A Heart Function Test with Continuous Registration of Oxygen Consumption and Carbon Dioxide Production

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The authors present a test of myocardial function based on the continuous registration of pulmonary exchange of oxygen and carbon dioxide during rest and a standard amount of work. The authors believe that the test is simple enough for wide clinical application. The "functiocardiogram" is of considerable physiologic and clinical interest. The normal values of the test are defined and a few examples of abnormal tests are discussed.

EVERY cardiologist would like at times to have a reliable test of heart function at his disposal. There appear to be 3 reasons why a test of heart function is so infrequently used as a routine method. First, really reliable tests of heart function are too complicated for everyday practice, with the exception perhaps of Nylin's test. Second, many cardiologists believe that x-rays and electrocardiograms give sufficient information about the cardiac function, but this attitude is surely disputable. Third, cardiologists often think that the history of the disease provides sufficient information about the functional state of the heart and circulation, so that special tests of function are of little if any use. This view is only partly true. By the time breathlessness on effort or venous congestion point to impaired cardiac function, circulatory failure is already on its way; so it still seems important to search for a method that, by imposing a certain strain on the circulation, can disclose impending circulatory failure.

In 1949 a test of cardiac function was described that is based on the continuous registration of pulmonary exchange of gas during rest and work. Since that time the apparatus has been developed further without change in principle. In normal healthy subjects of varying age and sex the normal values of the test were established and the test was applied in about 1,000 subjects. In this paper some tests in patients are discussed as examples; the application of the test in clinical cases is reported separately.

It was our aim to keep the test itself, the calculations, and its evaluation as simple as possible, so that the busy clinician without a special laboratory or specially skilled workers can apply it easily. The test is performed by the patient in about 24 min., and the necessary calculations take even less time. The conduct of the experiment and the evaluation of the graph can easily be done by a skilled technician.

In a simple way and in a short time, with only 1 apparatus our test gives insight into the adaptation of the circulatory system to a given amount of work, and therewith into the functional state of the heart in a given case. The cardiac function is recorded directly on a graph. Just as the cardiologist can get an impression of cardiac disease by a single glance at an electrocardiogram, so can he get an idea of the general function of the heart with 1 gaze at our "functiocardio gram." As with the electrocardiogram, more exact information can be obtained by analysis of the graph.

METHOD AND APPARATUS

By means of a diaferometer specially constructed for this purpose the oxygen consumption (and usually also the carbon dioxide production) was measured and recorded continuously during rest, during work, and again during the following rest.

To make the "functiocardiograms" easily comparable we usually followed a standard procedure. The work was performed on a bicycle ergometer or by climbing up and down a step at a fixed tempo. In the first case, the work amounted to 60 watts and in the latter instance to about 50 watts, depending on the weight of the subject. This amount of work was established, in a series of experiments with normal subjects, as easily performed during 8 min. without any sign of fatigue.

First the subject sat at rest for about 8 min., then he worked for exactly 8 min., and finally rested
FIG. 1. Photograph of the recording apparatus

FIG. 2. Diagram of the equipment. On the left is the fan blowing outdoor air through the helmet. This air escapes freely at the top of the helmet; a small sample is continuously removed by the small pump at the top right and sent through the diaferometer. A second small pump (top, middle) delivers outdoor air for the diaferometer. The stopcock (top, right) is in the measuring position (M); the position O shown with dotted lines is for the registration of the 0 lines. The air sample passes eventually through a tube of soda-lime (horizontal shading), and through a drying tube (oblique shading). Part of the sample is sucked by the third small pump through the measuring block of the diaferometers (CO₂ and O₂) and the rest of the sample escapes freely. The blocks contain the Wheatstone bridges. In the CO₂ apparatus 2 wires receive gas with CO₂ (marked +CO₂), the other 2, gas deprived of CO₂. In the O₂-apparatus 2 wires marked −O₂ receive patient air without CO₂ (and deprived of part of the O₂), the others outdoor air without CO₂. At the bottom to the right are the galvanometers and the photographic kymograph.
again in a sitting position for 8 min. During the whole time the gas exchange was recorded continuously.

