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Perioperative autotransfusion: haemodilution and red cell salvaging

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We have treated 129 cases of massive haemorrhage during surgery using our combined autotransfusion technique (HAT and SAT). No adverse reactions or complications have been noted and additional homologous blood transfusion has not been required. In addition, circulatory dynamics have been satisfactorily maintained. Although the red cell recycle rate has been maintained at over 85%, the salvaging rate of blood in the operating field has not yet reached 80%. Approximately 30% of the surgical haemorrhage appears to be discarded with surgical sponges or flow out of the operating field. Clearly the cooperation of surgeons is an important factor for success with SAT. Success in autotransfusion may be accomplished by combinations of autotransfusion techniques.

En utilisant une technique per-opératoire combinée d'autotransfusion par hémodilution et récupération des globules rouges, nous avons réussi à éviter toute transfusion de sang homologue lors de 129 épisodes d'hémorragie massive, et ce, sans complication et avec en prime, une stabilité hémodynamique satisfaisante. Toutefois, on perd toujours près de 30% du saignement dans les éponges ou en dehors du champ opératoire. On peut transfuser intacts au delà de 85% des globules rouges récupérés. Evidemment, la collaboration du chirurgien est essentielle à la récupération d'un maximum de globules rouges.

Haemodilutional autotransfusion (HAT) has been used for the treatment of operative haemorrhage in more than 2000 patients during elective surgery in our clinic since 1974. Intraoperative red cell salvaging autotransfusion (SAT) was introduced in 1982. By combining these techniques we have been able to perform extensive and complete intraoperative autotransfusion to avoid homologous blood transfusion.

In this presentation we describe the techniques we have developed. An important principle in the use of these systems is to maximize understanding and cooperation from the surgical team. At the present time we estimate that despite our well-developed autotransfusion protocols approximately 30% of the surgical blood loss is discarded from the operative field (sponges, wall suction). This remains a challenge in the realization of the full potential available from intraoperative cell salvaging.

Haemodilution procedure

We employ HAT (without SAT) when blood loss >400 ml is anticipated. Eight to ten minutes after induction of anaesthesia, 500 ml lactated Ringer's solution are infused into adult patients (Figure 1), after which 600 ml of the patient's blood is withdrawn as rapidly as possible into citrate-phosphate-dextrose (CPD) preservation bags, each holding 200 ml. Next, 600 ml of 6% dextran-70 solution is immediately infused into the patient. Thereafter, if blood loss of >600 ml is anticipated, blood collection and infusion of dextran-70 solution is repeated in the same fashion. If the patient's circulatory condition becomes unstable during the withdrawal of blood, collection is ceased and dextran-70 solution of the same amount as the blood withdrawn is infused. Dextran-70 may be infused simultaneously with blood withdrawal if there is concern for hypovolaemia.

Twelve hundred millilitres of blood should be sufficient in most patients for the treatment of operative blood loss of 1,800–2,000 ml according to our transfusion protocol (Figure 2). Intraoperative red cell salvaging (SAT) using the Haemonetics Cell Saver system is employed when it is anticipated that operative blood loss will exceed 2,000 ml. Haemorrhage of 3,000–4,000 ml

