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Version A: Conventional abridgement

Version B: Enhanced-abstract abridgement

Version C: Journalistic abridgement

The creation of the journalistic and enhanced-abstract abridgements was for the purpose of the survey only and did not involve the authors of the original published article.

Mechanical methods of reducing blood transfusion in cardiac surgery: randomised controlled trial

Neil McGill, Denise O'Shaughnessy, Ruth Pickering, Mike Herbertson, Ravi Gill

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Abstract

Objective To assess the effectiveness of two mechanical methods of blood conservation in reducing the need for allogeneic red blood cells or coagulation products during cardiac surgery.

Design Randomised controlled trial.

Setting Regional cardiac centre in a teaching hospital in Southampton.

Participants 263 adults aged 18-80 years undergoing elective coronary artery bypass surgery entered the study, of whom 252 completed the trial. All patients received routine perioperative care. Patients were allocated to one of three treatment groups: intraoperative cell salvage, intraoperative cell salvage with acute perioperative normovolaemic haemodilution, or no mechanical blood conservation. There were 84 patients in each group.

Main outcome measures Numbers of patients who received allogeneic blood or coagulation products, and the mean number of units of blood transfused per patient.

Results Of the patients in the intraoperative cell salvage group, 26 were given a transfusion of allogeneic blood, compared with 43 in the control group (odds ratio 0.43 (95% confidence interval 0.23 to 0.80)). The mean number of units of allogeneic blood transfused per patient in the intraoperative cell salvage group was 0.68 units (SD=1.55), compared with 1.07 (1.56) units in the control group. 32 of the patients in the intraoperative cell salvage group were given any blood product, compared with 47 in the control group (odds ratio 0.47 (0.25 to 0.89); $P=0.019$). Combining acute perioperative normovolaemic haemodilution with intraoperative cell salvage conferred no additional benefits.

Conclusions An intraoperative cell salvage device should be used in elective coronary artery bypass grafting. Pharmacological strategies may achieve further reductions in blood transfusions. Yet further reductions in blood transfusions could be achieved if the lower safe limit of haemoglobin concentration in patients undergoing cardiac surgery were known.

Introduction

The National Blood Service for England issues approximately 2.2 million units of blood a year, of which 10% are used in cardiac surgical units.^{1 2} Up to

92% of patients presenting for elective cardiac surgery receive blood.^{3 4} Patients who receive allogeneic blood risk contracting bloodborne or other infections or having a perioperative myocardial infarction.⁵⁻⁷ To minimise the risk of transmission of variant Creutzfeldt-Jakob disease, leucodepletion of all donated blood in this country has been introduced. This has quadrupled the cost of allogeneic red blood cells. The optimal use of this scarce, expensive, and potentially infectious resource is of international importance.

Intraoperative cell salvage is the most widely used method of mechanical blood conservation in elective cardiac surgery.⁸ Acute perioperative normovolaemic haemodilution is used in less than 20% of cardiac units.⁹ Both techniques have cost implications and have yet to become normal practice—perhaps due to the lack of data showing their effectiveness.^{10 11}

We report a randomised controlled trial in patients undergoing elective coronary artery bypass surgery. We compared a group of patients in whom intraoperative cell salvage was used with a control group and with a group in whom acute perioperative normovolaemic haemodilution was used in addition to intraoperative cell salvage.

Materials and methods

Selection of patients

Patients were approached on their admission the day before surgery in the cardiac unit at Southampton General Hospital. Written informed consent was sought from all patients thought to meet the inclusion criteria (box).

A total of 252 patients who met the inclusion criteria were randomised to one of the three groups. Intraoperative masking of mechanical red blood cell salvage treatment was not possible.

Trial protocol

All patients received standard care according to a protocol (see bmj.com).

Intraoperative cell salvage group A cell saver (Dideco Compact, Dideco, Mirandola, Italy) was used from incision until the end of surgery. After the termination of the bypass, patients received protamine, and any shed blood and the residual cardiopulmonary bypass circuit volume were washed and centrifuged by the intraoperative cell salvage machine then retransfused.

