ALL SURGERY PERFORMED on the heart or on the great vessels will inevitably lead to bleeding of varying magnitude. It is routine practice in cardiac surgery to use different methods to minimize blood loss or to recycle the blood, thereby reducing the volume discarded. The practice of cardiotomy suction was introduced early in cardiac surgery as a means of returning the blood collected in the surgical field to the cardio-pulmonary bypass circuit. Apart from this standard procedure, a multitude of pharmacologic, mechanical, and technical approaches exist to reduce blood loss. Despite these technologies, cardiotomy suction is still used in the majority of cases. However, several potentially negative effects have recently been attributed to retransfusion of shed blood by means of cardiotomy suction.

The obvious alternative to recycling the patient’s own blood is allogeneic blood transfusion. However, several reports have recently been published highlighting the adverse effects of allogeneic blood transfusion products. Four studies by Engoren et al,2 Kuduvalli et al,3 and Koch et al4,5 have shown that allogeneic blood transfusions negatively affect long-term survival after cardiac surgery. Engoren et al reported a 70% increase in 5-year mortality, after risk adjustment, for patients receiving allogeneic blood transfusions. Kuduvalli et al found a similar increase of 70% in mortality 1 year after surgery. In the studies by Koch et al, a similar and significant effect on survival was attributed to allogeneic transfusion of red blood cells.

Koch et al6 also studied the effects of blood products on the quality of life. They reported that transfusion of both red blood cells and platelets were strong predictors for adverse outcome in quality of life assessed by patients. In addition, red blood cell transfusion has been found be a risk factor for postoperative atrial fibrillation.

In addition to these long-term effects, transfusions are associated with several short-term risks. Spiess8 has compiled a list of 18 classic risks associated with transfusion, including virus transmission, allergic reactions, transfusion-associated lung inflammation (TRALI), and several others. Thus, there is mounting evidence suggesting that allogeneic transfusions during and after surgery should be reduced as far as possible. The most obvious source of nonallogeneic red blood cells is the pool of blood collected in suction devices and discarded, in swabs and sponges that are also discarded, or in cardiotomy reservoirs or other reservoirs for later retransfusion. In addition, hemodilution by rinse fluids affects the true measurements of blood loss. An overview of the blood loss can be obtained by dividing the cardiac surgical procedure into 3 stages. The first stage is defined as the start of the operation and represents the period before heparinization and cannulation. The second stage is the period during which the cardiac procedure is performed and is defined as the period when the patient is heparinized. The third stage is the end of surgery and is defined as the period after protamine administration.

Several techniques have recently been proposed for intraoperative cell salvage and washing. Traditional centrifugal-based techniques are widely used both in clinical practice and in scientific studies.9-14 Filter-based techniques aimed at reducing leukocytes or lipid particles also have been studied.15-17 Ultra-sonic standing-wave technology18-20 and sedimentation21,22 have been proposed as methods of removing lipid particles. These techniques have focused mainly on meeting 1 specific need for handling salvaged blood. The composition of shed mediastinal blood during surgery is complex; besides normal blood, it also contains several components not naturally found in circulating blood, such as activated proteins, lipid particles, and debris. In this review, an attempt was made to define the amount of shed blood lost in adult cardiac surgery. In addition, the review aimed at examining the scientific data supporting either a removal or recovery of these components based on the beneficial or detrimental effects they may have.

METHODS

An extensive and comprehensive body of literature was collected in the following way. A MedLine search was first performed with the following search terms: blood, cardiac surgery, cell saver, thrombocytes, blood salvage, and lipid emboli in different combinations. Articles not addressing intraoperative blood salvage in adult cardiac surgery were excluded, and the remaining relevant articles from this search and well-known review articles were read. Articles not focused on an endpoint relating to specific treatment or blood constituents were excluded. Next, relevant references were chosen from these articles, and these articles were reviewed. For articles of special interest, forward tracking was performed by using the Institute for Scientific Information Web of Science. If there was any uncertainty in the interpretation of the results, authors of the article were contacted. Grading of evidence strength was performed according to American College of Chest Physicians guidelines.

RESULTS

The results of the review were collected to provide information on the amount of blood lost during the various stages of surgery and the different components of shed blood and the scientific basis for removing or recovering these components.

