Transmembrane Potentials of the Normal and Hypothermic Human Heart

By Baruch Bromberger-Barnea, E.E., Ph.D., Paolo Caldini, M.D., and George J. Wittenstein, M.D.

Transmembrane cardiac potentials from the human ventricles were recorded in 10 subjects during corrective cardiac surgery under normothermic or hypothermic anesthesia. The amplitude and shape of these transmembrane potentials are compared with simultaneously recorded electrocardiograms, and their relationships are discussed.

The amplitude and shape of the cardiac transmembrane potential in human subjects are of more than academic interest. The relationship of transmembrane potentials to the electrocardiogram is still largely unknown, despite the fact that the human electrocardiogram is probably one of the most studied of all physiological variables. It was felt that an investigation of these relationships during cardiac surgery in normothermic as well as hypothermic subjects might add valuable information.

The details of depolarization and repolarization can most accurately be determined only on the basis of single cell activity.

**METHODS**

Measurements were taken during cardiac surgery in a sterile field by means of the Ling-Gerard ultramicroelectrode (approximately .75 microns in diameter), as modified by J. W. Woodbury for flexible recording.¹ The neutral electrode was positioned on the exposed myocardium as close as was feasible to the microelectrode. Potentials were amplified by means of a high impedance amplifier and recorded simultaneously with the limb lead electrocardiogram, generally lead II, on a Sanborn 150M Four-channel Recorder. Potentials were also visualized on a 21 inch oscilloscope for monitoring. Calibration voltages of 100 mv. were introduced through the tissue via the neutral electrode. Transmembrane potentials were recorded successfully from 10 patients out of 16 cases examined (table 1). No adverse effect of any kind was observed. The introduction of the electrode did not produce any extrasystoles or other cardiac arrhythmias. Procedures were generally limited to 5 min. prior to the cardiac corrective surgery after the chest had been opened.

**RESULTS**

The average resting potential on the ventricles varied between −40 and −91 mv., with a mean of −73 mv. Action potential overshoot averaged +10 to +34 mv., with a mean of +21 mv. (figs. 1 and 2). Other statistical details are shown in table 1. The end of the T wave of the electrocardiogram usually corresponded to the end of the slow repolarization phase on the transmembrane potential. The beginning of depolarization of the transmembrane potential did not coincide with the beginning of the upstroke of the QRS complex of the limb lead electrocardiogram, and the time intervals between these two variables were measured. Progressively increasing time intervals were observed in hypothermia. The potentials correspond well both in shape and amplitude to those that have been reported previously in other mammals. The prolongation of the slow repolarization phase as reported in experimental animals during hypothermia² was not quite so pronounced. This might be due to the fact that the patients under hypothermia had heart rates and temperatures exceeding those reported for experimental animals during hypothermia. No differences in the amplitudes of the action potential, resting potential, and action potential overshoot were apparent between hypothermic and normothermic cases. No negative or positive after-potentials were seen.

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² Received for publication August 8, 1958.
TRANSMEMBRANE POTENTIALS OF HUMAN HEART

TABLE I.—Comparative Data on Transmembrane Potentials and Electrocardiograms

<table>
<thead>
<tr>
<th>Subj. sex. age</th>
<th>Diagnosis and surgery</th>
<th>Operative temperature</th>
<th>Anesthesia</th>
<th>Potentials</th>
<th>Repolarization</th>
<th>Position of electrode</th>
<th>No. of observations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Induction</td>
<td>Maintenance</td>
<td>Heart rate (b/min.)</td>
<td>Resting (mv.)</td>
<td>Action (mv.)</td>
<td>Overshoot (mv.)</td>
</tr>
<tr>
<td>C.S. M 27</td>
<td>Aortic insufficiency</td>
<td>Normothermic</td>
<td>Sodium pentothal</td>
<td>Cyclopropane ether N_2O-O_2</td>
<td>125</td>
<td>-91</td>
<td>124</td>
</tr>
<tr>
<td>J.R.S. F 10</td>
<td>Patent ductus</td>
<td>Normothermic</td>
<td>Sodium pentothal</td>
<td>Cyclopropane N_2O-O_2</td>
<td>80</td>
<td>-60</td>
<td>68</td>
</tr>
<tr>
<td>J.L. F 17</td>
<td>Mitral insufficiency, mitral stenosis</td>
<td>Normothermic</td>
<td>Sodium pentothal</td>
<td>Cyclopropane ether N_2O-O_2</td>
<td>84</td>
<td>-72</td>
<td>97</td>
</tr>
<tr>
<td>H.M. F 27</td>
<td>Coarctation of aorta</td>
<td>Normothermic</td>
<td>Sodium pentothal</td>
<td>Cyclopropane ether N_2O-O_2</td>
<td>129</td>
<td>-88</td>
<td>112</td>
</tr>
<tr>
<td>W.P. M 18</td>
<td>Mitral stenosis</td>
<td>Normothermic</td>
<td>Sodium pentothal</td>
<td>Cyclopropane ether N_2O-O_2</td>
<td>110</td>
<td>-59</td>
<td>93</td>
</tr>
<tr>
<td>J.R. M 14</td>
<td>I.V. septal defect</td>
<td>Hypothermic 32 C.</td>
<td>Ether N_2O</td>
<td>N_2O</td>
<td>100</td>
<td>-67</td>
<td>96</td>
</tr>
<tr>
<td>S.C. F 5</td>
<td>Pentalogy of Fallot</td>
<td>Hypothermic 28.5 C.</td>
<td>Cyclopropane ether</td>
<td>N_2O</td>
<td>86</td>
<td>-88</td>
<td>100</td>
</tr>
<tr>
<td>D.W. M 21</td>
<td>I.A. septal defect</td>
<td>Hypothermic 29.5 C.</td>
<td>Cyclopropane ether</td>
<td>N_2O</td>
<td>92</td>
<td>-88</td>
<td>122</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>29.5 C. (Postop)</td>
<td>56</td>
<td>-56</td>
</tr>
<tr>
<td>W.J.R. F 9</td>
<td>I.A. septal defect</td>
<td>Hypothermic 29 C.</td>
<td>Cyclopropane</td>
<td>N_2O</td>
<td>65</td>
<td>-63</td>
<td>82</td>
</tr>
</tbody>
</table>

