Electrical Activation and Mechanical Asynchronism in
the Cardiac Cycle of the Dog

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With the technical assistance of William H. Meyer, Jr., M.D., and Louis Lemberg, M.D.

Right and left ventricular pressure curves and electrocardiogram were recorded in the
dog during sinus rhythm and during mechanically induced right and left ventricular
premature systoles. The normal range during sinus rhythm for the relationship between
onset of right and left ventricular contraction was determined. At one extreme, right
ventricular contraction commenced 0.02 second before the left; at the other extreme,
left ventricular contraction started 0.03 second before the right. In most instances, the
onsets of ventricular contraction were either temporally identical or one ventricle con-
tracted 0.01 second prior to the other.

Dissociation of electrical and mechanical events in the cardiac cycle has been
reported by several observers. Previous studies have suggested that electrical ventricu-
lar asynchronism (complete bundle branch block, ventricular premature beats, Wolff-
Parkinson-White Syndrome, and complete heart block with idioventricular rhythm) does
not necessarily lead to mechanical ventricular asynchronism in onset of ventricular con-
traction. However, divergent data have been presented. The literature pertaining to this subject has recently been summarized.

In most of the published investigations, right and left ventricular pulse pressure
curves could not be compared directly; conclusions were therefore drawn from indirect
evidence only. In two studies in man direct recording of right and left ventricular pres-
sure curves was performed. Braunwald and Morrow performed simultaneous right and
left heart catheterization in 15 patients with complete bundle branch block (5 with left
bundle branch block, and 10 with right bundle branch block). Asynchronous contraction of
the two ventricles was absent in all 5 patients with left bundle branch block and 6 with
right bundle branch block. Samet et al. have recorded right and left ventricular curves dur-
ing 100 ventricular premature beats obtained in the course of simultaneous right and left
heart catheterization. Mechanical asynchronism in onset of ventricular isometric con-
traction was found in only 28 of 100 ventricular premature systoles with widened aberrant
QRS complexes.

The present study was designed to extend
to the dog these observations on the mechan-
ics of ventricular contraction during ventricu-
lar premature complexes. The presence of
catheters within the lumen of the right and
left ventricle in the study of man could theo-
retically obscure mechanical asynchronism by
endocardial stimulation near the interventric-
ular septum.

Methods

Simultaneous right and left ventricular pressure
curves were registered in 31 dogs under barbiturate
anesthesia (pentobarbital sodium, 30 mg./Kg.,

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TABLE 1.—Relationship between Onset of Isometric Contraction in the Right and Left Ventricles (in Seconds)

<table>
<thead>
<tr>
<th>Sinus tachycardia</th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode*</td>
<td>2</td>
<td>4</td>
<td>15</td>
<td>5</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Range†</td>
<td>6</td>
<td>12</td>
<td>19</td>
<td>14</td>
<td>10</td>
<td>1</td>
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<tr>
<td>Premature systole</td>
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<tr>
<td>R.V.</td>
<td>1</td>
<td>0</td>
<td>11</td>
<td>29</td>
<td>102</td>
<td>66</td>
</tr>
<tr>
<td>L.V.</td>
<td>2</td>
<td>9</td>
<td>32</td>
<td>44</td>
<td>36</td>
<td>6</td>
</tr>
</tbody>
</table>

*Most frequent value during S.T.
†The two extreme values in each dog.

I.V.) with the chest open, during sinus rhythm. The electrocardiogram was recorded simultaneously, generally lead V5. Respiration was maintained via intermittent inspiratory positive pressure.

Plastic catheters 1.5 mm. I.D. were sewn into the right and left ventricular chambers* and connected to Statham P23AA strain gages with 48 inch lengths of black polyvinyl tubing.† Pressures were recorded on a photographic 6 channel unit.‡ After suitable control observations, right and left ventricular premature systoles were produced by tapping the exposed ventricular epicardial surface with a sharp instrument in an area distant from the interventricular groove so as to avoid stimulation near the interventricular septum. Multiple premature beats suitable for subsequent analysis were induced in 15 animals during simultaneous recording of the electrocardiogram and right and left ventricular pressure pulses.