Volume of Blood Lost

It is difficult to define a typical volume of blood loss during cardiac surgery because several factors affect both blood loss and methods of measuring blood loss. Normally, blood is collected in suction devices and discarded, in swabs and sponges that are also discarded, or in cardiotomy reservoirs or other reservoirs for later retransfusion. In addition, hemodilution by rinse fluids affects the true measurements of blood loss. An overview of the blood loss can be obtained by dividing the cardiac surgical procedure into 3 stages. The first stage is defined as the start of the operation and represents the period before heparinization and cannulation. The second stage is the period during which the cardiac procedure is performed and is defined as the period when the patient is heparinized. The third stage is the end of surgery and is defined as the period after protamine administration.

Table 1 presents the results of the overview of the articles regarding the amount of blood lost during surgery. For off-pump surgery, it was assumed that all blood loss during the entire procedure was collected and measured. The majority of studies concern coronary artery bypass graft procedures, on
pump and during heparinization (ie, the second stage) when blood is normally collected by cardiotomy suction. The mean volume ranges from 500 to 900 mL, and the mean hematocrit level ranges from 17% to 21%. Five studies have been reported in which the volume of collected blood was measured before and after this period (ie, stages 1 and 3). The mean range is between 300 and 500 mL. The most comprehensive study is that by Engstrom et al,24 who investigated a consecutive series of 2,469 patients and included all blood loss, including loss in swabs. They found a mean blood loss of 501 ± 596 mL (standard deviation). Their surprisingly high standard deviation was explained by the fact that they included all patients, some of whom had substantial bleeding, which will also yield a skewed distribution. From their study, it can be concluded that 65% of patients have a blood loss of less than 500 mL.

Only 1 study has addressed the issue of bleeding during valve surgery.25 Few patients were, however, reported, and they have included the blood loss at the start and conclusion of the operation together with the residual volume in the cardiopulmonary bypass circuit. In addition, they only reported the volume after processing. A mean volume of 410 mL after processing with a cell saver infers that the volume before processing was greater than 1,000 mL. Only 1 study has reported data from off-pump surgery, and the total volume lost during the entire procedure was reported to be 271 ± 144 mL.26

From these studies, it can be concluded that in routine procedures the volume of blood lost is normally around 700 mL during stage 2. However, no adjustments were made for heprinization of the operation. Niranjan et al26 and Hall et al27 reported that the average number of units of erythrocytes could be reduced by almost 1 unit. In the study by Tempe et al,25 the need for allogeneic blood was reduced by 3 units if compared to

**Table 1. Articles Reviewed**

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Patient Population</th>
<th>Volume (mL)</th>
<th>HCT (%)</th>
<th>Stage of Operation</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Westerberg et al</td>
<td>2006</td>
<td>CABG, on pump</td>
<td>13</td>
<td>477 ± 36</td>
<td>NA</td>
<td>2</td>
</tr>
<tr>
<td>Westerberg et al</td>
<td>2004</td>
<td>CABG, on pump</td>
<td>29</td>
<td>267 ± 37</td>
<td>NA</td>
<td>2</td>
</tr>
<tr>
<td>Svenmarker et al</td>
<td>2003</td>
<td>CABG, on pump</td>
<td>17</td>
<td>627 ± 83.2</td>
<td>20.2 ± 1.3</td>
<td>2</td>
</tr>
<tr>
<td>Appelblad et al</td>
<td>2006</td>
<td>CABG, on pump</td>
<td>20</td>
<td>418</td>
<td>~21</td>
<td>2</td>
</tr>
<tr>
<td>Engstrom et al</td>
<td>2003</td>
<td>CABG, on pump</td>
<td>10</td>
<td>NA</td>
<td>16.6 ± 1.0</td>
<td>2</td>
</tr>
<tr>
<td>Jönsson et al</td>
<td>1999</td>
<td>CABG, on pump</td>
<td>8</td>
<td>932 ± 406</td>
<td>NA</td>
<td>2</td>
</tr>
<tr>
<td>de Haan et al</td>
<td>1995</td>
<td>CABG, on pump</td>
<td>40</td>
<td>842 ± 110</td>
<td>NA</td>
<td>2</td>
</tr>
<tr>
<td>De Vries et al</td>
<td>2004</td>
<td>CABG, on pump</td>
<td>14</td>
<td>1,102 ± 152</td>
<td>19 ± 1.4</td>
<td>2</td>
</tr>
<tr>
<td>Ortalano et al</td>
<td>2002</td>
<td>CABG, on pump</td>
<td>27</td>
<td>918 ± 242</td>
<td>NA</td>
<td>2</td>
</tr>
<tr>
<td>Carrier et al</td>
<td>2006</td>
<td>CABG, on pump</td>
<td>20</td>
<td>753 ± 552</td>
<td>NA</td>
<td>2</td>
</tr>
<tr>
<td>Rubens et al</td>
<td>2007</td>
<td>CABG + valve, on pump</td>
<td>134/132</td>
<td>605/636</td>
<td>NA</td>
<td>2</td>
</tr>
<tr>
<td>Djaiani et al</td>
<td>2007</td>
<td>CABG</td>
<td>112</td>
<td>800</td>
<td>NA</td>
<td>2</td>
</tr>
<tr>
<td>Tempe et al</td>
<td>2001</td>
<td>Valve (all)</td>
<td>60</td>
<td>(410 ± 138)*</td>
<td>NA (assumed 20%)</td>
<td>1</td>
</tr>
<tr>
<td>Ikeda et al</td>
<td>1992</td>
<td>All with CPB</td>
<td>2,497</td>
<td>(321 ± 222)*</td>
<td>NA</td>
<td>1</td>
</tr>
<tr>
<td>Niranjan et al</td>
<td>2006</td>
<td>CABG, on pump</td>
<td>20</td>
<td>433 ± 155</td>
<td>NA</td>
<td>1</td>
</tr>
<tr>
<td>Winton et al</td>
<td>1981</td>
<td>CABG and valve</td>
<td>20</td>
<td>285 ± 95</td>
<td>NA</td>
<td>1</td>
</tr>
<tr>
<td>Engstrom et al</td>
<td>2002</td>
<td>CABG, on pump</td>
<td>2,469</td>
<td>501 ± 596</td>
<td>NA</td>
<td>1</td>
</tr>
<tr>
<td>Niranjan et al</td>
<td>2006</td>
<td>CABG, off pump</td>
<td>20</td>
<td>(271 ± 144)*</td>
<td>NA</td>
<td>1</td>
</tr>
</tbody>
</table>

