Reply by Dr. Wolfson

In answer to the first point, the Volemetron has, for the first time, provided me with equipment for obtaining reasonably accurate blood volume estimations made by myself or by a junior house officer at any time of the day or night, rapidly and without calling on expert laboratory help (which is in this context both scarce and expensive).

I have no personal experience of estimating blood volume by the method described by Dr. Hobbs, but I doubt whether, in the circumstances of the treatment of acute trauma, such observations would be practicable or, if practised, accurate in the hands of simple clinicians.

On the second point, I have, in fact, stressed the value of clinical assessment in my paper. Nevertheless, blood volume estimation has often proved clinically useful even with experienced clinicians in this field and would doubtless be even more so where fewer major injuries are seen. In practice such inaccuracy as may occur during blood volume estimations at the acute phase, because of the loss of indicator during the brief period of dilution, does not seem to be of great clinical importance. In fact, the results make good clinical sense.

Thirdly, cardiac output measurement at present does not appear to me to be as simple to carry out or as clinically useful as blood volume estimation with the semi-automatic machine I have described.

ESTIMATION OF BLOOD LOSS DURING SURGERY

by

J. A. Thornton, F.F.A.R.C.S.

Senior Lecturer in Anaesthetics, University of Sheffield

THE PRINCIPAL INDICATION for transfusion of blood is acute haemorrhage which, if the loss is allowed to continue unreplaced, will result in lowered blood volume and cardiac output. Under anaesthesia, a haemorrhage of up to 1.5 litres may occur with only a slight increase in pulse rate or fall in blood pressure, in the normal fit adult male. If oligaemia is not corrected in such patients they are liable to sudden post-operative hypotension (de Wardener *et al.*, 1953). Stanton and his co-workers (1949) have also stressed the importance of adequate replacement of whole blood during and after surgical operations. They have demonstrated that, although there is a compensatory increase in plasma volume following uncompensated blood loss, there is no increase in the number of red cells. Without blood transfusion the red cell volume does not return to normal for several weeks.

This uncompensated red cell loss leads to reduction in the oxygen-carrying power of the blood. This may result in varying degrees of hypoxia, which tend to prolong post-operative recovery and, in patients already possessing a diseased myocardium, may lead to cardiac and circulatory disturbances and possibly cardiac failure.

Coller, Crook and Iob (1944), and Crook, Iob and Coller (1946) suggest that patients benefit most when the blood loss is replaced by blood given as the loss occurs. They also believe that even minimal blood loss retards convalescence, and that all blood loss, in poor risk patients, should be replaced with equal quantities of whole blood.

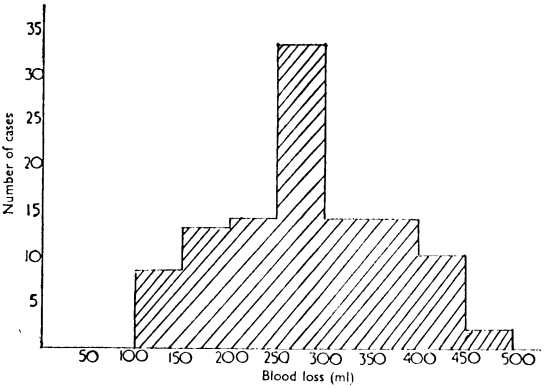

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Fig. 1. Normal range of blood loss during mitral valvotomy.

It is felt by some that blood loss in a normal fit adult male, lightly anaesthetized, will only require to be replaced when the loss exceeds 500 ml. It is clearly unsound to take a figure in an arbitrary manner such as this, and the need for replacement is dependent on many factors amongst which are the duration of operation, the response of the patient to the operative procedure, the experience of the anaesthetist, and his familiarity with the expected requirements based on the need of patients in the past.

