Analysis of the Orthogonal Electrocardiogram and Vectorcardiogram in Ventricular Conduction Defects With and Without Myocardial Infarction

By Mervin J. Goldman, M.D., and Hubert V. Pipberger, M.D.

SUMMARY
Correlations were computed for 320 electrocardiographic measurements and variables of ventricular conduction defects in 452 unselected patients. The variables consisted of right and left ventricular conduction defects with and without myocardial infarction. Quantitative criteria were established which led to the identification of infarction in the presence of a ventricular conduction defect. The data were analyzed by two methods; (1) using four independent measurements, and (2) discriminant function analysis in conjunction with a likelihood ratio test using 9 or 10 measurements. Both techniques yielded similar results. In the presence of left ventricular conduction defects, 52% of the cases of infarction were identified with a 14% false positive diagnosis of infarction. In the cases of right ventricular conduction defects the results were 54% and 11%, respectively. In both, the sensitivity could be increased at the expense of an increase in the false positive frequency. This study confirms the difficulties in the electrocardiographic diagnosis of infarction in the presence of left ventricular conduction defects. In addition, it emphasizes that a similar problem exists with right ventricular conduction defects, a finding which has not been adequately appreciated to date.

Additional Indexing Words:
Computer analysis                Bundle-branch block

Since the introduction of corrected orthogonal lead systems reports are available which describe the vectorcardiographic diagnosis of myocardial infarction in association with bundle-branch block (ventricular conduction defects). Most authors have emphasized the difficulties of such a diagnosis in the presence of left bundle-branch block and the relative ease in association with right bundle-branch block. Neuman and associates1 pointed out the high incidence of infarction in association with atypical left bundle-branch block and the almost complete absence of evidence of infarction in typical left bundle-branch block. The features of atypical left bundle-branch block as reported by these authors on the basis of 48 cases are (1) initial anterior forces of less than 0.01 sec, (2) malrotation of anterior forces (to the right around the E point), (3) enlargement of the initial anterior forces so that the 0.0275 sec vector is anterior to the E point, (4) displacement of the afferent limb to the right so that the loop rotates counterclockwise in the horizontal plane, and (5) uniform inscription of the entire loop. Of 26 cases demonstrating atypical left bundle-branch block, 12 were autopsied cases and 14 were not. Infarction was documented in 11 of the 12 autopsied cases and in 12 of the 14 without autopsy. Of 22 patients with typical left bundle-branch block, 10 cases were autopsied, and myocardial infarction was identified in 9 of the 10 cases.
block records the seven in whom autopsy was done did not have infarction; but three of the 15 patients without autopsy received a clinical diagnosis of infarction. Massie and Walsh emphasized the significance of initial right and anterior forces in left bundle-branch block with septal infarction, with the maximal rightward vector in the horizontal plane between $+95^\circ$ and $+145^\circ$. In uncomplicated left bundle-branch block, when a rightward and anterior force was present, this maximal vector was never to the right of $+95^\circ$ in the horizontal plane. The duration of the initial right vector equalled 0.02 to 0.03 sec in association with infarction and did not exceed 0.015 sec in uncomplicated left bundle-branch block. Cabrera and associates emphasized the anterior enlargement of the Q loop in left bundle-branch block with infarction. In the majority of cases initial forces were directed anteriorly and rightward. Medrano and coworkers listed the following criteria for the diagnosis of infarction in the presence of left bundle-branch block: (1) infarction of the lower one third of the left septal mass: a Q loop that increases in voltage, becomes narrower, and points more anteriorly and sometimes rightward; (2) infarction of the right and left septal masses: decrease in the initial force in the horizontal plane; and (3) infarction of right lower septal mass: decrease or disappearance of the Q loop in the horizontal plane with initial forces to the right and posterior. Scott reported the presence of clockwise rotation of the initial portion of the QRS loop in the horizontal plane with orientation to the right and anteriorly in septal infarction with left bundle-branch block. With infarction of the free wall of the left ventricle in the left bundle-branch block, the late forces are directed to the right and posteriorly. Burch and DePasquale noted marked posterior displacement of the QRS loop in anterior infarction with left bundle-branch block. Marked distortion of the QRS loop was also considered a sign of infarction. Doucet and associates, on the basis of a study of 32 cases, described the following as helpful in the diagnosis of infarction in the presence of left bundle-branch block: (1) initial QRS oriented anteriorly and to the right in massive infarction of the interventricular septum; (2) immediate far posterior and leftward inscription of the entire first portion of the QRS loop in the horizontal plane in anteroseptal infarction; (3) rightward inscription of at least the last portion of the afferent limb of the QRS loop in infarction of the free wall of the left ventricle; and (4) rightward displacement of the QRS loop in the frontal plane either as a complete inscription to the right or as a sudden change to the right from the expected leftward orientation associated with marked distortion of the loop. The same authors reported their findings in 40 cases of right bundle-branch block with clinical evidence of infarction. In all cases the first portions of the QRS loop were influenced by the infarction. The 0.02-sec and maximal mean instantaneous vectors fell within the range of patients with infarction without right bundle-branch block. The presence of infarction did not obscure the vectorcardiographic diagnosis of right bundle-branch block.