The difference in electrical-mechanical transmission time in the above recording system was determined by the method of Gordon et al.§ and noted to be 0.004 second. This interval was not considered significant since the electrical-mechanical time intervals are reported only to the nearest 0.01 second interval in the present study. During both control and experimental observations, the interval between the onset of the QRS complex and the onset of the right and left ventricular pulse rise was measured, and determination made of the time relationship between onset of the two ventricular pressure curves. The side of mechanical ventricular stimulation, i.e., left or right, was observed directly and recorded on the electrocardiogram. A widened aberrant QRS complex, upward in lead V5, was produced by right ventricular stimulation. Left ventricular stimulation led to an aberrant widened QRS complex predominantly downward in lead V5.

More than 1,000 ventricular premature beats were recorded in this fashion. Of these, 424 (obtained in 15 different dogs) were selected for study. The remainder were discarded because either the left or right ventricular curve was considered technically inadequate for detailed time measurements, generally because of the degree of prematurity of the ventricular beat. Accurate measurement of the onset of the right or left ventricular pressure curve was difficult or impossible when the extrasystole occurred early in the cardiac cycle.

RESULTS

The electrical-mechanical ventricular relationships during sinus rhythm in 31 dogs may be summarized as follows. The onset of the QRS complex to onset of the right ventricular pressure upstroke interval ranged from 0.03 to 0.08 second. The QRS to left ventricular pressure upstroke interval also ranged from 0.03 to 0.08 second. The right and left ventricular pressure upstroke values varied considerably. At one extreme the onset of right ventricular isometric contraction preceded that of the left by 0.02 second; at the other extreme left ventricular systole started 0.03 second ahead of the right. In most instances the onsets of ventricular contraction were either temporally identical or one ventricular contracted 0.01 second prior to the other (table 1). A QRS ventricular pressure upstroke time of greater than 0.10 second has, somewhat arbitrarily, been defined as demonstrating a delayed upstroke time. 424 ventricular premature systoles were analyzed—293 right and 131 left complexes.

The relationship between the onset of right and left ventricular contraction during the
ventricular premature systoles is shown in table 1. During sinus rhythm, the mode relationship is 0.00 second, i.e., the onset of isometric contraction is simultaneous in the two ventricles. The mode value for 293 right ventricular premature systoles is 0.02 second, right ventricle ahead. The corresponding figure for 131 left ventricular extrasystoles is 0.01 second, left ventricle ahead. On analysis, the differences between the first two figures, between the first and third values, and between the latter two values are all statistically significant, \( p < 0.001 \). The 95 per cent confidence limits are 0.017 to 0.025 second, 0.007 to 0.015 second, and 0.007 to 0.013 second respectively.

The time intervals between the onset of the QRS complex and the onset of left ventricular isometric contraction are listed in table 2. The mode value during sinus tachycardia is 0.05 second. The corresponding mode figures during right and left ventricular premature systoles respectively are 0.07 and 0.06 second. The differences between 0.05 and 0.07 second, and 0.05 and 0.06 second, and 0.06 and 0.07 second are all statistically significant, \( p < 0.001 \). The 95 per cent confidence limits are 0.002 to 0.012 second, 0.015 to 0.024 second, and 0.009 to 0.016 second respectively.

The same data may also be approached from another viewpoint. As noted above, the nor-

**Table 2.**—Time Interval between Onset of QRS Complex and Onset of Left Ventricular Isometric Contraction (in Seconds)

<table>
<thead>
<tr>
<th>QRS — L.V.</th>
<th>.03</th>
<th>.04</th>
<th>.05</th>
<th>.06</th>
<th>.07</th>
<th>.08</th>
<th>.09</th>
<th>.10</th>
<th>.11</th>
<th>.12</th>
</tr>
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<tbody>
<tr>
<td>Sinus tachycardia</td>
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<td></td>
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<tr>
<td>Mode*</td>
<td>8</td>
<td>15</td>
<td>20</td>
<td>19</td>
<td>6</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Range†</td>
<td>1</td>
<td>15</td>
<td>20</td>
<td>19</td>
<td>6</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Premature systole</td>
<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>R.V.</td>
<td>1</td>
<td>21</td>
<td>70</td>
<td>79</td>
<td>56</td>
<td>36</td>
<td>22</td>
<td>6</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>L.V.</td>
<td>14</td>
<td>18</td>
<td>40</td>
<td>33</td>
<td>15</td>
<td>7</td>
<td>4</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

*Most frequent value during S.T.
†The two extreme values in each dog.

