The Anatomic Basis for High-Frequency Components in the Electrocardiogram

By Nancy C. Flowers, M.D., Leo G. Horan, M.D., J. R. Thomas, M.D., and William J. Tolleson, M.D.

SUMMARY
In a correlative study between selected body-surface potential recordings and anatomic findings, multilead sets of high-fidelity, high-speed records from 128 persons were studied in connection with the results of our detailed postmortem dissections of their hearts. Attention was focused on high-frequency components (notching and slurring of the expanded QRS) as described by Langner.

We found that (1) groups with ventricular enlargement without scarring were indistinguishable from groups with infarction on the basis of the number of high-frequency components; (2) both of these groups were clearly distinguishable from normal subjects on this basis alone; and (3) the high-frequency component count in the group with ventricular enlargement showed high negative correlation with age and high positive correlation with right and left ventricular weights.

These findings suggest that the appearance of high-frequency components in the vectorcardiogram or electrocardiogram may relate to the struggle between competing generator sites of ventricular enlargement as well as to the classic concept of shattering of the wave of activation on the shoals of infarction.

Additional Indexing Words:
Anisotropy Biventricular enlargement First derivative of ECG
High-frequency notching Myocardial infarction QRS notching and slurring
Radial spread of activation

The use of an expanded time scale or increased frequency response to increase electrocardiographic detail has occasionally been reported since the early 1930's.1,2 However, it was Langner in the early 1950's who first appreciated that clinically pertinent, otherwise obscure electrocardiographic information might be detected in this fashion.3-5 In 1949, Gilford,6 and in 1960, both Scher and Young7 and Langner with Geselowitz8 looked into the frequency spectrum of the electrocardiogram. The latter investigators recognized in 1962 the value of the first derivative of the electrocardiogram. By the derivative's representation of the rate of change of the original electrocardiographic potential with respect to time, notches in the original QRS complex of even very small amplitudes and durations may cause relatively wide swings across the base line of the derivative, thus aiding detection.9,10 A number of investigators have in one fashion or another attempted to assign meaning to bites and notches out of

From the Section of Cardiology, Medical Service, Forest Hills Veterans Administration Hospital, the Department of Medicine, Medical College of Georgia, Augusta, Georgia, and the Section of Cardiology, Medical Service, Kennedy Veterans Administration Hospital and the Division of Cardiovascular Diseases, Department of Medicine, University of Tennessee, Memphis, Tennessee.

This study was supported by Grants HE-5586, HE-08861, and HE-09495, from the National Institutes of Health, U. S. Public Health Service, and research grants from the Georgia Heart Association and the Tennessee Heart Association.

Paper was presented in part at the 41st Scientific Sessions of the American Heart Association, Bal Harbour, Florida, November 23, 1968.

Address for reprints: Nancy C. Flowers, M.D., Chief, Section of Cardiology, FHD, Veterans Administration Hospital, Augusta, Georgia 30904.

Circulation, Volume XXXIX, April 1969 531
High-speed, high-fidelity scalar leads (XYZ) of the axial vectorcardiogram (VCG) and leads I, Vf and V1 to V6 of the electrocardiogram (ECG) from a patient with both biventricular enlargement and a large apical myocardial infarction. Note the prominent notching (n) and slurring(s) in both XYZ and Vf to V2. This is particularly prominent in V4 and V5. Notching represents both change in slope and change in sign (direction) while slurring represents change in slope alone. Primary directional changes are not counted, for example, peak of R.

For the purpose of this study notches will be defined as any departure in both slope and sign from the primary electrocardiographic or vectorcardiographic curve after the artifacts of noise have been excluded. Furthermore, these departures will be exclusive of the fundamental directional changes of the QRS complex. For example, the nadir of a Q, the peak of an R, or nadir of an S would not be included. Slurs will be defined as changes of slope without changes of sign (fig. 1). Except where indicated notches and slurs will be summed.

On 1,300 male patients admitted to Kennedy Veterans Administration Hospital, McFee-axial system18 vectorcardiograms in both scalar (XYZ leads) and loop form as well as electrocardiographic leads I, Vf, and V1 to V6 were recorded at the time of each admission by means of Polaroid photography from the face of a cathode ray oscilloscope. Sweep speeds were at 500 and 200 mm/sec. V4 was constantly recorded as a control lead.