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Eligibility criteria

Inclusion criteria:

- Age 18-80 years
- Ejection fraction >30%
- Serum creatinine concentration <150 µmol/l
- International normalised ratio and activated partial thromboplastin time <1.5
- Platelet count >150 × 10⁹/l
- Haemoglobin concentration >120 g/l
- Haematocrit >0.36
- Weight >60 kg

Exclusion criteria:

- Emergency operation
- Redo procedures and multiple procedures
- Known carotid stenosis >50%
- Myocardial infarction in past three weeks
- Heparin or warfarin taken in previous five days
- Antiplatelet treatment other than aspirin
- Cerebrovascular disease
- History of liver disease
- Jehovah's Witnesses

Combined treatment group After induction of anaesthesia 10 ml/kg of blood was removed from the central venous line while being replaced at the same time with an equivalent volume of modified gelatin (Gelofusine). The Harvest Blood Stream Recovery System, an autologous recovery system, was used to remove blood. The recovered blood was stored at room temperature. After protamine administration the autologous blood collected after induction of anaesthesia was retransfused. The cell saver was used in the same manner as in the intraoperative cell salvage group.

Control group The residual cardiopulmonary bypass circuit volume was retransfused into the patient after protamine administration.

All patients were under the care of cardiac intensivists, who were blind to the allocation of patients to study group. The threshold for transfusion of

allogeneic red blood cells was the same in all groups: haemoglobin concentration <90 g/l and haematocrit <0.27. Administration of allogeneic blood coagulation products (fresh frozen plasma and platelets) was at the discretion of the cardiac intensivists.

Statistical analysis

Percentages of patients receiving the various blood products were compared in logistic regression models, controlled for surgeon. Differences between groups in these percentages were deemed significant if they achieved significance of $P < 0.025$ in the Wald test. The Kruskal-Wallis one way analysis of variance was used to compare the differences between the groups in the amounts of blood products used and in the secondary outcomes.

Results**Baseline characteristics**

The distributions of sex, age, weight, left ventricular function, aspirin administration, and Parsonnet scores, which allow preoperative risk stratification, were similar across the three groups.

Primary outcomes

Fewer patients in the intraoperative cell salvage group than in the control group were given allogeneic red blood cells, or any blood product, and the mean number of units of red blood cells transfused per patient was less in the intraoperative cell salvage group than in the control group (table 1). The combination of acute perioperative normovolaemic haemodilution and intraoperative cell salvage did not show any additional benefit over intraoperative cell salvage alone.

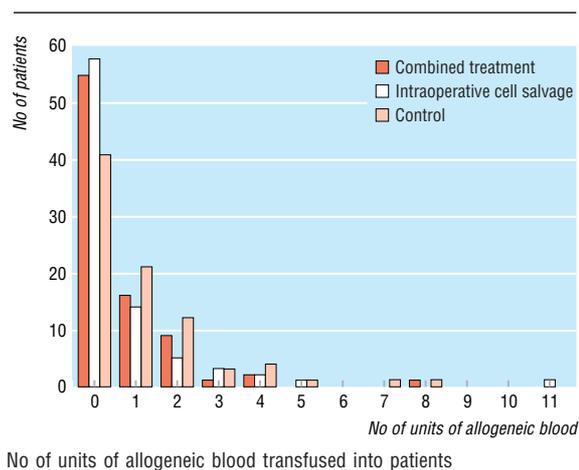
Most patients were not given allogeneic blood (figure). Nine patients needed a markedly higher amount of transfused blood (≥ 3 units). A surgical cause of bleeding was found in seven of these patients (three in the control group and two in each of the two treatment groups).

The variations in haemoglobin concentration from before the operation to day 3 after the operation were similar in the three groups (see bmj.com). No patient

Table 1 Blood products given to patients (n=84 in each group) during their perioperative course

Blood product received	Control	Intraoperative cell salvage	Combined treatment	Kruskal-Wallis P value	Intraoperative cell salvage* v control		Combined treatment v intraoperative cell salvage*	
					Odds ratio (95% CI)	Wald test P value	Odds ratio (95% CI)	Wald test P value
Allogeneic blood:								
No of patients	43	26	29		0.43(0.23-0.80)	0.008	1.18(0.62-2.24)	0.622
Mean (SD) No of units received per patient	1.07(1.56)	0.68(1.55)	0.63(1.22)	0.015				
Range	0-8	0-11	0-8					
Fresh frozen plasma:								
No of patients	13	14	13		1.1 (0.47-2.53)	0.831	0.91(0.40-2.11)	0.831
Mean (SD) No of units received per patient	0.49(1.25)	0.57(1.47)	0.43(1.12)	0.952				
Range	0-6	0-8	0-6					
Platelets:								
No of patients	15	11	15		0.68(0.29-1.62)	0.386	1.46(0.62-3.47)	0.386
Mean (SD) No of units received per patient	0.29(0.67)	0.20(0.62)	0.31(0.81)	0.601				
Range	0-3	0-4	0-4					
No of patients given any blood product	47	32	33		0.47(0.25-0.89)	0.019	1.05(0.56-1.98)	0.872

*Controlled for surgeon.



was given a transfusion of allogeneic blood after leaving the intensive care unit.