The recording apparatus is shown in figure 1, and a diagram of the whole equipment in figure 2. We used 2 types of recording apparatus, 1 recorded only oxygen consumption and the other also recorded carbon dioxide production, whereby the respiratory quotient (R.Q.) could also be determined. In most cases the record of oxygen consumption alone was sufficient.

In principle, the oxygen recorder consisted of 4 platinum wires forming a Wheatstone bridge, heated by a constant electric current. The wires were enclosed in slits cut in a brass block. Along these wires air samples passed continuously that were obtained in the following way. The head and shoulders of the subject were enclosed in a roomy helmet, through which outdoor air at a constant current of 100 L./min. was passed. This air was reduced in oxygen and enriched in carbon dioxide by the subject. A sample was sucked from the outgoing air, dried and deprived of carbon dioxide by soda-lime, and passed with constant speed along 2 of the platinum wires. Along the other 2 wires outdoor air, similarly dried and deprived of carbon dioxide, was passed at the same speed. The only difference between the 2 samples was the ratio between oxygen and nitrogen: the greater the difference in this ratio, the greater was the difference in the cooling of the heated wires by the air stream. The consequent change in temperature of the wires produced a change in electric resistance and a disequilibrium of the Wheatstone bridge, which was recorded by a galvanometer. The deflection of the galvanometer was calibrated so that it measured the reduction in oxygen content of the outdoor air by the subject.

To measure the carbon dioxide production of the subject a similar procedure was used. Here the dry air from the subject was compared with similar air deprived of carbon dioxide, the only difference between the samples being the carbon dioxide content.

In an apparatus without amplification, sensitive but very stable mirror galvanometers and photographic recording were used. The photographic recording could also be omitted, since the deflections of the galvanometer could be read on a scale every 30 sec. and a curve could be drawn through the assembled points. An ink-writing recorder was also used after amplification.

**FUNCTIONCARDIOGRAM AND ITS EVALUATION**

Figure 3 shows the graph of a normal healthy man, 45 years old, with a very good performance on the bicycle ergometer (60 watts). The oxygen consumption during any period of the experiment was easily measured as the area above the 0 baseline. Each millimeter of deflection of the galvanometer represented a known percentage of oxygen taken by the subject from the liters of air passing per minute through the helmet. Absolute data could then be calculated, both for oxygen consumption and carbon dioxide production. As a routine, we did not proceed in this way; for the sake of simplicity, we routinely calculated only the relative values.

The gas exchange was shown as an undulating line, rather than a steady one. Nevertheless, the average could easily be drawn (solid line AB) through the oxygen line of the first period of rest before the work. This line, representing the mean oxygen consumption at rest before work, was extended across the graph. At the point C where it intersected the oxygen line of the recovery period after the work, the oxygen consumption regained the initial resting value. At the start of the work the oxygen line went up, but it took some time for the organism to become adapted to the work. Then the oxygen line again became level: the subject was then in the "steady state" so far as the oxygen uptake was concerned. Through this more or less undulating oxygen line the average line DE was drawn. With a planimeter or any other suitable method the areas of the 3 figures BDG, BGEF, and FEC were measured. The area BGEF represented the extra oxygen consumption above the resting value during the work; we call it $O_w$. Area FEC represented the extra oxygen consumption
during the recovery; it is the total oxygen debt and we called it $O_r$. The sum of $O_w$ and $O_r$ constituted the total extra oxygen consumption needed for the work. Area BDG represented the quantity of oxygen that was lacking in the adaptation period; we called it the initial oxygen debt, or $O_i$.

Of special interest were the initial debt ($O_i$) as a measure of the adaptation to the work and the total debt ($O_r$) as an indication of how well the oxygen uptake per minute in the steady state covered the oxygen requirement. To obtain relative values the initial debt ($O_i$) and the total debt ($O_r$) were expressed as percentages of the total extra oxygen consumption ($O_w + O_r$). The quotients $\frac{O_i \times 100}{O_w + O_r}$ was called $Q_i$ (per cent) and the quotients $\frac{O_r \times 100}{O_w + O_r}$ was called $Q_r$ (per cent). The same procedure was, in principle, followed by Kaplan and Kaplan.

