Coagulopathy and blood component transfusion in trauma

D. R. Spahn1* and R. Rossaint2

1Department of Anaesthesiology, University Hospital Lausanne, Lausanne, Switzerland. 2Department of Anaesthesiology of the University Hospital, RWTH, Aachen, Germany

*Corresponding author: Department of Anaesthesiology, University Hospital Lausanne, CHUV, rue du Bugnon 46, CH-1011 Lausanne, Switzerland. E-mail: donat.spahn@chuv.hospvd.ch

Trauma is a serious global health problem, accounting for approximately one in 10 deaths worldwide.75 78 Trauma accounts for 5 million deaths per year, of which 1 million are in Europe.78 It is estimated that by 2010 the annual trauma-related mortality worldwide will increase to 8.4 million.74 Almost 50% of injury-related mortality is in young people between the ages of 15 and 44 yr.78 Hence, the burden to society due to loss of productivity is enormous, amounting to a total of 182 million disability-adjusted life years lost annually.78

Resuscitation of trauma patients has improved significantly over the years. However, uncontrolled bleeding remains a major challenge, accounting for around 40% of trauma-related deaths.46 47 91 and uncontrolled bleeding is the leading cause of potentially preventable and early in-hospital death.46 91 Hence, effective control of bleeding may decrease mortality.

Life-threatening bleeding in trauma patients is usually caused by a combination of vascular injury and coagulopathy. Injury to major vessels often requires surgical intervention, but arterial embolization can be a useful approach to bleeding control, even in patients with multiple trauma.35 76 Coagulopathy-related diffuse bleeding is difficult to manage. The causes of coagulopathy are multifactorial and interrelated, including consumption and dilution of coagulation factors and platelets, dysfunction of platelets and the coagulation system, increased fibrinolysis, compromise of the coagulation system by the infusion of colloid, hypocalcaemia, and disseminated intravascular coagulation-like syndrome.29 30 36 52 71 86 87 Coagulopathy in conjunction with hypothermia and acidosis is often referred to as the ‘lethal triad’ because of the high mortality.36 48 58

Resuscitation of trauma patients with critical bleeding involves the infusion of large volumes of crystalloid and colloid followed by red blood cell (RBC) transfusion. However, RBC concentrates contain negligible amounts of platelets and coagulation factors. As a result, RBC transfusion, while improving oxygen transport, does not correct depletion of coagulation factors and platelets and can result in coagulopathy. Current management for coagulopathy-related bleeding is mainly based on transfusion of fresh frozen plasma (FFP), platelets, coagulation factor concentrates.
Fig 1 Simplified diagram showing the key steps of the haemostasis process.
continuing bleeding causes further depletion of these haemostatic constituents from the circulation.

**Increased fibrinolysis**

Laboratory evidence has demonstrated both hypofibrinolytic and hyperfibrinolytic states in trauma patients.\(^23\)\(^24\)\(^87\) The fibrinolytic status of trauma patients will vary with the severity of injury and the time from injury to the assessment of fibrinolytic activity. Simmons and colleagues have shown that immediately following trauma fibrinolytic activity increases. It returns to normal after the first 24 h in patients with mild to moderate injury, but remains elevated in those with major injuries.\(^97\) In the presence of hypothermia, fibrinolytic activity is increased.\(^106\) However, it should be noted that studies showing increased fibrinolysis in trauma patients were mainly published before 1990. It is conceivable that advances in emergency care, changes in fluid resuscitation policy, and improved quality of blood components might produce different results if such studies were performed today.

**Hypothermia-induced coagulopathy**

In trauma patients without pre-existing disease or massive head injury, the following conditions have been identified as significant risk factors for life-threatening coagulopathy: injury severity score >25, systolic blood pressure <70 mmHg, acidosis with pH <7.10 and hypothermia with a body temperature <34°C.\(^16\) The interrelationship between hypothermia, metabolic acidosis and progressive coagulopathy is referred to as the 'lethal triad'; each factor exacerbates the others, leading to life-threatening bleeding or exsanguination (Fig. 3).\(^16\)\(^28\)\(^48\)\(^58\)\(^72\) The causes of hypothermia are multifactorial and interdependent, including altered central thermoregulation, decreased heat production due to tissue hypoperfusion in haemorrhagic shock, exposure to low ambient temperature, and infusion of inadequately warmed resuscitation fluids and blood components.\(^79\)