*L.V. = Left ventricle.
†R.V. = Right ventricle.

DISCUSSION

These observations show that transmembrane cardiac potentials can be recorded in situ by means of ultramicroelectrodes during cardiac surgery without danger to the patient. Because human transmembrane cardiac potentials are similar to those recorded in experimental animals, it seems fair to assume that the same experimental criteria can be applied. The shape of the potential curve has been related to the ionic relationships of intracellular and extracellular ions, especially of sodium and potassium. It would be expected that in the human heart, changes in these ions would produce the same changes in shape of the transmembrane potential, especially in the curve of repolarization, as have been reported in the experimental animal. Techniques must be further advanced before these potentials can be used for the immediate determination of ionic changes. Nevertheless, this possibility is evident.

Our data confirm clinical speculation based on the widening of the QRS complex during hypothermia and stipulating delayed intraventricular conduction time. Time delays up to 80 msec, between the beginning of the QRS complex and the beginning of the depolarization curve of the transmembrane potentials were recorded during hypothermia. It is interesting, however, that comparative electrocardiograms taken with conventional electrocardiographic leads by themselves did not reveal these time differences. The number of cases presented here is too small to warrant a statistically useful conclusion. It appears that ventricular conduction time changes uniquely throughout both ventricles and that the electrocardiogram might cease to be an accurate indicator of left or right ventricular function.

The shape of the transmembrane potential is determined not only by temperature but also by heart rate. The potentials recorded...
Transmembrane potentials from normothermic left ventricle. 1 = 100 mv. calibration signal.

from some of our patients with fast heart rates during hypothermia show no essential difference from those recorded at normal temperature with similar heart rates.

**SUMMARY**

Transmembrane cardiac potentials from the human ventricles were recorded during cardiac surgery in 10 human subjects out of 16 attempted. This included 5 cases of hypothermia and 5 cases of cardiac surgery at normal temperature. The Ling-Gerard ultramicroelectrode as modified by J. W. Woodbury for flexible recording was used. Resting potentials of -40 to -91 mv. with a mean of -73 mv. and action potential overshoots of +10 to +34 mv. were obtained. The time of slow and fast repolarization varied with temperature and heart rate in a nonlinear manner. The relationships of the transmembrane cardiac potential and the simultaneously recorded limb lead electrocardiogram are discussed.

**SUMMARIO IN INTERLINGUA**

In 10 ex 16 essayos, le registration del potentiales cardiac transmembranal in le ventriculos human esseva effectuate a bon successo in le curso de interventiones chirurgic in le corde. Le serie include 5 casos de operation sub hypothermia e 5 casos a temperatura normal. Le ultramicroelectrodo de Ling-Gerard, in le modification de J. W. Woodbury pro registrationes flexible, esseva empleate. Potentiales de reposo de -40 a -91 mv. con un valor medie de -73 mv. e excessos de resalto in le potentiales de action amontante a inter +10 e +34 mv esseva obtenite. Le tempore del lente e rapide repolarisation variava con le temperatura e le frequentia cardiac de maniera non-linear. Es discutite le relationes inter le potential cardiac transmembranal e le electrocardiogrammas a derivation extremital que esseva registrate simultaneemente.

**REFERENCES**


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