From figure 3 in this way we found the $Q_i$ to be 11 per cent and $Q_r$ to be 12 per cent. Thus the initial debt during the adaptation period amounted to 11 per cent of the total extra oxygen consumption, and the total debt to 12 per cent. The values were rounded off to whole figures, since errors in measuring the areas made the decimal places invalid. Therefore, we may say that in figure 3 $Q_i$ and $Q_r$ were essentially alike; this means that this subject did not develop any extra oxygen debt during the steady state, in other words he covered his oxygen requirement per minute.

If the subject had clinically normal lungs, we may say that the oxygen uptake was a function of the amount of blood passing through the lungs, that is, of the cardiac output. Under such circumstances the graph, which we called the "funetio cardiogram," reflected the work done by the heart.

If the function of the heart was normal, its work was soon adapted to the standard amount of work imposed upon it, so that the initial debt ($O_i$) was small in relation to the extra oxygen consumption; furthermore, since this work was very moderate, the oxygen consumption in the steady state covered the oxygen requirement, so that the total debt ($O_r$) was almost equal to the initial debt.

On the other hand, if the function of the heart was subnormal for any reason, adaptation to work was slower, so that the initial debt ($O_i$) was abnormally large. Furthermore, a truly steady state may not be reached. Instead, the oxygen uptake might stop at a level that was too low to cover the oxygen requirement; as a result the total debt ($O_r$) might be higher than the initial debt ($O_i$).

In summary, it is possible to conclude from the general appearance of the oxygen consumption curve whether or not the cardiac function was normal, and to gain more exact information by expressing $O_i$ and $O_r$ in percentage of the total extra oxygen consumption during work.

The curve of carbon dioxide production may be treated in the same way as the oxygen line. Although it may give valuable information in some cases, we did not as a rule use it, but usually simply determined the respiratory quotient at the end of the working period in the following way. The elevations above their 0 lines of the oxygen and carbon dioxide lines at the end of the work were measured. In the original graph of figure 3 the values were 62.2 mm. for the vertical distance $ME$ between the 2 solid lines for oxygen, and 69.0 mm. for the distance between the dotted 0 line at $F$ and the uppermost dotted line for carbon dioxide. On this graph 1 mm. represented 0.0176 per cent for oxygen and 0.0144 per cent for carbon dioxide. Since the external air flow passing through the helmet contained 0.03 per cent carbon dioxide, 2 mm. $\left(\frac{0.03}{0.0144}\right)$ was subtracted from the measured carbon dioxide. Thus the work $R.Q.$ was

$$\frac{(69.0 - 2.0) \times 0.0144}{62.2 \times 0.0176} \text{ or } \frac{69.0 - 2.0}{62.2} \times 0.818 = 0.88.$$  

The factor 0.818, once determined, was fixed for the apparatus. This $R.Q.$ during work supported the conclusions drawn from the values of $Q_i$ and $Q_r$. In normal subjects, who performed this moderate work easily, the $R.Q.$ of the steady state was almost similar to the resting $R.Q.$,
with a possible slight rise above the resting value. But in subjects with heart failure, who may develop a relative lack of oxygen during work, lactic acid may accumulate in the blood and liberate carbon dioxide from bicarbonate. In such cases the expired carbon dioxide was derived not only from combustion, but also from bicarbonate; therefore the R.Q. may rise above 1.00.

In the case of the normal subject of figure 3 the R.Q. of work or steady state amounted to 0.88, a normal value. This steady state R.Q. could be compared with the R.Q. in the resting period before work and at the end of the recovery period. In figure 3 the 3 R.Q.'s were about the same: 0.89, 0.88, and 0.90. Since the excursion of the galvanometers in both the resting periods was small (in most cases less than 20 mm.), a slight inaccuracy in measuring the elevations might result in large errors of the R.Q. Therefore we usually restricted ourselves to the R.Q. at the end of the work, which is surely the most interesting of the 3.