The coagulation process consists of multiple enzymatic reactions, which are temperature-dependent and function optimally at 37°C. The deleterious effect of hypothermia on coagulopathy in trauma patients has been well documented,\(^28\)\(^54\)\(^77\)\(^104\) and when occurring in conjunction with metabolic acidosis, can result in a mortality rate as high as 90%.\(^28\)\(^54\) The effect of hypothermia on coagulopathy is difficult to identify by routine coagulation screening tests, such as prothrombin time (PT) and activated partial thromboplastin time (aPTT), because these tests are routinely carried out at 37°C. Nevertheless, when PT and aPTT tests are carried out at low temperatures, as seen in hypothermic patients, both are significantly prolonged.\(^34\)\(^90\)\(^105\) In addition, both in vitro and in vivo studies have shown that hypothermia significantly impairs platelet function and the formation of a platelet plug\(^70\)\(^100\)\(^104\)\(^105\) and activates fibrinolysis.\(^106\)

In summary, hypothermia impairs thrombin generation\(^69\) and the formation of platelet plugs and fibrin clots, and at the same time increases clot lysis, resulting in coagulopathy and uncontrollable bleeding. Routine coagulation tests usually underestimate the degree of coagulopathy in a hypothermic patient and this should be taken into consideration when interpreting the results and correcting the coagulopathy.

---

**Table 1** The major causes of coagulopathy in trauma patients

<table>
<thead>
<tr>
<th>Cause</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blood loss</td>
</tr>
<tr>
<td>Consumption of platelets and coagulation factors</td>
</tr>
<tr>
<td>Dilution of coagulation factors and platelets</td>
</tr>
<tr>
<td>Increased fibrinolysis</td>
</tr>
<tr>
<td>Impaired functions of platelets and coagulation factors</td>
</tr>
<tr>
<td>Coagulation-compromising effect of colloids</td>
</tr>
<tr>
<td>Hypothermia</td>
</tr>
<tr>
<td>Hypocalcaemia</td>
</tr>
</tbody>
</table>

---

**Fig 2** The coagulation process. For explanation see text.
Decreased levels of coagulation factors and platelets

Infusion of large volumes of crystalloid and colloid during resuscitation reduces the concentrations of platelets and coagulation factors. In addition, thrombocytopenia is seen commonly in patients who have received massive blood transfusion, and has been thought to be a major cause of coagulopathy. Although platelets are present in whole blood, storage at 4°C severely damages them and the remaining platelets disappear from the circulation almost immediately after transfusion. In current practice, RBCs in additive solution rather than whole blood are widely used. Consequently, RBC units contain negligible amounts of coagulation factors and platelets, and thrombocytopenia and subnormal levels of coagulation factors often occur at an early stage during massive RBC transfusion.

The effect of acute RBC loss on coagulation

The specific effect of RBCs on coagulation is unclear. In vitro experiments have shown that RBC membranes contain the enzyme elastase, which can activate factor IX and may serve as a triggering mechanism for blood coagulation. In normal volunteers, an acute reduction in haematocrit results in reversible platelet dysfunction. In contrast, using thromboelastography, Iselin and colleagues have found that an isolated reduction in haematocrit does not compromise coagulation. As no data from trauma patients are available, the effect of acute RBC loss on coagulation in this group of patients is unknown.

Effect of massive RBC transfusion on coagulation

Blood transfusion in the past was largely dependent on the use of whole blood, whereas modern practice is based on the concept of specific component therapy. In developed countries, most whole blood units are separated within 18–24 h into RBCs, platelets and plasma, and, in some blood centres, cryoprecipitate is prepared after thawing FFP at 2–4°C. Blood component therapy optimizes the use of resources by allowing components to be used in different patients. It avoids the potentially harmful effects caused by the transfusion of surplus constituents. For example, transfusion of whole blood instead of RBCs in additive solution to an anaemic patient increases the risk of plasma-associated transfusion reactions such as TRALI (transfusion-related acute lung injury), which is related to the presence of antibodies to HLA or leucocytes in the donor’s plasma.