Secondary outcomes

There were no differences between the groups in mediastinal drainage, time in intensive care, or length of stay in hospital. The median duration of acute perioperative normovolaemic haemodilution was 13 minutes. Patients in the combination treatment group spent the longest time in the anaesthetic room. Groups were similar with respect to total anaesthesia and surgery times, and times on cardiopulmonary bypass and with the aorta cross-clamped (see bmj.com). Perioperative complications were evenly distributed across the groups (table 2).

Discussion

Intraoperative cell salvage

A recent meta-analysis of cell salvage in cardiac and orthopaedic surgery found that in cardiac surgery cell salvage marginally reduced use of allogeneic blood products (relative risk 0.85 (0.79 to 0.92)).¹⁰ However, none of the trials washed the salvaged blood before returning it to the patient, and the intraoperative cell salvage devices were used only postoperatively. Trials in which intraoperative cell salvage machines were used intraoperatively failed to meet standard eligibility criteria for the meta-analysis. Our method of intraoperative cell salvage maximised surgical salvage of red blood cells, and our washing of the residual cardiopulmonary bypass volume allowed optimal haemoconcentration, accounting for the greater efficacy of intraoperative cell salvage. Our study is the first to compare intraoperative use of intraoperative cell salvage with control treatment.

Acute perioperative normovolaemic haemodilution

Acute perioperative normovolaemic haemodilution is not well established in cardiac surgery. A meta-analysis of the treatment across surgical specialties concluded that it reduces the need for allogeneic red blood cells (odds ratio 0.31 (0.15 to 0.62)), but that the evidence in cardiac surgery was less compelling (0.51 (0.26 to 0.99)).¹¹ This meta-analysis included 11 randomised controlled trials in cardiac surgery.^{12–22} However, the quality of the evidence from these trials varied, only four of the trials having a transfusion protocol.^{17 18 21 22} Overall the evidence for the benefit of acute

perioperative normovolaemic haemodilution in reducing use of allogeneic red blood cells during cardiac surgery was equivocal.

Our results indicate that acute perioperative normovolaemic haemodilution does not confer additional benefits in terms of reduced use of allogeneic transfusion. This may be because not enough blood was removed at the start of the procedure. Given the patients' severe coronary artery disease, we decided not to exceed a predonated volume of 10 ml/kg. Removing a greater volume of blood preoperatively may expose patients to ischaemic events and decreased myocardial contractility.²³

Limitations

Just over half (43/84) the patients in the control group were given a transfusion—a considerably lower proportion than that reported for our institution in a previous study.⁴ We believe the main reason for this was that the transfusion threshold was reduced between the two studies from a haemoglobin concentration of 100 g/l to 90 g/l.

The lack of a protocol on the use of allogeneic blood coagulation products means that caution is needed in interpreting differences between the groups in the use of fresh frozen plasma and platelets. Our trial involved patients undergoing elective coronary artery bypass grafting. Although intraoperative cell salvage may be useful in more complex cardiac surgery or for patients with pre-existing coagulopathy, our findings cannot necessarily be extrapolated to such patients.

Intraoperative masking of mechanical conservation technique was not possible. This might have led to transfusion practice being driven by knowledge of allocation to group. This effect would be pronounced if no transfusion protocol were used. Because the intensive care staff were blinded to allocation to group, and no protocol violations occurred, we assume that the reduction in allogeneic red blood cell transfusion is related to the efficacy of intraoperative cell salvage.

