Measurement of the Cardiac Output in Dogs by a Conductivity Method after Single Intravenous Injections of Autogenous Plasma

By Richard S. Goodwin, M.S. and Leo A. Sapirstein, Ph.D., M.D.

Equations are developed for the estimation of cardiac output from hematocrit dilution, using the continuously recorded conductivity of whole blood drawn from an artery through a conductivity cell, after a single intravenous injection of autogenous plasma. The equipment used is described, the results are compared with those of simultaneously performed measurements of dye dilution and the advantages of the method are discussed.

The use of hypertonic saline as the indicator in the determination of cardiac output by the indicator dilution technic has been proposed by several authors. The fact that the indicator concentration is continuously monitored by recording the resistance of flowing arterial blood has the obvious advantages of doing away with the necessity of collecting and analyzing a large number of individual blood samples and of yielding an immediate permanent record of the actual indicator dilution curve. The major disadvantages of hypertonic saline are (1) indicator losses may occur in the lungs and (2) the resistance of the blood is not predictably related to indicator concentration. This latter makes necessary an empirical calibration in vitro; it has never been ascertained that the in vitro calibration describes the in vivo situation.

Both these difficulties can be circumvented if autogenous plasma is substituted for hypertonic saline as the indicator. Since autogenous plasma alters neither the crystalloid nor colloid osmotic pressure of blood, it is reasonable to expect that no losses of label (or hemodilution) will occur in the lung. Further, it has been shown that autogenous plasma has an effect on the conductivity of blood which precisely follows theoretical predictions for a suspension of nonconductors in a conducting medium.

The conductivity changes produced by plasma are due to changes in cellular concentration rather than changes in the concentration of plasma electrolytes. It is appropriate, therefore, to describe the present method which employs autogenous plasma as the indicator as an hematocrit dilution method.

Cardiac Output by Hematocrit Dilution (Theory)

Hematocrit Change After Autogenous Plasma. If the cardiac output is Q ml./min., and if the hematocrit of the blood is Hctₐ before autogenous plasma is injected; and if I ml. of autogenous plasma is injected, then the average hematocrit of the arterial blood in the next minute is given by the equation:

\[ Hctₐ = \frac{Q \cdot Hctₐ}{Q + I} \]  

From which it follows that

\[ Q = \frac{Hctₐ \cdot I}{\Delta Hct} \]  

In this derivation, it is assumed that all of the injected plasma has been transferred from the venous to the arterial blood; that the hematocrit after injection is measured as the average hematocrit after injection with the elimination of recirculation effects; and finally that the cardiac output is increased during the minute after injection by the volume injected. The first two assumptions are identical with those made in the dye dilution estimation.
of the cardiac output; the last assumption can be shown to be trivial, since when the opposite assumption is made the expression for cardiac output merely becomes

$$Q = \frac{Hct \cdot I}{\Delta Hct}$$

and $Hct_t$ and $Hct_k$ differ from each other by a quantity ($\Delta Hct$) which is negligibly small in relation to either one of them.

Hematocrit Determination from Measurement of Blood Resistance. Maxwell's equation describing the resistance of suspensions of conducting spheres in a conducting suspension has been modified by Velick and Gorin who derived an equation for the resistance of a suspension of nonconducting ellipsoids. Using somewhat different notation their equation may be written

$$R_b = \frac{1}{R_p} + \frac{Hct}{FF}$$

where $R_b$ is the specific resistance of whole blood, $R_p$ is the specific resistance of plasma, $Hct$ the ratio of the volume occupied by cells to the volume of the blood, and $FF$ is a constant related to the shape and orientation of the suspended blood cells. Equation (4) assumes that the specific resistance of blood cells is very large in comparison to that of whole blood, a valid statement when resistance is measured at the frequency employed in this study (2500 c.p.s.) but not at higher frequencies such as that used by White (80,000 c.p.s.).

