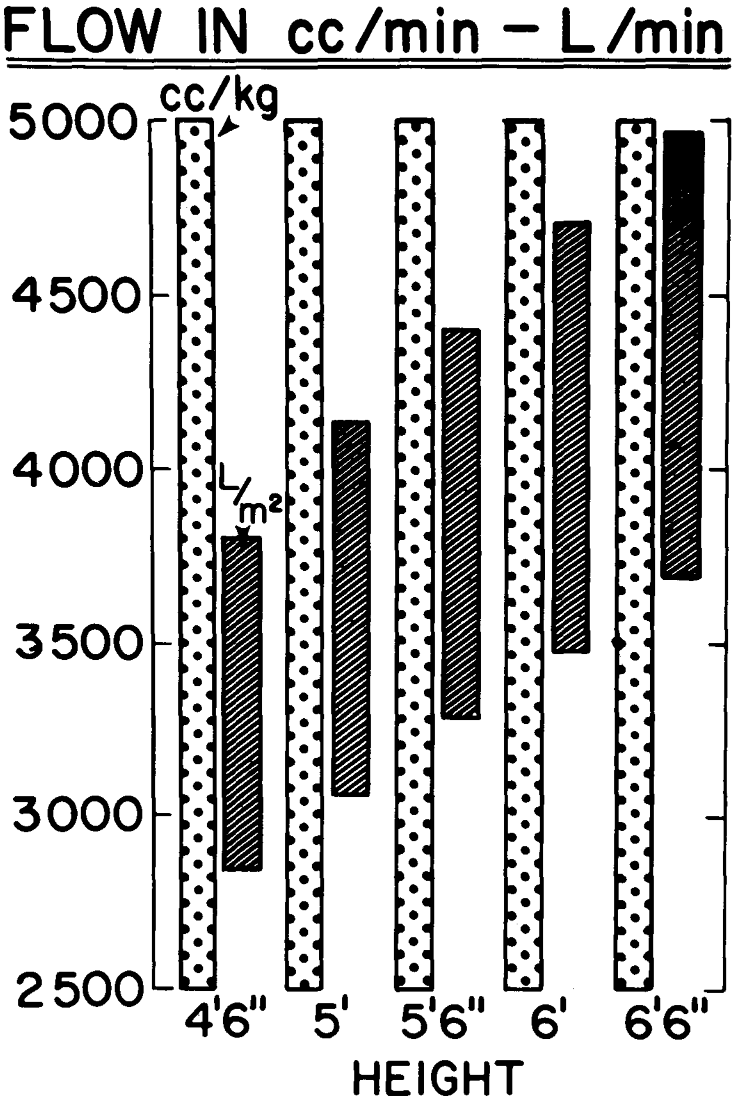


A Comparative Method for Determining Blood Flow During Extra-Corporeal Circulation

By SHANNON LUCAS

Kansas City Veterans Administration Hospital
Bio-Science Laboratories, Surgery
Kansas City, Missouri

The preparation and response is vital to the understanding of the pump operator and surgeon during extra-corporeal circulation. The information should be given in a manner that will paint a picture using as few words as possible. The language should be universal, since there are still many observers that come to the cases. The planning of flow rate for patients during extra-corporeal circulation is usually determined by liters per square meter of body surface area and by cubic centimeters per kilogram of body weight. In our cases, we set up in both—cc/k_2 and L/m^2 and call the planned flow 100%, correlating the number of cc/kg. in liter per meter square. Therefore, we can respond in the same manner for both, reemphasizing the importance of the percentage of planned flow.

Methods

Preparation:

1. The patient's weight record is reviewed.
2. His true height and weight is taken the day before the case.
3. The pre-calculated flow scale is set up in both liter per square meter (1.2 through 2.6) and cc per kilogram (30 through 90).
4. 100% is given to the desired flow rate, and the percentage for the other flows is indicated (i.e. 2.2 L/m^2 equals 100%, and 2.0 L/m^2 equals 90% cc per kilogram would be included in the same manner).
5. The priming solution is determined.
6. The additive solution is determined.
7. The probabilities are discussed (surgeon and operator).

Operational Procedure:

1. The starting time is given.
2. 100% flow is indicated.
3. The desired temperature is indicated when reached when hypothermia is used.
4. The word is given to start rewarming.
5. Normothermia is indicated.
6. The word is given to go off.