It is therefore appropriate to emphasize that accurate replacement of blood loss during operative surgery depends on the accurate measurement of blood loss as it occurs. I shall now consider the problem of estimating this blood loss, for armed with this knowledge the anaesthetist and surgeon are in a strong position to influence the cardio-vascular homeostasis of their patient. They must of course relate this loss to the pre-operative status and condition of the patient, to the anticipated response of the particular individual to haemorrhage and his reaction to the operative procedure.

Blood losses during various surgical procedures have been reported by

many authors. There is a definite relationship between the amount of blood lost, the nature of the surgical procedure and the dexterity of the surgeon. Where a routine procedure is involved, in which the surgeon and anaesthetist have been working together for some years, the average blood loss occurs within a relatively narrow range as can be seen in Figure 1. Here measurement of blood loss by swab weighing was made during the operation of mitral valvotomy in 120 patients of both sexes, whose ages varied from 20 to 60 years (mean 42 years; S.D. $\pm$9.88). Patients undergoing re-operation were excluded from this series, as blood loss is much greater than at the first operation. The average blood loss for the operation of mitral valvotomy was 316 ml. (S.D. $\pm$144). The smallest blood loss was in the region of 100 ml. and the maximum 500 ml.

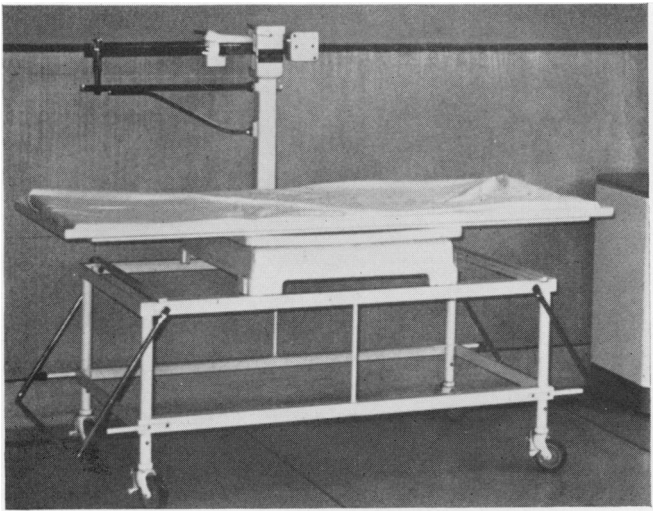

Fig. 2. Patient weighing table.

METHODS OF MEASUREMENT OF BLOOD LOSS

Subjective estimation

Subjective estimation by visual assessment is extremely unreliable, and should certainly not be relied upon in any but the fittest of adult patients for the simplest of operations. Such a method should never be used in cardiac, traumatic or paediatric surgery. We have heard one of the previous speakers state that blood loss in trauma can be readily underestimated: accumulation of blood or plasma in the soft tissues and postoperative oozing cannot be predicted nor determined by haematocrit change or visual estimation. The method however has the advantage of being inexpensive, rapid and continuous but in differentiating between 500 and 1,500 ml. loss observers are extremely inaccurate. Bonica and

Lyter (1951), in summarizing the work of 17 other investigators, concluded that the blood loss as estimated by the surgeon is always less than that actually measured.

Gravimetric

Patient weighing. A large weighing table can be used to measure the pre- and post-operative weight of the patient. Unfortunately the blood balance cannot be assessed concurrently during the course of the operative procedure. Allowance must be made for drains, dressings, infusions, insensible water loss and the removal of tissue. The method allows an accuracy of not less than ± 10 G. and the inaccuracy is probably much greater. However, patient weighing is a useful check for other methods.

Swab weighing. It is customary to assume that 1 ml. of blood weighs 1 G. However the average specific gravity of red corpuscles is 1.0293 and of plasma 1.0270. The discrepancy between the assumed and actual specific gravity is a source of error but a correction can be applied to reduce this error. The method originally necessitated the use of dry swabs, although Bonica and Lyter (1951) have modified this so that swabs may be moistened with known quantities of saline. The swabs must be weighed as soon as possible after contamination with blood so that the loss by evaporation is minimized. Furthermore there is the added disadvantage that in cardiac surgery there is inevitable loss on to gowns and drapes, and this loss is not included in the final " balance ".