While specific component therapy provides both logistic and economic benefits, in massive RBC transfusion, coagulopathy due to low levels of platelets and clotting factors occurs at an earlier stage compared with the use of whole blood. A unit of whole blood contains approximately 200 ml of plasma with sufficient amounts of stable clotting factors, especially fibrinogen. In contrast, only a negligible amount of plasma—and therefore coagulation factors and platelets—remains in an RBC unit, and a plasma-free additive solution is added to the unit to provide nutrients and energy to RBCs, as well as pH buffering during storage. During the Vietnam war, when stored whole blood was used, it was found that the platelet count did not fall below \(100\times10^9\) litre\(^{-1}\) even after transfusion of 6 litres. Nowadays, in contrast, 85% of patients receiving at least 10 units of RBCs in additive solution develop thrombocytopenia.

The relationships between volume of blood loss, replacement volume and the reduction in coagulation factor and platelet levels are difficult to establish. This is due to several factors including the dynamics of blood loss, the difficulties in estimating true blood loss, the interindividual variations in clotting factor levels and the functionality of organ systems involved in haemostasis, i.e. the liver, spleen, and bone marrow. Martinowitz and colleagues found that in 36 patients with severe trauma, after massive RBC transfusion with a median of 21 units, the median fibrinogen level
was 1.5 g litre\(^{-1}\) (interquartile range 1.1–2.6 g litre\(^{-1}\)).\(^{66}\) A similar finding was reported by Hiippala and colleagues, who found fibrinogen levels <1.0 g litre\(^{-1}\) after replacement of approximately 1.5 blood volumes in 60 major surgery patients.\(^{42}\) However, McLoughlin and colleagues found that fibrinogen levels below 1.0 g litre\(^{-1}\) occurred after replacement of only 0.5 blood volume.\(^{68}\) Nevertheless, this study was carried out in eight patients who had unusually low baseline levels of fibrinogen (around 1.6 g litre\(^{-1}\)).

In principle, the timely measurement of haemostatic competence should provide guidance for the management of individual patients. Unfortunately, the commonly used tests, PT and aPTT, are global tests which were originally developed to monitor anticoagulant therapy and their predictive value in trauma or surgical settings has never been validated.\(^{21}\) Repeated measurement of fibrinogen concentration can help determine when fibrinogen replacement therapy is required in an individual patient. Thromboelastograph\(^{21}\) data provide a qualitative and dynamic assessment of coagulation process from clot formation to clot lysis and use of the Thromboelastograph\(^{21}\) may be useful in trauma patients.\(^{18}\)

The increased acid load from RBC units may also contribute to coagulopathy. The pH of an RBC unit is low, and decreases progressively during storage, due to the production of lactic acid by RBCs, from around 7.0 initially to around 6.3 at the end of its shelf-life.\(^{53}\) Because of the high buffering capacity of plasma in the circulation, transfusion of RBCs with such low pH does not usually cause acid–base disturbance. However, in the case of trauma patients who are already acidic, massive transfusion of RBCs further increases the acid load,\(^{7}\) which may in turn exacerbate the ongoing coagulopathy.

RBC transfusion is certainly life-saving in trauma patients with haemorrhagic shock. However, with the modern RBC components, which do not contain platelets and coagulation factors, coagulopathy occurs at an early stage during massive RBC transfusion.

Excess amounts of citrate anticoagulant are present in FFP. Trauma patients, particularly those with hypovolaemic shock or hypothermia, who have received large volumes of FFP may develop hypocalcaemia through citrate binding to circulating ionized calcium.\(^{3,19,81}\) Because ionized calcium is one of the essential elements in coagulation, hypocalcaemia may contribute to coagulopathy.

Unresolved issues regarding blood transfusion in trauma

Optimal replacement therapy for FFP and platelets

It is well recognized that patients receiving massive RBC transfusion should also be given FFP, platelets, fibrinogen concentrate or cryoprecipitate. However, there are no universally accepted guidelines for the replacement of these haemostatic components. Current recommendations are usually based on experts’ opinions or personal experience rather than evidence from randomized controlled trials.

