The Value of High Fidelity Electrocardiography Using the Cathode Ray Oscillograph and an Expanded Time Scale

By Paul H. Langner, Jr., M.D.

The cathode ray is practically free from inertia and therefore an ideal instrumentality for studying variations in electrical potential. A cathode ray oscilloscope with an amplifier system of high frequency response and an expanded time scale, 330 mm. per second, were employed to record electrocardiograms. Such tracings revealed considerable notching, slurring, and other peculiarities not seen in the conventional electrocardiographic records on the same individuals. An instrument should have a frequency response curve flat to well over 330 cycles per second to record faithfully the human electrocardiogram. This is much higher than the frequency response of instruments usually used for electrocardiography.

The cathode ray oscillograph and the high speed camera are presented as a method for the more detailed study of electrocardiographic patterns. The cathode ray oscillograph has been used in electrocardiography chiefly to study the vectorcardiagram or QRS and T loops. Our study is concerned with the use of the cathode ray oscillograph together with a high speed camera to record the standard extremity and precordial leads. Records obtained with this method reveal a wealth of detail that remain obscured in the conventional electrocardiographic record. Whether this additional detail will prove to be of value in routine electrocardiography has not yet been determined and will require considerable study. However, it seemed worth while now to present a brief account of the results obtained with this method and to report upon the application of this method to a particular field of investigation for which it seems eminently suited. This field is the study of electrocardiographic patterns and their distribution throughout the body and on its surface.

In order to exploit the advantages of the cathode ray oscillograph, the time scale must be greatly expanded. This is done by increasing the speed with which the recording paper moves from the usual 25 mm. to 300 mm. per second or more. The vertical amplitude of the record is also increased proportionately by increasing the amplification so that 1 mv. can be made to give a deflection of 6 cm. instead of the conventional 1 cm. The apparatus used for this study consisted of Dumont Cathode Ray Oscilloscope, type 304H, using the D-C amplifier and a Sanborn preamplifier* built especially

* The following description of the preamplifier was supplied by Dr. Arthur Miller:

The amplifier preceding the Dumont oscilloscope is a two stage battery-operated device whose first stage uses a conventional push-pull circuit in order to provide for a true differential input. The first stage is then direct coupled to the second stage, which is also arranged in a push-pull circuit. The output of one plate of this second stage tube is condenser-coupled to the oscilloscope input. The coupling network also includes a phase correction circuit so that the response to a suddenly applied constant voltage (the decay curve) will show an initial plateau lasting for about 0.5 second. This form of decay curve is entirely adequate to record even the slowest variations of the cardiac voltage without distortion. (Since the oscilloscope's own amplifier is direct coupled throughout, the low frequency behavior of the complete system is determined entirely by this coupling network between the preamplifier and the oscilloscope.)

As pointed out above, the oscilloscope is coupled to only one of the plates of the preamplifier output stage. The second plate is ignored because the commercial version of the 304 Oscilloscope has only a single ended input. Although this means that half of the preamplifier output is not used, the gain of this preamplifier is sufficient to provide an over-all sensitivity of at least two inches of oscilloscope deflection per millivolt input to the preamplifier. In addition, the in phase response of the preamplifier is so attenuated by its own pair of cascaded push-pull stages.
for this oscilloscope. The oscilloscope trace was photographed by a Westinghouse Oscilloscope Camera, Model ph 33671-1, using Kodak Linagraph paper No. 697. This type of instrumentation is widely used by neurophysiologists for recording action potentials in nerves but it has received scant attention in the field of electrocardiography. The use of a considerably expanded time scale revealing increased detail has been reported previously by Groedel and Reid and Caldwell. Recently a cathode ray oscillograph made expressly for electrocardiography has become commercially available, but since it uses the conventional time scale and limited amplification it is not comparable to the instrument which is the subject of this report. Gilford used the cathode ray oscillograph and a Fairchild camera for recording electrocardiograms. He observed increased detail in the tracings but concluded, after a limited study, that it did not contribute significantly to clinical interpretation. He also concluded that a frequency response flat to about 200 cycles would give faithful recording for most human electrocardiograms.