Equation (4) may be written to show the hematocrit as follows:

$$Hct = \frac{R_b - R_p}{R_b + \frac{R_p}{FF}}$$

Relationship Between Change in Hematocrit and Change in Resistance of Blood. Equation (5) may be differentiated with respect to $R_b$ to yield,

$$\frac{\Delta Hct}{\Delta R_b} = \frac{R_p \left(1 + \frac{1}{FF}\right)}{\left(R_b + \frac{R_p}{FF}\right)^2}$$

or

$$\frac{\Delta Hct}{\Delta R_b} \sim \frac{R_p \left(1 + \frac{1}{FF}\right)}{\left(R_b + \frac{R_p}{FF}\right)^2}$$

When $\Delta R_b$ is small in relation to $R_b$, the error in the approximation of equation (7) is entirely negligible.

Cardiac Output from Resistance Changes. Equation (5) supplies a value for $Hct$; equation (7) may be solved for $\Delta Hct$. Substituting the values obtained in equation (2) or (3), we find:

$$Q = \frac{I[R_b - R_p] \left[R_b + \frac{R_p}{FF}\right]}{R_p \left[1 + \frac{1}{FF}\right] \Delta R_b}$$

Equation (8) describes the cardiac output as a function of the measurable quantities, $R_b$ and $R_p$, and $\Delta R_b$, and a constant (form factor). Since resistance terms occur in both numerator and denominator, actual resistance values may be substituted for specific resistance provided all are made with the same technic and the cell constant does not change between measurements. For convenience, since $\Delta R_b$ is measured as a displacement of a galvanometer needle in millimeters, it may be expressed as $\Delta mm$, and multiplied by a calibrating factor, ohms/mm. Furthermore, since it represents a value summed to infinity (excluding recirculation) it will be useful to adopt the usual notation of the dye dilution method and to express the value as follows:

$$\Delta R_b = \sum_{1}^{60} mm \times \frac{ohms}{mm}$$

$\sum mm$ is determined by making a summation of the real and extrapolated values of millimeter displacement at 1 sec. intervals on a semilogarithmic plot as in the dye dilution method.

Substituting this value and the calibrating factor for ohms/mm in equation (8) we obtain:

$$Q = \frac{60I[R_b - R_p] \left[R_b + \frac{R_p}{FF}\right]}{\sum_{1}^{60} \left(\frac{ohms}{mm}\right) \left[R_p\right] \left[1 + \frac{1}{FF}\right]}$$
Note the concealed assumption here that there is a linear relationship between $\Delta R_b$ and $\Delta mm$. In actual operation, this assumption is justified when the experimental conditions to be described are employed.

**Determination of Form Factor**

**Determination of Hematocrit**

The use of equation (5) for the electric determination of hematocrit change requires an evaluation of the "form factor" in the conditions of the determination. If the form factor is constant this can be accomplished by measuring $R_b$ and $R_e$ in bloods of precisely known hematocrit. Alternatively, the manner in which the resistance of whole blood is changed as the blood is diluted serially by plasma additions may be used for graphic solution of the "form factor" for bloods of unknown hematocrit. The second method, originally proposed by Velick and Gorin, is cumbersome, and, in our hands, gives inconsistent values for form factor even for individual blood samples. We have no explanation for this. We therefore turned directly to the measurement of the hematocrit for the estimation of "form factor."

Since, in our experience, the measurement of the hematocrit of dog blood by the Wintrobe method is highly erratic, and corrections for "trapped plasma" undependable, our hematocrit determinations were made by a dye dilution method.

We initially employed Evans blue and $K^o$. When these were found to yield identical results, only Evans blue was used. The method was as follows: about 1 ml. of a solution of Evans blue containing about 0.4 mg./ml. was pipetted into a 25 ml. Erlenmeyer flask. The water was then removed in a drying oven. Ten milliliters of whole blood was taken in the flask and the contents agitated for 5 min. One milliliter of whole blood was then pipetted into 10 ml. of saline and centrifuged. The remaining blood was centrifuged and 1.0 ml. of the dyed plasma pipetted into 10 ml. of saline. The optical density of both supernates was measured in a Beckman DU spectrophotometer at 620 $\mu$.

