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The theory and practice of bloodless surgery

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Abstract

The application of blood conservation strategies to minimise or avoid allogeneic blood transfusion is seen internationally as a desirable objective. Bloodless surgery is a relatively new practice that facilitates that goal. However, the concept is either poorly understood or evokes negative connotations. Bloodless surgery is a term that has evolved in the medical literature to refer to a peri-operative team approach to avoid allogeneic transfusion and improve patient outcomes. Starting as an advocacy in the early 1960s, it has now grown into a serious practice being embraced by internationally respected clinicians and institutions. Central to its success is a coordinated multidisciplinary approach. It encompasses the peri-operative period with surgeons, anaesthetists, haematologists, intensivists, pathologists, transfusion specialists, pharmacists, technicians, and operating room and ward nurses utilising combinations of the numerous blood conservation techniques and transfusion alternatives now available. A comprehensive monograph on the subject of bloodless surgery along with detailed coverage of risks and benefits of each modality (some modalities are discussed in more detail elsewhere in this issue) is beyond the scope of this article. Accordingly, a brief overview of the history, theory and practice of bloodless surgery is presented, along with the clinical and institutional management requirements. © 2002 Elsevier Science Ltd. All rights reserved.

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1. Introduction

Bloodless surgery is a comprehensive peri-operative approach that has as its goal allogeneic transfusion avoidance with a view to improving patient outcomes. Initially an advocacy, providing

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Table 1
Factors making bloodless surgery desirable

Transfusion-transmitted infections
ABO incompatible transfusion reactions
Transfusion-associated immunomodulation (TRIM)
Increased infection risk
Dissemination of malignant cells
Negative effects of the storage lesion
Dwindling blood supplies
Increasing cost of haemovigilance
Improved patient outcomes
Evidence suggesting reduced morbidity, mortality and reduced hospital stays
Evidence suggesting reduced overall costs
Litigation
Motivation for more discriminating transfusion practice
Health care team satisfaction
Accommodates patient preference

surgical care for patients refusing blood transfusion for religious reasons, it was the domain of a few dedicated clinicians and institutions. In the modern era it has captured the imagination of many in the mainstream medical community. It is now seen as a desirable approach for all patients (see Table 1) [1,2]. The practice has been defined as "a safe, effective team approach to medicine and surgery that reduces blood loss and uses the best available alternatives to allogeneic transfusion therapy while focusing on the provision of the best possible medical care to all patients" [3].

Integral to bloodless surgery is a coordinated peri-operative multidisciplinary multimodal approach. Recent evidence suggests that the application of bloodless surgery principles may result in improved patient outcomes, reduced morbidity and mortality, shorter hospital stays, significant overall cost savings to the health care system and reduced strain on a finite blood supply [1,4,5].

2. Background

Landsteiner's discovery of the ABO blood system, Lewison's development of anticoagulant storage in 1913 and the establishment of blood banks after World War II led the way to transfusion becoming standard practice for the treatment of blood loss anaemia. An ample supply of "safe" blood freed surgeons from the concerns of haemorrhage to develop more complex surgical procedures such as open heart, major orthopaedic operations and organ transplantation. However, a small but significant number of the community, because of their refusal of blood for religious reasons, was virtually excluded from such major surgery.

Texas heart surgeon Denton Cooley and his team saw the need to provide surgical care for these patients and in the early 1960s they pioneered open-heart surgery without transfusion [6]. They developed a method of priming the heart lung machine without blood which came to be known as a "bloodless prime" [7]. Subsequent surgical and anaesthetic techniques developed to minimise blood loss and avoid transfusion were at times referred to as "bloodless techniques" [8]. Thus the expression "bloodless surgery" evolved—referring to the avoidance of allogeneic transfusion.

Cooley and his group reported on over 1000 of these cases in the literature. Noting the good results and the apparent avoidance of complications often associated with transfusion, his team recommended the broader application of these techniques [9,10].