Conclusions

The need for allogeneic red blood cell transfusion in elective coronary artery bypass grafting can be reduced by using intraoperative cell salvage. Acute perioperative normovolaemic haemodilution with intraoperative cell salvage confers no additional benefit. The lower safe limit of haemoglobin concentration in patients undergoing cardiac surgery—either while they are on bypass or postoperatively—is unknown. If this limit was known, and made use of, the combination of optimal pharmacological strategies with intraoperative cell salvage could achieve yet further reductions in the numbers of patients who

Table 2 Numbers of patients with perioperative complications (n=84 in each group)

	Control	Intraoperative cell salvage	Combined treatment
Without complications	42	46	46
Inotropes required after 24 hours	9	12	11
Surgical bleeding	3	2	2
Cerebrovascular accident	2	1	1
Arrhythmias	27	17	20
Renal failure	0	1	2
Proven infection	7	11	7
Myocardial infarction	10	5	4

What is already known on this topic

Patients undergoing elective coronary artery bypass surgery often need a blood transfusion

Recent meta-analyses have shown that the mechanical blood conservation techniques of intraoperative cell salvage and acute perioperative normovolaemic haemodilution may reduce the need for transfusion, but flawed methods in trials mean that clear evidence in cardiac surgery is lacking

What this study adds

Intraoperative cell salvage significantly reduces the number of patients needing an allogeneic blood transfusion

Combining acute perioperative normovolaemic haemodilution with intraoperative cell salvage does not confer any additional benefit

need to be given transfusions of allogeneic red blood cells and blood coagulation products.

Mr S Yates, manager of Haematology and Transfusion Laboratories, provided essential laboratory and transfusion support, without which this study could not have occurred. Dr D C Smith, consultant cardiac anaesthetist, reviewed the paper and made helpful comments.

Contributors: See bmj.com

Funding: This study was supported by a grant from the local blood transfusion service.

Competing interests: None declared.

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SAMPLE NOT FOR PUBLICATION

THE AUTHORS OF THE ORIGINAL PAPER
HAVE NOT BEEN INVOLVED IN THE
DEVELOPMENT OF THIS VERSION

VERSION B

Mechanical methods of reducing blood transfusion in cardiac surgery: randomised controlled trial

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We hypothesised that during cardiac surgery intraoperative cell salvage would reduce the need for allogeneic red blood cell transfusion compared with control management and that combining acute perioperative normovolaemic haemodilution with intraoperative cell salvage would lead to a further reduction.

Abstract

Objective To assess the effectiveness of two mechanical methods of blood conservation in reducing the need for allogeneic red blood cells or coagulation products during cardiac surgery.

Design Randomised controlled trial.

Setting Regional cardiac centre in a teaching hospital in Southampton.

Participants 263 adults aged 18-80 years undergoing elective coronary artery bypass surgery entered the study, of whom 252 completed the trial. All patients received routine perioperative care. Patients were allocated to one of three treatment groups: intraoperative cell salvage, intraoperative cell salvage with acute perioperative normovolaemic haemodilution, or no mechanical blood conservation. There were 84 patients in each group.

Main outcome measures Numbers of patients who received allogeneic blood or coagulation products, and the mean number of units of blood transfused per patient.

Results Most patients were not given allogeneic blood, 51 patients received one unit of blood, and 25 received two. Of the patients in the intraoperative cell salvage group, 26 were given a transfusion of allogeneic blood compared with 43 in the control group (odds ratio 0.43, 95% confidence interval 0.23 to 0.80). The mean number of units of allogeneic blood transfused per patient in the intraoperative cell salvage group was 0.68 units compared with 1.07 units in the control group (table). Thirty two of the patients in the intraoperative cell salvage group were given any blood product compared with 47 in the control group (0.47, 0.25 to 0.89; $P=0.019$). Combination of acute perioperative normovolaemic haemodilution with intraoperative cell salvage conferred no additional benefits. Perioperative complications were evenly distributed across the groups. There were no differences between the groups in mediastinal drainage, time in intensive care, or length of stay in hospital.

Conclusions An intraoperative cell salvage device should be used in elective coronary artery bypass grafting. Pharmacological strategies may achieve further reductions in blood transfusions. Yet further reductions in blood transfusions could be achieved if the lower safe limit of haemoglobin concentration in patients undergoing cardiac surgery were known.

Background

The National Blood Service for England issues approximately 2.2 million units of blood a year, of which 10% are used in cardiac surgical units.^{1 2} Up to 92% of patients presenting for elective cardiac surgery receive blood.³ In our own institution recently this proportion was 82%.⁴ Patients who receive allogeneic blood risk contracting bloodborne or other infections or having a perioperative myocardial infarction.⁵⁻⁷ To minimise the risk of transmission of variant Creutzfeldt-Jakob disease, leucodepletion of all donated blood in this country has been introduced. This has quadrupled the cost of allogeneic red blood cells. The optimal use of this scarce, expensive, and potentially infectious resource is of national importance.