The purpose of this report is to present the quantitative analysis of the factors which are important in the electrocardiographic and vectorcardiographic diagnosis of infarction in the presence of ventricular conduction defects. In this article the latter terminology will be used in preference to bundle-branch block.

**Methods**

The subjects included in this study were patients admitted to the Veterans Administration Hospitals in San Francisco (also Oakland and Martinez), California, Washington, D. C.; West Roxbury, Massachusetts, Birmingham, Alabama; Batavia, New York; Minneapolis, Minnesota; and Durham, North Carolina. Cases were selected at these hospitals with a wide variety of cardiac abnormalities according to study protocol specifications. As stated by Boyle and Anderson, it is obvious that the initial samples of patients for study must be properly selected. A random sample would be best. As this is seldom feasible, a consecutive series of new patients would probably be close to randomness, but care must be taken to ensure as far as possible that the population of patients selected to provide

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data for the probability matrix is comparable to the population which is to be diagnosed. The population of patients selected in this study is comparable to the population which is to be diagnosed in a general hospital with an adult male population. The authors had no influence upon the choice of cases at the seven different hospitals. At no point were ECG criteria used for case selection. By the above method a total of 452 patients with ventricular conduction defects were collected. Records were classified as ventricular conduction defects when the QRS interval exceeded 0.126 sec. The upper normal limit of QRS duration is 0.112 sec.10 To aid in exclusion of cases with slight QRS prolongation, as seen in ventricular hypertrophy, the value of 0.126 sec was arbitrarily selected.

Right ventricular conduction defects (RVCD) were defined as those with terminal QRS forces directed rightward and anteriorly. Left ventricular conduction defects (LVCD) were those in which the QRS was directed leftward and posteriorly. Detailed case histories were reviewed on all patients. The RVCD and the LVCD groups were divided into those with and without myocardial infarction (MI) based on clinical (393 cases) and autopsy (89 cases) data. The infarction group included only those patients with unequivocal clinical evidence of recent or old and documented infarction or autopsy proven infarction. Clinical selection of the cases of infarction was based on unequivocal history, clinical course, and enzyme elevation. The electrocardiogram was not used in this selection and hence is not a preselected discriminant factor. Patients with a clinical history of angina alone or nondocumented old infarction were excluded from the study. It is appreciated that unrecognized infarction may be present in the noninfarction groups, but such cannot be avoided until sufficient autopsy material is available to base the diagnostic separation on such data alone. Four groups of cases were thereby selected (table 1).

The Frank lead system11 was used in this study with the left, inferior, and posterior poles of leads X, Y, and Z positive, respectively. The three orthogonal leads were recorded simultaneously on magnetic analog tape using FM channels. These were subsequently digitized and analyzed by a digital computer, as previously described by Pipberger and associates.12, 13 A total of 320 ECG measurements was determined from each record, by a technique similar to that used in the study of normal individuals.10

A t-test was performed on each of the 320 measurements. The t-values were ranked, in other words, the highest on top, the second next, and so forth. Then 96% ranges of the noninfarction groups were determined and the number of cases of infarction were determined which were outside these limits. Thus the t-test was used to find the “best” discriminations. By comparing a series of measurements side by side from this list of candidates, those which did not contribute independently to the discrimination could be eliminated. Reducing the number of measurements decreased at the same time the number of false positives because each measurement contributes 2%. A similar study was done at the 90% ranges.

