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# FLUID VOLUME CONTROL IN HEART-LUNG BYPASS OPERATIONS IN OPEN-HEART SURGERY

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In this article 25 consecutive heart-lung bypass operations are discussed; these are cases 7 - 31 of those performed in Johannesburg. Only 13 of them are considered in the post-operative studies discussed, because in 6 cases the records were incomplete on account of bed-wetting and spillage, and 6 patients died.

Before the chest is opened, a polythene tube is inserted into a vein at the elbow and advanced into the superior vena cava, and a similar tube passed into the inferior vena cava from a vein in the groin. The former is used for the measurement of venous blood pressures and the latter for the administration of blood and fluid. A polythene tube inserted into the brachial artery is used for monitoring the arterial pressure.

The venous blood pressure is measured in the superior vena cava to preclude the build-up of a high venous pressure in the head, with its attendant dangers. The tube is attached to a 3-way tap, into which leads a drip of 5% dextrose in water. Into the remaining outlet of the tap a 2-foot piece of blood-transfusion tubing is fitted. This is attached vertically to a drip-stand, in front of a centimetre scale marked on adhesive tape, of which the zero mark, determined with a spirit level, is at the level of the right auricle. Continuous readings of the venous pressure throughout operation are thus possible. The tubing thus arranged is used post-operatively in the ward; by placing the 3-way tap at the side of the chest on a level with the right auricle, and measuring the column of water above it with an ordinary ruler, the venous pressure can be read whatever the position of the patient. The femoral venous catheter is also left in for as long as it is required for the administration of blood.

On rare occasions, while the chest is pulled open by retractors, the veins in association with the superior vena cava become stretched or kinked. Under these circumstances the fluid level in the venous manometer becomes raised, fixed and inaccurate. We have found that the venous-pressure readings in the inferior and the superior vena cava are the same so that, where difficulty is encountered in obtaining satisfactory readings in the superior vena cava, the inferior vena cava is used. Whichever tube is not being used for measuring the venous pressure is used for the administration of blood.

## BLOOD VOLUME CONTROL

### *During the Operation*

Blood loss during the operation is estimated from the following sources:

1. Blood is sucked from the operation site into two 2-litre measuring cylinders under the operating table.

2. Swabs are weighed before autoclaving, and the weight is written on the swabs. After use, the swabs are again weighed, and the original weight is subtracted from the weight of the blood-stained swabs to ascertain the weight of blood lost.

3. A check is kept throughout on the volume of blood removed for the purpose of laboratory tests.

4. The quantity of blood lost in spillage is ascertained by wiping up the blood lost with a swab of known weight and weighing the blood-soaked swab.

5. Towels used at the operation site are weighed before and after operation.

6. The amount of saline used during the operation for moistening the heart is subtracted in arriving at the total quantity of blood and fluid lost.

The policy has been to keep the volume of blood transfused ahead of the volume lost. An extra amount of blood is given during the operation to replace the blood lost to the circulation, which cannot be immediately assessed. This loss, which occurs at the operation site, into the pericardial and pleural cavities, and in redistribution within the body, is recognized by the fall in venous and arterial pressures. The volume of blood needed is that required to keep the blood pressure at about the pre-operative level. In children of up to 50 lb. in weight a lead of up to 100 ml. of tranfused blood is maintained over and above the blood lost. In children of 50 - 100 lb. in weight a lead of 100 - 200 ml. of blood is maintained. In patients of over 100 lb. in weight the usual lead required is 200 - 400 ml. On 3 occasions the blood pressure was maintained to the end of the operation with a transfused blood volume which was less than the volume of blood lost; these patients had marked peripheral vasoconstriction.

The total quantity of blood lost during operation is represented in Fig. 1, which shows an average loss of 1,265 ml. The greatest quantity lost was 2,680 ml., and the smallest quantity was 500 ml. The average volume of blood lost into the suction pump was 898 ml., and that removed by the pathologists, 142 ml.; the average weight of blood lost in swabs was 152·4 g.; and that spilt was 74 gm. The average volume of blood replaced during the operation was 1,469 ml., showing an average positive balance of 204 ml. The average volume of heparinized blood used in replacement was 548 ml., and of citrated blood 921 ml.