Pharmacological and mechanical methods can reduce the need for transfusion of allogeneic red blood cells and blood coagulation products. The foremost mechanical methods of perioperative conservation of red blood cells are intraoperative cell salvage and acute perioperative normovolaemic haemodilution. Intraoperative cell salvage is the most widely used method in elective cardiac surgery.⁸ Acute perioperative normovolaemic haemodilution is used in less than 20% of cardiac units.⁹ Both techniques have cost implications and have yet to become normal practice—perhaps due to the lack of data showing their effectiveness.^{10 11}

Methodological details of the trial and technical details of the intervention are presented on bmj.com.

Interpretation

Our results are consistent with other published work. A recent meta-analysis of cell salvage in cardiac and

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Blood products given to patients (n=84 in each group) during their perioperative course

Blood product received	Control	Intraoperative cell salvage	Combined treatment	Kruskal-Wallis
P value	Intraoperative cell salvage* v control		Combined treatment v intraoperative cell salvage*	
					Odds ratio (95% CI)	Wald test P value	Odds ratio (95% CI)	Wald test P value
Allogeneic blood:								
No of patients	43	26	29		0.43 (0.23 to 0.80)	0.008	1.18 (0.62 to 2.24)	0.622
Mean (SD) No of units received per patient	1.07 (1.56)	0.68 (1.55)	0.63 (1.22)	0.015				
Range	0-8	0-11	0-8					
Fresh frozen plasma:								
No of patients	13	14	13		1.1 (0.47 to 2.53)	0.831	0.91 (0.40 to 2.11)	0.831
Mean (SD) No of units received per patient	0.49 (1.25)	0.57 (1.47)	0.43 (1.12)	0.952				
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*Controlled for surgeon.

orthopaedic surgery found that in cardiac surgery cell salvage marginally reduced use of allogeneic blood products (relative risk 0.85, 95% confidence interval 0.79 to 0.92).¹⁰ However, none of the trials washed the salvaged blood before returning it to the patient, and the intraoperative cell salvage devices were used only postoperatively. Trials in which intraoperative cell salvage machines were used intraoperatively failed to meet standard eligibility criteria for the meta-analysis. Our method of intraoperative cell salvage maximised surgical salvage of red blood cells, and our washing of the residual cardiopulmonary bypass volume allowed optimal haemoconcentration, accounting for the greater efficacy of intraoperative cell salvage.

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Limitations

Just over half (43/84) the patients in the control group were given a transfusion—a considerably lower proportion than that reported for our institution in a previous study.⁴ We believe the main reason for this was that the transfusion threshold was reduced between the two studies from a haemoglobin concentration of 100 g/l to 90 g/l.

We had no protocol on the use of allogeneic blood coagulation products. Accordingly, caution is needed in interpreting differences between the groups in the use of fresh frozen plasma and platelets. Our trial involved patients undergoing elective coronary artery bypass grafting. Although intraoperative cell salvage may be useful in more complex cardiac surgery or for patients with pre-existing coagulopathy, our findings cannot necessarily be extrapolated to such patients.

Intraoperative masking of mechanical conservation technique was not possible. This might have led to transfusion practice being driven by knowledge of allocation to group. This effect would be pronounced if no transfusion protocol were used. Our finding of a decrease in the number of patients who received a transfusion of allogeneic red blood cells may be related to the haemoglobin concentration that is used as the transfusion threshold, the efficacy of intraoperative cell salvage, or transfusion practices. Because the intensive care staff were blinded to allocation to group and no protocol violations occurred we can assume that the reduction in allogeneic red blood cell transfusion is related to the efficacy of intraoperative cell salvage.