Electrolyte conductivity

LeVeen and Rubricius (1958) introduced an automatic blood loss meter based on electrolyte conductivity. This method has the advantage of giving a continuous reading but is dependent on the constancy of the electrolyte content of the blood during the period of estimation.

Colorimetric method

Blood can be extracted by various means from the swabs and the concentration of the resultant solution can be used to determine the actual blood loss. The method relies on the constancy of the blood haemoglobin concentration during the course of the estimation. It is of particular value during trans-urethral bladder surgery (Liton and Emmett, 1959). Until recently extraction has been facilitated by manually washing the swabs, but during the last few years washing machines have been used in conjunction with flow through meters giving a continuous record (Roe *et al.*, 1962; Thornton *et al.*, 1963; and Rustad, 1963). The washing of the blood-contaminated swabs is carried out in a known volume of tap water, to which has been added sufficient ammonium hydroxide to give a 1 in 1000 dilution and a defoaming agent. During operation, swabs, blood from suction apparatus, towels, etc., are added and the concentration of the

resultant solution determined. With a knowledge of the patient's haemoglobin concentration, a value for the blood loss is readily calculated:

$$\text{Blood loss in ml.} = \frac{\text{Hb (G/100 ml.) washing fluid} \times \text{volume washing water}}{\text{Hb (G/100 ml.) patient's Hb} \times \text{dil. factor patient's Hb}}$$

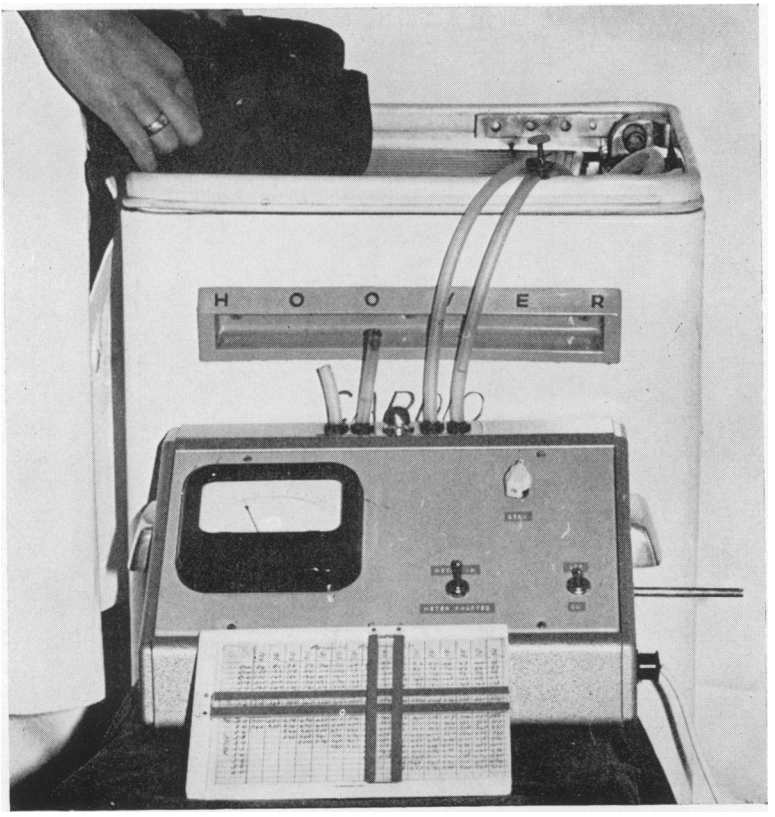

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Fig. 3. Washing machine, meter, and chart.