Intravenous citrated blood is used to replace the blood lost before and after bypass and in the post-operative period. During the bypass heparinized blood poured directly into the oxygenator reservoir is used for replacement. Measurement of the arterial and venous blood pressures are much more informative in maintaining the correct blood volume during bypass and after bypass than a knowledge of the exact balance of blood loss and replacement. In the absence of any marked haemorrhage a flow rate of 2·2 litre per minute per square metre (sq.m.) of body surface area (BSA),[1] a mean



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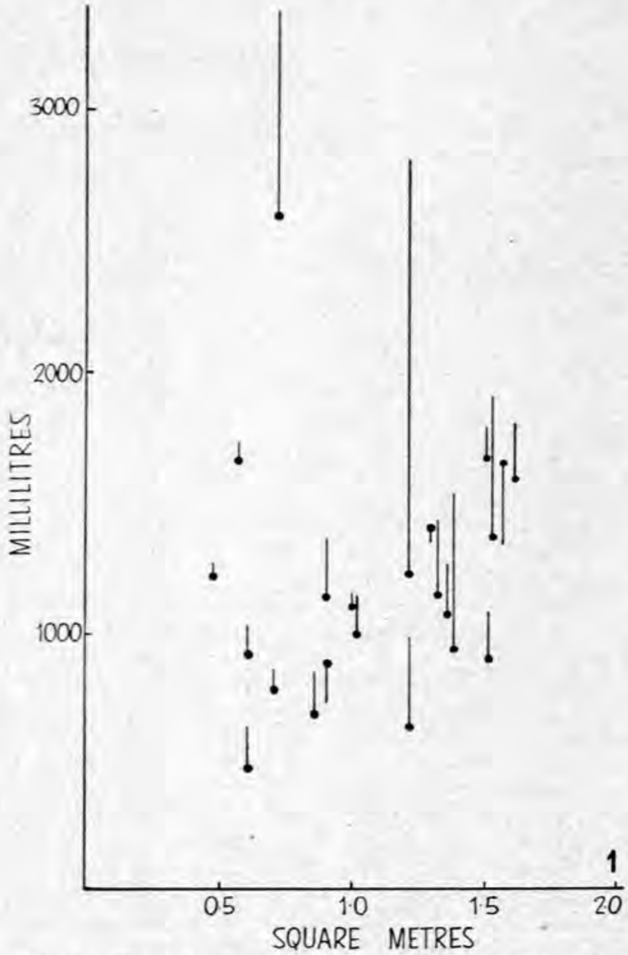


*Fig.* 1. Blood loss and replacement during operation, by sq.m. BSA. The dot denotes the volume of blood lost and the point at the end of the vertical line the volume replaced.

arterial blood pressure of 70 mm. Hg, and a venous blood pressure of 7 - 10 cm. $H_2O$, will produce a haemodynamic state in which the blood volume will be automatically regulated.[2] It is nevertheless valuable to keep the blood balance accurately throughout the operation for, in the event of a large haemorrhage, the exact amount of blood lost is known as it is lost, and is replaced immediately, so that the normal haemodynamics are preserved and shock or overperfusion prevented. Rapidly fluctuating blood-pressure levels are of serious consequence in that they cause peripheral vasoconstriction at the end of bypass. If the bloodpressure falls during or after bypass, it should be raised to the desired level as smoothly and speedily as possible and, if it rises to too high a level, it should be as gently and speedily lowered. A high blood pressure during bypass is indicative of an overperfusion state and too great a volume of blood in the patient, with its dangers of cerebral haemorrhage and pulmonary infarction. A high blood pressure after bypass is indicative of too big a circulating blood volume, with its attendant danger of heart failure.

During bypass, with the flow rate kept at 2·2 l. per sq. m. BSA per minute, the arterial blood pressure and venous blood pressures are kept at their respective desired levels by raising or lowering the venous drainage reservoir. Under this set of circumstances the circulating blood volume in the patient will remain normal and constant. If the blood level in the oxygenator falls, it should be topped up by the addition of heparinized blood to the oxygenator. The blood thus added to the pump oxygenator to maintain these pressures ensures the replacement of blood lost from surgery and the blood which often seems to transfer from the oxygenator to the patient as bypass proceeds beyond 30 minutes.[2] The latter represents a volume which is transferred to the patient and which cannot be accounted for purely on the basis of blood loss.