Scalar leads of a 69-year-old man with posterior-inferior myocardial scarring. Note the relatively smoother QRS complexes when compared with figures 1 and 4. In lower left corner direct writer recordings are shown with residual q waves of old infarction.
Surface potential from each site was recorded at both sweep speeds and a minimum of two such sets for each lead was obtained. At the time of each repeated admission, follow-up sets were obtained. Identical leads were recorded on 36 healthy male medical students. The frequency response of the system was 0.2 to 10,000 cycles/sec. Notches and slurs were counted by two independent observers using the techniques of Langner, Geselowitz, and Mansure. The totals represent the mean of the sums of notches and slurs in XYZ and V1 to V5.

At the conclusion of 4 years, 128 of the original 1,300 patients had expired in the hospital and autopsy permission had been obtained. Two or more of the authors performed fresh dissections of the hearts. The coronary tree was serially sectioned and again opened longitudinally from the ostium distally. The right ventricle was dissected free from the interventricular septum, and after removal of the fat was measured planimetrically and weighed. Fat was removed from the left ventricular free wall which was then weighed with the septum. Both the left ventricular free wall and septum were sliced longitudinally at 0.5-cm levels from apex to base. The results were recorded on special protocol sheets with notation of right and left ventricular masses, right ventricular area, lesions in the coronary arterial tree, and the exact site and size of the lesions in the myocardium. These lesions were also photographed in color. Thirteen subjects were eliminated from the study because of advanced conduction defects.

Results

In the course of study we developed a strong impression that notching and slurring

---

Figure 3

Heart of patient whose ECG is illustrated in figure 2. Above left, the interventricular septum and, above right, left ventricular free wall are seen from the left ventricular endocardial aspect. The specimens are oriented with the valve ring at the top and the ventricular apex at the bottom. Below, and similarly oriented, intramyocardial areas of septum (left) and free wall (right) are exposed. Note scarring of posterior septum and beneath posterior papillary muscle from valve rings to apex.
occurred at least as frequently in recordings from subjects with large, uninfarcted hearts as in recordings from those with myocardial scars or fresh infarctions. Two extreme examples follow: In figure 2 note the relatively smooth QRS complex in the scalar leads of this subject who had postero-inferior myocardial scarring seen in figure 3. In the electrocardiogram of a 47-year-old man with long-standing aortic insufficiency of rheumatic origin, however, notching is evident in many leads (fig. 4). Ventricular weights were excessive, the right ventricle weighing 100 g and the left weighing 578 g. Coronary arteries were large and wide open without evidence of even minimal atherosclerosis.

We set about to see if these impressions held up under statistical analysis. The criteria for ventricular enlargement were based upon our own work involving over 2,000 dissections and several autopsy studies reported by Saphir.19 The right ventricular upper limit of normal was assumed to be 50 g, while the left ventricle and septum were considered enlarged if they exceeded 180 g. The all-male groups represented in the bar graph (fig. 5) include 36 healthy medical students of mean age 25 years ("young normals"), and six persons with a mean age of 71 who had died from other than cardiac causes in whom no evidence of scarring or enlargement was found ("old normals"). These have been graphed separately for reasons which will become obvious.

In the ventricular enlargement group there were 46 subjects, with a mean age of 59. Hearts were included in this group if they (1) fulfilled the weight requirements and (2) had no gross evidence of myocardial scarring of any size. Though not a pre-set criterion for being included, no occlusion of any of the coronary arteries through the third

---

**Table 1**

Principal Etiologies of Heart Disease in Subjects with Ventricular Enlargement

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>Patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Systemic hypertension</td>
<td>18</td>
</tr>
<tr>
<td>Pulmonary</td>
<td>5</td>
</tr>
<tr>
<td>Rheumatic</td>
<td>6</td>
</tr>
<tr>
<td>Infections</td>
<td>1</td>
</tr>
<tr>
<td>Primary or secondary myocardal disease</td>
<td>13</td>
</tr>
<tr>
<td>Unclear</td>
<td>3</td>
</tr>
</tbody>
</table>

---

*Figures 4 and 5 are not included in this transcription.*

*Table 1 is not included in this transcription.*

---

*Circulation, Volume XXXIX, April 1969*
Figure 6

Total number of notches from each subject (XYZ plus V₁ to V₅) plotted against subject's own combined ventricular weights. Note positive correlation in enlargement groups but less in infarction group illustrated by regression lines. The very high correlation (0.97) in the old normals was not plotted due to small sample.