**Material**

Records were obtained from 36 apparently normal individuals without history, symptoms or signs of cardiovascular disease. Their ages ranged from 20 to 65 years. As a routine, leads I, II, III, aVn, aVL, aVF, V1, V3 and V5 were recorded. In some instances additional precordial leads V2, V4 and V6 were also recorded. Tracings were made with the subject recumbent in an electrostatically shielded and grounded room. Ten thousand ohm resistors were used in taking the “unipolar” extremity leads and the precordial leads. The subject must be free from tremor and completely relaxed; otherwise, skeletal muscle potentials will grossly distort the record. The film speed was 330 mm. per second.

**Analysis of Results**

To illustrate the results obtained by this method, tracings are reproduced (figs. 1 to 5), and certain generalizations about the characteristics of the records are made.

The T waves were essentially similar to those in conventional records. There was no notching or other hidden detail. Therefore, we shall not discuss the T wave further, and to conserve space this wave will be omitted from the illustrations.

The P waves showed a greater degree of notching than that seen in the conventional tracings from the same individual. An evaluation of these findings will not be attempted now. However, it seems that this method may be a useful tool for the study of auricular excitation.

This paper will be devoted entirely to a study of the form of the QRS complexes. In this small series of 36 cases, results must be preliminary and conclusions tentative, but certain definite tendencies seem to be clear. In the conventional electrocardiogram it is customary to accept as normal notching or slurring in all leads of low amplitude and in leads of large amplitude when the notching or slurring is near the isoelectric line. Therefore, we decided to accept the same criteria for cathode ray oscillograph tracings and, in addition, to scrutinize with special care those areas where notching and slurring usually do not occur in conventional tracings, namely leads of large amplitude in the two-thirds of the complex farthest from the isoelectric line.

**Extremity Leads**

Six extremity leads were obtained from each subject (I, II, III, aVR, aVL, aVF). First, the three largest leads from each individual, a total of 108 leads, were examined. None of these leads made with the conventional electrocar-
Figs. 1 and 2. Normal subjects. The leads are labeled. Only the QRS is shown in the cathode ray oscillograph record to conserve space. Immediately below each QRS is the P-QRS-T of the same lead made with the conventional electrocardiograph. In leads V₃ and V₄ of figure 2 the intrinsic-like deflection descends with such speed that it is not clearly registered in this photograph. All of the notching and slurring of these leads are true components of the deflections. None are artefacts or due to somatic muscle tremor. These distinctive notchings and slurings of the leads were present to the same degree in all complexes of the lead and the base line was quite smooth in both these cases. Two successive oscilloscope tracings of V₄ in figure 1 are mounted to demonstrate that the notching and slurring are constant and not due to artefacts.
diograph showed notching or slurring. However, 46 of these same 108 leads made with the cathode ray oscillograph and expanded time scale showed definite notching or slurring. The major deflection of the QRS in the leads of greatest amplitude was entirely smooth in the cathode ray oscillographic records in 30 of the 36 individuals, but in the six other cases exhibited one notch or slur. Two of the six exceptions are shown in figure 3.

A great majority of the tracings in this group had the largest limb lead deflections in leads II or aVR which is equivalent to saying the mean electrical axis was most commonly between 60 and 30 degrees. (See table 1.) Since leads II and aVR were frequently the largest deflections, this may account for the fact that they showed the greatest freedom from notching and slurring. However, as indicated in tables 1 and 2, although lead II was most frequently the largest deflection, lead aVR was most frequently free from either notching or slurring. In five cases where the axis was +60 degrees, lead II showed notching or slurring whereas lead aVR was free from these changes in the same individual. Another fact that is
brought out by tables 1 and 2 is that, while aV$_F$ in this series is larger than lead I in a majority of cases, lead I shows much lower incidence of notching and slurring than aV$_F$. A

Table 1.—Distribution of Mean Electrical Axis to Nearest 30° in 38 Normal Individuals

<table>
<thead>
<tr>
<th>Axis</th>
<th>Incidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>-30°</td>
<td>1</td>
</tr>
<tr>
<td>0°</td>
<td>2</td>
</tr>
<tr>
<td>+30°</td>
<td>10</td>
</tr>
<tr>
<td>+60°</td>
<td>19</td>
</tr>
<tr>
<td>+90°</td>
<td>4</td>
</tr>
</tbody>
</table>

Fig. 5. This figure shows two QRS complexes from different individuals reproduced in their original size to illustrate unusual notching. The left hand figure is V$_2$ from a subject with right bundle branch block.

