On Evaluating the Einthoven Triangle Theory

By J. Scott Butterworth, M.D., and John J. Thorpe, M.D.

The authors have attempted to treat a controversial subject in a different way by introducing a known potential into the cavity of the living human heart and determining the magnitude of this potential at the extremities. While the data may be subject to various interpretations it is suggested that this technic may be a valuable tool for further analysis of the spread of potentials in the body.

The validity of the Einthoven triangle theory has aroused considerable controversy among students of electrocardiography for a generation. A variety of methods have been used in an effort to prove or disprove the assertion that the triangle formed by the three standard leads of the electrocardiogram conforms to Einthoven's postulates. The work of Wilson and his co-workers in studying the spread of currents from electrodes placed in the cardiac area in the human cadaver stimulated us to perform experiments of a somewhat similar nature with electrodes situated on the surface of the body between which potentials could be impressed. These experiments were performed with single make and break shocks. Similar experiments performed with 25 cycle alternating current have recently been reported by Wilson. Our studies revealed that there were certain points on the anterior and posterior surfaces of the thorax between which make and break shocks produced no resultant deflections in any of the standard leads of the electrocardiogram. (The electrocardiograph patterns in each lead were disregarded.) When, however, the electrodes were moved even slightly away from these points, deflections resulted in the standard leads. These isoelectric points varied slightly in position from one individual to another, but in general, the anterior position was slightly above the xyphoid process in the midline and the posterior position was almost exactly opposite on the back.

Although these experiments indicated that the electrical center of the triangle formed by the three standard leads approximated the position of the heart, we were unable to exclude the possibility that the current was traveling over some special pathway through the skin or subcutaneous tissues and that our findings localized the isoelectric point of these tissues rather than to that of the heart. The logical solution to this difficulty appeared to be the introduction of suitable electrical impulses within the heart itself. For this purpose we had made a special solid cardiac catheter containing two insulated electrodes at its distal end. One electrode was situated at the tip of the catheter but was buried slightly so that it would not actually contact any cardiac structure. The second electrode was similarly buried at the side of the catheter 2.5 cm. proximal to the tip. The catheter was tested by placing it within the right ventricle of animals and introducing potentials up to 4.5 volts between the electrodes. No untoward events occurred, such as the production of arrhythmias, so it was considered safe to proceed with human subjects.

The first experiment was performed on October 28, 1948. The special catheter was inserted into the left antecubital vein and threaded forward into the right auricle under fluoroscopic control. The continuity of the electrodes was tested by taking endocardial electrocardiograms. Unfortunately, one lead had been damaged during sterilization and was not usable. The experiment was continued by attaching the intact electrode to one side of the circuit and the other side of the circuit was attached to a lead to (1) the left leg and

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* U. S. Catheter Corporation

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(2) the right arm. The resistance between the endocardial electrode and the extremities was constant. An initial reference impulse of 0.05 volt was used. Deflections were recorded in the standard leads and augmented extremity leads by a Cambridge Simplitrol Electrocardiograph but were of such small magnitude that quantitative measurement was difficult. (The patterns from the heart were disregarded.) For this reason the reference current was increased to 0.10 volt. Table 1 lists the recorded and corrected values of these deflections.

With a known direction of current from the heart to the leg or in the reverse direction (90 or 270 degrees from the horizontal plane) one would expect Lead I to pick up little or no potential change and leads II and III to be equal. The recorded deflections confirm this. Similarly aVR and aVL should be approximately equal and aVF should be double the value of either of the others. The recorded deflections are in accord and the sum of the extremity potentials approximates zero.

Table 2 lists the deflections recorded when 0.1 volt was used in a circuit between the endocardial electrode and the right arm electrode.

Calculation of the direction of the vector of this current reveals it to be 36 (or 216) degrees which corresponds well with the observed anatomic axis from the point of the catheter in the right auricle to the right shoulder. (An exact anatomic axis could not be accurately measured as it would have been difficult to know which point on the right shoulder to use for reference.)

The second experiment was performed on June 22, 1949. The double endocardial electrode was inserted into the midportion of the right auricle by way of the antecubital vein. The resistance between the two electrodes was 25,000 ohms. Beginning with 0.08 volt and increasing, suitable deflections were produced on the Cambridge Simplitrol Electrocardiograph using 1.35 volts. The axis of the catheter was recorded by a spot x-ray film. A reference opaque wire was placed in a vertical axis to the right and parallel to the sternum. Table 3 lists