The 30 measurements with the highest t-values were used as candidates for discriminant function analysis.14 First they were all considered simultaneously and coefficients of the discriminant functions were obtained. These can be considered as weight factors for each measurement. A smaller set, not exceeding the square root of the number of cases, was selected which consisted of the highest weight factors. They were subjected to the same process once more because the new and smaller combination of measurements led to new weights. Out of the resulting measurements a multidimensional vector was formed for each patient and a mean vector was obtained for each group. An unknown case was compared with the two means (without infarction and with infarction). The smaller the vector difference, the more likely it was that the unknown case belonged to this group (likelihood ratio test).

Results

Identification of Infarction in RVCD
(Tables 2 to 4)

Of the 320 measurements used, four proved to be the most efficient. These are* (1) %QRS-Z; (2) rS-Z; (3) Q/R ratio-Z; and (4) 0.04-sec B QRS-Y. The addition of other measurements, although relatively high on the ranked t-test listing, increased the percentage of false positives to a greater degree than

*See “Glossary of Terms” at end of this article.
they increased the identified cases, or they were completely redundant.

The % QRS-Z (value > 0.034 mv) identified 32 (34%) of the cases of infarction with a 5% false positive frequency. The presence of an rS in Z (in other words, absence of q) led to the identification of 35 cases of infarction, but only 17 were independent of the cases already selected by the % QRS-Z. This increased the percentage of cases of infarction identified by 18% but introduced a false positive frequency of 11%. The Q/R ratio in Z and the 0.04-sec B QRS-Y each identified an additional 4% with 2% false positives. Thus the total identification of infarction by these four measurements was 60% with 20% false positives. If the rS factor was eliminated the false positive frequency fell to 9%, but the identification rate fell to 42%.

The significance of QS in Z was independently analyzed since others have reported on its value as a diagnostic feature of posterior myocardial infarction associated with right ventricular conduction defect. In group 1 there was a frequency of 19% as opposed to 21% in group 2. This indicates the lack of diagnostic value of this finding.

**Multivariate Analysis**

Nine measurements were selected. The results of this analysis are expressed as percentages of cases identified to percentage of

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**Table 2**

**Recognition of Infarction in Right Ventricular Conduction Defects at the 96 Percentile Level**

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Min*</th>
<th>Max*</th>
<th>Cases independently recognized (A or B)</th>
<th>Recognized by</th>
<th>False positives (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4QRS-Z (mv)</td>
<td>-0.407</td>
<td>0.078</td>
<td>26 (A)</td>
<td>&gt;0.078 mv</td>
<td>2</td>
</tr>
<tr>
<td>rS-Z</td>
<td></td>
<td></td>
<td>17</td>
<td>rS-Z</td>
<td>11</td>
</tr>
<tr>
<td>0.04 sec B QRS-Y (mv)</td>
<td>-0.611</td>
<td>1.26</td>
<td>4 (B)</td>
<td>&lt;-0.611 mv</td>
<td>2</td>
</tr>
<tr>
<td>Q/R-Z</td>
<td>0.135</td>
<td>9.33</td>
<td>4 (A)</td>
<td>&gt;9.33 mv</td>
<td>2</td>
</tr>
</tbody>
</table>

*Minimal and maximal values in RVCD without infarction (group 1).
†A = above and B = below range of values in group 1.