Abbreviations: NA, not available; CABG, coronary artery bypass graft; CPB, cardiopulmonary bypass.

*The volume of blood before processing is not known. However, the volume after is known, and it was assumed that the ingoing hematocrit was 20%, and the outgoing hematocrit after cell washing was 60%.

†The residual volume of blood in the CPB circuit was also processed.
with a standard procedure group, but no reduction was observed if compared with an aprotinin control group.

**Leukocytes**

Systemic leukocyte reduction has been studied extensively during cardiac surgery, but few studies have addressed the issue in leukocyte reduction of shed blood collected during surgery. In a review article by Ortalano et al, it was pointed out that several authors had observed beneficial effects of systemic leukoreduction on several important endpoints. However, Ortalano et al also pointed out that others failed to corroborate these findings, and no beneficial effects of systemic leukoreduction were found. Another review concluded that leukocyte filtration makes a small improvement in lung function postoperatively, but no beneficial effects on other endpoints such as mortality or length of stay.

In a study specifically aimed at reducing leukocytes in salvaged shed blood, the authors found a decrease in pulmonary shunt fractions compared with the control group. They also found a tendency toward decreased pulmonary vascular resistance. These findings were corroborated by Ortalano et al, who also observed a lower pulmonary shunt fraction and lower pulmonary vascular resistance in the treated group than in the control group. It should, however, be noted that a Pall Leukokard filter (Pall Corp, East Hills, NY) was used in these studies, which also removes some of the lipid particles present in shed blood. Therefore, it cannot be concluded from these studies whether the observed beneficial effects were attributable to the depletion of leukocytes or lipid particles.

**Thrombocytes**

The need for sufficient, viable thrombocytes during and after cardiac surgery is obvious, and the pool in shed blood could constitute an essential contribution. However, data are scarce on the viability of thrombocytes in shed blood. Reents et al studied CD62 antigen as a measure of thrombocyte viability and found no increase in CD62+ thrombocytes, indicating viable thrombocytes. Boonstra et al have reported a decrease in thrombocyte function during surgery that could be attenuated by using an improved suction device for cardiotomy suction, but no beneficial effects on other endpoints such as mortality or length of stay.

In a study specifically aimed at reducing leukocytes in salvaged shed blood, the authors found a decrease in pulmonary shunt fractions compared with the control group. They also found a tendency toward decreased pulmonary vascular resistance. These findings were corroborated by Ortalano et al, who also observed a lower pulmonary shunt fraction and lower pulmonary vascular resistance in the treated group than in the control group. It should, however, be noted that a Pall Leukokard filter (Pall Corp, East Hills, NY) was used in these studies, which also removes some of the lipid particles present in shed blood. Therefore, it cannot be concluded from these studies whether the observed beneficial effects were attributable to the depletion of leukocytes or lipid particles.