Table 2

Comparative Correlations When Notching in XYZ and V₁ to V₅ were Analyzed Separately in the Noninfarction and the Infarction Groups

<table>
<thead>
<tr>
<th>Notes</th>
<th>Bivariate (r)</th>
<th>Multivariate (t)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Age</td>
<td>RVM</td>
</tr>
<tr>
<td>V₁-V₅</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No infarct</td>
<td>-0.42</td>
<td>0.42</td>
</tr>
<tr>
<td>Infarct</td>
<td>-0.11</td>
<td>0.14</td>
</tr>
<tr>
<td>XYZ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No infarct</td>
<td>-0.48</td>
<td>0.26</td>
</tr>
<tr>
<td>Infarct</td>
<td>-0.04</td>
<td>-0.00</td>
</tr>
</tbody>
</table>

Note: The numbers in the three bivariate analysis columns on the left are correlation coefficients as is the final column under multivariate analysis. Note that composite correlation exceeds any partial correlation for a group. The first three columns in the multivariate section on the right are all t values; those in italics are significant with \( P < 0.05 \) and the value in bold face is significant with \( P < 0.01 \).

Note greater dependence on right ventricular mass for V₁-V₅ notchings in the noninfarction group. Left ventricular mass shows the highest correlation with notchings in XYZ in the noninfarction group. Inverse age correlates well with notchings in both XYZ and V₁-V₅ for the noninfarction group.

Note lack of correlations in the infarction group.

branching was noted in any of the enlargement group. The cardiac diagnoses of this group are noted in table 1 by etiology.

In the infarction group there were 63 subjects with a mean age of 64. Hearts with diffuse or spotty, or tiny and single scars
FLOWERS ET AL.

MULTIVARIATE ANALYSIS OF DEPENDENCY OF NOTCH COUNT ON AGE, LEFT, AND RIGHT VENTRICULAR MASSES.

In the noninfarction group (above) multiple dependency is evident by the tendency of subjects with low notch counts (open rectangles and dots) to cluster about the higher ages but lower ventricular weights; subjects with higher notch counts (triangles and stars) hover nearer lower ages but higher ventricular weights. Such dependency is not apparent in the more random scatter of the infarction group (below).

were included as well as those with coalescent large scars. All had either complete occlusion or marked atherosclerotic narrowing of one or more branches.

By Cochran's approximations of Student's t-test, the myocardial infarction group and the ventricular enlargement group were each clearly distinguishable from both groups of normal subjects with $P < 0.01$ in the case of the "young normals," and $P < 0.05$ in the case of the "old normals." The infarction and enlargement groups, however, were indistinguishable from each other. It is obvious, then, from the graph that the "old normals" had more notches than the "young normals," but the most notches were seen in the enlargement group, with the infarction group following very closely.

Does the number of notches depend on age or ventricular mass? The answer is yes under certain circumstances, as illustrated in figure 6. Note that in the noninfarction group there is dependency of notch frequency on total ventricular mass as indicated by the regression line ($r = 0.35$), but in the infarction group, this dependency appears to be lacking, with an $r$ value of 0.09. In the enlargement ("old normal") group the dependency of notching on weight was striking ($r = 0.97$), but the sample was small. When the variables age, left ventricular mass, and right ventricular mass were each allowed to act singly as the
independent variable and the relationship to notches was tested, certain relationships became apparent (table 2). In the enlargement (noninfarction) group, there was a relatively high negative correlation with age. There was greater dependency on right ventricular than on left ventricular mass for notching in the electrocardiographic leads, but this dependency was reversed in the case of the vectorcardiogram, in which case the better correlation was between notching and left ventricular mass.