There are 2 more values we liked to determine in the functiocardiogram: The time between the beginning of the work and reaching the steady state of oxygen uptake (adaptation time), and the time between the end of the work and the return of the oxygen consumption to the original resting value (recovery time). These were the distances DG and FC in figure 3. In most cases, however, these values could not be obtained exactly, since the points of interception G and C were too dependent on local undulations of the oxygen line. These variations made very little difference in the areas FCE and DGE, but made large differences in the adaptation and recovery times. Therefore we did not determine these times by measuring DG and FC, but we arbitrarily chose other less variable distances. For the adaptation time we measured the time from the start of work until the extra oxygen uptake reached a value 25 per cent less than in the steady state of oxygen uptake. For the recovery time we took the time elapsed after the end of the work until the oxygen consumption was 25 per cent above the average resting value before work. Thus in figure 3 $DH = \frac{1}{4} BD$, and $FK = \frac{1}{4} FM$, and the dotted lines $HJ$ and $KL$ gave the initial time ($T_I$) and the recovery time ($T_R$) in minutes. These times were not really the initial and the recovery times, but only arbitrary intervals, which, however, could be measured exactly and could be compared in normal and abnormal subjects. In figure 3 $T_I = 1.23$ min. and $T_R = 1.68$ min.

**Functiocardiogram in Normal Subjects**

The normal values of the different characteristics of the functiocardiogram were determined in standard tests (60 watts for 8 min.) on 30 normal men and 15 normal women between 18 and 50 years of age. The results are shown in table 1.

In table 1 the average value of $Q_R$ is about 1 per cent higher than $Q_I$, but the difference is not significant, that is, in these normal subjects $Q_I = Q_R$, as indeed it should be. Only 1 man and 3 women had a $Q_R$ above 17 per cent.

In women $Q_R$ (total oxygen debt) was about 1 per cent higher than in men, but for the sake of simplicity the same standard may be used for both sexes and for ages between 18 and 50 years. It appears that a $Q_R$ of 15 per cent was about the average normal value; values below 15 per cent were very good and the upper limit of normal was 17 per cent. The same values apply to $Q_I$ (initial debt). In individual normal cases the same figure was not always found for $Q_I$ and $Q_R$; small differences may easily occur in the living subject. Since the difference between $Q_I$ and $Q_R$ was seldom more than 2 per cent in our 45 normal subjects, a difference of 2 per cent or less was considered normal and a difference of 3 per cent was borderline.

The “initial time” ($T_I$) and the “recovery time” ($T_R$) determined arbitrarily as described were also higher in women than in men (table

### Table 1. Average Values in Normal Subjects between Eighteen and Fifty Years

<table>
<thead>
<tr>
<th>Number of subjects</th>
<th>$Q_I$ (liters/min)</th>
<th>$Q_R$ (liters/min)</th>
<th>$T_I$ (min.)</th>
<th>$T_R$ (min.)</th>
<th>Respiratory quotient at end of work</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 men</td>
<td>14.0</td>
<td>15.0</td>
<td>1.50</td>
<td>2.09</td>
<td>0.80</td>
</tr>
<tr>
<td>15 women</td>
<td>15.6</td>
<td>16.3</td>
<td>1.66</td>
<td>2.32</td>
<td>0.93</td>
</tr>
<tr>
<td>45 total</td>
<td>14.5</td>
<td>15.4</td>
<td>1.55</td>
<td>2.17</td>
<td>0.90</td>
</tr>
</tbody>
</table>
1). For practical reasons this difference was also ignored. Since only 1 normal man and 3 women had a $T_R$ slightly above 1.80 min., we took 1.80 min. as the normal limit for $T_R$. The normal limit for $T_R$ was fixed at 2.50 min., there being only 2 men and 3 women of our normal subjects who exceeded this value slightly.

As might be expected, the average R.Q. at the end of the work (table 1) was well above the average R.Q. in men under basal conditions. In all normal subjects it was below 1.00, however, with a mean of 0.90.

To test the reproducibility of our standard heart function test (60 watts, 8 min.) we performed 16 experiments each with 2 subjects on successive or alternate days over a month’s time. As might be expected, table 2 shows that the values varied from day to day. These differences seem reasonable for tests that were expressly not done under basal conditions, since it was desired to use the test in everyday practice. All results of both subjects were normal except 1 borderline value ($Q_R = 16.7$ per cent).

**AMOUNT OF WORK**

A standard work load of 60 watts for 8 min. was used in all the tests in establishing normal standards and in evaluating cardiac patients. The amount of work chosen was very moderate, it required about 1 L. extra of oxygen per minute. Normal subjects could very easily get this quantity, but cardiac patients had more difficulty with it.