### Table 1.

<table>
<thead>
<tr>
<th>Lead</th>
<th>Standard-</th>
<th>Recorded Deflections</th>
<th>Corrected Deflections</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ization</td>
<td>cm.</td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>1.4</td>
<td>Make</td>
<td>±0</td>
</tr>
<tr>
<td>II</td>
<td>1.4</td>
<td>Make</td>
<td>-1.1</td>
</tr>
<tr>
<td>III</td>
<td>1.5</td>
<td>Make</td>
<td>-1.3</td>
</tr>
<tr>
<td>aVR</td>
<td>0.90</td>
<td>Make</td>
<td>+0.35</td>
</tr>
<tr>
<td>aVL</td>
<td>0.95</td>
<td>Make</td>
<td>+0.35</td>
</tr>
<tr>
<td>aVF</td>
<td>0.95</td>
<td>Make</td>
<td>-0.70</td>
</tr>
</tbody>
</table>

Voltage = 0.10 volt

### Table 2.

<table>
<thead>
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<th>Lead</th>
<th>Standard-</th>
<th>Recorded Deflections</th>
<th>Corrected Deflections</th>
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<tbody>
<tr>
<td></td>
<td>ization</td>
<td>cm.</td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>1.4</td>
<td>Make</td>
<td>+3.2</td>
</tr>
<tr>
<td>II</td>
<td>1.35</td>
<td>Make</td>
<td>+3.45</td>
</tr>
<tr>
<td>III</td>
<td>1.5</td>
<td>Make</td>
<td>+0.25</td>
</tr>
<tr>
<td>aVR</td>
<td>0.9</td>
<td>Make</td>
<td>-2.5</td>
</tr>
<tr>
<td>aVL</td>
<td>0.9</td>
<td>Make</td>
<td>+1.1</td>
</tr>
<tr>
<td>aVF</td>
<td>0.9</td>
<td>Make</td>
<td>-1.3</td>
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### Table 3.

<table>
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<tr>
<th>Lead</th>
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<th>Recorded Deflections</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>ization</td>
<td></td>
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<tr>
<td>I</td>
<td>1.0</td>
<td>Make</td>
</tr>
<tr>
<td>II</td>
<td>1.0</td>
<td>Make</td>
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<tr>
<td>III</td>
<td>1.0</td>
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<tr>
<td>aVR</td>
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<td>aVL</td>
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<td>aVF</td>
<td>1.0</td>
<td>Make</td>
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Voltage = 1.35 volts
the recorded values of these deflections. Inasmuch as the standardization was 1.0 cm.
throughout, no corrected values are necessary. Calculation of the vector indicates it to be
approximately 88 degrees which corresponded within the limits of error to the anatomic
axis of the electrodes as observed by x-ray. (It is extremely difficult to determine an exact
anatomic axis from a spot film because of such variable factors as the position of the central
beam in relation to the plane of the catheter and the plane of the reference vertical line.)

DISCUSSION

We have recently become acquainted with the work of Hafkenschiel and associates in
which they introduced 25 cycle alternating current into the right ventricular cavity of
dogs. Ventricular fibrillation resulted in the animals with input currents between 1 and
2 milliamperes. Certain differences exist between these experiments and those reported
in this paper. First, we have used make and break shocks at irregular intervals but not
faster than about once per second. Secondly, we used a special catheter in which both elec-
trodes were so located that neither one could come into contact with the endocardium. In
the experiments of Hafkenschiel and co-workers the electrodes were silver bands around
the circumference of the distal end of the catheter and it would seem that one or both electrodes
touched some part of the endocardium. We feel that these differences might very well account for the fact that we never observed any arrhythmias in either animal or human
cases. While we have had no difficulties in our limited experience, we would emphasize that
it is probably very important that the electrodes be prevented from coming into actual
contact with any cardiac structure. The difference between the use of make and break shocks
and alternating current of various cycle frequencies remains to be studied.

These experiments are of such limited scope that the results do not warrant detailed analy-
sis. We do not feel that they offer, at present, a definite solution of whether or not the body
acts as a homogeneous volume conductor and obeys all of Einthoven's postulates. On the
other hand, the potentials introduced within the heart seem to spread to the surface of the
body in such a way that the resultant deflections correspond within the limits of error to
the predictions based upon Einthoven's theory.

SUMMARY AND CONCLUSIONS

By means of a special double electrode cardiac catheter make and break shocks of low
voltage were introduced within the human heart. The deflections resulting at the surface
of the body were recorded by a Cambridge string galvanometer or Simpli-scribe in the
standard leads and the augmented extremity potentials. Calculation of the vectors of these
currents indicated close conformity with the anatomic axis of the electrodes.

It is felt that these experiments, while of a preliminary nature, seem to conform within the
limits of error to Einthoven's theory. A more detailed study of many cases will be necessary
to definitely establish such relationships. The method, though still subject to improvement
and further investigation, should be a useful tool in investigating the theory of unipolar
electrocardiography and spatial vectors.

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