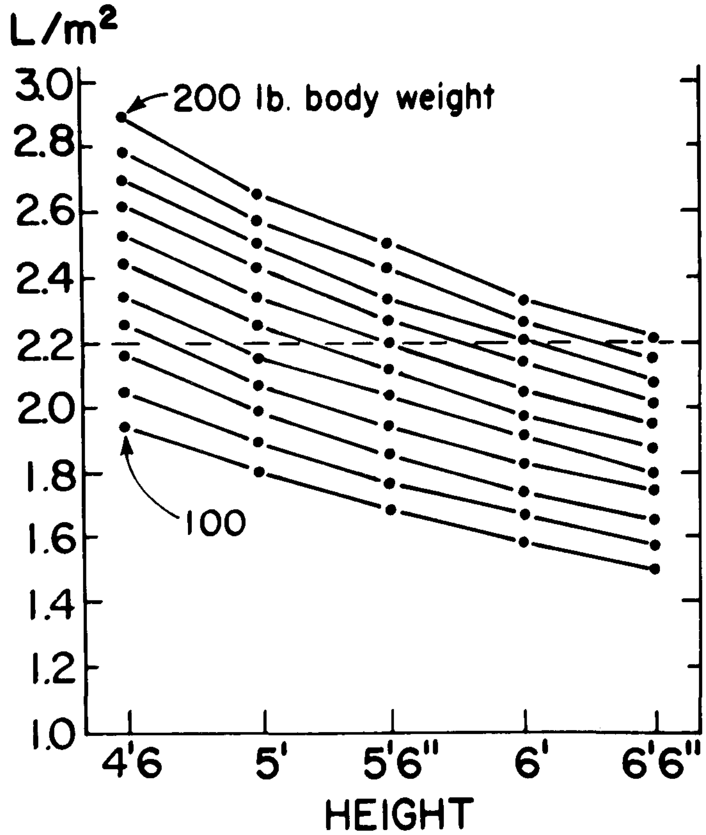
Comments

In reviewing a patient's weight one may find a fluctuation of weight from day to day. This is usually due to retention of fluid, and the weight recorded indicates both true weight and fluid. Sometimes it is necessary to make some allowance for fluid retention.

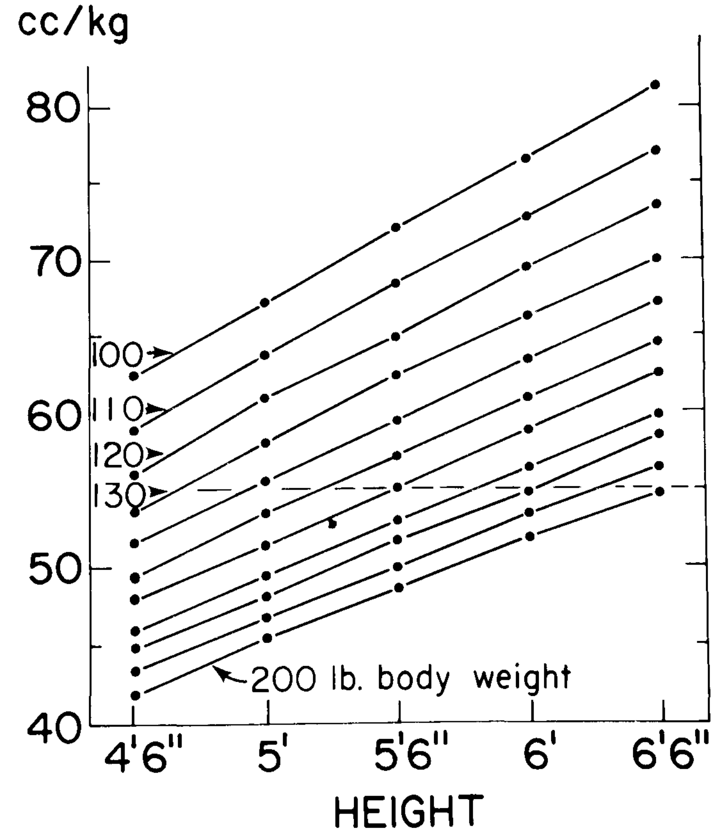
After determining the weight, usually in pounds, which is then converted to kg. by dividing by 2.2—this gives rise to calculating the flow in cc per kg.; the scale ranges from 30 through 90 cc per minute. To set up the flow scale for body surface area the height plus the weight must be used. Du Bois formula for figuring B.S.A. is as follows: $A = H^{0.725} \times W^{0.425} \times 71.84$. Application of this formula is shown here in figures 1 and 2. By means of the D'Ocayne nomogram, surface area