However, this was contrary to standard practice and so not widely applied. Additionally, negative connotations were attached to the practice because it was seen to be associated with a fringe religious group. The appearance of HIV/AIDS in the 1980s and a growing list of micro-organisms capable of being transmitted by blood forced a reassessment of transfusion practice. The response was multifold. Surgeons and anaesthetists relearned old, and developed new, techniques to minimise blood loss and transfusion and concurrently lowered the transfusion threshold. Industry developed new technologies and pharmaceuticals, and explored oxygen-carrying solutions as alternatives to transfusion. Improved blood banking, including careful donor selection and screening along with better testing to increase blood safety, was instituted. This, however, has come at a cost both financially and in the form of shrinking a blood supply already suffering from chronic shortages.

The last few years have seen further, perhaps less appreciated, reasons for the development of blood conservation and transfusion alternatives. In addition to new and emerging diseases such as vCJD, there is evidence for an immunomodulatory effect from stored blood with increased post-operative infection rates and dissemination of metastases. [11–13] The clinical consequences of other storage related problems are only now being appreciated. Amongst these are impaired tissue oxygenation, reduced microcirculatory flow, transfusion-related acute lung injury and coagulation disturbances [14–17]. Recent work suggests liberal transfusion practice may be associated with increased morbidity, mortality, hospital stays and cost [18–20]. This, along with a surprising lack of evidence from clinical trials for general transfusion efficacy, has led to a reassessment of transfusion practice and a more discriminating, evidence-based approach [21–26].

Contemporaneously, significant advances were being made in bloodless surgery. Hospitals started developing bloodless surgery programs to coadunate teams of specialists and health care professionals to provide for a growing patient demand. With the increasing involvement of clinicians and large respected teaching institutions it became evident that this approach was not just a matter of patient choice, but was in fact good medical practice. Comprehensive hospital-wide programs were developed, variously known as Centres for "Bloodless Medicine and Surgery", "Blood Conservation and Transfusion Alternatives" or, more recently, "Advanced Transfusion Practices and Blood Research" [27,28]. The goal: to provide improved cost-effective patient care by bringing together a hospital-wide team strategy to minimising patient exposure to allogeneic blood transfusion.

What was initially an advocacy was now becoming a driving force in the practice of medicine. The result has been that all major surgical procedures have now been performed without resort to allogeneic transfusion, including complex cardiac, vascular and orthopaedic surgery, and liver and lung transplantation [29–33]. Professional associations have been formed and an increasing literature including journals and textbooks has become available [34].

3. The coordinated team approach

Central to the success of bloodless surgery is an integrated team approach. It requires a committed hospital administration, specific policies and procedures, personnel to coordinate and manage the program, along with a full team of skilled, knowledgeable and motivated doctors, nurses, technicians and other support staff. A blood conservation program conjoins all departments including surgery, anaesthesia, haematology, critical care and nursing, along with pharmacy, pathology and the transfusion service.

A formal program structure is essential to facilitate this multidisciplinary team effort. Education is a key element, keeping all involved abreast of current estimates of transfusion risks and benefits, along with developments in blood conservation and transfusion alternatives [3,35].

There are two key positions in a successful program: the Program Coordinator who integrates the various individuals in the program and, the Program Medical Director who provides clinical continuum for a program that crosses multiple speciality lines. Close cooperation and communication between these two is essential. They need to be dedicated to keeping abreast of the very latest in theory and practice of blood conservation in order to maintain the dynamics of the program and sustain progressive practice.

Additionally, a blood conservation/transfusion committee with representatives from all departments is essential to review policies and practice, evaluate new technologies, monitor the program and manage quality control issues.

4. Specific patient considerations

Whilst a growing number of patients are seeking bloodless surgery for medical reasons [36], some seek it for religious reasons. To ensure a positive outcome, all members of the peri-operative team need an understanding of the philosophical and medical management approaches in this specific patient group [37,38]. Much has been learned from their care about optimising blood management [39,40].

Prior to surgery, patient preferences, treatment options and transfusion alternatives should be discussed thoroughly with the patient, along with risks and benefits. Decisions made should be documented and signed consent/refusal obtained.

5. The integrated peri-operative approach

In practice, bloodless surgery is an organised team utilising combinations of selected strategies in the peri-operative period. Each of the techniques listed in Tables 2–4 can limit blood loss and transfusion exposure. However, they are usually most effective when used in combinations as part of an overall peri-surgical blood conservation plan. Clinicians need to be aware of the indications and contraindications of each modality as well as the pharmacological and physiological implications of combined manoeuvres.