It is thus seen that, apart from the addition of blood to the pump oxygenator, regulation of the height of the venous drainage reservoir plays an essential part in maintaining the correct blood volume in the patient. During bypass, should the arterial blood pressure fall, more blood is needed in the patient to re-establish the pressure; this is achieved through cutting down the outflow of blood from the patient by raising the venous drainage reservoir. The blood that is being supplied by the pump is kept at the constant optimum flow, and in this way the amount of blood in the patient is increased, with a consequent rise in both the arterial and venous blood pressures. Should the blood pressure become unduly elevated, the venous reservoir is lowered, giving a greater drain-off of blood; thus, if the flow rate is kept constant, the volume of blood in the patient is diminished and the arterial and venous blood pressures are reduced to the desired levels. A low arterial blood pressure, low venous pressure, high flow rate, and high arteriovenous oxygen extraction, denote an inadequate volume of blood in the whole pump-oxygenator-patient system, which is only correctable by the addition of extra blood to the oxygenator. A high arterial blood pressure, high venous pressure, and low flow rate, denote too great a volume of blood in the system. This is corrected by lowering the venous reservoir and allowing the oxygenator blood level to rise.

### *Water Administration during Operation*

As little as 100 - 150 ml. of 0·9% sodium chloride or 5% dextrose in water was administered during the operation. This was kept low intentionally, for it was felt that earlier patients had developed a raised jugulovenous pressure from having been given too much fluid. This restriction is now felt to have been unnecessarily severe, and up to 1,500 ml. of 5% dextrose in water, depending on the size of the patient, will henceforth be administered during the operation. The insensible loss of water during chest operations has been stated to be of the order of 2·3% of the body weight in 2 hours of operation.[3]

### *Post-operative Blood Requirements*

During bypass, on occasions, considerable peripheral vasoconstriction occurs. In some of these cases the blood pressure is being maintained by a blood volume which is below that of the patient's total blood volume before operation. Such patients require the gentle addition of more blood to stimulate the reversal of the shock state and, as the peripheral arterial and venous tree dilates to normal, the additional blood is available to maintain the circulating blood volume. Another shock state which may develop is that of peripheral vasoconstriction with falling blood pressure due to a redistribution of blood, with pooling possibly in the viscera. This may necessitate the administration of blood well in excess of the estimated loss, in order to maintain the patient's circulating blood volume and blood pressure. As this state of shock wears off, the body overcomes this central pooling effect, and more blood is returned to active circulation. This results in cardiac overload, with left ventricular failure manifested by cough, wheezing, rhonchi and crepitations, which occur on the 2nd to the 4th post-operative day. A mercurial diuretic is most effective in combating this. This late overload is also a possible explanation of the raised jugulovenous pressure seen some days after operation, which is best treated with digitalis and diuretics.

Another peculiar state, which becomes less frequent as experience in heart-lung work increases, develops in the first 48 hours. The clinical picture comprises pallor, cold extremities, peripheral vasconstriction, and high rectal temperature rapidly progressing to hyperpyrexia. To me, the best explanation of this state is a redistribution of blood, with pooling in the viscera and depletion of the circulating blood volume. The response of the sweat glands becomes progressively less as the rectal temperature rises, and a critical point can be reached at which sweating stops and cooling ceases, with rapid and, without treatment, fatal results.[4] The treatment is the administration of sufficient blood to maintain the blood pressure and the institution of measures to curtail the hyperpyrexia, which should include a 4 oz. enema of ice water, cold sponging, and a cool room with the minimum of clothing. Incompatibility of blood is offered as an explanation of this syndrome. This may be right, but the peripheral arterial and venous constriction must be due to an associated diminution of the circulating blood volume, because hyperpyrexia also occurs in patients who are flushed and warm to the touch. This hyperpyrexia responds well to steroids.

The maintenance of a record of the loss and replacement of blood is essential in the post-operative period, for the following reasons:

1. To act as a check that the correct blood volume is being maintained.

2. If it becomes apparent that large volumes of blood are required to maintain the blood pressure, the presence of an internal haemorrhage must be suspected and sought after.

3. It is as well to have a record of the extra blood administered so that, when pooling passes off and blood is made available for circulation, the cardiac failure which may ensue can be treated with a fuller understanding.

A low venous-pressure reading is always an accurate reflection of the right auricular pressure, and this, together with a low arterial pressure, is an indication for administering more blood. A high venous pressure, on the other hand, if associated with a low arterial pressure, may denote heart failure, or cardiac tamponade from bleeding into the pericardial cavity. But in shock associated with intense constriction of the veins, the opening of the intravenous tube used for measuring the venous blood pressure may be gripped tightly by the vein, resulting in a false high reading, which may mislead one into withholding blood when it is an urgent necessity.

