**Perioperative cell salvage**

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The National Blood Service for England collects, tests, processes, stores, and issues ~2.1 million blood donations each year, and the optimal use of this scarce resource is of paramount importance. Allogeneic red blood cell (RBC) transfusion is associated with well-known adverse effects. These include febrile, anaphylactic, and haemolytic transfusion reactions, transfusion-related acute lung injury, and transfusion-associated circulatory overload. In addition, although rare, there are infection risks of viral, bacterial, parasitic, or prion transmission. In the laboratory setting, allogeneic blood has been shown to depress the immune function. Historically, there was also concern over the potential for increased risk of cancer recurrence related to allogeneic blood. In critically ill patients, blood transfusions have been associated with increased risk of sepsis, prolonged requirement for mechanical respiratory support, and multiple-organ dysfunction.¹

Autologous blood use is theoretically attractive as being less harmful than donated, allogeneic blood. Methods for collecting and using autologous blood include predeposition, perioperative normovolaemic haemodilution, and intraoperative or postoperative cell salvage. Cell salvage is the most effective mechanism, and its use was endorsed by the Chief Medical Officer in England as a key component of the Department of Health ‘Better Blood Transfusion Initiative’.

**Basic principles**

Cell salvage is the process by which blood from the surgical field is collected, filtered, and washed to produce autologous blood for transfusion back to the patient. This technique can be used during the intra- or postoperative periods. The technology of cell salvage has evolved since its inception in the 1960s. Initially, cell salvage was limited to simply filtering blood loss during surgery by gravity. More modern devices collect blood to which is added heparinized normal saline or citrate anticoagulant. Processing the collected blood involves filtering and washing to remove contaminants. Red cells are retained, while the plasma, platelets, heparin, free haemoglobin, and inflammatory mediators are discarded with the wash solution. This process may be discontinuous or continuous, and the resulting red cells are finally resuspended in normal saline at a haematocrit of 50–70%, and reinfused into the patient. Once primed, the cell salvage machine should be used within 8 h to prevent infective complications.

**Benefits of cell salvage**

A recent Cochrane review reported that cell salvage reduced the requirements for allogeneic transfusion by 40% without causing cardiovascular, neurological, and immunological adverse clinical outcomes.² Furthermore, cell salvage does not carry the risk of side-effects from substances such as antifibrinolytic agents, lysis analogues, and coagulation factor concentrates used to control bleeding, or the risk of transfusing the wrong unit of blood associated with preoperative autologous donation. Cell salvage requires no preoperative preparation of the patient, making it ideal for unexpected massive haemorrhage. Initially, only the disposables for the collection phase need to be set up, to reduce costs, and the processing phase can then be started once there is sufficient blood collected in the reservoir (usually >500 ml of blood).

**Complications of cell salvage**

Potential complications include electrolyte imbalance, air embolism, pyrexia with rigors, infection, fat embolism, microaggregates causing microembolism, and salvaged blood syndrome. Salvaged blood syndrome refers to activation of intravascular coagulation with increased capillary permeability causing acute lung injury and renal failure. This syndrome is related to the dilution of salvaged blood from large quantities of saline solution, which creates deposits of cellular aggregates when

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Intraoperative cell salvage significantly reduces the number of patients undergoing cardiac surgery needing an allogeneic blood transfusion. Most cardiac units now use intraoperative cell salvage for complex or combined procedures and some use it routinely for all cardiac surgery requiring cardiopulmonary bypass. It also has an important role in blunt and penetrating vascular surgery, ruptured aortic aneurysm, and trauma thoracotomy.