Bloodless surgery has four basic aims:

1. Optimise the patient pre-operatively.
2. Maximise haemopoiesis.
3. Minimise blood loss.
4. Maximise oxygen delivery.

This is accomplished in three integrated phases:

1. Pre-operative assessment, work-up and planning,
2. Intra-operative surgical, anaesthetic, technological and pharmacological strategies,
3. Post-operative blood conservation, maximising recovery of blood elements and providing optimum support.

In emergencies or trauma, where there is little time for patient optimisation, aggressive application of the intra- and post-operative principles are employed.

6. Pre-operative phase

Pre-operative preparation is a vital element in the success of bloodless surgery. This phase requires formulating a treatment plan specific to the procedure required and the condition of the patient.

It commences with comparing the estimated peri-operative blood loss for that particular procedure, with the calculated patient-specific tolerable blood loss, taking into consideration their age, weight, height, gender, commencement haemoglobin and co-morbidities such as cardiovascular or pulmonary disease. Formulae have been developed for this calculation [41]. If the estimated blood loss is greater than the tolerable blood loss, then strategies must be considered to optimise the patient's physiological condition, reduce blood loss and/or increase the patient's red blood cell mass.

Early cooperation and communication is required between the surgeon and anaesthetist. For more complex procedures, or where specific deficiencies are identified, a haematologist, an intensivist or possibly other specialist physicians may need to be involved in the preparation. A summary of the pre-operative phase is provided in Table 2.

6.1. Physiological assessment and optimisation

A thorough medical/surgical history along with a physical examination should be performed to identify the patient's physiological reserves and risk factors. Pre-operative treatment of pre-existing disease may be necessary.

6.2. Identify ways to reduce surgical bleeding

A bleeding history supported by judicious use of laboratory investigations is mandatory. Underlying disorders should be identified. Medications, including herbal preparations, that contribute to bleeding may need to be discontinued or dose modified [42].

At this stage consideration need be given for the use of pharmacological agents that can decrease peri-operative bleeding such as aprotinin, tranexamic acid, epsilon aminocaproic acid, desmopressin and vitamin K [43].

Table 2
Pre-operative assessment, workup and planning

- *Assess/optimise patient's fitness for operation*
  Medical/surgical history
  Physical examination: heart, lungs, general fitness, establish patient's reserves
  Treat coexisting cardiopulmonary disease
- *Compare estimated blood loss with calculated tolerable blood loss to formulate treatment plan.*
  Determine which patient and procedure specific modalities required to limit blood loss and/or maximise haemopoiesis
- *Haematological assessment*
  History of anaemia
  Bleeding history
    Abnormal bleeding during childhood, previous surgery, dental, pregnancy, bruising, etc.
    Laboratory: Full blood picture, reticulocyte count, iron studies, B_{12}/folate levels, coagulation status (platelet function and specific clotting factor assays if indicated)
- *Reduce surgical bleeding*
  Identify/correct underlying disorders
    Platelet dysfunction
    Kidney disease
    Liver disease
  Identify medications that increase bleeding
    Medications: aspirin, NSAIDs, anticoagulants, beta-lactam antibiotics, some cardiovascular and psychotropic drugs
    Herbals: Garlic, St Johns Wort (hypericum), feverfew, ginkgo, ginger, ginseng, etc
  Consider pharmacological agents to reduce bleeding
    Aprotinin, desmopressin, aminocaproic acid, tranexamic acid, vitamin K
- *Maximise haemopoiesis*
  Increase red blood cell mass
    Replenish or supplement haematinics: Iron (oral or parenteral), vitamin C, B_{12}, folic acid
    Epoetin alfa (appropriate iron supplementation with epoetin therapy is essential)
    Androgen therapy (when poor response to epoetin)
  White blood cells
    Granulocyte colony-stimulating factor
    Granulocyte-macrophage colony-stimulating factor
  Platelets
    Interleukin-11
    Steroids, immunosuppressive drugs (in ITP)
- *Correct clotting factor deficiencies*
  Vitamin K
  Recombinant Factor VIIa, VIII and IX are now available
- *Consider appropriateness of pre-operative autologous blood donation (PABD)*
  Maximise blood procurement and limit storage time with erythropoietic support: Epoetin alfa, iron (oral or parenteral), vitamin C, B12, folate.
- *Procedure planning and rehearsal*
  Ensure expeditious availability of all equipment and instruments
  Prepare for alternative manoeuvres and prompt handling of emergency contingencies
- *Management planning*
  Develop an individualised surgical/medical management plan
  Discuss the plan along with risks and benefits with the patient
  Obtain consent
  Communicate plan to all members of the team