**Natural Constituents of Plasma**

Little is known of the contributions of coagulation factors, fibrinogen, and other plasma proteins from the shed mediastinal blood to systemic coagulation and homeostasis. In a study performed by Boldt et al in which the residual blood in the cardiopulmonary bypass circuit was washed, they found that the postoperative blood loss increased by 60%. They processed all the residual blood, and from their study, it can be deduced that the volume was 2,000 mL. In addition, a recent study by Rubens et al in which a cell saver was used to wash shed blood during surgery, they found that the group who had their shed blood washed needed plasma transfusions twice as often as compared with the group in which cell saving was not used. This negative effect could be attributed to the removal of both thrombocytes and coagulation factors.

In a study by Svenmarker and Engstrom, no difference was found in postoperative blood loss in patients who had their shed blood washed compared with patients who had their shed blood retransfused without washing. In this study, a mean volume of 627 mL was processed. Therefore, it is likely that a small loss of plasma and thrombocytes in shed blood will not affect postoperative bleeding significantly.

**Reactive Constituents and Other Substances**

Removing plasma from shed blood and thereby removing most of the reactive proteins such as interleukin-1a (IL-1a), IL-2, IL-6, IL-8, tumor necrosis factor-alpha (TNF-alpha), myeloperoxidase, C3a, terminal complement complex, thrombin-antithrombin complex, tissue plasmin activator, thromboxanes, fibrin degradation products, free hemoglobin, and other inflammatory and complement factors has been studied by several authors. It has, for example, been shown that retransfusion increases systemic levels of IL-6 and TNF-alpha 2 to 3 times at most. Few studies have addressed the clinical effects of removing these reactive proteins. In a study by Westerberg et al, it was shown that retransfusion of unwashed blood led to a transient decrease in systemic vascular resistance, which lasted for a minute, and that this response could be reduced by removing these substances by cell washing. In a previous study, the same group found no difference in clinical outcome. In a study presented by Svenmarker et al, no significant changes in outcome were observed when the shed mediastinal blood was processed with a cell saver, thereby reducing the reactive proteins.

Among the substances not normally found in circulating blood, several may have a beneficial effect, such as anti-inflammatory proteins (eg, IL-10 and IL-1ra) and drugs administered to the patient. These substances constitute a group of nonnatural substances with a beneficial effect on the patient, and, thus, removal of these substances could have a negative effect. For instance, heparin has been shown to be almost completely eliminated by processing shed blood with a cell
saver. Thus, nonspecific removal of substances in plasma seems to have little or no effect on clinical parameters. If any, the effect will subside when the substance is cleared from the circulation, suggesting no effects on long-term outcome.

**Embolic Matter**

**Lipid Particles**

Several recent studies have described the presence of lipid microemboli (LME) in shed mediastinal blood. These lipid particles have been found to pass through the cardiopulmonary bypass circuit, forming emboli in different organs. Moody et al described small capillary arteriolar dilatations in histologic preparations in the capillary of the brain. These emboli also will find their way into most organs of the body; the kidneys seem to be highly affected.

Until recently, evidence that these emboli cause organ dysfunction has been lacking. However, 4 recent reports have linked LMEs to organ dysfunction. In a recent study by Djaiani et al., they reduced the incidence of postoperative neurocognitive decline from 15% to 6% by washing the shed mediastinal blood with a continuous cell saver. In addition, Whitaker et al. used a leukocyte-depleting arterial filter known to reduce the embolic load by half and found a tendency toward better neuropsychological outcomes. Although only a trend, it seems likely that a technology that reduces the embolic load has a small impact on neuropsychologic outcome. This study used an arterial filter that decreases both lipid emboli concentration and leukocyte concentration, and it is impossible to discern which of these effects is important. In another study, cell savers were used to reduce the embolic content in shed mediastinal blood, and the incidence of stroke was reduced by 50%. Carrier et al. described, in a similar study, the use of a cell saver that appeared to reduce the incidence of stroke. This was, however, not statistically significant. In a study that was similar in the design to the study of Djaiani et al., Rubens et al. found no difference in neuropsychologic outcome when they intervened with a cell saver. Given the fact that these emboli will end up in different organs and are not eliminated with time, the observations linking these to organ dysfunction should not be disregarded.