Implications

The need for allogeneic red blood cell transfusion in elective coronary artery bypass grafting can be reduced by using intraoperative cell salvage. Acute

What is already known on this topic

Patients undergoing elective coronary artery bypass surgery often need a blood transfusion

Recent meta-analyses have shown that the mechanical blood conservation techniques of intraoperative cell salvage and acute perioperative normovolaemic haemodilution may reduce the need for transfusion, but flawed methods in trials mean that clear evidence in cardiac surgery is lacking

What this study adds

Intraoperative cell salvage significantly reduces the number of patients needing an allogeneic blood transfusion

Combining acute perioperative normovolaemic haemodilution with intraoperative cell salvage does not confer any additional benefit

perioperative normovolaemic haemodilution with intraoperative cell salvage confers no additional benefit. We believe a transfusion rate of 31% of patients undergoing elective coronary artery bypass grafting is still unacceptable. The lower safe limit of haemoglobin concentration in patients undergoing cardiac surgery—either while they are on bypass or postoperatively—is unknown. If this limit was known, and made use of, the combination of optimal pharmacological strategies with intraoperative cell salvage could achieve yet further reductions in the numbers of patients who need to be given transfusions of allogeneic red blood cells and blood coagulation products.

Mr S Yates, manager of Haematology and Transfusion Laboratories, provided essential laboratory and transfusion support, without which this study could not have occurred. Dr D C Smith, consultant cardiac anaesthetist, reviewed the paper and made helpful comments.

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Competing interests: None declared.

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VERSION C

Mechanical blood conservation reduces blood transfusion in cardiac surgery

Neil McGill, Denise O'Shaughnessy, Ruth Pickering, Mike Herbertson, Ravi Gill

A randomised controlled trial from Southampton has shown that a mechanical method of blood conservation, intraoperative cell salvage, can reduce the need for blood transfusion during elective cardiac surgery.

Why carry out this study?

A randomised controlled trial was carried out to see if intraoperative cell salvage during elective cardiac surgery would decrease the need for allogeneic red blood cell transfusion, and whether a combination of both intraoperative cell salvage and acute perioperative normovolaemic haemodilution would reduce the need for transfusion even further.

Background

Each year 10% of available blood from the National Blood Service in England is used in cardiac surgery alone,^{1 2} and up to 92% of patients presenting for elective cardiac surgery receive blood.³ Patients who receive allogeneic blood (from a donor) risk contracting bloodborne or other infections or having a perioperative myocardial infarction.⁴⁻⁶ To minimise the risk of transmission of variant Creutzfeldt-Jakob disease all donated blood in this country now undergoes leucodepletion. This has quadrupled the cost of allogeneic red blood cells. The optimal use of this scarce, expensive, and potentially infectious resource is thus of national importance.

The most widely used methods for conserving red blood cells during elective cardiac surgery are intraoperative cell salvage⁷ [box 1] and, less commonly, acute perioperative normovolaemic haemodilution (box 2).⁸ While recent meta-analyses have shown that these techniques may reduce the need for transfusion during surgery, until now there has been no clear evidence for their specific use in cardiac surgery.^{9 10}

How was the study performed?

Patients were recruited in hospital on the day before elective coronary artery bypass surgery and randomised to one of three groups: either intra operative cell salvage, combined treatment (cell salvage plus haemodilution; see box 2), or a control group, in which the residual cardiopulmonary bypass circuit volume was transfused into the patient. There were 84 patients in each group. Intraoperative masking of the mechanical red blood cell salvage treatment was not possible.

Postoperatively, all patients were under the care of cardiac intensivists who were blind to the allocation of patients to each study group. The threshold for transfusion of allogeneic red blood cells was the same in all groups: haemoglobin concentration < 90 g/l and haematocrit < 0.27. Administration of allogeneic blood coagulation products (fresh frozen plasma and platelets) was at the discretion of the cardiac intensivists.

What were the main findings?

Intraoperative cell salvage significantly reduced the number of patients needing an allogeneic blood transfusion or blood coagulation products during the operation compared with patients who were operated

Box 1 Intraoperative cell salvage

Usually during surgery blood from the site of the operation is suctioned and discarded. In intraoperative cell salvage all shed blood is collected in a storage system and heparin is added to prevent clotting. At the end of cardiopulmonary bypass, blood remaining in the bypass circuit is added to that in the storage system. This fluid is then centrifuged to leave a solution of red blood cells with a haematocrit of 0.5-0.6. This solution of homologous blood is then transfused into the patient.

Box 2 Acute perioperative normovolaemic haemodilution

After the patient is anaesthetised blood is removed and replaced with an equivalent volume of colloid. The blood is anticoagulated during removal to prevent clotting. This blood has a haematocrit equal to that of the patient, usually 0.35-0.45. The blood is labelled and stored during the operation. After the termination of bypass the patient's haematocrit will usually be considerably lower than that of the stored blood. This blood is then transfused, so increasing the patient's haematocrit.