A larger series of cases including a number of normal individuals with marked right or left axis deviation will be necessary to determine whether the direction of the mean electrical axis has a constant relation to the degree of notching or slurring encountered in the various limb leads. In this series lead aV$_R$ showed the lowest incidence of notching or slurring, regardless of the direction of the mean electrical axis. A summary of the cathode ray oscillograph records showing no notch or slur or only one notch or slur in the QRS complex is given in table 2. These figures refer to the two-thirds of the major deflection of the QRS farthest from the isoelectric line. This criterion was used because notching and slurring are accepted as normal in the initial and terminal portions of the QRS in most instances, even in conventional records.

Precordial Leads

In 31 cases there was no close resemblance between any precardial lead and any one of the extremity leads. In five cases where close resemblance did occur it was in instances where both leads were free from notching, slurring, or any other characteristic detail.

Table 2.—Notching and Slurring in the QRS Complex of the Six Extremity Leads recorded by the Cathode Ray Oscillograph in 38 Normal Individuals. Figures refer to the two-thirds of the largest deflection farthest from the isoelectric line in any given QRS

<table>
<thead>
<tr>
<th>Lead</th>
<th>Per Cent Having No Notch or Slur</th>
<th>Per Cent Having One Notch or Slur</th>
<th>Per Cent Having More Than One Notch or Slur</th>
</tr>
</thead>
<tbody>
<tr>
<td>aV$_L$</td>
<td>3</td>
<td>14</td>
<td>83</td>
</tr>
<tr>
<td>I</td>
<td>61</td>
<td>17</td>
<td>22</td>
</tr>
<tr>
<td>aV$_R$</td>
<td>83</td>
<td>17</td>
<td>0</td>
</tr>
<tr>
<td>II</td>
<td>67</td>
<td>28</td>
<td>5</td>
</tr>
<tr>
<td>aV$_F$</td>
<td>22</td>
<td>22</td>
<td>56</td>
</tr>
<tr>
<td>III</td>
<td>6</td>
<td>11</td>
<td>83</td>
</tr>
</tbody>
</table>

Table 3.—Characteristics of Precordial Leads in 38 Normal Individuals

<table>
<thead>
<tr>
<th></th>
<th>V$_1$</th>
<th>Transitional Zone Complex</th>
<th>V$_6$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Notched</td>
<td>20</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>Slurred</td>
<td>5</td>
<td>12</td>
<td>2</td>
</tr>
<tr>
<td>No notch or slur</td>
<td>11</td>
<td>15</td>
<td>34</td>
</tr>
<tr>
<td>Broad peak</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Broad nadir</td>
<td>12</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>
Electrocardiographic Pathways

One immediate field for investigation in which the expanded cathode ray oscillograph tracings should prove useful is in the relationship of the limb leads to the precordial and esophageal leads. Judging from records of standard precordial positions the various patterns are more different and distinctive than the conventional records. This will permit their identification as separate entities more accurately. Thus we can better determine the relationship of complexes written by different "views of the myocardium" and determine how these patterns contribute to the more remote body surface patterns, especially those of the extremity leads. In this way we can determine more precisely how the cardiac action currents are distributed in the body and on its surface. Wolferth, Livezey and Wood have shown how patterns of potential variation are distributed on the body surface and have demonstrated pathways over which the contour of patterns is uniform and only decrement of the voltage occurs. These investigators used an electrode over the spine of the right scapula as their reference electrode. Myers and Klein, using a central terminal as a reference electrode, concluded, "If a sufficient number of semidirect leads were taken, the counterpart of the QRS-T pattern of each of the unipolar limb leads could be demonstrated in a precordial or esophageal lead and a pathway along which the QRS-T complex maintained a fairly uniform configuration could be found bridging the gap between the extremity and the point on the thorax near the heart where the corresponding semidirect lead was obtained."

We studied the question of pathways as follows. Using the central terminal as a reference electrode, and a conventional direct-writing electrocardiograph, a pathway was located over which the contour of the patterns was uniform from a point on the thorax such as Cb to an extremity. Sometimes these pathways occurred on the anterior body surface or axillary areas; sometimes it was necessary to explore the posterior surface of the body. In any case only one narrow pathway could be found over which all characteristics of the patterns of the QRS-T complexes except decrement remained uniform from a certain point on the thorax to the extremity. Great care must be taken that all leads for a given pathway be taken with the body in exactly the same position and in the same phase of respiration. Four individuals were selected in whom pathways over which the QRS-T pattern from points on the thorax to each extremity respectively remained uniform in contour as recorded by the conventional direct writer. We discovered that it was not possible to find such pathways in which the patterns were uniform in contour in all individuals. In each of these individuals, once such a given pathway was established, tracings were immediately made from exactly the same points, with the body in the same position and phase of respiration, using the cathode ray oscillograph and expanded time scale. This procedure was employed for pathways to each of the three extremities in four subjects, a total of 12 pathways. In all cases each pathway as recorded by the conventional direct writer showed patterns of uniform contour, varying only in voltage due to decrement. However, when the records of the cathode ray oscillograph were examined for a given pathway there was definite change from one complex to another due to notching, etc., or actual change in wave form. These changes were obscured in the conventional tracing. The result of an experiment is illustrated in figure 4.

