Exercise Stress Testing and an Electromechanical S Wave of the Electrocardiogram

DOES THE S-WAVE VOLTAGE CHANGE WITH INCREASING WORK RATE?

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SUMMARY

A new view of the electrocardiogram, first proposed by Posel and arising from Craib's travelling dipole concept, predicts an electromechanical relationship between S-wave amplitude changes and cardiac mechanical function changes. In an attempt to determine whether the S-wave voltage changes with increasing work rate, 10 male subjects were tested at rest and at maximum exercise. A statistically significant increase in the S wave occurred with increased mechanical work. The theoretical prediction of an electromechanical S wave is thus validated and a request is extended to other workers to verify or refute its existence.


'Re there are scientists who will not accept a new truth because the rationale is not clear. Such a position has unfortunately too often obstructed progress.' E. Levin

The exercise cardiologist R. E. Phillips recently stated that the electrocardiographic response to exercise is a fundamental observation. He subsequently cautioned that the mounting mass of accumulated data leaves many crucial questions unanswered.

The recent description of cardiac mechanically linked changes of the S-wave amplitude of the electrocardiogram, based on the work of Craib, Posel, Bruce et al. and Wolf, raises a further as yet unanswered query. Does the S-wave voltage of the electrocardiogram change with increasing work rate?

This study, which is part of a more detailed research programme, examines the effects of incremental exercise on the S wave of the electrocardiogram in 10 subjects. This is an attempt to elucidate the above unresolved physiological phenomenon in the belief that too few analyses of this major wave of the electrocardiogram before and after exercise have been carried out, owing to a concentration of massive research programmes on the ST segment changes.

METHODS

For the purpose of this study 10 healthy male university students were chosen at random. A single transthoracic bipolar electrocardiographic lead was placed with the negative electrode at V4R and the positive electrode between V2 and V4, so that an S wave was present. After the subject had rested for 5 minutes, seated on an electrically braked bicycle ergometer, his electrocardiogram was recorded while he held his breath in the relaxed expiratory position, in order to minimise the effects of respiration on the electrocardiogram.

Exercise was commenced with a pedalling frequency of between 60 and 75 revolutions for 3 minutes at each work rate. At the end of 3 minutes, exercise was interrupted and the electrocardiogram was recorded on a direct writing electrocardiograph while the subject held his breath after normal expiration. Exercise recommenced at a work rate which was increased by 150 kpm/min (25 watts) (1 kpm = 9.81 N.m), and continued until exhaustion or distress.

RESULTS

Typical electrocardiographic records taken at rest and at maximum work rate are shown in Fig. 1. All show visible, even dramatic, changes in the S wave which are often associated with R-wave and T-wave changes. The results, showing the mean values and standard deviations at rest and at maximum work rate, are shown in Table 1, and the mean values are depicted graphically in Fig. 2.

Statistical testing of the changes in the S wave between rest and maximum exercise, using Student's t-test, was performed, and the changes are shown as 'significant' if \( P < 0.01 \).

Associated ST depression frequently occurs at or just before exhaustion, but the S-wave change almost always presents at a significantly lower work rate. This sequence is depicted in Fig. 3.

DISCUSSION

This study shows unequivocally that the S wave of the electrocardiogram, when recorded as described, increases when the subject under test performs maximum exercise. Thus the S-wave increment must be related to increased
mechanical activity of the heart. If confirmation of these changes is forthcoming, then the entire method of electrocardiographic analysis on stress testing and the theoretical basis of the electrocardiogram, which has led to dogmatic teaching such as ‘Whatever an electrocardiogram is, it is certainly no indicator at all of the function of the heart, which can only be determined by the analysis of stroke volumes ejected at known pressures,” and ‘It does not record mechanical cardiac events, only electric events’ will have long been overdue for review in the light of the Craib-Posel travelling dipole model which predicts these changes.

Retrospective perusal of the literature reveals numerous electrocardiographic records where the S wave has increased on exercise, and reference to a few examples in recent publications is given. The implications of an electromechanical S wave as a cardiac function transducer on exercise, and in facilitating myocardial salvage by the titration of inotropic therapy in acute myocardial infarction, raises a series of further

![Fig. 1. Typical electrocardiographic records taken at rest and at maximum exercise.](image1)

![Fig. 2. Graphs showing the change in the S wave from rest to maximum exercise.](image2)

**TABLE I. RESULTS**

<table>
<thead>
<tr>
<th>Subject</th>
<th>Mean S wave (± 1 SD)</th>
<th>Maximum work rate (kpm/min)</th>
<th>At rest</th>
<th>At maximum exercise</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>900</td>
<td>9.17</td>
<td>10.79*</td>
<td>&lt;0.01</td>
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</tr>
<tr>
<td>2</td>
<td>750</td>
<td>0.29</td>
<td>0.57</td>
<td>&lt;0.05</td>
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<td>3</td>
<td>1350</td>
<td>5.33</td>
<td>6.69*</td>
<td>&lt;0.001</td>
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<tr>
<td>4</td>
<td>1200</td>
<td>0.29</td>
<td>0.80</td>
<td>&lt;0.001</td>
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</tr>
<tr>
<td>5</td>
<td>1050</td>
<td>17.13</td>
<td>19.89*</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>600</td>
<td>0.10</td>
<td>0.80</td>
<td>&lt;0.001</td>
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</tr>
<tr>
<td>7</td>
<td>1050</td>
<td>7.50</td>
<td>15.81*</td>
<td>&lt;0.001</td>
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<tr>
<td>8</td>
<td>1050</td>
<td>10.13</td>
<td>14.56*</td>
<td>&lt;0.001</td>
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<tr>
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<td>1.21</td>
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</tr>
<tr>
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<td>900</td>
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<td>0.64</td>
<td>&lt;0.001</td>
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</tbody>
</table>

* Denotes an increase.
questions. What is the effect of training on the magnitude of the S-wave changes? What is the importance of the fact that these changes precede ST segment changes? What is the predictive value of these changes from an individual and actuarial point of view? Is it possible that a definite statistical risk value could make a number of currently uninsurable cardiac cases insurable? Finally, what is the basis of these changes and what other parameters of cardiac mechanical function are reflected by the electrocardiogram?

The investigations with echocardiography and animals now being undertaken at this university, imply a positive answer to the question asked in the title of this article. Such a physiological finding would contradict the most current undergraduate teaching on the nature of electrocardiography, and reinvestigation of this topic should be initiated to resolve the differences between current dogma and the presented theoretically predicted experimental findings.

**CONCLUSION**

In contradiction to an electrical, non-mechanical approach to the human electrocardiogram, evidence has been presented for the existence of an electromechanical relationship on exercise. It is concluded that the theoretical basis of electrocardiography would require review if these results can be confirmed. That such confirmation or refutation is an urgent necessity arises from the possible application of an atraumatic cardiac function transducer, which is more sensitive than ST depression, especially with respect to acute myocardial infarction, angina, and exercise stress testing as well as health testing for personal and insurance purposes.

**REFERENCES**


Fig. 3. Electrocardiograms at rest, at 300 kpm/min, and at 1050 kpm/min, showing that the S-wave change has occurred before the ST segment change.