6.3. Maximise blood production

Anaemia needs to be identified along with its causes and wherever possible corrected. Epoetin (recombinant human erythropoietin) has been shown to be an effective way of increasing the red blood cell mass pre-operatively. Epoetin may need to be used even in the absence of anaemia to

Table 3
Intra-operative management

- *Surgical approaches*
  - Careful planning (including contingency plans), and surgical team communication
  - Patient positioning
  - Meticulous surgical technique and careful haemostasis
  - Arterial embolisation
  - Mechanical occlusion of bleeding vessels
  - Local vasoconstrictive agents
  - Topical hemostatic agents
  - Tourniquet for extremities
  - Reduced operating time/enlarged surgical team
  - Prompt availability of all equipment and prostheses
  - Staging complex surgical procedures
  - Minimally invasive procedures
- *Surgical devices to assist haemostasis*
  - Electrocautery
  - Electrosurgery
  - Laser surgery
  - Argon beam coagulator
  - Ultrasonic scalpels
  - Microwave coagulating scalpels
  - Water jet dissector
  - Radiation therapy
  - Cryosurgery
- *Anaesthetic management*
  - Autotransfusion options:
    - Hypervolaemic haemodilution
    - ANH
    - A-ANH
    - Intra-operative and post-operative blood salvage
    - Plasma and platelet pheresis
    - Control or minimise haemodilution in cardiac surgery
  - Other management considerations
    - Regional anaesthesia
    - Controlled hypotension
    - Maintenance of normothermia intra- and post-operatively
    - Hypothermia (to reduce oxygen consumption used with caution and only in special situations)
    - Appropriate oxygen support
    - Hyperoxic ventilation
  - Judicious use of fluids (maintain normovolaemia)
    - Fluid choices:

Crystalloids	*Colloids*
Ringer's Lactate	Dextran
Hartmann's solution	Haemaccel
Normal saline	Gelofusine
Hypertonic saline	Plasmion
Hypotonic saline	Gelofundiol
Dextrose	Hetastarch
Plasma-Lyte	Pentastarch
	Low molecular weight starch

Combined colloid/crystalloid electrolyte solutions
Artificial oxygen-carrying substances:
  Recombinant and modified haemoglobin solutions
  Perfluorocarbon solutions
Pharmacological agents to reduce bleeding

Table 3 (*continued*)

Antifibrinolytics	*Topical hemostatic agents*
Aminocaproic acid	Microfibrillar collagen
Tranexamic acid	Microfibrillar collagen hemostat spray
Aprotinin	Absorbable collagen
Vasoconstrictors	Collagen fleece
Desmopressin	Absorbable gelatin sponge
Vasopressin	Absorbable oxidized cellulose
Conjugated estrogens	Thrombin
Norethisterone	Bone wax
(norethindrone)	*Tissue adhesives*
Medroxyprogesterone	Fibrin glue
Vitamin K	Platelet gel
Tolerate lower haemoglobin	