Radioactivity of blood loss

Radio-isotopes may be employed in the estimation of blood loss by measuring the activity of blood on swabs collected during the course of an operation. This involves the injection intravenously of a small but known amount of isotope (Murray and Potts, 1960). There are serious disadvantages however as the technique demands time, expensive apparatus, and there is leakage, if tagged albumen is used, of tracer into non-vascular compartments. If red-cells are used the patient's cells have to be taken

and labelled pre-operatively. This radio-isotope technique at present appears to have little to offer over existing gravimetric and colorimetric techniques.

Blood volume measurements

Dye method. Techniques have been employed using the intravenous injection of certain dyes such as Evans blue.

These dyes must neither be catabolized nor rapidly lost from the circulation. They carry many disadvantages amongst which is colouring of the patient's blood and subsequent disadvantages when further measurements are contemplated within a short space of time.

Radio-isotopes. Plasma. ^{131}I is commonly used for " tagging " albumen. This method carries certain disadvantages in that there is a tendency for albumen to " leak " into non-vascular compartments.

Red cells. The " tagging " of red cells affords greater accuracy than " tagging " plasma protein. It is possible to measure the red cell volume of a patient pre-operatively using red cells labelled with ^{51}Cr, according to the method described by Mollison and Veall (1955). The post-operative red cell volume can be measured using red cells labelled with ^{32}P according to the method of Reeve and Veall (1949). The use of two isotopes in the same patients at the same time is practicable and safe as, in the ^{51}Cr method, gamma radiation is counted in a scintillation counter and ^{32}P method beta particle emission is measured in a Geiger-Mueller counter. Thus one count interferes minimally with another. Measurement in the change of blood volume is dependent on the haematocrit and inaccuracies can arise when the circulation is disturbed in conditions of severe oligaemia. Correction must be made for trapped plasma and for the whole body/venous haematocrit ratio. The method cannot be relied upon to give concurrent blood loss values during the course of an operative procedure. It requires technical staff and is relatively expensive. Investigations have shown that erroneous results can be obtained when inadequate dilution and mixing result from the injection of the tracer into a circulation suffering vasomotor instability.

MEASUREMENT OF BLOOD LOSS BY SUCTION

In cardiac and vascular surgery considerable haemorrhage may occur which is removed from the operation field by suction. Such suction is contained in the jar on the apparatus and inaccuracies can arise as a result of the large area of cross section. These inaccuracies can be reduced by having a measuring cylinder in the suction line and at the same time filling it with a small quantity of defoaming agent.

COMPARISON OF METHODS

The results of a comparative study of measurement of blood loss by

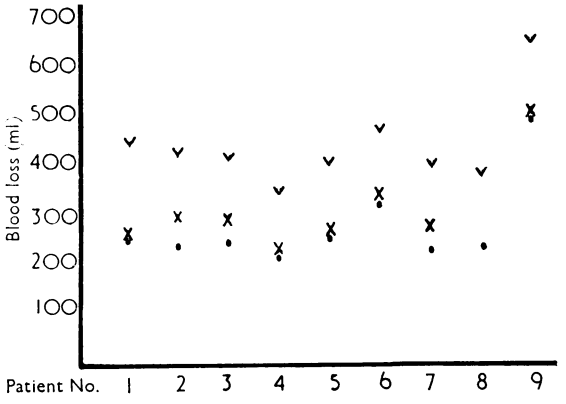

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Fig. 4. Comparison of blood loss by gravimetric, colorimetric, and blood volume methods in the same patients.

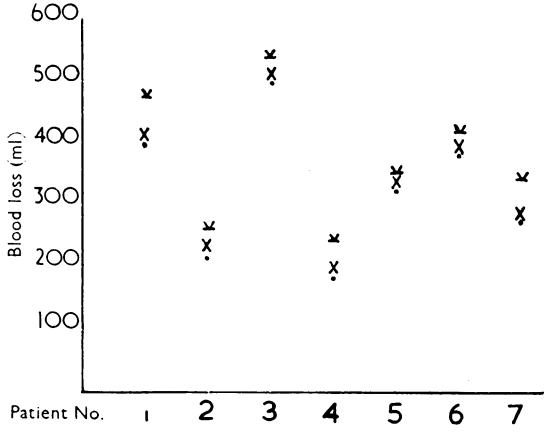

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Fig. 5. Comparison of blood loss by gravimetric, colorimetric and patient weighing methods in the same patients.