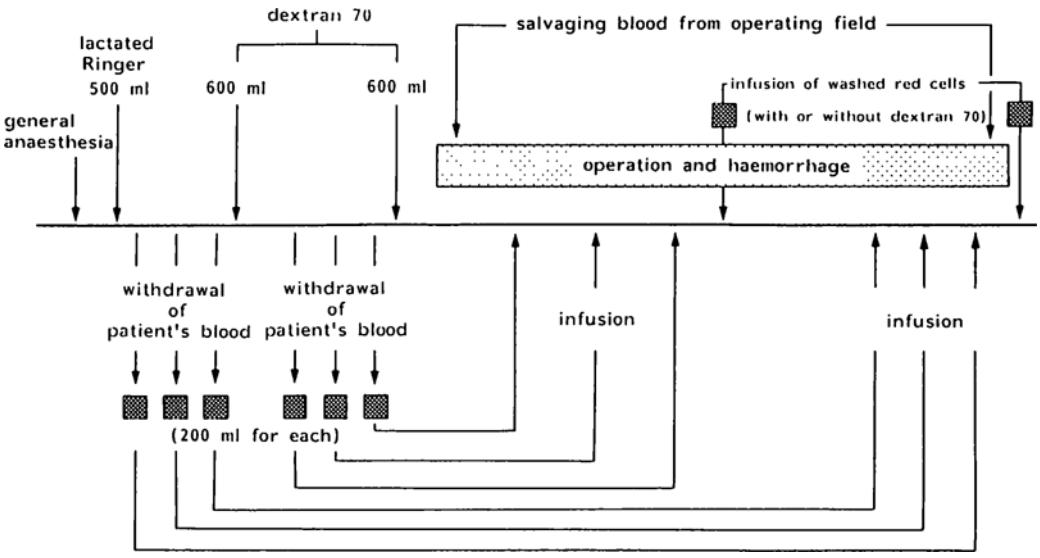

FIGURE 1 Schematic diagram for combined HAT and SAT.

can be successfully replaced by a combination of HAT (1,200 ml) and SAT such that circulatory dynamics, metabolism and haemostasis are maintained.

Indications and contraindications

Autotransfusion may be employed to treat operative blood loss during all kinds of surgery. We do not use autotransfusion techniques in patients with the following conditions:

1 Severe anaemia (haematocrit less than 24%). Theoretical haemodilution curves have been constructed for a normal male with a circulating blood volume of 4000 ml (Figure 3). From these curves a haematocrit of 24% seems to be the minimum starting value which would result in maintenance of oxygen delivery after 1200 ml blood collection.[1]
2 Cardiac failure, valvular heart disease, and intra- or extracardiac shunting. The normal adaptive response to a decrease in oxygen carrying capacity is an increase in cardiac output. Therefore, limitation of the ability to increase cardiac output is a contraindication to HAT.
3 Respiratory insufficiency requiring mechanical ventilation. Oxygen delivery (arterial oxygen content, cardiac output) is frequently compromised in this group of patients.
4 Haemostatic defect.
5 Purulent infectious lesion in the operating field.

Autotransfusion is considered to be contraindicated during surgical removal of a malignant tumour, to prevent disseminated metastases. However, we have used SAT during cancer surgery being careful to avoid the salvage of blood which is massively contaminated with malignant cells. During such procedures we use the anticancer drug mitomycin-C during preparation of the erythrocyte concentrate.

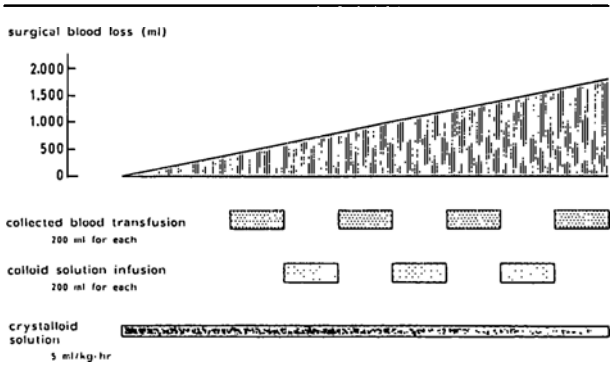

FIGURE 2 Schematic diagram of volume replacement with the collected (autologous) blood and colloid solution in response to surgical bleeding. When surgical blood loss reaches 400 ml, either 200 ml of the collected blood or 200 ml of the colloid solution is infused alternately for each 200 ml of surgical blood loss.