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on without any mechanical blood conservation. Patients in the combined treatment group did not experience any additional benefit.

Of those in the intraoperative cell salvage group, only 26 were given allogeneic red blood cells compared with 43 in the control group (odds ratio 0.43, 95% confidence interval 0.23 to 0.80; $P=0.008$). The mean number of units of allogeneic red blood cells transfused per patient was 0.68 and 1.07 units respectively. Thirty two patients in the intraoperative cell salvage group were given any blood product compared with 47 in the control group (odds ratio 0.47, 0.25 to 0.89; $P=0.019$).

Compared with intraoperative cell salvage the combined procedures showed no additional benefit in relation to the number of patients needing allogeneic red blood cell transfusion, the mean number of units of allogeneic red blood transfused per patient, or the number of patients given any allogeneic blood product.

Most patients were not given allogeneic blood, although nine patients needed three or more units. These patients were returned to the operating theatre for re-exploration of the mediastinum. A surgical cause of bleeding was found in seven of these patients (three in the control group and two each in the intraoperative cell salvage group and the combined treatment group).

The variations in haemoglobin concentration from before the operation to day 3 after the operation were similar in the three groups. No patient was given a transfusion of allogeneic blood after leaving the intensive care unit.

There were no differences between the groups in mediastinal drainage, time in intensive care, or length of stay in hospital. Patients in the combined treatment group spent the longest time in the anaesthetic room and the median duration of acute perioperative normovolaemic haemodilution was 13 minutes. Groups were similar with respect to total anaesthesia and length of surgery and time on cardiopulmonary bypass and with the aorta cross-clamped. Perioperative complications were evenly distributed across the groups (table).

Why are these results important?

Intraoperative cell salvage means fewer allogeneic red blood cell transfusions in elective coronary artery bypass grafting. Even further reductions could be achieved using a combination of pharmacological methods with intraoperative cell salvage, if the lower safe limit of haemoglobin concentration in patients undergoing cardiac surgery were known.

Numbers of patients with perioperative complications (n=84 in each group)

	Control	Intraoperative cell salvage	Combined treatment
Without complications	42	46	46
Inotropes required after 24 hours	9	12	11
Surgical bleeding	3	2	2
Cerebrovascular accident	2	1	1
Arrhythmias	27	17	20
Renal failure	0	1	2
Proved infection	7	11	7
Myocardial infarction	10	5	4

What is already known on this topic

Patients undergoing elective coronary artery bypass surgery often need a blood transfusion

Recent meta-analyses have shown that the mechanical blood conservation techniques of intraoperative cell salvage and acute perioperative normovolaemic haemodilution may reduce the need for transfusion, but flawed methods in trials mean that clear evidence in cardiac surgery is lacking

What this study adds

Intraoperative cell salvage significantly reduces the number of patients needing an allogeneic blood transfusion

Combining acute perioperative normovolaemic haemodilution with intraoperative cell salvage does not confer any additional benefit

The method of intraoperative cell salvage maximised surgical salvage of red blood cells, and washing of the residual cardiopulmonary bypass volume allowed optimal haemoconcentration. A recent meta-analysis of cell salvage in cardiac and orthopaedic surgery found that in cardiac surgery, cell salvage only marginally reduced use of allogeneic blood products.⁹ However, none of the trials washed the salvaged blood before returning it to the patient, the intraoperative cell salvage devices were used only postoperatively, and trials in which they were used intraoperatively failed to meet eligibility criteria for the meta-analysis.

Addition of acute perioperative normovolaemic haemodilution did not further reduce the need for allogeneic transfusion. This may be because not enough blood was removed at the start of the procedure. However, a predetermined volume of 10 ml/kg was not exceeded as removing a greater volume of blood preoperatively may expose patients to ischaemic events and decreased myocardial contractility.¹¹

Acute perioperative normovolaemic haemodilution is not well established in cardiac surgery. A meta-analysis of the treatment across surgical specialties concluded that it reduces the need for allogeneic red blood cells, but that the evidence in cardiac surgery was less compelling.¹⁰ However, the quality of the evidence from these trials varied, only four of the trials having a transfusion protocol. Overall the evidence for the benefit of acute perioperative normovolaemic haemodilution in reducing use of allogeneic red blood cells during cardiac surgery was equivocal.

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