If the amount of work were too small, there would be little difference between the curves of normal and cardiac patients. If, on the other hand, the work were heavy, most patients would not be able to do it. Most of the cardiac patients could perform this standard work with more or less difficulty. Some patients could not keep up the work for 8 min. and stopped early. All patients were told to stop if they felt tired. This fact alone proved that their cardiac function was below normal.

Instead of imposing a standard work load, one could determine the maximum work capacity of a patient and compare it with normal standards. We did not choose this as a routine method, because we did not like to subject all our cardiac patients to exhausting work, and because in such cases the psychic behavior, the will to proceed, would greatly influence the performance.

The bicycle ergometer is not entirely necessary; the test was not altered materially by the subject climbing up and down a step at a fixed tempo. With the ergometer the amount of work was the same for all subjects, whereas in stair climbing the amount of work depended on the body weight.

In figure 4 is a graph obtained from a normal subject while going up and down a step of 20 cm. every 4 sec. for 8 min. With a body weight of $g$ Kg., the work with every step up was $0.2 g$ Kg.M. If the work for the step down is taken as one third of the step up, the total work in every cycle of 4 sec. is $\frac{1}{3} \times \frac{1}{3} g$ Kg.M. Per second the work is $\frac{1}{4} \times \frac{1}{4} g$ Kg.M. or $\frac{1}{16} g \times 10$ watts = $\frac{1}{16} g$ watts. The work in watts thus equals two thirds of the body weight in Kg.

The body weight of the subject of figure 4 was 84 Kg.; thus the work performed was $\frac{1}{3} \times 84 = 56$ watts. Similarly, in most subjects, the work of the step test was less than the 60 watts of the bicycle test. We did not use a higher step or a faster cycle because the total extra oxygen consumption was higher in the step test than in the bicycle test due to its lower mechanical efficiency.

**Table 2.—Minimum, Maximum, and Average Values of Sixteen Experiments in Each of Two Normal Subjects**

<table>
<thead>
<tr>
<th>Subject</th>
<th>$Q_R$ %</th>
<th>$Q_R$ %</th>
<th>$T_R$ min.</th>
<th>$T_R$ min.</th>
<th>Respiratory Quotient</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>9.0 - 14.2</td>
<td>11.7 - 14.1</td>
<td>0.97 - 1.57</td>
<td>1.59 - 2.10</td>
<td>0.82 - 0.94</td>
</tr>
<tr>
<td>B</td>
<td>11.4 ± 1.5</td>
<td>12.7 ± 0.7</td>
<td>1.25 ± 0.16</td>
<td>1.80 ± 0.16</td>
<td>0.88 ± 0.03</td>
</tr>
<tr>
<td>A</td>
<td>12.9 - 15.7</td>
<td>13.2 - 16.7</td>
<td>1.31 - 1.59</td>
<td>2.01 - 2.68</td>
<td>0.86 - 0.98</td>
</tr>
<tr>
<td>B</td>
<td>14.1 ± 0.9</td>
<td>15.3 ± 1.1</td>
<td>1.46 ± 0.08</td>
<td>2.34 ± 0.18</td>
<td>0.91 ± 0.04</td>
</tr>
</tbody>
</table>
HEART FUNCTION TEST

Determination of Absolute Oxygen Values

The routine use of the relative values (Qi and Qs) together with the times, Tl and T_R and the work R.Q. gave sufficient information for evaluating the results, and their determination required only little calculation and little time. The areas of the 3 parts of the graph had to be measured. This was easily done with a planimeter, but for most purposes a special instrument was not needed. With an ink-writing apparatus the curve could be drawn directly on graph paper divided in 1 cm.² squares; with photographic apparatus the curve could be redrawn on graph paper by transillumination (fig. 5). Where the curve crossed a square the fraction belonging to each area could be estimated with sufficient accuracy.

Various absolute values could also be obtained from the graph, such as the oxygen debt and the oxygen uptake per minute during the work and the maximum oxygen uptake per minute if the subject worked to exhaustion. To evaluate absolute values the procedure was as follows. For the apparatus used in figure 3 the oxygen factor was 0.0176, that is, a vertical deflection of 1 mm. on the original graph corresponded to 0.0176 per cent of oxygen. The speed of the paper was 11 mm./min. Since 100 L. of air passed through the helmet per minute, a galvanometer deflection of 1 mm. during 1 minute, i.e., an area of 11 mm.², represented an oxygen consumption of 0.0176 per cent of 100 L. or 1.76 mL. In this case each mm.² of area stood for $\frac{17.6}{11}$, or 1.6 mL. oxygen, and any area in mm.² multiplied by 1.6 gave the oxygen consumption in the period concerned directly. The height of the oxygen line in mm. above the 0 line multiplied by 17.6 gave the total oxygen consumption per minute at that moment. These values of course required correction for pressure, temperature, and humidity.