If $z$ is taken as the optical density of Evans blue in the plasma of the original blood, then the optical density of the Evans blue in the diluted plasma is clearly $z/11$. The optical density of Evans blue in the whole blood is $z(1-Hct)$, and after the whole blood is diluted with saline it will be $Z(1-Hct)/11-Hct$. The ratio $(r)$ of the optical density of the diluted whole blood to the optical density of the diluted plasma will then be $11(1-Hct)/11-Hct$.

From this the hematocrit is readily calculated to be:

$$Hct = \frac{11(1 - r)}{11 - r} \quad (11)$$

**Measurement of Resistance**

**Conductivity Cell.** The cell was the same as that used subsequently in the cardiac output determinations. It consisted of a platinum cylinder 15 mm. long and 1.3 mm. in internal diameter, separated into two symmetrical halves by the removal of two 0.3 mm. sectors at opposite ends of a diameter. The two sections still separated by 0.3 mm. at each edge were then mounted in a molded plastic in such a manner that their inner surfaces opposed each other and formed the middle segment of the walls of a 1.3 mm. cylindrical hole. The remaining portion of the hole through the plastic unit was also 1.3 mm. in internal diameter. The molded plastic unit was 15 mm. in diameter and 60 mm. in length, and was fitted with standard male slip fittings for hypodermic needles at both ends.

The electrodes were platinized with 3 per cent platinum chloride containing 0.025 per cent lead acetate and were kept covered with 0.9 per cent saline when not in use. The cell was found to have a resistance of 48 ohms at 40 C. with 0.85 per cent saline, and a temperature characteristic of 2.1 per cent per degree.

**Bridge.** The bridge used was essentially similar to that used by Holt. Five hundred ohm resistances replaced 1500 ohm resistances in the fixed arms. The variable resistance was a 500 ohm ten turn Helipot fitted with a Duodial. The Helipot was checked for accuracy against a Leeds and Northrop Decade Resistor and found to be accurate to ± 1 per cent over its entire range. Nulling of the bridge was accomplished with a standard tuning eye circuit rather than with earphones. It should be noted here that it is possible to null the bridge with the Sanborn galvanometer (see below) but occasionally a false null can be noted, and it is advantageous to have an external nulling device.

**Oscillator and Detector.** A commercial carrier amplifier (Sanborn strain gage amplifier model no. 64-500 A) was used as the oscillator (frequency 2500 c.p.s.) and detector. The galvanometer was used for final nulling. Since the compensating resistance and capacitor balances of the amplifier-detector introduce an unknown element into the bridge they were removed entirely from the circuit with double pole single throw switches.

**Constant Withdrawal Pump.** In the cell employed, alternation of withdrawal rate from 5 to 50 ml./min. caused a 3 ohm resistance change in whole blood with 150 ohm resistance. This presumably resulted from variation in cell orientation. Since the resistance

* Similar cells can be obtained from Mr. Elmer Lusk, Columbus, Ohio.
changes produced by injected plasma were usually less than 10 ohms, it was necessary to maintain the withdrawal rate quite constant. This was accomplished by the use of a motor driven syringe* which withdrew blood at 10 ml./min. through the cell.

Evaluation of Form Factor

Three types of experiments were performed in order to evaluate the form factor. In the first set heparinized arterial and venous blood was separated into a cell rich layer and a plasma layer by mild centrifugation. The two layers were recombined in various proportions to yield bloods of a variety of hematocrits.

In the second series measurements were made on fresh, heparinized samples of venous or arterial blood drawn from unselected street dogs.

In the final series blood was drawn directly into the cell from the femoral artery and the value of hematocrit was determined as described elsewhere.

