Evidence is presented, that in the completely isolated nonworking dog heart oxygen consumption is higher during a period of electrically induced fibrillation than during a period of rhythmical contraction and that this increase is not due to the electric stimulus per se.

Electric induction of ventricular fibrillation during cardiac surgery has been proposed recently, as a means of providing a quiescent organ and of diminishing the danger of air embolism. However before this procedure is adopted for routine clinical use, more should be known about its safety. Since myocardial damage may result when metabolic requirements are not met by the available oxygen, knowledge of the metabolic rate during fibrillation is of importance in evaluating the safety of induced fibrillation. The published data bearing on this question are scant and inconclusive. Thus Hooker and Kehar reported an increase in the rate of CO2 output and glucose utilization during fibrillation, while Senning found no change in the rate of oxygen consumption. Paul and co-workers observed a decreased oxygen consumption in fibrillation, but on the basis of a comparison with the working heart. Inasmuch as fibrillation would appear to be applicable only to procedures involving an empty, bypassed heart, measurements of the oxygen requirement in fibrillation to be meaningful, must be compared with values obtained for the empty heart with regular rhythm. What factors may be responsible for the apparent discrepancy between the data of Hooker and Kehar and of Senning cannot be judged from the published reports. The possibility is not excluded, however, that in the few experiments on which Senning bases his conclusions, the heart was doing more than a negligible amount of work.

In the present study the oxygen utilization has been compared in the completely empty heart during periods of sinus rhythm and of ventricular fibrillation.

METHODS

Oxygen consumption of the completely isolated dog heart was measured using a closed-system spirometer technic, modified to permit perfusion by the Langendorff method.

Healthy mongrel dogs of either sex weighing about 12 pounds were anesthetized with Nembutal (35 mg./Kg. i.v.). About 150-200 ml. of blood were withdrawn from the carotid artery into a flask containing 100 mg. of heparin, and used to fill the perfusion system. The animal was then intubated and maintained with a positive pressure respiratory pump while a conventional heart-lung preparation was made. An additional 200 mg. of heparin were injected into the circulation just before cannulating the superior vena cava and brachiocephalic artery. The heart-lung stage was maintained for 15 to 20 minutes before beginning perfusion by the Langendorff method. Both atria were widely incised, the atrioventricular valves were cut and the heart suspended from the apex to insure proper drainage of blood from its cavities. Blood flow through the coronary system was maintained throughout the entire procedure except for brief periods in a few cases where technical difficulty was encountered.

Perfusion pressure was kept at 65 mm. Hg. In a series of preliminary experiments it was found that at perfusion pressures of 65 mm. Hg and above, the oxygen consumption was independent of pressure. The lowest value was chosen because at lower pressures myocardial edema developed to a lesser extent and the longevity of the preparation was correspondingly increased. With a pressure of 65 mm. Hg it was possible to maintain an adequate
coronary flow and in control experiments the oxygen consumption was found to remain unaltered for periods of at least 3-4 hours. The temperature of the system was kept constant within .03 C for a given experiment and varied between 37.3-37.8 C. from one experiment to another. Pulse rate and coronary flow were observed at 10-12 minute intervals while the oxygen consumption was recorded continuously on a kymograph.

Fibrillation was produced by single brief shocks of low intensity (.1-.2 amperes) from a fibrillator designed by R. T. Bruss and made by Doughboy Industries. For defibrillation brief shocks of high intensity (1-3 amperes) from a clinical defibrillator were used. Both fibrillatory and defibrillatory stimuli were given through a pair of spoon shaped copper electrodes padded with saline-soaked gauze.

RESULTS AND DISCUSSION

Experiments in this study can be grouped into three series, results for which are graphically summarized in figure 1.

The control series consisted of 6 experiments in which the preparation, made as outlined above, was permitted to follow its natural course for a period of 3 to 4 hours. In any given experiment very little if any tendency was observed for the oxygen consumption to change systematically with time over this period. The mean oxygen uptake for the series was 2.20 ± .0199 cc./min./100 Gm. wet weight.

The fibrillation series also comprised 6 experiments in which the heart was fibrillated as described above after a 50 minutes control interval and remained in fibrillation for an additional 50 to 60 minutes. Mean oxygen uptake was 2.58 ± .039 cc./min./100 Gm. wet weight during the control period and rose to 3.66 ± .159 cc./min./100 Gm. wet weight during the period of fibrillation. The control value in this series is higher than the mean for the control series. This difference is very likely due to the choice of wet weight as the reference standard, since the perfused hearts undergo a progressive hydration with time. Hearts in this series were weighed after two hours of perfusion and appeared less edematous than the hearts used in the control series which were weighed after 3 to 4 hours.

The defibrillation series, carried out in an effort to evaluate the contribution of the electrical stimulus to the foregoing results, was made up of five experiments in which the heart was fibrillated at the outset (except for an initial 10 minutes equilibration period), left in fibrillation for 50 to 60 minutes and then defibrillated. Mean oxygen consumption during fibrillation was 3.80 ± .157 cc./min./100 Gm. wet weight and fell following defibrillation to 2.73 ± .048 cc./min./100 Gm. wet weight. In all of these experiments the record showed a transient rise of oxygen consumption during the first 1 to 2 minutes after the defibrillatory stimulus, followed by a pronounced fall. Since, except for the first 10 minutes following the stimulus, the rate of oxygen uptake after defibrillation was not very different from the control value of the fibrillation series, this initial stimulation may well account for the somewhat higher mean observed during the time of rhythmical contraction in the present series.