Table 1 Advantages and disadvantages of cell salvage

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
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<tbody>
<tr>
<td>Reduce risk of transmission of infection</td>
<td>Initial equipment cost</td>
</tr>
<tr>
<td>No risk of ABO incompatibility</td>
<td>Cost of disposables</td>
</tr>
<tr>
<td>Option in the case of rare blood group and antibodies</td>
<td>Staff training and competencies</td>
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<tr>
<td>Acceptable for some Jehovah’s Witnesses</td>
<td>Complex device</td>
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<td>Normal concentration of 2.3 DPG</td>
<td>Delay in processing red cells</td>
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<tr>
<td>Removal of activated clotting factors and inflammatory cytokines</td>
<td>Risk of bacterial contamination</td>
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<tr>
<td>Cells reinfused at room temperature</td>
<td>Electrolyte imbalance</td>
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<td>Air and fat embolism</td>
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used with the fixed volume bowl system. Other complications include haemolysis, and increased amounts of free haemoglobin, which can lead to renal damage. Cell-salvaged blood contains no platelets or coagulation factors; therefore, in cases of massive haemorrhage, it is likely that the patient will require allogeneic (donor) blood components, for example, platelets, fresh-frozen plasma, and cryoprecipitate. Anticipate coagulation factor deficiency after more than 2 litres blood loss with continued bleeding and repeat full blood count, prothrombin time, and activated partial thromboplastin time and fibrinogen levels after the reinfusion of each litre of salvaged blood in order to detect and appropriately treat coagulopathy (Table 1).

General indications for cell salvage

(i) Anticipated intraoperative blood loss >1 litre or >20% of blood volume.
(ii) Preoperative anaemia or increased risk factors for bleeding.
(iii) Patients with rare blood group or antibodies.
(iv) Patient refusal to receive allogeneic blood transfusion.
(v) The American Association of Blood Banks suggest cell salvage is indicated in surgery where blood would ordinarily be cross-matched or where more than 10% of patients undergoing the procedure require transfusion.

Specific indications for cell salvage

Jehovah’s Witnesses

Cell salvage may be acceptable to some Jehovah’s Witnesses with their consent, provided that the blood remains in continuity with the patient’s own circulation. The decision to use cell salvage should be made before operation and the mechanism of cell salvage should be discussed with patients and consent obtained during the pre-assessment consultation.

Cardiothoracic and vascular surgery

Intraoperative cell salvage significantly reduces the number of patients undergoing cardiac surgery needing an allogeneic blood transfusion. It also has an important role in blunt and penetrating vascular surgery, ruptured aortic aneurysm, and trauma thoracotomy.

Orthopaedic surgery and trauma

The procedures most frequently requiring blood transfusion are revision joint arthroplasty, major pelvic and spinal surgery, bilateral joint arthroplasty, and major trauma surgery. A meta-analysis of the effectiveness of cell salvage in minimizing perioperative allogeneic transfusion concluded that devices that wash or do not wash salvaged blood considerably decrease the percentage of orthopaedic surgery patients who receive allogeneic transfusion.

Paediatric surgery

Cell salvage is effective in infants and small children in reducing allogeneic blood exposure. Continuous processing is preferable to fixed volume bowl collection. Continuous systems are faster and require only small volumes of salvaged blood for processing and produce blood with high haematocrit. Allogeneic blood transfusion was significantly reduced in volume and frequency when used in cranio-facial, major orthopaedic surgery, for example, acetabuloplasty and scoliosis correction, and in complex cardiac surgery.

Special circumstances and controversies

Cell salvage is not recommended by the manufacturers in the presence of sickle-cell disease, sickle-cell trait, and other RBC disorders, although there have been case reports of its successful use in patients with sickle-cell trait and thalassaemia. Although a small proportion of red cells may change shape in the hypoxic reservoir, after transfusion, the cells should be restored to their normal shape. Homologous blood from donors with sickle-cell trait has been safely transfused into adult patients.

Cancer surgery

Cell salvage is not recommended by the manufacturers in patients undergoing surgery for malignancy because of the possibility of reinfusion of tumour cells, potentially giving rise to distant metastasis. There is good evidence that there is no difference in biochemical recurrence or long-term survival after radical prostatectomy and cystectomy between patients receiving cell salvage and those who received no blood.

A recent prospective study on patients undergoing cancer surgery also showed no difference in recurrence rate between those who did and did not receive cell-salvaged blood. Currently, the use of cell salvage for urological malignancies is approved by NICE. It is recommended that leukodepletion filters should be used before transfusion to filter malignant cells and further elimination of malignant cells can be achieved by irradiation.
**Bowel surgery**

Bowel surgery, penetrating abdominal injury, or surgery where infection is present creates a situation where collected blood might be contaminated with bacteria. However, there is no evidence that cell salvage in this setting is associated with an increased risk of bacteraemia and sepsis when compared with allogeneic transfusion.\(^6\) However, cell salvage should be commenced after initial decontamination of the bowel contents and infected wound, and the use of liberal amounts of normal saline to wash the contaminated area. The use of broad-spectrum antibiotics is recommended.