Red cell aspirator (suction tip)

The aspirator provided in commerically available blood salvaging kits was initially constructed to mix irrigation fluid (anticoagulant and saline) with blood in the proximal lumen of the handle. Because blood clots frequently developed in the lumen of the handle, and at the proximal end of the aspirator, we rebuilt the aspirator such that the irrigation fluid was mixed with blood at the tip of the aspirator. This has resulted in no further problem with blood clotting. Additional modifications have been made to reduce obstruction of the lumen of the aspirator with

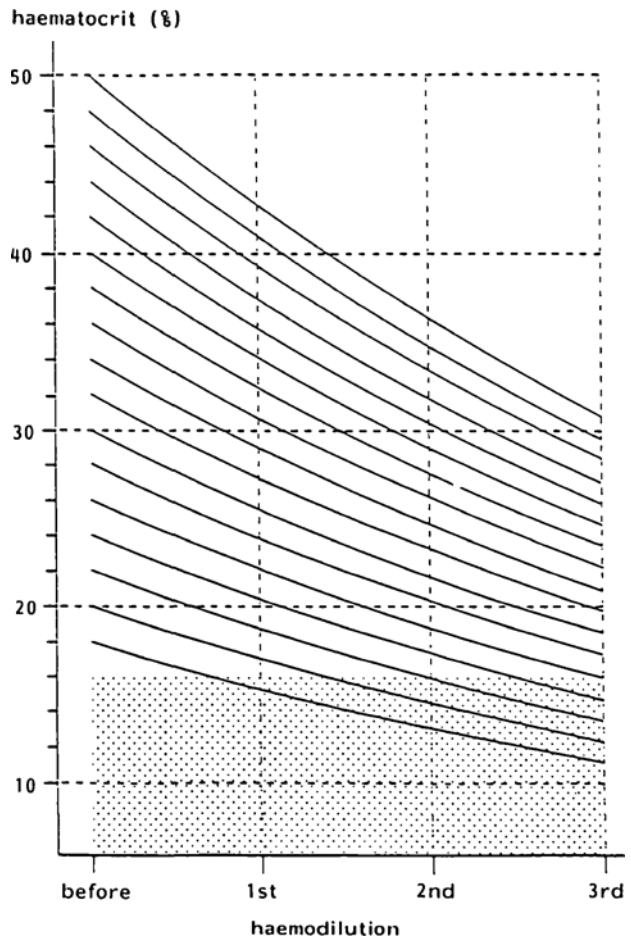

FIGURE 3 Theoretical haemodilution curves for a male with a blood volume of 4000 ml. Each haemodilution consists of 600 ml of blood collection and replacement by the same amount of dextran 70 solution. The stippled area represents the haematocrit value at which oxygen supply to the whole body can not be maintained by compensatory mechanisms.[1]

tissue fragments. After these modifications, which have now been adopted by the manufacturer, we have obtained a red cell recycle rate expressed by the following formula:

$$\frac{A}{A+B} \times 100$$

where

A: red cell mass recycled for SAT (volume × haematocrit)
B: red cell mass loss due to haemolysis (volume × haematocrit)

of approximately 90%.

Irrigation fluid

Since the introduction of SAT we have made several modifications to the composition of the irrigation fluid.

TABLE I Red cell recycle rates for various irrigation fluids

Physiological saline	81.0 ± 6.6
Physiological saline + 4% poloxamer 188	82.9 ± 5.0
Physiological saline + 8% poloxamer 188	81.2 ± 7.6
Haemaccel4	87.3 ± 5.6*
Haemaccel4 (hypertonic)	86.7 ± 3.3*
6% Hydroxyethyl starch	87.2 ± 3.9*
6% Hydroxyethyl starch (hypertonic)	88.3 ± 4.1*

*Comparison with physiological saline: $P < 0.01$ $n = 11$ mean ± SD.

Initially we used physiological saline with 10 ml of 10% sodium citrate and 2000 units of heparin per litre. By studying the red cell recycle rate with different solutions we concluded that colloid solution allows a better recycle rate (Table I). The addition of a surface active agent (poloxamer 188) or hypertonic saline conferred no benefit. Our current solution is shown in Table II.