Table 4
Post-operative strategies

- *Minimise blood loss*
  - Vigilant monitoring for post-operative bleeding
  - Avoid secondary haemorrhage
    - Avoid hypertension
    - Maintain normothermia
  - Reduce iatrogenic loss
    - Minimise volume and frequency of tests
    - Microsampling
    - Non-invasive monitoring
    - Monitor drug interactions that may increase anaemia or bleeding
  - Post-operative blood salvage
  - Prompt intervention to stop active bleeding (surgical, endoscopic or angiographic)
  - Maintenance of normothermia/active patient warming (unless hypothermia specifically indicated)
  - Regular assessment of coagulation status
    - Pharmacological agents for bleeding/clotting problems
      - Aprotinin, desmopressin, ϵ-aminocaproic acid, tranexamic acid, conjugated estrogens, vasopressin, vitamin K, recombinant clotting factors, H2 blockers, sucralfate.
- *Maximise blood production*
  - Epoetin alfa
  - Other haematinics: iv iron, folic acid, vitamin B_{12}
  - Androgens
  - Nutrition
  - Other haemopoietic growth factors: G-CSF, GM-CSF, Ill-11
- *Maximise oxygen delivery*
  - Maximise cardiac output— inotropic support
  - Maintain intravascular volume
  - Maximise oxygen supply
    - Mechanical ventilation
    - High FiO_2
  - Hyperbaric oxygen therapy (as last resort in patients where compatible blood is not available or patient has absolute refusal of blood for religious reasons)
- *Minimise oxygen consumption*
  - Avoid infections/treat early if develop
  - Mechanical ventilation
  - Sedation
  - Paralysis
  - Hypothermia (with caution)
  - Adequate analgesia

prepare patients for surgery where the anticipated blood loss is large. This enables more aggressive pre-operative blood procurement, intra-operative haemodilution and more rapid post-operative haemoglobin recovery.

If epoetin therapy is undertaken, careful attention must be given to iron supplementation. Without it, epoetin therapy may be ineffective, even in patients with normal iron stores. Oral iron may be insufficient to keep pace with epoetin stimulated erythropoiesis and intravenous iron may be indicated [44]. Using iron polymaltose, careful dosage calculation and slow infusion rates, the authors have not seen significant side effects in over 10 years experience. Intravenous iron also appears to enable the use of lower, and therefore more cost-effective, dosage of epoetin. This has been the authors' anecdotal experience and this group is now investigating the broader application of this approach and its potential reductions in transfusion requirements and hospital stays.

In some cases, intravenous iron therapy alone may be sufficient to rapidly correct anaemia secondary to iron-deficiency. Vitamin B_{12} and folate supplementation is also an important part of the haemoglobin maximisation regimen.

6.4. Laboratory investigations

Careful clinical assessment can reduce the need for many laboratory investigations. Phlebotomy should be dictated by surgical or patient indications with a view to limiting iatrogenic blood losses. Limiting the volume and frequency of blood sampling in the peri-operative period is vital.

6.5. Surgical planning

Pre-operative surgical planning and rehearsal can reduce unnecessary delays that can prolong the operation. Reducing operating time reduces blood loss.

6.6. Treatment plan

From the above, an individualised surgical/medical management plan should be developed. The risks, benefits and limitations of the plan should be discussed with the patient and informed consent obtained. It is essential that the treatment plan be communicated to all members of the peri-operative treatment team and close communication be maintained throughout. This is where effective documentation and the role of a program coordinator are essential.

7. Intra-operative phase

The intra-operative phase requires close communication and cooperation between all personnel involved. Factors that help in reduction of blood loss can be considered under the following headings:

7.1. Planning

Prior planning is probably the most important. This is especially so when a large inventory of equipment or prostheses are required. Planning needs to incorporate the possibility of intra-operative difficulties or predictable complications (even if unlikely) with an alternate strategy developed *in advance* should such eventuate. This may necessitate the immediate availability of additional appliances in theatre, sterile and ready to go.

The threshold at which a surgeon will abandon a procedure or approach and switch to an alternate strategy should be tempered by individual patient factors and clinical circumstances, and considered in advance.

For instance it may be appropriate in a healthy individual to continue a difficult minimally invasive procedure but more judicious to abandon this and convert to an open operation in an unwell anaemic patient if troublesome bleeding is encountered. It is inexcusable if prior planning did not provide for such an eventuality and valuable time is wasted obtaining and preparing equipment.

7.2. Communication

Prior planning needs to be communicated to the entire theatre team so all are prepared for eventualities. In the event of major blood loss an alternate surgical strategy may necessitate additional equipment which needs to be ready in advance. Time can be wasted with such simple things as operating table positioning or adjusting the patient's position. This can be avoided if all theatre personnel are aware in advance of the planned strategy. Should extended surgical exposure be required, the patient should be draped in a fashion to obviate re-draping.