**Table 3**

**Recognition of Infarction in Right Ventricular Conduction Defects at the 90 Percentile Level**

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Min</th>
<th>Max</th>
<th>Cases independently recognized (A or B)</th>
<th>Recognized by</th>
<th>False positives (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4QRS-Z (mv)</td>
<td>-0.311</td>
<td>0.034</td>
<td>32 (A)</td>
<td>&gt;0.034 mv</td>
<td>5</td>
</tr>
<tr>
<td>rS-Z</td>
<td></td>
<td></td>
<td>17</td>
<td>rS-Z</td>
<td>11</td>
</tr>
<tr>
<td>0.04 sec B QRS-Y (mv)</td>
<td>-0.477</td>
<td>0.912</td>
<td>4 (B)</td>
<td>&lt;-0.477 mv</td>
<td>5</td>
</tr>
<tr>
<td>0.01 sec E QRS-Z (mv)</td>
<td>-0.173</td>
<td>0.033</td>
<td>6 (B)</td>
<td>&lt;-0.173 mv</td>
<td>5</td>
</tr>
</tbody>
</table>

**Table 4**

**Cumulative Data for Recognition of Infarction in Right Ventricular Conduction Defects**

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Min, Max</th>
<th>Recognized</th>
<th>Independently recognized</th>
<th>Recognized by</th>
<th>False positives (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4QRS-Z (mv)</td>
<td>-0.311, 0.034</td>
<td>32</td>
<td>32</td>
<td>&gt;0.034 mv</td>
<td>5</td>
</tr>
<tr>
<td>Q/R-Z</td>
<td>0.135, 9.33</td>
<td>5</td>
<td>4</td>
<td>&gt;0.9.33 mv</td>
<td>2</td>
</tr>
<tr>
<td>0.04 sec B QRS-Y (mv)</td>
<td>-0.611, 1.26</td>
<td>5</td>
<td>4</td>
<td>&lt;-0.611 mv</td>
<td>2</td>
</tr>
<tr>
<td>rS-Z</td>
<td></td>
<td>35</td>
<td>17</td>
<td>rS-Z</td>
<td>11</td>
</tr>
</tbody>
</table>

*Recognition to false positive percentages vary according to the number of measurements used.
false positives. The range was from 75% identified with 37% false positives to 54% identified with 11% false positives (table 5). These rates are changed by addition of a constant to one vector difference which brings the unknown case relatively closer to the other mean. This was done for both the cases with and without infarction and thereby changed both the percentage of identified cases and the percentage of false positives.

### Table 5

**Recognition of Infarction in Right Ventricular Conduction Defects by Discriminant-Function Analysis and Likelihood Ratio Test**

<table>
<thead>
<tr>
<th>Measurements</th>
<th>Coefficients of discriminant functions</th>
<th>% Identified to false positives</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) $\frac{1}{4}$ QRS-Z</td>
<td>-1.00</td>
<td></td>
</tr>
<tr>
<td>(2) 0.01 sec E QRS-Z</td>
<td>0.9219</td>
<td>75-37</td>
</tr>
<tr>
<td>(3) Max T mag. hor. pl. *</td>
<td>0.7258</td>
<td>72-31</td>
</tr>
<tr>
<td>(4) Max T mag. sag. pl. †</td>
<td>-0.4916</td>
<td>65-23</td>
</tr>
<tr>
<td>(5) Point J-Z</td>
<td>-0.4223</td>
<td>61-21</td>
</tr>
<tr>
<td>(6) 0.04 sec B QRS-Z</td>
<td>0.2619</td>
<td>57-18</td>
</tr>
<tr>
<td>(7) 0.05 sec B QRS-Z</td>
<td>-0.2115</td>
<td>54-11</td>
</tr>
<tr>
<td>(8) 0.03 sec B QRS-Y</td>
<td>0.1872</td>
<td></td>
</tr>
<tr>
<td>(9) 0.03 sec B QRS-Z</td>
<td>0.0059</td>
<td></td>
</tr>
</tbody>
</table>

*Maximal T magnitude in the horizontal plane.
†Maximal T magnitude in the sagittal plane.