Two different approaches to blood component replacement have been recommended and each has advantages and disadvantages. The first approach is to transfuse FFP and platelets prophylactically after a certain number of units of RBCs have been transfused.\(^{27,42}\) However, there is no consensus on the optimal ratios; these vary widely, ranging from 1:10 to 2:3 for FFP:RBCs and from 6:10 to 12:10 for platelets:RBCs.\(^{27,42,43}\) More importantly, there is no conclusive evidence that such a practice prevents the development of coagulopathy or improves bleeding.\(^{64,82}\) There is no apparent relationship between bleeding and the total volume of plasma transfused.\(^{82}\) The benefit of prophylactic platelet transfusion is also inconclusive, despite the fact that thrombocytopenia is commonly seen in patients who have received massive RBC transfusion.\(^{38,40,85}\) Many studies have shown that thrombocytopenia does not always correlate with abnormal bleeding.\(^{17,39,82}\) It is plausible that both platelet function and platelet count are fundamental for effective haemostasis.

The second approach is to transfuse FFP, platelets or cryoprecipitate only when there is clinical or laboratory evidence of coagulopathy.\(^{25,37,42,86,98}\) For instance, when there is microvascular bleeding, a PT or aPTT >1.5 times normal value, thrombocytopenia with a platelet count <50–100×10\(^3\) litre\(^{-1}\) or fibrinogen concentration <1 g litre\(^{-1}\) (Fig. 4).\(^{1,14,25,27,64}\) The guidelines for blood component therapy recommended by the American Society of Anesthesiology Task Force on Blood Component Therapy are summarized in Table 2.\(^{1}\) This approach also has its shortcomings. Clinical evidence of coagulopathy such as microvascular bleeding at an occult site can be difficult to
This approach poses major logistic problems. Fusion has been proposed as means of overcoming coagulation factor deficiency. The use of ‘fresh’ (24 h old) unrefrigerated whole blood will not correct massive transfusion-related coagulopathy and is a rather impractical option. Moreover, the use of fresh whole blood would preclude adequate screening testing, which would dramatically decrease the safety of blood transfusion.

Clearly, the current practice of component replacement therapy in trauma patients with life-threatening bleeding is not ideal. Evidence from randomized controlled trials for a conclusive, optimal strategy is still lacking. Nevertheless, it may not be feasible to carry out such trials for ethical and logistic reasons. There is a limit on what can be achieved by blood component replacement therapy in trauma patients with uncontrollable bleeding.

### Effect of RBC transfusion on longer-term outcome in trauma

Over the years, the risk of transfusion-transmitted infections caused by known pathogens, such as hepatitis B, hepatitis C and human immunodeficiency virus (HIV), has been significantly decreased. However, there remains a residual risk of infection caused by these pathogens. There is increasing concern over infection caused by emerging pathogens, such as the agent of variant Creutzfeldt–Jacob disease (vCJD), hepatitis G virus, and West Nile virus. In addition, blood transfusion is associated with a number of acute and delayed non-infectious complications (Table 3).3

<table>
<thead>
<tr>
<th>Coagulation parameter</th>
<th>Recommended therapy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prothrombin time &gt;1.5 times normal</td>
<td>Fresh frozen plasma, prothrombin complex concentrate</td>
</tr>
<tr>
<td>Activated partial thromboplastin time &gt;1.5 times normal</td>
<td>Fresh frozen plasma</td>
</tr>
<tr>
<td>Fibrinogen &lt;1.0 g litre⁻¹</td>
<td>Fibrinogen concentrate, cryoprecipitate</td>
</tr>
<tr>
<td>Platelets &lt;50 × 10⁹ litre⁻¹</td>
<td>Platelets</td>
</tr>
</tbody>
</table>

### Multiple organ failure

Multiple organ failure is a serious post-injury complication resulting in prolonged intensive care unit (ICU) stay, requirement for mechanical ventilation for a longer period, and high mortality. Once MOF has developed, the mortality rate can be as high as 36%. RBC transfusion has been shown to be an independent risk factor for post-injury MOF and there is a strong dose–response relationship between early RBC transfusion and the development of MOF. Analysis of a database consisting of 513 patients with major trauma, severe bleeding and haemorrhagic shock indicated that patients who developed MOF received an average of 13 units of RBCs in the first 12 h after injury compared with 3.8 units in patients who did not develop MOF. Moreover, the age of transfused RBC has been shown to be an independent risk factor for post-injury MOF. A decrease in the volume of RBCs transfused may decrease the risk and severity of MOF.