The value of the form factor was calculated from the following equation obtained by rearrangement of equation (4):

\[ FF = \frac{Hct}{R_b - R_p (1 - Hct)} - 1 \]

Animal Procedure. Twenty-four dogs (6 to 35 Kg.) were anesthetized with sodium pentobarbital 30 mg./Kg. i.v. Twenty to 100 ml. of blood was taken for the preparation of autogenous plasma in a syringe moistened with heparin in isotonic saline. The plasma was separated and added to 100 ml. of dry Evans blue, a small quantity being saved for subsequent determination of plasma conductivity. The plasma-Evans blue mixture was centrifuged to remove a small quantity of a gelatinous precipitate which regularly developed.

Cournand needles were placed in both femoral arteries and a thin-walled no. 16 needle was introduced into a jugular vein. Two to three milliliters of saline containing 20 to 30 mg. of heparin was injected into the animal. Saline at 40 C. was drawn through the conductivity cell for 2 min. to bring the cell to the approximate temperature of the dog, and the conductivity cell then attached to one of the femoral arterial needles. Blood was then drawn through the cell and the bridge was balanced with the aid of the tuning eye and the resistance of the blood noted. An injection of 10 ml. of .85 per cent NaCl was then made as a trial for the adjustment of the sensitivity of the recording galvanometer and the volume of plasma to be used. (The curve generated with the saline solution differed substantially from the final curve and was not employed in the actual determinations; in any 1 dog, only one preliminary saline injection was required to establish the conditions of the actual determination.)

The syringe pump was now emptied and the procedure repeated up to the point of injecting saline. Now, however, the injection consisted of dye labeled plasma. The volume of plasma used was usually of the order of 5 to 10 ml./L./min. of expected cardiac output. (See also legend to fig. 1). Blood samples were taken for the dye determination from one femoral artery with a sample collector described elsewhere while conductivity recording was made upon blood drawn from the other. The total volume of blood withdrawn for any one measurement was 15 to 20 ml. Once the curve was recorded, the blood could be returned to the animal.

Calibration. As soon as the curve of conductivity change had been generated, the cell was disconnected and the collection of dye samples was discontinued. A Leeds and Northrup resistance box set at the resistance recorded for flowing blood was substituted for the conductivity cell and the galvanometer deflection produced by a reduction in resistance of 10 ohms was recorded. In later experiments a 10 ohm calibrating resistance was included directly in the bridge circuit.

Cardiac Output by Dye. This was determined in the usual manner. The sample collections were made in the first 10 comparisons at 35/min.; in later comparisons they were made at 54/min. Whole blood was pipetted and standards prepared from the injected material in the presence of whole blood, as de-

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**Table 1.—Form Factor in Dog Blood**

<table>
<thead>
<tr>
<th>Blood source</th>
<th>No. of samples</th>
<th>Hematocrit</th>
<th>Form factor ± S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reconstituted bloods</td>
<td>16</td>
<td>0.17-0.71</td>
<td>1.11±.11</td>
</tr>
<tr>
<td>Street dogs selected at</td>
<td>18</td>
<td>0.31-0.59</td>
<td>1.25±.21</td>
</tr>
<tr>
<td>random, in vitro</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In vivo arterial blood</td>
<td>4</td>
<td>0.40-0.55</td>
<td>1.07±.25</td>
</tr>
<tr>
<td>(each determination in duplicate)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td></td>
<td>1.17</td>
<td></td>
</tr>
</tbody>
</table>

*Obtainable from the WAM Manufacturing Company, Columbus, Ohio.
Fig. 1. Conductivity recordings in 6 experiments. Three top records, typical for normal dogs. Three lower records show the curves obtained with 1 very large and 2 very small cardiac outputs.