*Size of Patient*

We have never weighed our patients before and after operation, for lack of a suitable scale. A comparison of the pre-operative and post-operative weights would be helpful. A post-operative weight less than the pre-operative weight would denote a definite deficit of blood or water; but a post-operative weight equalling or exceeding the pre-operative weight would give no indication of the adequacy of the

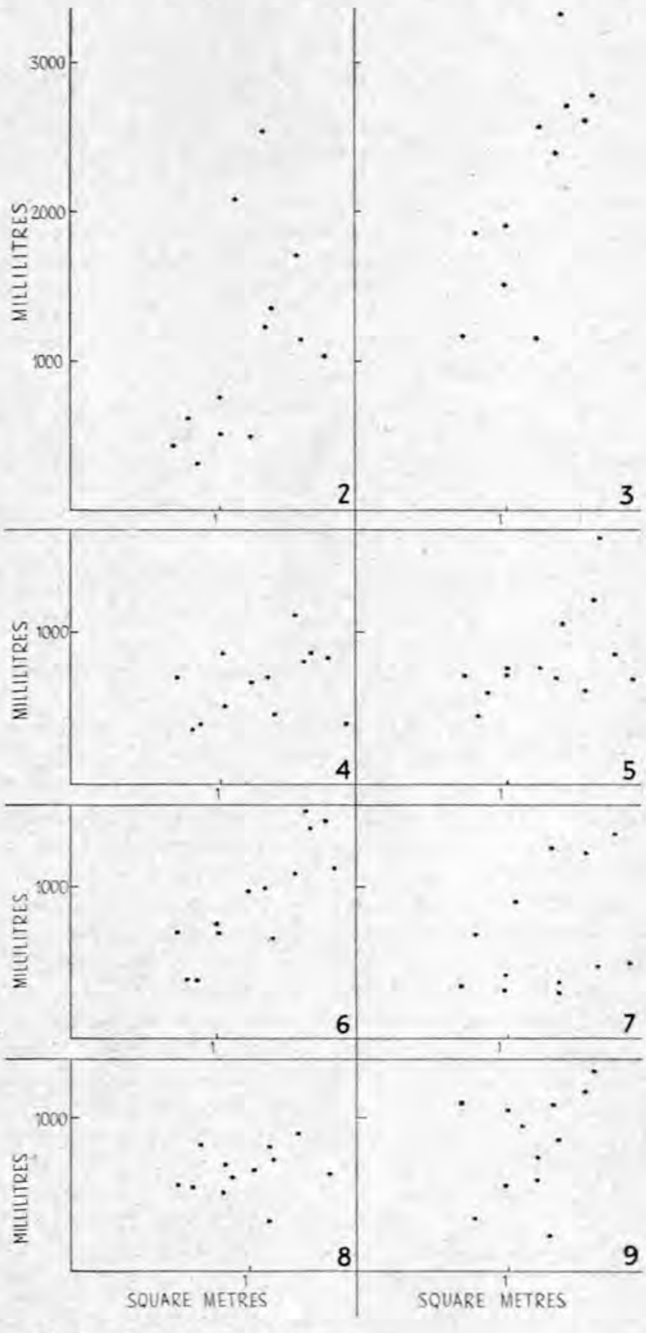


*Fig.* 2. Post-operative blood loss.
*Fig.* 3. Blood loss during and after operation.
*Fig.* 4. Fluid intake in the first post-operative 24 hours.
*Fig.* 5. Fluid intake in the second post-operative 24 hours.
*Fig.* 6. Fluid intake in the third post-operative 24 hours.
*Fig.* 7. Urine output in the first post-operative 24 hours.
*Fig.* 8. Urine output in the second post-operative 24 hours.
*Fig.* 9. Urine output in the third post-operative 24 hours.

circulating volume, the extent of redistribution, or the amount of blood lying free in the chest from haemorrhage, which can only be satisfactorily estimated by frequent X-ray examinations.

The size of the patient bears no relationship to the amount of blood lost during an operation. Fig. 1 shows that as much blood may be lost during the operation on a small child as on an adult. On the other hand, in the post-operative period, the amount of blood lost is roughly proportional to the size of the patient. The bigger the patient, the greater the anticipated blood loss. In a patient of 1 sq.m. BSA the anticipated post-operative blood loss is in the neighbourhood of 500 ml. In a patient of 1·5 sq.m. BSA the anticipated post-operative blood loss is of the order of 1,200 ml. (Fig. 2). Nearly all the post-operative blood drainage from the chest takes place in the first 12 hours. The total blood loss during and after the operation increases with the size of the patient (Fig. 3); the difference is attributed to the greater loss in the bigger patients after operation.