Article available at https://ject.edpsciences.org or https://doi.org/10.1051/ject/1970021005

NO. OF L/m² TO EQUAL FLOW AT 55cc/kg/min



NO. OF cc/kg TO EQUAL FLOW AT 2.2 L/m²/min



according to the Du Bois formula, can be estimated from height and weight without arithmetical calculation. There are nomograms for estimating surface from weight and height according to Du Bois' formula, which is used almost all the time. This scale is set up to read from 1.2 through 2.6 liters per meter square.

Now that the comparative scale of L/m^2 and cc/kg. is set up and the planned flow rate is given the value of 100%, and the rest of the scale is given the percent that they equal, the pump operator is set to give the value of whatever the flow is instantly in precise detail to his surgeon or to an observer in the manner in which he is accustomed to using. The system can also be compared without study or delay. We feel that all probable information should be handled in this manner.

In other words the pump-oxygenator operator should be able to understand and relay all information in its entirety that deals with whatever his duties call for. In our case many other duties are added to the pump team. It is expected that they reply in this manner.

Discussion

According to Brown et al., 1958; Sealy et al., 1958 and 1959; Young et al., 1959; and the text book "Surgery of the Chest" by John Gibbon, Jr., M.D. —the pump flow rates employed in infants and children are 50-60 ml. per kilogram per minute. Ordinarily, for adults the initial pump flow rate is set at about 35 to 50 ml. per kg. per minute for partial bypass or for short duration (less than 20 to 30 minutes of total bypass). In longer duration, the flow rate should be increased (75 to 100 ml. per kg., in infants and children, and about 60 to 80 ml. per kg. per minute for adults). An attempt to maintain a systolic arterial pressure of 80 mm Hg or above at these flow rates is desired.

Although the flow rate gives specific consideration for flow range with respect to age, it does not consider specifics for body build within age range. It does not indicate whether one should take the upper or lower scale for the heavy or thin patient within a given age range.

Figure no. 3 is flow base on a consistent 55 cc per kilogram, and the flow rate for a given size can be compared to the number of liter per square meter of surface area and what that flow would amount to at that size. Notice that the short and heavy would indicate excess perfusion, and the tall and thin would indicate insufficient perfusion according to the body surface.

This would give rise to suspicions that the range of flow to equal liter per meter square would vary with the build of a given patient. A medium sized person would not vary too much; the thinner one is, the more one would have to increase the number of cc per kilogram; the heavier one is, the more his cc per kilogram should be decreased. The range may vary more than 35-50 or 60-80 per kilogram depending on his body build.

A IS EQUAL TO

$$H\ 165^{0.725} \times W\ 68.18^{0.425} \times 71.84$$

$$2.21748 \times 0.725 + W\ 1.8366 \times 0.425 + 1.85637$$

$$H\ 1.607673 + W\ .7793055 + 1.85637$$

$$2.386979 + 1.85637$$

$$4.243349\ (\text{ANTILOG})$$

$$1.75\ M^2$$

In theory an arterial blood flow rate approximating 3 to 4 liters per minute per square meter of body surface is desirable. In practice somewhat lower flow rates (2.2 in adults and 2.4 in children) have been found to be satisfactory (McGoon et al., 1960).

Cardiac output, oxygen uptake, and mixed venous blood saturation in man with a body surface of one square meter during basal conditions and during anesthesia at 37° C. The values during anesthesia are based on the assumption that both cardiac output and oxygen uptake are reduced 25% by anesthesia. This example illustrates the manner in which similar consideration led to this choice of flow at 2.2 and 2.4 L/m².

Kirklin and others, 1958, Gross and others, 1960, have found that adequate perfusion rate in patients is maintained between 2,200 and 2,400 ml. per minute per square meter of body surface area (the higher of the two rates being used for cyanotic patients with polycythemia).