Values necessary for the calculation of the cardiac output as follows:

<table>
<thead>
<tr>
<th>Figure</th>
<th>Volume injected (ml.)</th>
<th>Rb (basal) (at 40 C.) (ohms)</th>
<th>Rp (at 40 C.) (ohms)</th>
<th>Calibration (ohms/mm.)</th>
<th>Cardiac output (L./min.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>24</td>
<td>132.5</td>
<td>36</td>
<td>.24</td>
<td>2.06</td>
</tr>
<tr>
<td>B</td>
<td>30</td>
<td>127.0</td>
<td>60</td>
<td>.38</td>
<td>3.09</td>
</tr>
<tr>
<td>C</td>
<td>25</td>
<td>107.0</td>
<td>85</td>
<td>.16</td>
<td>3.85</td>
</tr>
<tr>
<td>D</td>
<td>28.5</td>
<td>125.0</td>
<td>157</td>
<td>.54</td>
<td>6.55</td>
</tr>
<tr>
<td>E</td>
<td>10</td>
<td>142</td>
<td>137</td>
<td>.33</td>
<td>0.33</td>
</tr>
<tr>
<td>F</td>
<td>5</td>
<td>148</td>
<td>148</td>
<td>.46</td>
<td>0.72</td>
</tr>
</tbody>
</table>

scribed previously. Because of this manner of pipetting samples, the output determinations were as whole blood and no hematocrit determinations were required. The dye concentrations were read in the Beckman DU spectrophotometer, plotted on two cycle semilog paper and extrapolated as usual.

In the calculation, the product of collections per minute, reading of the dye standard, and the dilution of the injected dose, was divided by the sum of real and extrapolated dye concentrations.

**Cardiac Output by Conductivity.** The deflections of the tracing (fig. 1) were transcribed to semilog paper and extrapolated in the same manner as the dye curve. Readings of the curve were made as millimeter deflection from the base line at 1 sec. intervals.

The cardiac output was calculated from equation (10), using the observed resistance of blood at body temperature, the observed resistance of plasma after elevation to body temperature in vitro and the sum of the linear deflections, real and extrapolated.

In the experiments reported here the resistance of dog plasma proved to be quite constant. In the cell employed, the extreme range was from 53 to 60 ohms at 40 C. At this temperature the resistance of .85 per cent NaCl was 48 ohms. For obvious reasons withdrawal rate is without effect on plasma resistance.

**Results**

The results of 24 consecutive determinations are presented in table 2. The larger outputs were obtained simply by using very large dogs. The smaller outputs were observed in small dogs, in dogs subjected to hemorrhage, and in a small group of dogs which received 35 mg./Kg. of Nembutal i.p.

In column 4 of the table the deviations between the two values are given. The greatest single deviation is 21.8 per cent. The average deviation is 0.3 per cent. There is no evidence of systematic deviation.
Table 2.—Cardiac Output of Dogs Measured Simultaneously by Dye Dilution and Hematocrit Dilution

<table>
<thead>
<tr>
<th>Dog no.</th>
<th>Cardiac output (L/min.)</th>
<th>Per cent deviation (conductivity-dye X 100)/Dye</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.91</td>
<td>3.23</td>
</tr>
<tr>
<td>2</td>
<td>1.10</td>
<td>.93</td>
</tr>
<tr>
<td>3</td>
<td>2.63</td>
<td>2.38</td>
</tr>
<tr>
<td>4</td>
<td>3.38</td>
<td>3.24</td>
</tr>
<tr>
<td>5</td>
<td>3.78</td>
<td>3.97</td>
</tr>
<tr>
<td>6</td>
<td>2.70</td>
<td>2.96</td>
</tr>
<tr>
<td>7</td>
<td>3.64</td>
<td>3.84</td>
</tr>
<tr>
<td>8</td>
<td>1.10</td>
<td>.98</td>
</tr>
<tr>
<td>9</td>
<td>.23</td>
<td>.22</td>
</tr>
<tr>
<td>10</td>
<td>1.91</td>
<td>2.07</td>
</tr>
<tr>
<td>11</td>
<td>1.08</td>
<td>1.25</td>
</tr>
<tr>
<td>12</td>
<td>.52</td>
<td>.53</td>
</tr>
<tr>
<td>13</td>
<td>.32</td>
<td>.33</td>
</tr>
<tr>
<td>14</td>
<td>2.10</td>
<td>2.00</td>
</tr>
<tr>
<td>15</td>
<td>2.25</td>
<td>2.33</td>
</tr>
<tr>
<td>16</td>
<td>4.09</td>
<td>3.98</td>
</tr>
<tr>
<td>17</td>
<td>6.38</td>
<td>6.55</td>
</tr>
<tr>
<td>18</td>
<td>2.91</td>
<td>3.08</td>
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<tr>
<td>19</td>
<td>3.27</td>
<td>3.27</td>
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<tr>
<td>20</td>
<td>6.10</td>
<td>6.06</td>
</tr>
<tr>
<td>21</td>
<td>3.88</td>
<td>3.85</td>
</tr>
<tr>
<td>22</td>
<td>2.24</td>
<td>2.31</td>
</tr>
<tr>
<td>23</td>
<td>3.21</td>
<td>3.09</td>
</tr>
<tr>
<td>24</td>
<td>2.93</td>
<td>2.67</td>
</tr>
<tr>
<td>Avg....</td>
<td>2.70</td>
<td>2.71</td>
</tr>
</tbody>
</table>