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### Identification of Infarction in LVCD (Tables 6 to 8)

Four measurements proved to be the most efficient: (1)* J-Z; (2) T magnitude in the horizontal plane; (3) 0.02-sec B QRS-X; and (4) 0.04-sec B QRS-Z. As in the above RVCD data, other measurements were relatively high on the ranked t-test listing but did not improve the identification rate because they were redundant or resulted in a greater increase in the frequency of false positives. The J-Z value ($>-0.036$ mv) identified 20 cases (20%) with a false positive frequency of 5%. The T magnitude in the horizontal plane ($<0.213$ mv) independently identified 15 cases with 5% false positives. The 0.02-sec B QRS-X ($<-0.134$ mv) added another 10% with 2% false positives. The 0.04-sec B QRS-Z ($<-0.206$ mv) independently identified 5% with a 2% false positive frequency. Thus the total identification by these four measurements was 50% with 14% false positives.

### Multivariate Analysis

Ten measurements were selected. The results of this analysis are expressed as the percentage of cases identified to the percentage

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### Table 6

**Recognition of Infarction in Left Ventricular Conduction Defects at the 96 Percentile Level**

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Min.</th>
<th>Max.</th>
<th>Cases independently recognized (A or B)</th>
<th>Recognized by</th>
<th>False positive (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>J-Z (mv)</td>
<td>-0.636</td>
<td>-0.000</td>
<td>13 (A)</td>
<td>$&gt;-0.009$ mv</td>
<td>2</td>
</tr>
<tr>
<td>0.02 sec B QRS-X (mv)</td>
<td>-0.134</td>
<td>0.520</td>
<td>10 (B)</td>
<td>$&lt;-0.134$ mv</td>
<td>2</td>
</tr>
<tr>
<td>0.04 sec B QRS-Z (mv)</td>
<td>-0.206</td>
<td>2.93</td>
<td>5 (B)</td>
<td>$&lt;-0.206$ mv</td>
<td>2</td>
</tr>
<tr>
<td>T mag. sag. pl. (mv)*</td>
<td>0.156</td>
<td>1.24</td>
<td>8 (B)</td>
<td>$&lt;0.156$ mv</td>
<td>2</td>
</tr>
</tbody>
</table>

*Same abbreviation as in table 5.

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### Table 7

**Recognition of Infarction in Left Ventricular Conduction Defects at the 90 Percentile Level**

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Min.</th>
<th>Max.</th>
<th>Cases independently recognized (A or B)</th>
<th>Recognized by</th>
<th>False positives (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>J-Z (mv)</td>
<td>-0.594</td>
<td>-0.036</td>
<td>20 (A)</td>
<td>$&gt;-0.036$ mv</td>
<td>5</td>
</tr>
<tr>
<td>T mag. hor. pl. (mv)</td>
<td>0.213</td>
<td>1.24</td>
<td>15 (B)</td>
<td>$&lt;0.213$ mv</td>
<td>5</td>
</tr>
<tr>
<td>0.02 sec B QRS-X (mv)</td>
<td>-0.115</td>
<td>0.311</td>
<td>10 (B)</td>
<td>$&lt;-0.115$ mv</td>
<td>5</td>
</tr>
<tr>
<td>0.04 sec B QRS-Z (mv)</td>
<td>-0.073</td>
<td>2.33</td>
<td>6 (B)</td>
<td>$&lt;-0.073$ mv</td>
<td>5</td>
</tr>
</tbody>
</table>
of false positives. The range was from 72% identified with 30% false positives to 52% identified with 14% false positives (table 9).

**Discussion**

This study encompasses one of the largest groups of patients (452) with ventricular conduction defects in whom the electrocardiographic criteria for the identification of infarction has been sought. This large group represents a totally unselected sample in which ECG criteria did not enter into case selection. It again emphasizes the difficulty in making a diagnosis of infarction in the presence of a left ventricular conduction defect. However, contrary to most previous reports which are based on much smaller numbers of patients, the data indicate similar difficulties in the diagnosis of infarction in the presence of right ventricular conduction defects.

It must be emphasized that 320 measurements were analyzed in each record. Only four measurements in groups 2 and 4 were of optimal value in the identification of infarction. Only a single electrocardiographic record per patient was examined, so no information is available as to the added value of serial tracings.