Theatre booking information should include instructions of equipment or special needs that might be required during the procedure.

7.3. Surgeon

An individual surgeon needs to consider his skill, expertise and experience relevant to the individual clinical circumstances of the patient. In a seriously ill patient, or where blood transfusion is not an available option, a skilled and experienced surgeon can substantially minimise blood loss with resultant reduction in morbidity and mortality. A surgeon in training who may adequately perform the procedure in normal circumstances might best defer to a senior surgeon in such circumstances.

Similarly if blood loss is likely to be a major issue, even a skilled and senior surgeon should consider whether his expertise is the most relevant to the patient's procedure or consider referral to someone whose experience is more relevant to the surgery being considered.

7.4. Surgical technique/strategies

All surgery attempts to respect anatomy and dissect along tissue planes to achieve relative haemostasis. A crucial factor in "bloodless surgery" is the meticulous nature of haemostasis required during surgical dissection and procedure. Technical aids help facilitate this as outlined in Table 3.

By example the harmonic scalpel can dissect through soft tissues where no anatomic plane exists such as liver resection with vast reduction in blood loss compared to other options. Argon beam coagulation can quickly control haemorrhage from exposed bony surfaces where traditional electrocautery is ineffective. Some simple "lower technology" techniques such as preloaded vascular clips can very quickly be applied to control medium sized vessel bleeding in soft tissue dissection.

The crux of surgical technique is meticulous attention to haemostasis, and speed in achieving this. Skill can be acquired predominantly by repeated practice. Very minute adjustment to surgical techniques achieves this. Some practical examples are as follows:

Partial dissection: Incise a portion of the wound or a portion of the depth of the wound, achieve haemostasis then complete in stages.

Avoid stripping: Stripping of fat layer off fascia makes identification of layers easier for closure but increases blood loss.

Packing: The wound should be packed immediately. Achieve haemostasis in one area and reposition packs so only a small portion of the wound is exposed at any one time. Once exposure is achieved, pack off all the wound leaving only necessary area exposed.

Blood salvage: Cell salvage is used only to mop up any blood spillage for re-use. Better to stop bleeding with packs until cautery is performed rather than use suction to take away blood. Packs may be washed to salvage absorbed blood.

Fast hands: Quick, but not careless, hands with diathermy and packing saves blood.

Supplementary percutaneous portals: In limb surgery, particularly long bone trauma, surgical exposure can be limited to a smaller incision with further access via percutaneous incisions for placement of fixation screws.

Staged procedures: In certain circumstances where blood volume is precarious separate procedures can be performed in staged fashion, or even sequential stage performance of a single procedure.

Surgical approach: Selection of surgical exposure may be varied if blood loss is likely to be a substantial issue. On some occasions a larger and more extensile surgical exposure may be preferred if substantial reduction in total operative time is to be achieved. What may appear initially a "more bloody" exposure sometimes significantly reduces total operative blood loss.

7.5. Scrub team

Experienced surgical assistants and scrub nurses are invaluable in saving operative time and conserving blood. A team who works together regularly will predict the sequence of the procedure, not waiting for instruction or prompting, such that it is a team of three operating on a patient rather than one surgeon and two helpers.

Situations where blood conservation is critical will be best served by such a team, rather than attempt such surgery with an ad hoc group. In difficult procedures two surgeons operating together can be very valuable. Additional scrub team members can do preparatory "back table" preparation of instruments/implants and facilitate the speed of surgery, helping to limit blood loss.

7.6. Theatre organisation/discipline

The above remarks emphasise the need for coordination between the members of the surgical team. Ideally this should exist in all theatre settings, but clinicians are aware that logistically this is not always achieved or achievable. It is imperative that an appropriate level of staffing, expertise and theatre environment exists if "bloodless surgery" is to be achieved.

7.7. Anaesthetic considerations

The anaesthetist plays a significant role in bloodless surgery, intra-operatively contributing to reducing bleeding and maximising oxygen delivery.

General factors such as adequate depth of anaesthesia and muscle relaxation, avoidance of hypertension and hypercapnia, choice of anaesthetic agents and technique (regional verses general), and decreasing intra-abdominal and inferior vena caval pressure all contribute to reducing bleeding [45].