Next, we subjected these groups to multivariate analysis as illustrated in figure 7. This is a scatter graph of the noninfarcted group above, and the infarcted group below plotted along three axes representing age, left ventricular mass, and right ventricular mass. The tops of the figures indicate grouping by numbers of notches. Note in the noninfarcted group that the dependency on age and ventricular weights is graphically illustrated by the tendency of subjects with the lower notch counts (triangles and stars) cluster at higher weights but lower ages. Randomness prevails in the scatter of subjects with infarction.

We concluded, therefore, that there was a significant inverse dependence on age and a direct dependence on right and left ventricular mass in the noninfarction subjects. Such dependence was not demonstrated in the infarction subjects. Table 3 summarizes the statistical analysis.

**Table 3**

<table>
<thead>
<tr>
<th>Notches</th>
<th>Bivariate (r)</th>
<th>Multivariate (t)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Age</td>
<td>RVM</td>
</tr>
<tr>
<td>No infarct</td>
<td>-0.47</td>
<td>0.39</td>
</tr>
<tr>
<td>Infarct</td>
<td>-0.10</td>
<td>0.04</td>
</tr>
</tbody>
</table>

*Note: High negative correlation with age and positive correlation with right and left ventricular masses in the noninfarction groups. Correlations are much lower in the infarction group.*

**Table 4**

*Hypotheses as to Notch Formation in the ECG*

1. Classical shattering of the wave of activation on the zone of infarction
2. Departure from even radial spread of activation through the ventricular wall due to
   a. Microinfarction
   b. Functional microblock
3. Accentuation of 2 by ventricular hypertrophy (competing generator sites)
4. Relationship of anisotropy to above

_Circulation, Volume XXXIX, April 1969_
striking occurrence of the most notches in patients with ventricular enlargement from many etiologies other than atherosclerotic suggests, at the least, multiple causation.

From whatever cause, when the normally smooth, radial spread of activation from the endocardium outward is interrupted, and more tangential, less efficient detours are taken, distortion of the QRS curve results. Anisotropy of propagation in the case of the myocardial syncytium implies differences in conduction along the long axis as compared to conduction across the muscle fiber. We would like to suggest tentatively that the anisotropic properties of the myocardium may be accentuated and compounded by many structural or functional changes. More practically, we may presuppose a number of necessary deviations in the activation pathway, but in the presence of ventricular hypertrophy the powerful pull of the generator in either ventricle tends to accentuate any unevenness of the spread of activation in the alternate ventricle.

The detection of high-frequency notching may prove to be a screening device for heart disease of any etiology leading to biventricular enlargement, as well as for classical atherosclerotic heart disease.

Acknowledgment

We are grateful to Mrs. Hazel G. Wall for assistance in preparation of the manuscript and to Mrs. Patricia Orander, Mrs. Diane Lafferty, and Mr. Charles Eddlemon for technical assistance. The continuing cooperation of Dr. Joseph Young, Chief of Laboratory Service at the Kennedy Veterans Administration Hospital, made possible the detailed dissections and Mr. James A. Irby of the Medical College of Georgia Computer Center provided helpful statistical advice.

References


Circulation, Volume XXXIX, April 1969

Types of Critics

The capacity of public somnolence to retard change illuminates the role of the critic. In the early years of this century Abraham Flexner touched off a revolution in medical education by placing before the public a brilliant exposé of existing medical schools. Critics who call attention to an area that requires renewal are very much a part of the innovative process. (Of course, all critics are not heralds of the new. Some are elegant connoisseurs of that which has arrived, and when they approve of something it is likely to be long past its creative period. Like Hermes conducting the souls of the dead to Hades, they usher ideas and art forms into the mausoleums of “the accepted.”) — John W. Gardner: Self-Renewal: The Individual and the Innovative Society. New York, Harper & Row, Publishers, 1963 and 1964, p. 30.
The Anatomic Basis for High-Frequency Components in the Electrocardiogram
NANCY C. FLOWERS, LEO G. HORAN, J. R. THOMAS and WILLIAM J. TOLLESON

_Circulation_. 1969;39:531-539
doi: 10.1161/01.CIR.39.4.531

_Circulation_ is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1969 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circ.ahajournals.org/content/39/4/531

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in _Circulation_ can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to _Circulation_ is online at:
http://circ.ahajournals.org//subscriptions/