**Obstetrics**

Cell salvage is increasingly used in the UK in obstetrics in the management of major obstetric haemorrhage. Concerns about amniotic fluid embolism, fetal debris contamination, and rhesus sensitization previously limited such use. However to date, there have been no proven cases of amniotic fluid embolism caused by reinfusion of salvaged blood in the literature. There is increasing evidence supporting the safety of cell salvage in obstetrics, and this has been approved by NICE.\(^7\) In pregnancies involving an Rh-negative mother and an Rh-positive fetus, a Kleihauer test should be performed in the immediate post-partum period. This will allow the calculation of the appropriate dose of anti-D immuno-globulin (usually 125 IU ml\(^{-1}\) of fetal blood) if required.

Several precautions should be taken when salvaging blood in obstetrics. Aspiration of amniotic fluid should be minimized through a double suction set-up. One suction should be connected to the cell salvage reservoir and used for suctioning of blood and the other should be connected to the regular wall suction and used only for aspiration of amniotic fluid. The utilization of leucodepletion filters during transfusion of salvaged blood can reduce the fetal squamous cell contamination to a level comparable with maternal blood contamination. However, it is not recommended that salvaged blood be pressurized through these filters as it may cause hypotension from the release of vasoactive substances such as bradykinin.

**Postoperative cell salvage**

Postoperative cell salvage usually involves collection of blood from surgical drains, and the device used during surgery may be used. Postoperative collection and reinfusion devices are commonly used in orthopaedic surgery, as postoperative bleeding is usually slow and constant. This process can be extended up to 12 h after operation but to minimize infection risk, blood should be reinfused within 6 h after the start of collection. There is some preliminary evidence that reinfusion of the unwashed drainage has a beneficial immunostimulatory effect and may reduce postoperative infection.\(^8\) Vacuum-operated systems help to prevent haemolysis and haematoma formation, and closed-system devices prevent airborne infections. Blood collected in this manner will not clot, however it must be filtered (washing is optional) before it is returned to the patient.

**Procedure**

During surgery, blood loss can be recovered from the operative site by a combination of suction and swabs. Blood loss from swabs during surgery has been estimated at between 30% and 50% of the total surgical blood loss. By washing swabs, the blood that is normally discarded can be collected and the overall efficiency of red cell recovery improved. A separate suction should be used to discard substances not licensed for i.v. use, for example, topical anticoagulants, topical antibiotics, bone cement, alcohol, hydrogen peroxide, betadine, chlorhexidine, fibrin adhesives, and distilled water. Pleural effusions, amniotic fluid, gastric, and pancreatic secretions should be aspirated or drained before using the cell salvage suction. A large-bore suction tube tip, minimum 4 mm, should be used to minimize damage to red cells, and surface skimming of shed blood should be avoided to reduce red cell damage. Low vacuum pressure suction (\(<150\) mm Hg or 20 kPa) is recommended to prevent haemolysis. Great care must be taken to administer the correct amount of anticoagulant. The recommended ratio is 1:5 (20 ml of anticoagulant to 100 ml of blood) if heparin is used and 1:7 (15 ml of anticoagulant for 100 ml of blood) if citrate is used as an anticoagulant. Heparin saline is usually prepared with 30 000 units of heparin in 1 litre of normal saline. A rate of 60–80 drops per minute if heparin saline is used and 40–60 drops if premixed citrate-based anticoagulant is used.

The following steps describe the cell salvage process (Fig. 1):

**Step 1: Suction**

The blood is sucked away from the operative site via a dual-lumen tube, which mixes the blood immediately with the anticoagulant into a custom-made reservoir.

**Step 2: Filtration**

The contents of the reservoir are filtered to remove large clots and debris. Most collection reservoirs have filters in the 40–150 \(\mu\)m range.

**Step 3: Separation**

The remaining volume is drawn into a centrifuge to be processed. Sterile isotonic saline solution is pumped into the centrifuge bowl. The force supplied by the centrifuge holds the more dense RBCs against the outer wall of the bowl. The less dense plasma moves towards the centre of the bowl where it spills over into a waste bag. Almost one-third of red cell volume may be lost in the scavenging device during processing, depending on the type of device in use. Photo-optics are used to detect the maximum cell density and then to initiate the washing of the packed suspension with a selected volume of saline.
Step 4: Disposal

Waste products, including white blood cells, platelets, plasma, anticoagulant, fat, clotting factors, and free plasma haemoglobin are collected in a bag and are disposed of as clinical waste.