swab weighing and the colorimetric method are shown in Figures 4 and 5. It is apparent that the colorimetric method and swab weighing method compare well, thus confirming the work of Baronofsky *et al.* (1946), who advocated the general adoption of the swab weighing method because of its simplicity. However, it does not include loss on to drapes. The blood loss as estimated from patient weighing is consistently greater than the loss as determined by swab weighing (Fig. 5). Some of this difference can no doubt be attributed to loss of fluid on to drapes, perspiration, loss of water and possibly nitrous oxide from the lungs.

Figure 4 shows a comparative study of blood loss measured by swab weighing, colorimetric and blood volume studies in the same patients. It is apparent that the blood loss estimated by blood volume studies is greater than when measured by other methods. Cacères and Whittembury (1959), studying a series of 29 mastectomies, also demonstrated this relationship and noted that the value of the blood loss as determined by swab weighing, plus 25 per cent., is equivalent to the true operative blood loss. The assumption must therefore be made that the actual blood loss during a surgical procedure is more than can be measured by swab-weighing, colorimetric or any other method dependent on measuring blood lost to the exterior of the patient. This "concealed" haemorrhage, revealed by red cell volume studies, does not appear outside the body. It presumably consists of leaking of blood into the tissue spaces around the operation site, in the incision, and due to the immobilization of blood in vessels proximal to ligatures. Although this blood is within the body confines it is unavailable blood and is lost to the circulation.

The colorimetric method described for measuring blood loss provides a practical and simple method for use during the course of an operation in which blood lost on the gowns and drapes can be included in the final measurement. The colorimetric method compares well with swab weighing. Red cell volume studies serve to remind us that there is additional bleeding into the operation site, during the operation and immediately post-operatively, and this amount should be anticipated and added to the blood loss measured by other methods. It must also be remembered that swab weighing estimates only the minimal blood loss, and is the minimum amount of whole blood that should be replaced.

Finally I should once again like to stress that accurate replacement of whole blood acts as a prophylaxis against circulatory collapse and also aids in decreasing post-operative morbidity. Less blood is required to prevent hypotension than to correct it; therefore ideally, blood should be replaced as it is lost, thus helping to maintain cardio-vascular homeostasis. In order to facilitate this state of affairs, accurate and up-to-date balance sheets must be kept and account must be taken of the fact that 540 ml. of "stored" blood contains only 420 ml. of whole blood. Stick-on

labels (Fig. 6) can be used so that the amount of transfused whole blood given at any one moment can be readily determined.

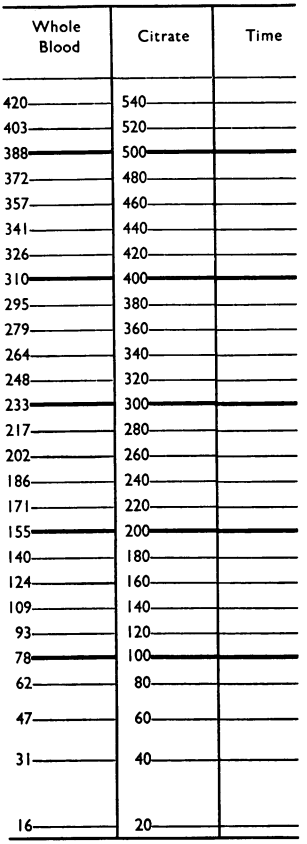

Fig. 6

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Question from Professor F. A. R. Stammers

There is no doubt that with modern types of surgery, particularly those concerning major blood vessel work and cardiac surgery, where sudden loss of blood may occur, or where it is recognized that removal of a clamp from the aorta may be followed by a sudden hypotension, a method for immediately measuring any blood loss would be of great value. The simpler methods of swab weighing seem still to be the most practical. During the War, Professor Grant of Guy's Hospital, who was in Italy with an M.R.C. Unit, working particularly on blood loss resulting from gunshot wounds, gave us a very rough guide, namely that if the amount of exposed or destroyed muscle totted up to 1, 2, 3 or 4 fistfuls one could reckon on one pint of blood per fist having been lost.

