.

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known rhythmicity of the two centers, impulses from both might reasonably be expected.

3. P-S time. The P-S (or P-J) time of the fusion beat cannot be shorter than the P-R of the sinoatrial beat. This is evident because, for fusion to occur, the sinoatrial impulse must have had time at least to reach the ventricles (P-R interval) before they were fully activated by the ectopic center. Indeed, as stated above, the sinoatrial impulse must arrive in the ventricles considerably before they have been completely activated (see under 4, below); in fact, the P-S time of a fusion beat is therefore always definitely longer than the sinoatrial P-R.

4. The P-R time. The fusion beat may either be equal to or shorter than the P-R interval of the sinoatrial beat. When the P-R is shorter, the amount of shortening may not exceed 0.06 second. This figure again assumes that conduction from any ectopic ventricular site to the bifurcation of the bundle requires no more than 0.06 second. If this is so, it is impossible for any descending supraventricular impulse to enter the ventricular myocardium later than 0.06 second after the beginning of an ectopic beat; and therefore the opportunity for fusion can only develop within the first 0.06 second of an ectopic complex.

5. Initial vector. When the P-R time of the fusion beat is shorter than that of the sinoatrial beats (evidence that ventricular activation was initiated by the ectopic impulse), the initial vector of the fusion complex must differ from that of the sinoatrial beat. On the other hand, if the P-R of the fusion beat is the same as that of the sinoatrial beat, the initial vector may or may not differ—depending upon whether the sinoatrial impulse alone or the two impulses simultaneously initiate ventricular activation.

6. Terminal vector. In all fusion beats the terminal vector differs from that of the sinoatrial beats because it is impossible for the sinoatrial impulse alone to write the last portion of the ventricular complex; it must be written either by the ectopic impulse alone or by the two impulses simultaneously. Subtle changes in the terminal vector may not be apparent in a single scalar lead; it may therefore be important to obtain specimens of the suspected fusion beats in several leads.

Exceptions to Criteria

1. In the presence of bundle-branch block, the contour and duration of the fusion beat need not be intermediate between those of the competing pacemakers. For example, in left bundle-branch block, if an ectopic impulse arises in the left ventricle at the same moment that the descending sinoatrial impulse enters the right ventricle, the resulting fusion complex may be of normal duration and relatively normal contour (fig. 4) in contrast to the bizarre and widened complex of either impulse individually.

2. In the presence of varying P-R intervals, as during Wenckebach periods, the criteria outlined under 3, 4, and 5 cannot be rigidly applied, since they depend for their validity upon the assumption of unvarying atrioventricular conduction.
3. In the presence of parietal intraventricular conduction delay the "0.06 rules" are presumably invalidated; for in such circumstances it is theoretically possible for an ectopic impulse to require more than 0.06 second to reach the bifurcation of the bundle. The P-R interval could therefore be shortened by more than 0.06 second and the QRS interval of the fusion beat could exceed the sinoatrial QRS by more than 0.06 second.

Inadequacy of Conventional Diagrams
An inconsistency prevails in conventional diagrams. It has been customary to diagram cardiac events with sloping bars (representing passage of time) only in the atrioventricular section of the diagram, while vertical bars (ignoring passage of time) represent atrial and ventricular activation. It is more realistic to use sloping lines to represent time occupied in traversing both atrial and ventricular myocardium. With antegrade conduction, the angle of slope in the ventricular segment of the diagram is determined by the width of the QRS complex. It is not accurate, however, to adjust the slope of atrial depolarization to match the width of the P wave; long before atrial activation is complete, the impulse has reached and penetrated the atrioventricular node. Since the sinoatrial impulse has been calculated to require about 0.04 second to reach the atrioventricular node, the sloping bar of atrial depolarization should represent only 0.04 second. The balance of atrial depolarization is indicated by the broken line in A of figure 1.

Similarly, the full width of retrogradely conducted ectopic ventricular beats cannot be satisfactorily portrayed by a sloping line representing the full width of the QRS complex, since it requires no more than 0.06 second for the impulse to reach the bifurcation. The slope of such beats should therefore represent 0.06 second or less. The balance

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Figure 4
Selected strips from lead V1, illustrating fusion between the sinoatrial impulse and an ectopic ventricular impulse in the presence of left bundle-branch block. In the upper strip the second and fourth beats show sinoatrial rhythm with left bundle-branch block; the last five beats represent a run of ventricular tachycardia. The first, third, and fifth beats represent fusion between the two pacemakers. The third beat is of normal duration and relatively normal contour, being much narrower (0.08 second) than the bundle-branch block complexes (0.15 second) or the ectopic complexes (0.12 second). The lower strip shows left bundle-branch block alternating with ventricular fusion beats. (We are indebted to Dr. Leo Schamroth for this tracing.)

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of ventricular activation is indicated by the broken line in E of figure 1.

Despite its manifest imperfections, the sloping-line diagram for the portrayal of some arrhythmias is superior to the vertical-bar diagram in common use. In attempts to illustrate the finer points of fusion beats, this refinement is essential.7

Overemphasis of Fusion Beats in Parasystole

Fusion beats, though often emphasized as an important criterion for the diagnosis of parasystole, are not essential for diagnosis and should be viewed in proper perspective. They add nothing to the evidence for independent rhythmicity and protection, which are the hallmarks of parasystolic rhythm. They are merely visible expressions of the predictable fact that, at given rates of the two independent pacemakers, certain discharges of the ectopic pacemaker will overlap and fuse with the QRS complexes of sinoatrial origin. Their presence is undeniably helpful in drawing attention to the possibility of parasystole because they indicate an ectopic ventricular discharge that is not coupled to the preceding beat.

Summary

Relatively precise criteria are proposed for the recognition of ventricular fusion beats. Apart from the obvious and widely accepted criteria involving contour, duration, and time of appearance, other less obvious characteristics have been adduced: (1) the P-S time of the fusion beat must always be considerably longer than the P-R interval of the component sinoatrial beat; (2) the P-R interval of the fusion beat is generally not more than 0.06 second shorter than the sinoatrial P-R; (3) the terminal vector of the fusion beat is always different from that of the sinoatrial beat, while the initial vector may or may not differ. Exceptions to these criteria are seen in the presence of bundle-branch block, during periods of inconstant atrioventricular conduction times, and presumably in the presence of diffuse intraventricular conduction delays.

The shortcomings of conventional diagrams for depicting the mechanisms of arrhythmias are noted, and a plea is made for the use of more accurate symbols in their construction.

Fusion beats are not an indispensable criterion for the diagnosis of ventricular parasystole.

References

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