Step 5: Cell salvage

Packed RBCs are collected in a separate bag. The quality of the collected red cells depends upon the volume of wash solution used, the degree of concentration achieved, and the quality of the blood before washing, the type of surgery, and the presence of residual contaminants.

Step 6: Reinfusion

The collected red cells can be reinfused immediately or for up to 4 h after processing if kept at room temperature. If citrate is used as an anticoagulant, rapid liver metabolism makes citrate toxicity unlikely, but in compromised liver function, correction with small doses of calcium (10 ml of 10% calcium gluconate) provides immediate and non-toxic reversal. It is recommended that the standard UK label should be used for the cell-salvaged blood. Labelling of autologous salvaged red cells is as important as the labelling of allogeneic (donor) units. To address this issue and to help promote the safe and appropriate use of cell salvage, the UK Cell Salvage Action Group has developed a generic label for salvaged blood. The aim is to help standardize practice through the routine labelling of cell salvage blood in all hospitals throughout the UK.

Processing details

It is recommended that cell salvage machines be run in automatic mode. There are different systems available to complete the various stages of processing.9

Fixed volume bowl systems

Fixed volume bowl systems require a minimum volume of RBCs in the bowl for processing to be started. The fixed volume bowl may be available in a range of sizes depending on the manufacturer. Bowl volumes as small as 55 ml have been used in paediatric cell salvage machines. The smaller bowl will take longer to process a large volume of blood, whereas a large bowl requires a large volume of blood (>500 ml) to start processing.

Variable volume disk systems

This system will require only a very small volume of blood for processing to begin, and will process 100 ml of reservoir contents at a time. If the volume of red cells being drawn into the disk from the reservoir is <15 ml, the system will concentrate more batches of blood before washing. It will deliver a variable volume of red cells with a fixed haematocrit.

Continuous rotary system

Washing and processing takes place continuously and produces a higher haematocrit. Owing to the volume independence of the
wearing chamber, the initial volume of packed red cells required is very small (15–30 ml), minimizing wastage.

**Operational management**

A recent study demonstrated that only 53% of hospitals in the UK use intraoperative cell salvage. Recommendations state that there should be a lead clinician working in the theatre setting to provide information, support, and take responsibility for promoting the service. A senior theatre manager should take the responsibility to organize and facilitate the service. The operation of the cell-saver device requires training, and in most institutions, its use is supervised either by a perfusionist, an anaesthetic technician, or a member of the theatre team.

Regular continuous audit of the cell salvage service should be undertaken, and each individual unit of salvaged blood must have an audit trail. To maintain these standards, all cell salvage procedures and volumes of blood reinfused must be documented in the patient’s records using a dedicated collection form. It is also essential to report any adverse events to Serious Hazards of the patient’s records using a dedicated collection form. It is also necessary to maintain the standards of the service. A senior theatre manager should take the responsibility to organize and facilitate the service. The operation of the cell-saver device requires training, and in most institutions, its use is supervised either by a perfusionist, an anaesthetic technician, or a member of the theatre team.

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**Cost implications**

The price of a single unit of donated blood is approximately £135 (more if it is leucodepleted). The average cost associated with using cell salvage per case is approximately £70–£190 depending on the level of activity. Various studies have shown that cell salvage costs £150–£190 per case based on activity of 50 operations per annum. The cost per case is approximately £70, where there is substantial activity (up to 1000 cases per annum). Systematic reviews of cell salvage performed in elective settings have shown that the more frequently cell-salvaged blood was used, the greater the likelihood of it being cost-effective. When choosing a supplier, the cost of the machine, disposables, and the cost of maintenance needs to be taken into account. Machines will be an expensive wasted resource without trained operators and operational infrastructure to ensure regular use.

**Conclusion**

Cell salvage has an excellent, longstanding safety record. Despite the costs of the initial set-up, disposables, and staff training, it may be cost-effective when compared with the cost and scarcity of allo-geneic blood and has many potential physiological and pathological advantages. A successful cell salvage service will require investment in equipment and personnel, and anaesthetists would appear to be ideally placed to promote, audit, and support its safe and effective use.

**Conflict of interest**

None declared.

**References**


Please see multiple choice questions 5–8.