During normal use irrigation fluid is infused into the aspirator at 10–25 ml · min^{-1}. In an attempt to improve the rate and completeness of aspiration of blood from the operating field, we request that the surgeon pour a volume of irrigation fluid on to the operating field to dilute the blood. This is done with a volume of 25–30 ml every 10–15 min. This procedure appears to facilitate red cell salvaging and minimize red cell damage, particularly with long operative times (five to six hours). In addition, this procedure seems to decrease bacterial contamination in the prepared erythrocyte concentrate.

Bacterial contamination

Microorganisms cultured from the erythrocyte concentrate were found in 11 of 23 cases (48%) in the period between March 1982 and July 1984. Therefore, we added 0.2% ampicillin to the irrigation fluid and 0.4% lactamox-ef to the rinse solution in 1984. As a result, positive microorganism culture findings decreased to five of 37 patients (13.8%) by March 1986. Thereafter we have used more than two litres of the irrigation solution as described above, and microorganism culture findings have been negative in 68 cases.

Contamination by malignant cells

Intraoperative blood salvaging for autotransfusion is usually contraindicated in surgery involving the excision of malignancies. The massive haemorrhage which so often accompanies these operations has led us to adopt a modified use of SAT. We have been encouraged in this technique after reports that homologous blood transfusion may augment recurrence of malignant disease after surgery.[6–8]

Fujimoto *et al.*[9] reported that they had separated hepatoma cells from red cells during the preparation of the red cell concentrate. However, in the same manner, Dale

TABLE II Composition of irrigation fluid

Heparin sulphate	2 mg
10% Sodium citrate	10 ml
10% Poloxamer-188 (Pleuronic F-68)*	40 ml
Ampicillin†	2 g
Physiological saline‡	1000 ml

*Used in 22 cases but excluded now.
†After July, 1984.
‡Substituted by 6% Hetastarch ("Hespan") in 0.9% saline.

et al.[10] demonstrated that malignant cells could not be separated satisfactorily. Very little data have been published on the cytocidal effect of anticancerous drugs *in vitro*. We conducted a number of investigations (unpublished) in our laboratory to determine whether a limited exposure to mitomycin-C (MMC) could kill human cancer cells. In addition, we implanted cancer cells treated in this way into laboratory mice to verify the results *in vivo*. Our investigations have led us to use a concentration of 300 $\mu g \cdot ml^{-1}$ of MMC in the centrifuge bowl for a period of 20 minutes (using the Haemonetics Cell Saver) during cancer surgery. The MMC is added after the initial packing of red cells in the centrifuge but before rinsing.

To date, this procedure has been used in nine patients. Microscopic examinations of the erythrocyte concentrate were performed, and a few enlarged ghost cells suspected to be of malignant origin were found in two cases. We have not seen any generalized dissemination of malignant neoplasma. During three years of follow-up one of the nine patients died of myocardial infarction and one of local recurrence. Autopsies did not reveal distant metastases. Therefore, although the use of SAT during cancer surgery is considered contraindicated, our experience suggests that the use of MMC mixed with the concentrated red cells in the centrifuge bowl may kill malignant cells.

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Safety of blood transfusion: risks and use of predonation, the Canadian experience

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A variety of measures has been introduced in Canada to improve the safety of the blood supply. An autologous blood transfusion pilot study in British Columbia indicated that this form of transfusion is well tolerated and accepted in low-risk patients undergoing elective breast reconstructive surgery. While the use of autologous blood in Canada is not common at present, with broad donor criteria and increased concern about the hazards of homologous blood transfusion autologous transfusion is likely to increase in Canada in the future.

Plusieurs mesures ont été prises afin d'améliorer la sûreté des stocks sanguins au Canada. En Colombie-Britannique, une étude préliminaire a démontré que la transfusion de sang autologue est bien tolérée par les patientes présentant peu de risques lors de reconstructions mammaires électives. L'usage de sang autologue est peu répandu au Canada pour l'instant toutefois, l'élargissement des critères d'éligibilité et l'inquié-