**Gaseous Emboli**

Gaseous emboli are a well-studied entity in cardiac surgery. They can be detected by transcranial Doppler and have been linked to different adverse outcomes. It is not known whether cardiotomy suction causes these emboli. It is possible that handling of the shed blood in suction devices will lead to cavitation phenomena that may induce bubbles. If gaseous emboli are formed in shed blood, they obviously should be removed.

**Other Debris**

Any blood collected from a surgical field will contain debris in different forms. Particulate matter such as cellular debris, fibrin clots, bone wax, and fibers from dressings will be found in the blood. Such debris can be identified in shed blood by scanning electron microscopy (Fig 1). No reports on the dangers of retransfusing this debris were found; however, it must be assumed that it will not have positive effects, but it most likely will have negative effects, and thus should be removed.

**CONCLUSION**

The question of cell salvage during cardiac surgery is still plagued by controversy. On the one hand, it may beneficial to recover several of the components of the shed blood; whereas, on the other hand, it may be better to remove other components. Regarding some components, such as erythrocytes and lipid particles, there is abundant evidence that they either belong in the patient or the waste bag. For other components, such as proteins in plasma, it is much more difficult to determine the best practice.

Many of the studies presented share a common weakness, which further obscures the best handling of shed blood. The studies are designed with 2 nonrandomized groups and the authors try to intervene at a specific endpoint, such as the removal of systemic inflammatory proteins. They then apply a method for doing so, often cell savers or filters. However, the technologies used are often nonspecific and alter the composition of the shed blood in more than 1 respect. Cell savers, for example, remove natural components of plasma as well as systemic inflammatory proteins and complement factors. In addition, they substantially reduce the number of thrombocytes, leukocytes, and lipid particles. Thus, intervention aimed at 1 specific parameter also will have secondary effects. Many filters used in other studies have a similar effect. For instance, lipid and leukocyte removal filters do not specifically remove either lipid particles or leukocytes but reduce the concentration of both. Therefore, the effect studied, for instance decreased postoperative bleeding, may not necessarily be because of the intended intervention, such as the removal of complement factors. The effects observed after an intervention are the results of a combination of effects of the technology applied in the intervention. A cell saver may, for instance, work to both worsen and improve the endpoint measured. For the sake of argument, effects of different components of blood have been attributed to the intended interventions in this review.
The strength of evidence has been graded. The appropriate management of shed mediastinal blood could have several potentially beneficial effects for the patient. It could reduce the need for allogeneic transfusions, thereby decreasing long-term mortality and improving quality of life. Another potentially beneficial effect would be a decrease in the number of neurologic complications. Several studies indicate that especially lipid particles play an important role in the pathologic process behind both adverse cognitive outcome and focal ischemic damage. In addition, it has been suggested that LME could even be involved in renal dysfunction after surgery.

Regrettably, this review cannot give unequivocal guidance on the management of shed blood during surgery nor can it recommend any specific technology for the processing of this shed blood. However, some guidance of best practice can be outlined in Table 2, but because no single technique fulfills the performance requirements to meet the criteria listed in this table, no technology can be recommended. Moreover, the documentation for the different techniques is diverse, and techniques are very seldom directly compared. Hopefully, further studies will help clinicians better understand how to handle shed mediastinal blood and which technology to use.

### Table 2. Components of Shed Blood and Basis for Recovery and Removal

<table>
<thead>
<tr>
<th>Recovery</th>
<th>Evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blood cells</td>
<td></td>
</tr>
<tr>
<td>Erythrocytes</td>
<td>1C</td>
</tr>
<tr>
<td>Leukocytes</td>
<td>None</td>
</tr>
<tr>
<td>Thrombocytes</td>
<td>2B</td>
</tr>
<tr>
<td>Particulate matter</td>
<td></td>
</tr>
<tr>
<td>Lipid particles</td>
<td>None</td>
</tr>
<tr>
<td>Debris</td>
<td>None</td>
</tr>
<tr>
<td>Plasma</td>
<td></td>
</tr>
<tr>
<td>Natural</td>
<td>2B</td>
</tr>
<tr>
<td>Reactive</td>
<td>None</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Removal</th>
<th>Evidence</th>
</tr>
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<tbody>
<tr>
<td>Blood cells</td>
<td></td>
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<tr>
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<tr>
<td>Particulate matter</td>
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<td>Plasma</td>
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<tr>
<td>Natural</td>
<td>None</td>
</tr>
<tr>
<td>Reactive</td>
<td>2B</td>
</tr>
</tbody>
</table>

NOTE. The different components of shed blood and the basis for removing or recovering them accordingly is based on the literature reviewed. The strength of evidence has been graded.

### REFERENCES