Oxygen uptake during both normothermia and hypothermia whole body perfusion is related to flow rate (Anderson and Senning, 1958). At 37° C. and with perfusion flow rates of 2.2 to 2.4 liters per minute per square meter of body surface, oxygen uptake is about 100 to 125 cc per minute per square meter. Uptake does not appear to be affected by the arterial oxygen saturation that usually exists during clinical perfusions, but it may be affected by the anesthetic agent (Underwood et al., 1960).

During perfusion, arterial blood pressure is related to systemic blood flow rate, viscosity of the blood, systemic peripheral resistance, and venous pressure. When the heart is effective, systemic blood flow is augmented by the output from the left ventricle.

At the start of normothermic perfusion with constant perfusion flow rate, the mean arterial blood pressure is usually low, but it rises during perfusion (McGoon et al., 1960). Mean arterial pressure at a flow rate of 2.2 to 2.4 liters per minute per square meter of body surface is usually 50 to 80 mm of mercury. Arterial pressure is usually somewhat higher during perfusion with moderate hypothermia. In our cases we never have trouble maintaining an adequate blood pressure unless the pressure is very bad before we start, and at that we have been able to no less than maintain the pressure mentioned above.

By setting up for our cases on a comparative method, but using mostly liter per square meter of body surface as previously indicated—it became apparent that for each size patient the number of cc per kilogram to equal the same flow as liter per meter square was different, varying mostly with the construction of the body. Figure 4 is based on 2.2 liters per square meter of body surface area, and shows the number of cc per kilogram one would have to flow a patient to compare to the same flow as one flowing a constant 2.2 liter per square meter of surface area. This shows that a thin patient would be under-perfused and the heavy patient would be over-perfused.

On the basis of clinical experience it is known that the body requires only 100 ml of oxygen per minute per square meter of body surface, (Cross and others, 1960). In actual practice, it has been shown that if the oxygen supply is regulated to about twice the blood flow, an adequate amount of oxygen will be made available with an excess to compensate for unequal distribution to the surface area.

With pure oxygen there is a danger of losing excessive amounts of carbon dioxide, thereby producing a respiratory alkalosis. Prior to starting the bypass a blood gas level is determined for possible inadequate ventilation of the lungs by the anesthetist. This could alter the rate of gas flow and disc speed at the beginning of the case. Increasing the rate of flow of the gasses, or the speed of the disc, or omitting gasses containing CO_2, lower the pCO_2 and raised the pO_2. The reversal of these, decreasing the rate of flow of the

(Continued on Page 16)

DUBOIS FORMULA FOR BODY SURFACE AREA

$$A = H^{0.725} \times W^{0.425} \times 71.84$$

H = HEIGHT IN CM

W = WEIGHT IN KILOS

71.84 = CONSTANT

THE LOG OF $H^{0.725} \times W^{0.425} \times 71.84$

IS FORMULATED FOR 5'5" & 150 LBS

gasses or the speed of the disc, or using gasses containing CO_2 raises the pCO_2 and lowers the pO_2. These techniques are used in respiratory acidosis or alkalosis.

When metabolic acidosis or alkalosis is indicated drugs are used for correction. If a combination of the two exists, a combination is used for correction. Normally there are 20 cc of oxygen in 100 cc of venous blood (15 volume percent), percent oxygen saturation is approximately 100% in arterial blood and 75% in venous blood of patients with normal circulation.

Conclusion

Based on the comparison of both cc per kilogram and liter per square meter without regard to age, it appears that both systems lean toward under-perfusing the thin and over-perfusing the heavy.

Figure No. 5 shows the actual flow range for a given height over a weight range of 100 to 200 pounds in both cc per kg. on L/m^2. The cc per kilogram is based on weight alone without regard to height and is thus consistently the same at each height range. L/m^2 is based on height and weight and thereby shows a difference at each height indicated. The L/m^2 moves upward and the span increases as the height increases over the same weight range. The L/m^2 shows the greatest difference at 200 pounds, indicating more flow to the tall.

Since both scales when compared indicated over-perfusion to the obese and under-perfusion to the thin the L/m^2 seems to show better protection for both obese and thin. Even at that, one can easily notice the difference in the amount the two methods would flow a patient.