Discussion

Of the extremity leads, I, aVR, and II showed the least notching and slurring and of all the six leads aVR was most commonly "smooth." One explanation of this finding in II and aVR is that these were most commonly the largest deflections. But such an explanation would not also account for the frequent smoothness of I as compared with the usual notching in aVF, since aVF was on the average larger than I. The fact that the potential variations of the right arm contribute equally to leads I, aVR and II may have some bearing on the problem. To elucidate this further would require study of more normal individuals with marked right and marked left axis deviation.

The precordial leads revealed wave forms, notching and slurring that were not apparent
in the conventional records. The clinical value of this wealth of detail remains to be established. One outstanding finding is the consistent lack of notching and slurring in $V_5$ and $V_6$, as contrasted to the other precordial leads. This may prove to be of diagnostic value in distinguishing normal from pathologic records.

In the lower row of tracings illustrated in figure 3 there is a notch near the peak in lead II. The width of this notch is less than 1 mm. at its base. Since the time scale is 330 mm. per second, the electrical phenomena causing this notch have a duration of less than 3 milliseconds. Therefore, an electrocardiograph should have a frequency response of well over 330 cycles per second to give a faithful recording of this type of deflection.

In the study of pathways over which the contour of a pattern remains constant we selected the central terminal as a reference electrode. Therefore, our results have no bearing upon the findings of Wolferth, Livesey and Wood. When the central terminal is used the failure to demonstrate a pathway over which a given pattern remained constant from a point near the heart to an extremity is not surprising. Had the pattern remained constant in all its detail it would have been a coincidence because the body, though nonhomogeneous, is a volume conductor. Therefore, the potential variations of an extremity are the resultant summation of all the various patterns of potential variation which reach the extremity over the body surface and through the body tissues. Another possible explanation for the failure to obtain a pathway over which the pattern contour remained constant is that the central terminal may have deviated significantly from field zero potential.

This study was not an attempt to reach any conclusions about distribution of patterns but only to show the possibilities of the cathode ray oscillograph in this field. Patterns which look approximately the same in the conventional records may vary significantly in cathode ray oscillograph records because of characteristic detail such as notching, slurring, beading, speed of ascent or descent of the deflection, broad or flat peak or nadir, or contour not adequately described by any of these terms.

It is not known what significance these differences between the conventional and expanded cathode ray oscillograph records may have in clinical diagnosis but it would seem that an electrocardiograph with higher fidelity and more expanded time scale than the instruments commonly used today would be desirable for fundamental investigative work.

Another field in which the expanded cathode ray oscillograph tracing should prove useful is the determination of whether all the significant details that can be obtained from records made from points close to the heart (such as $V_2$, $V_3$, and $V_4$ and esophageal leads) can be faithfully reconstructed from the spatial QRS loop. We believe this is an open question. For theoretic reasons which we have discussed elsewhere it is possible that the QRS loop recorded from electrodes relatively distant from the heart may not reflect with precision all the details present in records made from electrodes close to the heart, especially when the expanded cathode ray oscillograph tracing is used as the criterion. If such discrepancies exist their significance should receive careful study.

**Summary and Conclusions**

1. Electrocardiograms made by the cathode ray oscillograph and expanded time scale reveal considerable detail such as notching, slurring beading, and unique contour that is obscured in the conventional electrocardiograph. The findings in 36 normal cases are presented.

2. The value of this increased detail in routine clinical electrocardiography has not been determined and deserves further study.

3. The application of this method to the study of the distribution of body surface patterns is illustrated.

4. On the basis of these 36 normal tracings it is believed that an electrocardiograph should have a frequency response curve relatively flat to over 330 cycles per second and probably much higher in order to record faithfully the human electrocardiogram.

**References**


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