Table 3.—Dependence of Calculated Cardiac Output on the Value of the Form Factor Employed in the Calculation

<table>
<thead>
<tr>
<th>True hematocrit</th>
<th>Approximate Wintrobe hematocrit</th>
<th>Rb/Re = (Resistance of blood)/(Resistance of plasma)</th>
<th>CO2/CO2 = (Cardiac output for form factor) (N^*/(Cardiac output for form factor 1.17))</th>
</tr>
</thead>
<tbody>
<tr>
<td>N = .92</td>
<td>N = 1.17</td>
<td>N = 1.42</td>
<td>N = 1.42</td>
</tr>
<tr>
<td>.35</td>
<td>.39</td>
<td>2</td>
<td>.96</td>
</tr>
<tr>
<td>.44</td>
<td>.48</td>
<td>2.5</td>
<td>.95</td>
</tr>
<tr>
<td>.52</td>
<td>.57</td>
<td>3.0</td>
<td>.94</td>
</tr>
</tbody>
</table>

* Values chosen for N are the mean value found in all determinations, and the mean value ± 1 S.D.

Discussion

The agreement between the results obtained by the present method and the dye dilution method suggests that the present method measures the cardiac output. This method has 3 major advantages over pre-existing ones: The substitution of a continuous physical recording for the analysis of samples collected discontinuously is an obvious technical advantage. The use of autogenous plasma all but eliminates the possibility of pulmonary losses of indicator. Finally, the conductivity changes produced by small changes in hematocrit are so large that a considerable number of determinations can be carried out without appreciable change in the background—in this case the basal hematocrit. In the experiments reported here, the basal hematocrit changed less than 1 per cent per determination; and the peak change in hematocrit was usually less than 5 per cent.

The unique assumption of the present method is that the hematocrit can be determined from a knowledge of whole blood resistance. It is known that whole blood resistance depends on the hematocrit, the plasma resistance, and the form factor. The last is, in effect, a number which describes the shape and orientation of the cells with respect to the electrodes. If the blood and plasma resistance and the form factor are all known, then the hematocrit can be determined.

Although the form factor must be known, it need not be known very accurately. This results from the fact that it appears in both the numerator and denominator of the equation (10) although in slightly different relationships. It is shown (table 3) that variation in the form factor from 0.92–1.42 (which was substantially the range encountered) influences the calculated values for the cardiac output to a very minor extent. The error increases as the hematocrit increases; but in the range of hematocrit found in most dogs it will rarely exceed 5 per cent if the mean value for form factor (1.17) is employed. It must, however, be noted that the form factor should be determined for every new cell and for every withdrawal rate employed.