Specific manoeuvres include controlled hypotension, hypervolaemic and acute normovolaemic haemodilution (ANH), intra- and post-operative cell salvage and plasma and platelet pheresis. The latter technique has enabled the performance of very large blood volume loss procedures without allogeneic blood or product support [32].

The efficacy of ANH can be enhanced with pre-operative epoetin therapy [46,47]. Hyperoxic ventilation may also extend the limits of haemodilution and further minimise transfusion [48]. Advanced clinical trials are also investigating the use of oxygen-carrying solutions in a technique referred to as augmented acute normovolaemic haemodilution (A-ANH) [49].

The rigorous maintenance of normothermia has been shown to be important in reducing blood loss [1,50]. While controlled hypothermia has been used in specific surgeries in combination with other techniques to reduce oxygen consumption in extreme haemodilution, it must be used with caution because of its deleterious effect on coagulation [51].

Maintenance of normovolaemia is critical [52]. Judicious use of fluids and oxygen management enables the acceptance of a lower haemoglobin.

A range of pharmacological agents also makes up the intra-operative armamentarium.

7.8. Other considerations

Only the modalities necessary to achieve the optimal outcome need be recruited for a given patient and specific procedure. However, there must be preparedness for the unexpected. As the experience of the team grows, they will learn to limit their choice of what is necessary. In the early years of the authors' program, cell salvage was used extensively in joint replacement surgery. Other surgical and anaesthetic techniques have so reduced blood loss that cell salvage is now rarely used.

In a series of 47 total hip replacement operations [53] (37 primary and 10 revision procedures) only one patient was transfused (a total of 1 unit). This compares with transfusion rates between 9% and 85% elsewhere for primary hip replacement [54]. The one transfused patient had pernicious anaemia (87 g/l pre-operatively) and was not prepared to await haemoglobin maximisation. In addition to careful surgical technique the only therapies used were intravenous iron, ANH and controlled hypotension. Neither pre-operative epoetin, nor intra- or post-operative cell salvage was employed. Only three patients pre-donated their own blood.

8. Post-operative phase

There are multiple therapeutic manoeuvres that can be used in the post-operative period to reduce blood loss, maximise blood production, maximise oxygen delivery and minimise oxygen consumption as listed in Table 4 and briefly discussed here.

8.1. Minimise blood loss

Attention to details such as avoiding hypertension, maintaining normothermia and being conscious of drug interactions that may increase bleeding and iatrogenic anaemia can make a valuable contribution. Vigilant monitoring should distinguish between normal post-operative blood loss and active bleeding. There should be preparedness for prompt intervention to arrest active bleeding. Careful attention to the frequency and volume of blood sampling is peremptory. Studies have shown that ICU patients can have as much as 70 ml withdrawn per day, contributing to transfusion exposure [55]. Microsampling techniques along with non-invasive monitoring and careful planning of tests can significantly reduce iatrogenic blood loss. Active blood loss management may also include appropriate salvage and reinfusion of drain blood and the use of pharmacological agents to assist haemostasis.

8.2. Maximise erythropoiesis

Pre-operative haemoglobin maximisation should mean that most patients would require minimal post-operative haemopoietic support. However, severe anaemia secondary to significant blood loss may require more aggressive treatment. Whilst anaemia is well tolerated, studies have suggested it is associated with increased complications which allogeneic transfusion may have limited ability in ameliorating [56].

By means of a literature review and multidisciplinary clinical experience the authors developed a haemoglobin rescue regimen for bloodless management of severe acute anaemia in critically ill patients. Its application has achieved relatively rapid haemoglobin rises in patients transferred to the ICU with intra-operative haemorrhage and multiple trauma [57].

Although the combination of epoetin and intravenous iron appears to result in a more rapid restoration of haemoglobin [58], at times with appropriate nutritional support intravenous iron alone may be sufficient [59,60].