**Table 3.**—Time Interval between Onset of QRS Complex and Onset of Right Ventricular Isometric Contraction (in Seconds)

<table>
<thead>
<tr>
<th>QRS — R.V.</th>
<th>.03</th>
<th>.04</th>
<th>.05</th>
<th>.06</th>
<th>.07</th>
<th>.08</th>
<th>.09</th>
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<tr>
<td>Mode*</td>
<td>1</td>
<td>7</td>
<td>10</td>
<td>6</td>
<td>6</td>
<td>1</td>
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<td></td>
</tr>
<tr>
<td>Range†</td>
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<td>16</td>
<td>14</td>
<td>10</td>
<td>16</td>
<td>5</td>
<td></td>
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<tr>
<td>R.V.</td>
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<td>50</td>
<td>70</td>
<td>74</td>
<td>38</td>
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<td>32</td>
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<td>7</td>
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<td></td>
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</table>

*Most frequent value during S.T.
†The two extreme values in each dog.
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ormal range for the relationship between the onsets of right and left ventricular isometric contraction is from 0.02 second, right ventricle ahead, to 0.03 second, left ventricle ahead. In 250 of the 293 right ventricular premature systoles the relationship between the onset of right and left ventricular contraction is within the normal range described above. In 41 extrasystoles mechanical asynchronism was noted, that is, the onset of right ventricular contraction preceded the left by more than 0.02 second. In two right ventricular extrasystoles, however, left ventricular contraction preceded that of the right by more than 0.03 second. In 129 of 131 left ventricular premature systoles the upstrokes of the two ventricular pressure curves were also within the normal range. In two instances the left ventricular upstroke preceded that of the right by more than 0.03 second, demonstrating mechanical asynchronism in onset of ventricular contraction.

Some of these relationships are illustrated in figure 1. In the beat labeled NSR, the right ventricular upstroke is 0.01 second earlier than the left. In “VPC 10” a right ventricular extrasystole, the right ventricular pressure upstroke starts 0.01 second prior to the left. In “VPC 11” the right ventricular upstroke is 0.02 second earlier than the left. These intervals are both within the normal range.

In contrast to the data in man in whom a delayed onset of QRS complex to onset of ventricular pressure upstroke is not infrequent during ventricular premature extrasystoles, electrical-mechanical delay was rarely noted in the dog during similar circumstances (table 2 and 3). In the 293 right ventricular extrasystoles, the onset of QRS to onset of right ventricular pressure upstroke was greater than 0.10 second in 4 instances; the QRS to left ventricular pressure upstroke interval was delayed in a like number of beats. In four other extrasystoles biventricular delay was found. In the remainder the electrical-mechanical onset intervals were 0.10 second or less for both ventricles. In the 131 left ventricular extrasystoles, right ventricular delay was noted in four pressure upstrokes. All other electrical-mechanical intervals were within normal limits.

DISCUSSION

It has been demonstrated in experimental bundle branch block in the dog that the free wall of the ipsilateral ventricle on the interrupted side is depolarized about 0.04 second after the contralateral normally depolarized ventricle. This interval is the period required for trans-septal electrical depolarization. In right and left ventricular premature systoles produced by tapping the epicardial surface of the ventricle in areas away from the interventricular septum, electrical depolarization differences of at least 0.08 second would therefore be expected. That is, if point A is on the free wall of the right ventricle, and point B on the free lateral wall of the left ventricle, stimulation at point A would start a wave of depolarization arriving at point A at least 0.04 second (time for electrical depolarization). Actually this time interval would be even greater than 0.04 second, since depolarization of the free wall of the right or left ventricle plus septal depolarization would be required for transmission of the wave of depolarization from point A to point B or vice versa.
trans-septal depolarization) prior to arriving at point B. Similarly, stimulation at point B would produce a depolarization wave arriving at point A 0.04 second later than at point B. Thus in a right ventricular premature systole point A would be depolarized 0.04 second earlier than point B; during a left ventricular premature systole the reverse would be true. The difference between a right and left ventricular systole would thus be at least 0.08 second. If differential electrical activation (electrical asynchronism) necessarily resulted in mechanical asynchronism, it would be expected that the onset of right ventricular isometric contraction would precede that of the left ventricle by at least 0.04 second in right ventricular premature systoles; the reverse order of onset of isometric contraction would be anticipated in left ventricular premature systoles. The over-all mode difference would be 0.04 minus (—0.04 second) or 0.08 second.