*Post-operative Fluid Intake*

Fluid in the post-operative phase was administered as 5% dextrose in water, intravenously, and as water by the mouth when the patient was able to swallow. The water intake in the first 24 hours (Fig. 4) averaged 524 ml. per sq.m. BSA. In the second 24 hours the average was 690 ml. per sq.m. BSA—a slight increase over the first 24 hours (Fig. 5). The amount of water administered in the third 24 hours was greater in the bigger than in the smaller patients (Fig. 6), the average being 727 ml. per sq.m. BSA. It is felt that these patients have been kept unnecessarily dry, and up to 1,500 ml. of 5% dextrose in water is to be administered to the patient in the early stages of operation and a 50% increase in the daily intake of fluid is planned. The following are comparative figures: (1) Sturtz *et al.*[5] administered 500 ml. per sq.m. BSA on the first post-operative day, 750 ml. on the second day, and 750 ml. on the third day, The patients were nursed in an oxygen tent with the humidity kept as near to 100% as possible, which reduced the insensible loss to a minimum. (2) Cleland[6] administered 400 ml. per sq.m. BSA on the first post-operative day and 800 ml. on the second day. Thereafter the patients were allowed to take fluids by the mouth as they wished. (3) Phillips *et al.*[7] administered 1·5 - 2 ml. per kg. of body weight per hour. (4) Heeley, *et al.*[8] in a survey of children with different illnesses who were in bed in the wards at a temperature of 76°F, calculated that the average insensible loss of water per sq.m. BSA per day was 1,200 ml. in children 0 - 3 years old, 950 ml. in those 3 - 8 years old, and 700 ml. in those of 8 years and older.

*Urine Output*

The patients passed urine before the operation and were not catheterized after the operation. There is no absolute relationship between the size of the patient and the output of urine in the first 24 hours (including that passed during the operation); the bigger patients who secreted more urine (Fig. 7) had bigger intakes during the operation, because greater liberty was taken with a possible overload of fluid in the bigger patients than in the smaller. The average quantity of urine secreted in the first post-operative 24 hours was 505 ml. per sq.m. BSA. In the second 24 hours, the volume of urine (Fig. 8) secreted was more uniform for all patients; the average volume was 562 ml. per sq.m. BSA. In the third 24 hours (Fig. 9) there was a tendency towards a greater output in the bigger patients; the average output was 505 ml. per sq.m. BSA.

*Proteinuria, Glycosuria, Urine Specific Gravity*

Protein in the urine was found post-operatively in 3 patients (out of 13), +++ in one and + in the other two. The protein disappeared in all 3. Sugar was not detected in the urine on any occasion.

The specific gravity of the urine was, on the whole, high. During the first 3 post-operative days, in 6 cases it was 1,030 or over, in 4 cases 1,025 – 1,029, and in 3 cases 1,020 – 1,024. The highest values were seen on the first post-operative day, but subsequent values were also high. This denotes that these patients were being kept dry, which, indeed, was the intention. There does not seem to be good reason for keeping the patients quite so dry, and henceforth they are to be given more fluid.

SUMMARY

The control of blood and fluid volume in patients undergoing open heart surgery, both while on the heart-lung oxygenator and during the post-operative 3 days, is considered.

The blood and fluid volumes in 25 consecutive cases are analysed.

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REFERENCES

1. Du Bois, E. F. (1936): *Basal Metabolism in Health and Disease*, 3rd ed. London: Ballière, Tindall and Cox.
2. Kirby, C. K. *et al.* (1959): Arch. Surg., **78**, 193.
3. Sturtz, G. S., Kirklin, J. W., Burke, E. W. and Power, M. H. (1957): Circulation, **16**, 1000.
4. Editorial (1957): Lancet, **2**, 460.
5. Sturtz, G. S., Kirklin, J. W., Burke, E. W. and Power, M. H. (1957): Circulation, **16**, 988.
6. Cleland, W. P. (1958): Brit. Med. J., **2**, 1369.
7. Phillips, W. L. and Barnard, C. N. (1958): Med. Proc., **4**, 722.
8. Heeley, A. M. and Talbot, N. B. (1955): Amer. J. Dis. Child., **90**, 251.