More detailed statistical analysis is given in tables 1 and 2. In the plot of oxygen consumption with time for each individual experiment, no systematic trend was noted during either
TABLE 1.—Oxygen Consumption Data for the Fibrillation Series

<table>
<thead>
<tr>
<th>Experiment No.</th>
<th>O$_2$ Consumption$^*$ Control (a)</th>
<th>Fibrillation (b)</th>
<th>$b - a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.76 ± .22</td>
<td>4.03 ± .16</td>
<td>1.27</td>
</tr>
<tr>
<td>2</td>
<td>3.13 ± .22</td>
<td>4.21 ± .12</td>
<td>1.08</td>
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<tr>
<td>3</td>
<td>2.17 ± .082</td>
<td>2.87 ± .14</td>
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<tr>
<td>4</td>
<td>2.15 ± .22</td>
<td>3.84 ± .25</td>
<td>1.69</td>
</tr>
<tr>
<td>5</td>
<td>1.71 ± .082</td>
<td>2.02 ± .14</td>
<td>.31</td>
</tr>
<tr>
<td>6</td>
<td>3.56 ± .24</td>
<td>4.38 ± .082</td>
<td>.82</td>
</tr>
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<td>6.47</td>
</tr>
</tbody>
</table>

$b - a = 1.08$
S.E.d = .08
$p = .003$

* cc./min./100 Gm. wet weight.

TABLE 2.—Oxygen Consumption Data for the Defibrillation Series

<table>
<thead>
<tr>
<th>Experiment No.</th>
<th>O$_2$ Consumption$^*$ Fibrillation (a)</th>
<th>Defibrillation (b)</th>
<th>$a - b$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.66 ± .301</td>
<td>3.50 ± .182</td>
<td>.18</td>
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<tr>
<td>2</td>
<td>3.02 ± .188</td>
<td>2.65 ± .103</td>
<td>.37</td>
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<td>3</td>
<td>3.93 ± .334</td>
<td>2.90 ± .183</td>
<td>1.33</td>
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<tr>
<td>4</td>
<td>4.17 ± .224</td>
<td>2.63 ± .230</td>
<td>1.54</td>
</tr>
<tr>
<td>5</td>
<td>4.33 ± .283</td>
<td>2.83 ± .018</td>
<td>1.45</td>
</tr>
<tr>
<td></td>
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<td></td>
<td>5.37</td>
</tr>
</tbody>
</table>

$a - b = 1.07$
S.E.d = .40
$p = .022$

* cc./min./100 Gm. wet weight.

The period of fibrillation or the period of regular beat (correl. coeffic. = −.01). It is therefore justified to average the data for each experimental period and to compare the means. For the fibrillation series the mean difference is 1.08 ± .27 cc./min./100 Gm. wet weight, the corresponding probability being .003. For the defibrillation series the mean difference is 1.07 ± .40 cc./min./100 Gm. wet weight with a probability of .022.

On the basis of the data presented it is concluded that in the type of preparation employed, the metabolic requirements of the heart are higher during fibrillation than during rhythmical contraction. It also appears that this increase is not due primarily to the electrical stimulus as such, but is characteristic of the state of fibrillation. This is in agreement with the data obtained by Hooker and Kehar on CO$_2$ output with a similar experimental design.

Assuming that an adequate coronary flow can be assured during surgery by some extra-corporeal circulatory device, the increased oxygen requirement during fibrillation may be regarded as of little importance in judging the merits of induced fibrillation as an adjunct to surgery. However, should the surgical procedure involve transient compromise of the coronary circulation, either by design or accident, a marginal oxygen supply might be rendered inadequate by the presence of fibrillation.

SUMMARY

Oxygen consumption of the completely isolated non-working dog heart, perfused by the Langendorff technic has been measured during rhythmical contraction and electrically induced ventricular fibrillation. The period of fibrillation is characterized by a significant increase in oxygen utilization which cannot be accounted for by the electric stimulus and must therefore be ascribed primarily to the arrhythmia per se.

ACKNOWLEDGMENT

The authors are greatly indebted to Dr. J. E. Bearman and Mr. M. H. Johnson of the department of Biostatistics for valuable advice on the interpretation of data.

SUMMARIO IN INTERLINGUA

Le consumption de oxygene in le completelymente isolate e non-laborante corde del can, perfundite per medio del technica de Langendorff, essaeva mesurate durante le contraction rhythmic e le electricamente inducite fibrillation ventricular. Le periodo de fibrillation es characterisate per un significative augmento del utilisation de oxygene. Iste augmento non es explicable per le stimulus electric e debe esser ascrisite primarmente al arrhythmia per se.
REFERENCES


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<th>Probable Publication Date:</th>
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<td>June 4</td>
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Oxygen Consumption of the Completely Isolated Dog Heart In Fibrillation
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Circ Res. 1956;4:144-147
doi: 10.1161/01.RES.4.2.144

Circulation Research is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 0009-7330. Online ISSN: 1524-4571

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