In our normal subjects the average surface of $O_w + O_R$ (i.e., the total extra oxygen consumption needed for the work of 60 watts during 8 min. on the bicycle ergometer) was about 4,000 mm.². This corresponded to 4,000 $\times$ 1.6 = 6,400 mL. oxygen. Since 60 watts equal about 6 Kg.M./sec., the total amount of work is $8 \times 60 \times 6$ Kg.M. = 2,880 Kg.M. The caloric value of 1 mL. oxygen being about 5 calories or $5 \times 0.426$ Kg.M. = 2.13 Kg.M.,

the mechanical efficiency was $\frac{2.880}{6,400 \times 2.13} \times 100$ per cent = 21 per cent.

Respiratory Quotient

In many cardiac patients the $R.Q.$ was above 1.00 at the end of the 8 min. of work. This means that the oxygen uptake during the work did not cover the oxygen requirement. For those patients the standard work represented severe work. It is clear that the same high $R.Q.$
Fig. 6. Functiocardiogram of a normal subject on the bicycle-ergometer. Work 180 watts during 8 min. R.Q. at the end of the work 1.07; oxygen-uptake in the "steady state" 2.8 L./min. Airflow through the helmet 200 L./min.

Fig. 7. Functiocardiogram of a normal subject on the bicycle ergometer with increasing load. Airflow through helmet 233 L./min. The work R.Q. increased to 1.21; oxygen uptake at the highest load 3.97 L./min.

may appear in normal subjects if they perform severe work. Figure 6 gives an example of an experiment in a normal subject on the bicycle ergometer in which the work performed for 8 min. was 180 watts. The work R.Q. amounted to 1.07. Since the airflow through the helmet in this case was 200 L./min. and the oxygen deflection after the adaptation to the work was 80 mm., the oxygen uptake in this period amounted to $80 \times 0.0176 \times \frac{200}{100} = 2.8$ L./min.

Figure 7 represents the result of an experiment on the bicycle ergometer in a normal subject in which the work was increased step by step, until the subject was near exhaustion. In the first period the work was 120 watts and the work R.Q. was 0.96; in the second period the work was 160 watts and the R.Q. 1.02; in the third the figures were 200 watts with R.Q. of 1.06; and in the last, 240 watts with R.Q. of 1.21. At the end of the last period the sub-

ject thought that he was at his maximum load and we concluded that his oxygen uptake was maximal. Since the flow of air through the helmet was 233 L./min. in this case and the deflection of the galvanometer on the original graph at the end of the last period was 97 mm., the maximal oxygen uptake of the subject was $97 \times 0.0176 \times 2.33 = 3.97$ L./min. The total oxygen debt as estimated from the surface $O_R$ was about 5 L., which proved indeed that the subject was not quite exhausted but near to it; he said he might have gone for some minutes more. By continuing the work his debt shortly would have grown to its maximum.

Some Functiocardiograms of Patients

The functiocardiogram of patients with different kinds of heart diseases will be extensively described in subsequent publications. Here we wish to show some graphs differing from normal.

Figure 8 shows the graph of a female patient with mitral stenosis but with only slight complaints. She reached the steady state a bit late; $Q_I = 19$ per cent, $Q_R = 20$ per cent, both

Fig. 8. Functiocardiogram of a patient with mitral stenosis and slight complaints. Bicycle-ergometer, 60 watts, airflow 100 L./min.

Fig. 9. Graph of a patient with mitral stenosis and moderate complaints. Bicycle-ergometer 60 watts, airflow 100 L./min.
are too high. They are equal, so that the oxygen uptake per minute in the steady state covered the requirement; correspondingly, the R.Q. was normal at 0.92. The conclusion is that the cardiac function at this amount of work (60 watts, 8 min.) was below normal.