**Right Ventricular Conduction Defects**

The measurements and their values which are significant in the diagnosis of infarction center around the early portion of the QRS. The total identification rate, either by the four-measurement analysis (table 4) or multivariate analysis (table 5), is not high. In this large, unselected sample not more than 50 to 60% of RVCD with infarction can be identified with a false positive rate of 10 to 20%. However, the electrocardiographer (or computer), by using the data above, can appreciate the diagnostic accuracy of one or more measurements and know the expected frequency of a false positive diagnosis. For example, the finding of a value of >0.034 mv for the % QRS-Z will be indicative of infarction in 95% of cases. The 0.02-sec QRS vector which has been reported to be of diagnostic value in the identification of infarction was not of additional diagnostic value in this study because its information was contained in the % QRS-Z. One must, therefore, appreciate the difficulty of the electrocardiographic diagnosis of infarction in the presence of RVCD and never exclude such a possibility because of the absence of the “usual diagnostic features of infarction.”
Left Ventricular Conduction Defects

The most significant measurement for the identification of infarction in association with LVCD is J-Z. A value greater than $-0.136 \text{ mv}$, indicating minimal anterior orientation or in fact posterior orientation of J-Z, was indicative of infarction at the 95th percentile level. A T magnitude in the horizontal plane of less than $0.213 \text{ mv}$ identified infarction at the 95th percentile level. A 0.02-sec B QRS-X value of less than $-0.134 \text{ mv}$ is indicative of infarction at the 98th percentile level. This is in keeping with clinical experience and the reports mentioned above, namely, the significance of initial rightward QRS forces. A value of less than $-0.206 \text{ mv}$ for the 0.04-sec B QRS-Z also recognized infarction at the 98th percentile level. This is in agreement with earlier reports\textsuperscript{1-5} which indicate the significance of relatively prominent early anterior forces.

Using the above four measurements, the total identification rate was 50% with 14% false positives. Multivariate analysis using 10 measurements identified 52% of the infarct cases with 14% false positives. The identification rate could be progressively increased but with an associated rise in the frequency of false positives.

It is of interest that scalar parameters were found to be superior to vector measurements in this study of conduction defects and is in contrast to other abnormalities which have been studied. Since all known vector measurements were included in the 320 measurements used, the results obtained cannot be attributed to failure of such analysis.

A major contribution of this report lies in the large numbers of records available, their completely random selection, and the greater chance that results can be reproduced in additional cases. Previous reports, especially in the RVCD groups, have their shortcomings because of much smaller numbers of cases and controls.

Acknowledgment

The valuable assistance of Mrs. Ruby C. Harris, B. S., and Mr. George P. Murphy, M.A., is gratefully acknowledged by the authors.

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Glossary of Terms

$\% \text{ QRS}^*$ The QRS interval is divided into eights. The $\% \text{ QRS}$ represents the instantaneous vector at this moment in the QRS.

$0.04$-sec \text{ B QRS}^*$ B refers to the beginning of QRS; this is the instantaneous vector 0.04 sec after the onset of QRS.

$0.01$-sec \text{ E QRS}^*$ E refers to the end of QRS; this is the instantaneous vector 0.01 sec before the end of QRS.

References


10. Pipberger, H. V., Goldman, M. J., Leitmann, D., Murphy, G. P., Cosma, J., and Snyder, J. R.: Correlations of orthogonal electrocardiogram and vectorcardiogram with constitution-

*These terms as used in the text refer to instantaneous scalar variables.

A New Ecclesiastes

Human life being so profoundly influenced by the evolutionary, experimental, and social past, it is certain that the science of man cannot possibly be based exclusively on knowledge of the reactions exhibited by components isolated from the body. The past, like the mind, disappears when the organism is taken apart. The statement that most responses involve the whole organism functioning as an integrated unit is so obvious as to seem trivial. But it has large implications for medical teaching and medical research.

The time has come to give to the study of the responses that the living organism makes to its total environment the same dignity and support which is being given at present to the science of parts and reactions isolated from the organism. Exclusive emphasis on the reductionist approach will otherwise lead medicine into blind alleys. Unless a program of organismic and environmental research is vigorously prosecuted, medicine will be unable to support the loads placed on it by the health problems arising from the new environmental forces created by modern life.—René Dubos: Hippocrates in Modern Dress. Proc Inst Med Chicago 25: 249, 1964-65.
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