Another type of case is where post-operative oozing may continue, such as any conversion of one type of gastrectomy to another for continued dyspeptic symptoms, in which type of case adhesions may be massive and are often vascular.

Reply by Dr. Thornton

Where the blood loss is contained, i.e. within the pleural or abdominal cavities, simple rapid suction into a graduated cylinder placed in series on the suction line is reliable. It is important, of course, that a de-foaming agent is added to the cylinder contents in order to achieve an accurate reading of the loss.

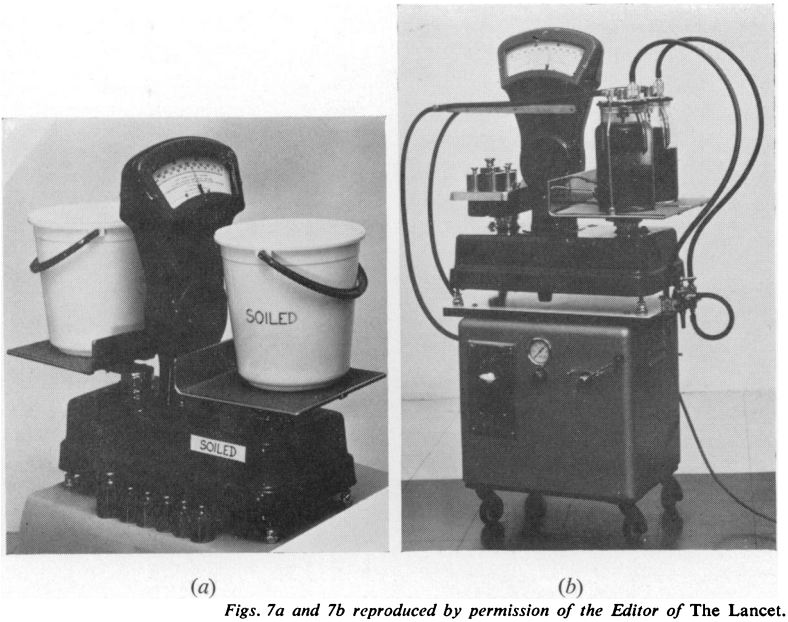
Where post-operative loss is likely to occur, carefully kept balance charts of loss into drainage bottles and replacement of loss must be insisted upon.

Where oozing occurs within the body confines, measurement of loss is much more difficult. However, when blood volume studies are carried out, they serve to remind us that this loss is extra-vascular.

Contribution from Dr. Howat

Dr. Howat (St. George's) said that the following method of measuring blood loss was in use at St. George's Hospital for major surgery, particularly intra-cardiac surgery.

(*a*) A converted Avery scale with plastic pails on each pan; soiled swabs are placed on one side and dry swabs on the other (Fig. 7*a*). Blood contained in the swabs is read off directly on the scale calibrated up to 500 gm.; at this point a 500 gm. weight is placed on the "dry" pan and the needle reverts to zero so that further swabs can be weighed.



(*a*) (*b*)

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Fig. 7. (*a*) A converted Avery scale with plastic pails on each pan. (*b*) Collecting sucker attached to a converted Avery scale.

(*b*) Blood sucked out of the patient is collected in a bottle attached to the converted Avery scale (Fig. 7*b*), so that the amount sucked out can be read off directly.

This is an effort to make the measurement of blood loss simple and gives an indication of the minimum amount of blood to be replaced. This is important in intra-cardiac surgery, when the loss of blood may be anything up to 4 or 5 litres of blood.