Figure 9 is the functiocardiogram of a patient with mitral stenosis with more complaints. He reached what seemed to be a steady state with a normal initial debt ($Q_I = 15$ per cent); thus the adaptation to the work seemed normal. However, since the total oxygen debt was much greater ($Q_r = 28$ per cent), he did not cover his requirement during the “steady state” but made an extra debt. It seems that he was at the limit of his oxygen uptake; the R.Q. in this period of 1.08 was in agreement. The recovery time was also too long. The cardiac function was far below normal.

Figure 10 is the graph of a female patient with mitral stenosis with very serious complaints. She could sustain the work of 60 watts for only 2 min. She did not reach a steady state, and it appears from the graph that the total oxygen debt was 75 per cent of the total extra oxygen consumption needed for the work; that is, three quarters of this small amount of work was done on credit. The “recovery time” (3.18 min.) was extremely long for the work done. This is an example of very bad cardiac function.

Figure 11 shows the graph of a woman with cardiac complaints in which the cardiologist could not find clinical cardiac disease. She stopped the work (60 watts) after 5 min. The $Q_I$ was $20$ per cent and the $Q_r$ $24$ per cent of the total extra oxygen consumption during this 5 min. of work. Of course these percentages are not directly comparable with the usual percentages for 8 min. of work. The patient reached a steady state; if she had continued the work for 3 min. more, at the same rate, $Q_I$ would have been about $5\frac{5}{8} \times 20$ per cent = $12\frac{1}{2}$ per cent and $Q_r$ $5\frac{5}{8} \times 24$ per cent = 15

Figure 12. Functiocardiogram of a patient with mitral stenosis before surgery. Bicycle-ergometer 60 watts, airflow 100 L./min. The work was stopped after 4 min.

Figure 13. Same patient as in figure 12 after operation. Bicycle-ergometer 60 watts, airflow 100 L./min. The different values were still too high, but the graph indicated that the condition of the patient was much improved.
per cent. These latter values would have been within the normal range, and the difference between \(Q_t\) and \(Q_k\) would also have been normal, though borderline. From these observations we may conclude that the oxygen requirement per minute was covered by the oxygen uptake in the steady state. The R.Q. at the end of the steady state was 0.97, a rather high value but below 1.00; thus the R.Q. did not indicate failure to cover the oxygen requirement. Everything seemed to be rather normal and the functiocardigram gave no reason why the patient stopped the work after 5 min. This was in agreement with our impression that the patient was not exhausted after 5 min. of work. The conclusion must be that she stopped the work prematurely.

Figures 12 and 13 show functiocardograms of a patient with mitral stenosis before and after cardiac surgery. Preoperatively (fig. 12) the patient had to stop work (60 watts) after 4 min.; about 60 per cent of this small amount of work was delivered on credit and the “recovery time” was very long (5.0 min.). At the end of the work the R.Q. was 1.24, proving that the oxygen requirement was not met. From this graph it appears that the heart function was bad.

After the operation (fig. 13) the patient could perform the same work (60 watts) without distress for 8 min. The function of the heart was not yet normal, for \(Q_t\) of 20 per cent and \(Q_k\) of 19 per cent were both too high, but their equality meant that the oxygen requirement per minute was covered in the steady state, as was indicated by the R.Q. of 0.92 at the end of the work. According to this improvement in the graph the patient gained much by the surgery. This impression was in close agreement with the clinical observations of the cardiologist.

**Summary**

A heart function test is described that was applied in about 1,000 cases. The apparatus was based on the principle of the diaferometer and gave the results in a graph. The evaluation of the graph was kept as simple as possible, to make it apt for clinical use where there is little accommodation for extensive experimental work.

**Summario in Interlingua**

Es describite un test de function cardiaque que eseva applicate a circa 1.000 casos. Le apparatus utilisa le principio del diaferometro e presenta su resultatos in un forma graphic. Le evaluation del graphico eseva rendite le plus simple possibile pro assecurar le usabilitate del metodo pro objectivos clinic sub conditiones que non offere facilitates pro extense labores experimental.

**REFERENCES**


Let us now peruse our ancient authors, for out of the old fields must come the new corn.—Edward Coke, 1552–1634.
A Heart Function Test with Continuous Registration of Oxygen Consumption and Carbon Dioxide Production

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