The data in table 1, however, reveal a difference of only 0.01 minus (—0.02 second) or 0.03 second between the modes of right and left ventricular pressure rises during right and left extrasystoles. There is little doubt that the onsets of pulse pressure rise are more out of phase during ventricular extrasystoles than during sinus rhythm. The differences between the mode values for onset of right and left ventricular isometric contraction are significantly different (p < .001) when the mode values for sinus rhythm are compared to the right and left extrasystole mode values and when the latter two modes are compared to one another. However the magnitude of this difference is far less than would be predicted on theoretic grounds if physiologically significant mechanical asynchronism were to result from asynchronous electrical depolarization.

The same comments may be made relative to the data in tables 2 and 3. The intervals between onset of QRS to onset of ventricular pressure rise are significantly different statistically during sinus rhythm and ventricular extrasystoles, but these differences are much less than predicted and are of questionable physiologic significance.

The fact that the relative onsets of most right and left ventricular contractions during ventricular extrasystoles are in the normal range of 0.02 (right ventricle ahead) to 0.03 (left ventricle ahead) established during sinus rhythm (table 1) is also in accord with the thesis that the mechanical asynchronism in onset of ventricular contraction during ventricular extrasystoles is of limited magnitude and import. The possible explanations for these findings have recently been discussed in detail elsewhere, and include dissociation of electrical and mechanical events in the cardiac cycle and consideration of the basic anatomy of the ventricles. Each ventricle is composed of the same four discrete muscle bundles —superficial sinospiral and bulbospiral, and deep sinospiral and bulbospiral muscles. Gregg and Rushmer believe that both deep muscle bundles play an important role in emptying the two ventricles. Under these circumstances it is difficult to visualize a marked degree of mechanical ventricular asynchronism.

**Summary**

Right and left ventricular pressure curves and electrocardiograms have been recorded in 31 dogs. The normal onset of QRS complex to onset of ventricular isometric contraction interval, as well as the relative timing of right and left ventricular pressure upstrokes, has been determined.

In 15 dogs multiple right and left ventricular extrasystoles were produced mechanically and analyzed—293 right and 131 left ventricular premature systoles. In the majority of such extrasystoles the relationship between the onset of right and left ventricular isometric contraction remained within the normal range. Statistical analysis revealed a significant difference in right and left ventricular mechanical relationships during right and left ventricular premature systoles. The magnitude of this difference is far less than that expected on theoretic grounds.

**Summario in Interlingua**

Esseva obtenite, ab 31 canes, curvas del tension dextero- e sinistro-ventricular e etiam registrationes electrocardiographic. Esseva determinate le normal intervallo inter le declaration del complexo QRS e le declaration
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del isometric contraction ventricular e etiam le interrelation chronometric del ascenditas del dextere e del sinistre tension ventricular.

In 15 canes, multiple extrasystoles dextero- e sinistro-ventricular esseva producete mecanicamente. Lor analyse mostrava un total de 293 prematur systoles dextero-ventricular e 131 prematur systoles sinistro-ventricular. In le majoritate de tal extrasystoles, le relation inter le declaration del contraction isometric dextero-ventricular e le declaration del contraction isometric sinistro-ventricular remaineva intra le limites del norma. Nonobstante, le analyse statistic revelava un differentia significative con respecto al relations mechanic dextero- e sinistro-ventricular inter le prematur systoles dextero-ventricular e le prematur systoles sinistro-ventricular. Le magnitude de iste differentia es molto inferio a lo que esseva expectate super le base de considerationes theoretic.

REFERENCES

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