At any rate, if the flow is set up using both methods, and given the planned flow a value of 100%, as well as calculating the percentage for the other values, one could easily respond in both systems at the same time giving the percentage, L/m^2, and cc/kg. whatever the flow happened to be. These values are determined ahead of time in our cases. Flow based on cardiac output during cardiac catheterization is not considered a good criterion, because stenosis of the valves, septal defects, etc., tend to lead to cardiac insufficiency.

Summary

Both methods vary somewhat in the total flow one would receive during bypass. Also, if one relied on percentage of planned flow, there would be no correlation from one method to the other unless the flow was determined by both methods. For simplicity of responding to the surgeon, and sometimes to an observer who may be familiar with the other method, and at times when the surgeon would like to know for some reason, we find it helpful to set a comparative flow scale using L/m^2/min., and cc/kg./min. with percentage at each interval. By using a comparative method and noticing that when compared both lean toward a possible need to compensate for the very thin and the obese—it is felt that maybe some arrangement should be made for other variants (e.g., age range).

References

Anderson, M. N., and Senning, A.: Studies in oxygen consumption during extracorporeal circulation with a pump oxygenation. **Ann. Surgery, 1958, 59, 148.**

Brown, J. W., Jr., and Young, W. G., Jr.: A report on the use of both extracorporeal circulation and hypothermia of open-heart surgery. **Ann. Surg., 1958, 147, 603.**

Clauss, R. H., M.D., Associate Professor of Surgery, New York University School of Medicine.

Gross, R. E., Sauvage, L. R., Pontius, R. G. and Watkins, E., Jr.: Experimental and clinical studies of a siphon-filling disc-oxygenator system for complete cardiopulmonary bypass. **Ann. Surg., 1960, 151, 285.**

Kirklin, J. W., Theye, R. A. and Patrick, R. T.: The stationary vertical screen oxygenator in extra corporeal circulation. J. G. Allen, Editor, Springfield, Ill., Charles C. Thomas, 1958, 57.

McGoon, D. C., Moffitt, E. A., Theye, R. A. and Kirklin, J. W.: Physiologic studies during high flow, normothermic, whole body perfusion. **J. Thoracic Surg., 1960, 39, 275.**

Sealy, W. C., Brown, I. W., Jr., Young, W. G., Jr.: Report on the use of both extra corporeal circulation and hypothermia for open heart surgery. **Ann. Surg., 1958, 147, 603.**

Sealy, W. C., Brown, I. W., Jr., Young, W. G., Jr., Smith, W. W. and Lesage, A. M.: Hypothermia and extra corporeal circulation for open heart surgery. **Am. Surg., 1959, 150, 627.**

Gibbon, J. H., Jr., M.D.: "Surgery of the Chest".

Lindskog, G.: "Thoracic and Cardiovascular Surgery with Related Pathology".

Underwood, R. J., Roth, J. C. and Starr, A.: The influence of anesthetic technique on oxygen consumption during total cardiopulmonary bypass. **Anesthesiology, 1960, 21, 263.**

Young, W. G., Jr., Sealy, W. C., Brown, I. W., Jr.: Metabolic and physiologic observation on patients undergoing extra corporeal circulation in conjunction with hypothermia. **Surgery, 1959, 46, 175.**

Small Prime . . .

Discussion

The importance of the stationary boundary layer of blood next to the membrane, which interferes with the gas exchange, has been recognized by other investigators. Obviously intermittent compression, although it effectively breaks up the boundary layer, is not a practical method. Presently we are designing an apparatus to replace hand-squeezing either mechanically or pneumatically. A prototype of a pneumatic apparatus has been constructed; it exposes the oxygenator to alternating positive and negative pressures within a plastic case.

The agitation must be sufficient to break up the boundary layer in order to improve the oxygen transfer rate, but not so excessive or abrupt as to destroy erythrocytes. Improved design and additional testing are required before the oxygenator can be recommended for clinical use—either for open heart surgery or the management of respiratory distress syndrome.

References

1. Zingg, Walter; Membrane Oxygenator for Infants; Transactions, American Society for Artifical Internal Organs; vol. XII, 1967.
2. Chamberlain, G., Lee, H. A., and Ames, A. A.; Membrane Oxygenator-Dialyzer for the Newborn; Journal Amer. Med. Assoc.; Vol. 202-304, Oct., 1967.