8.3. Maximise oxygen delivery/minimise consumption

Current thinking espouses that red cell transfusions should be used only when there is a clinically defined need for improvement in oxygen delivery. An alternative to transfusion may involve manoeuvres to maximise oxygen delivery and reduce tissue oxygen needs:

Maximise DO_2: Maintain intra-vascular volume while avoiding circulatory overload. Oncotic pressure instability may dictate fluid choices. Provide appropriate ventilatory support with high FiO_2. Maintenance of optimal haemodynamics is mandatory. This may require inotropic support.

Minimise VO_2: Appropriate analgesia and sedation, with or without neuromuscular blockade, can significantly reduce oxygen consumption [61]. Normothermia is usually indicated, however, hypothermia has been used to further reduce oxygen requirements in specific situations [62]. Consider the use of beta blockers to reduce excessive tachycardia but not more than 10% (ten percent) reduction, and administered slowly [63,64].

Hyperbaric oxygen therapy: In very extreme cases involving patients refusing blood or for whom compatible blood has not been available, and where there is an ongoing oxygen debt despite the above interventions, hyperbaric oxygen therapy has been used successfully [65].

8.4. Trauma

A number of bloodless surgery centres have integrated aggressive blood conservation into their trauma units with encouraging early results. In time, no doubt, their published data will make a significant contribution to our knowledge of transfusion and transfusion avoidance in this difficult field [34].

9. Acceptance of a lower haemoglobin

Beginning with the 1988 NIH consensus conference on peri-operative red blood cell transfusion the traditional transfusion trigger of a haemoglobin value of 100 g/l has come under critical review [66]. Clinical and physiological evidence suggests a much greater human tolerance of anaemia. Healthy resting volunteers were bled isovolaemically to a haemoglobin of 50 g/l with no signs of compromised oxygen delivery [67]. A subsequent group was bled to a haemoglobin of 48 g/l and administered beta blockade to minimise cardiac compensation. No evidence of inadequate systemic oxygenation was apparent [68]. Successful management of Jehovah's Witness patients has revealed a remarkable tolerance of severe acute anaemia [61,69].

Tolerable of course does not mean optimal. However, this knowledge can be used as a strategy to minimise transfusion. Lowering the transfusion trigger from 100 to 70 g/l in critically ill patients in intensive care reduced red cell unit transfusions by 54% and improved clinical outcomes [18]. While a number of practice guidelines have been published suggesting a transfusion trigger in the range of 60–70 g/l they caution that a single figure should not become a substitute for clinical judgement [26,70]. Good knowledge of the physiological response to blood loss anaemia and patient specific factors that affect its tolerance along with alternative manoeuvres to manage it allows the acceptance of a lower intra- and post-operative haemoglobin as a bloodless surgery strategy.

10. Conclusion

Blood transfusion has made a significant contribution to the development of medicine and surgery. Nevertheless, as with all medical practice, the passing of time necessitates reassessment in the light of advancing science and technology along with the changing economic and social environment. The last two decades forced considerable focus on infectious complications of transfusion with the result being a blood supply that is arguably safer than it has ever been. There remain, however, unavoidable inherent risks with transfusion along with yet to be defined hazards. This has led to the recent shift to questions of efficacy. A paucity of evidence for a general benefit to patients has led to calls for clinical trials to establish more appropriate evidence-based practice. Early studies are challenging traditional paradigms. Cost and supply have become major issues. Contributing further to the complexity is a more informed patient population that desires greater treatment choice and an increasing number requesting to avoid transfusion.

Bloodless surgery is making a valuable contribution toward these issues. Each of the "bloodless" strategies referred to in this article makes a contribution toward minimising or avoiding allogeneic transfusion in major surgery. While not universally applied, a number are already the standard of care in a growing number of institutions. However, the aggressive application of all modalities in combination is still reserved for specific situations. Institutions with formal programs are, as part of their standard of care, selectively drawing upon all these modalities in a coordinated patient and procedure specific manner with very good results. From their experience the authors believe that the basic principles of bloodless surgery are good medical practice. If applied in a coordinated peri-operative team approach it can significantly reduce blood loss, transfusion usage and improve patient outcomes. Bloodless surgery is proving to be a safe, effective and cost-efficient approach that satisfies patient preference, is extremely satisfying to health care teams, eases demand on a finite blood supply, and is making a significant contribution to advancing transfusion science.

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