One circumstance which should be guarded against is the possibility that the form factor may change at the precise moment when the measuring plasma is injected. Although it is difficult to imagine how this circumstance
could be produced in most experimental situations, we encountered it accidentally in attempting to use rose bengal, a dye which is known to change form factor, as the “validating” dye in our earlier experiments. The cardiac output estimated by conductivity in these circumstances was regularly 20 to 40 per cent less than that measured by dye. Rough calculations of the effects of rose bengal on cells in vitro showed that errors of this magnitude were to be anticipated solely from changes in cell shape produced by the dye at the moment of injection.

Examination of the recorded conductivity curves (fig. 1) reveals two phenomena limiting the useful sensitivity of the recording system. One is a pulsatile variation of resistance of blood correlated with the cardiac cycle, the other a slower change in resistance correlated with respiration. While we feel the rapid change in resistance may be due to an orientation effect on the blood cells, we can offer no interpretation of the slow change at this time. The practical result of these phenomena is to necessitate the use of larger injected volumes of plasma rather than increased amplifier sensitivity at large cardiac outputs, since the area under the curve decreases with increased cardiac outputs.

**Summary**

The use of hypertonic saline solutions for the determination of the cardiac output by indicator dilution, using the conductivity of the blood for the measurement of indicator concentration has two major drawbacks: (1) indicator losses may occur in the lungs (2) the relationship between indicator concentration and blood conductivity cannot be determined except by an empirical calibration in vitro. The substitution of autogenous plasma, as an isoconducting, isoosmotic indicator, which accomplishes changes in blood conductivity by virtue of the fact that it alters the hematocrit eliminates these difficulties. Indicator is neither lost nor gained in the lungs and the relationship between indicator concentration and blood conductivity is easily derived from elementary physical considerations.

The present report concerns the principle of a method for cardiac output determination based upon recording conductivity changes in the arterial blood of the dog receiving autogenous plasma. The theoretical relationships are derived, and the single necessary constant is evaluated.

The method is free from the disadvantage of increasing “background” found with other dye dilution methods; it may be repeated at 1 min. intervals as often as desired. The equipment used is commercially available or easily fashioned in any laboratory.

The results of simultaneous determinations of the cardiac output by use of Evans blue and autogenous plasma in 24 dogs are presented. The average deviation is less than 7 per cent and the difference between the two means is about 0.3 per cent.

**Summario in Interlingua**

Le uso de hypertonic solutiones salin pro determinar le rendimento cardiac per medio de dilution del indicator—con le uso del conductivitate del sanguine pro mesurar le concentration del indicator—ha duo major disavantages: (1) Perditas del indicator pote occurrer in le pulmones, e (2) le relation inter le concentration del indicator e le conductivitate del sanguine non pote esser determinate excepte per medio de un calibration empiric in vitro. Le substitution de plasma autogene como indicator isoconducente e iso-osmotic, que effectua alterationes del conductivitate del sanguine gratias al facto que illo altera le hematocrite, elimina iste difficultates. Nulle indicator es perdite o ganiate in le pulmones, e le relation inter le concentration del indicator e le conductivitate del sanguine es facilmente derivate ab elementari considerationes physic.

Le presente reporto concerne le principio de un metodo pro le determination del rendimento cardiac que es basate super le registration de alteraciones del conductivitate in le sanguine arterial de canes recipiente plasma autogene. Le relationes theoretic es derivate, e le sol requirite constante esevalutate.

Le metodo es libere del disavantage de un crescente factor “ambienta” que es incontecrate in le application de altere methodos a dilution de colorante. Illo pote esser repetite a in-
CARDIAC OUTPUT BY HEMATOCRIT CHANGE

tervallos de 1 min tanto frequentemente como on lo desea. Le apparratura es commercialmente disponibile o facilmente fabricate in omne laboratorio.

Es presentate le resultatos de determinaciones simultanees del rendimento cardiac in 24 canes per medio del metodo a blau de Evans e a plasma autogene. Le deviation medie es minus que 7 pro cento, e le differentia inter le duo valores medie es circa 0,3 pro cento.

ACKNOWLEDGMENT
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RICHARD S. GOODWIN and LEO A. SAPIRSTEIN

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