The precise mechanism of RBC transfusion-related MOF is yet to be established. Nevertheless, recent evidence supports the hypothesis that, during storage, bioreactive lipids, which have polymorphonuclear cell priming activity, are generated from RBCs. While the initial insult caused by tissue damage and hypoxia primes the inflammatory system,
Subsequent transfusion of stored RBCs containing these bioreactive lipids activates a systemic inflammatory response resulting in MOF.\textsuperscript{73}

**Post-injury infection**

Infection is a common complication in trauma patients. RBC transfusion has been shown to be an independent risk factor for the development of post-injury infection,\textsuperscript{15,22} and several mechanisms have been proposed. The exposure of patients to large amounts of foreign antigens may lead to down-regulation of the immune system.\textsuperscript{101} The presence of leucocytes in RBC units has been thought to be a major contributory factor to the immunosuppressive effect of allogeneic blood transfusion.\textsuperscript{9,10} Nevertheless, results from clinical trials are inconclusive as to whether leucodepletion eliminates the immunosuppressive effect of allogeneic blood.\textsuperscript{80,101} An alternative non-immune-mediated mechanism of post-injury infection has been proposed. Stored RBCs are less deformable and more rigid, and once transfused they may obstruct capillary blood flow, predisposing tissue to ischaemia and infection as well as poor delivery of prophylactic antibiotics.\textsuperscript{63,80,101}

A prospective observational study by Claridge and colleagues\textsuperscript{15} revealed that the infection rate in trauma patients receiving at least one unit of RBCs during the first 48 h of hospital admission was significantly higher than that in the patients receiving none (33.0 vs 7.6%, \textit{P}<0.0001), and there was a strong dose-dependent correlation between the amount transfused and the development of infection. However, the odds ratio of RBC transfusion as a risk factor for the development of post-injury infection was only 1.084 (95% confidence interval 1.028–1.142, \textit{P}=0.0028).

In a prospective observational study, Malone and colleagues\textsuperscript{62} analysed data from 15534 trauma patients, of whom 1703 received RBC transfusion with a mean of 6.8±6.7 units. The results showed that, after controlling for severity of shock, RBC transfusion within the first 24 h was associated with increased mortality, admission to the ICU and lengths of ICU and hospital stays, which may be related to an increased risk of nosocomial infection. Nonetheless, there was no supportive evidence for a cause–effect relationship.

The development of infection might be associated with the length of storage of transfused RBCs. Based on 269 patients undergoing coronary artery bypass graft surgery, Vamvakas and Carven\textsuperscript{102} found that the risk of post-operative pneumonia increased by 1% per day of increase in the mean storage time of the transfused RBC. In addition, a similar finding was observed by Leal-Noval and colleagues,\textsuperscript{57} who conducted a study in 897 patients undergoing cardiac surgery. The results showed that each day of storage of the oldest unit increased the risk of pneumonia by 6% and transfusion of RBC units that were stored for \textit{>28} days could be a risk factor for nosocomial pneumonia.

It is noteworthy that studies on the effect of RBC transfusion on post-injury infection are mainly observational studies and should be interpreted with caution. Such studies cannot clearly define whether RBC transfusion causes post-injury complications or whether trauma patients who require RBC transfusion have had more severe illnesses, and, therefore, are more likely to develop complications. Only randomized prospective trials will provide a definitive answer. However, conducting such trials in severe trauma patients is extremely difficult, if not impossible, as exemplified by Schulman and colleagues.\textsuperscript{93,94} They conducted a randomized prospective trial to establish the effect of varying age of RBCs on clinical outcome in trauma patients. Patients were only to be randomized if there were at least 15 units of ‘young’ (<11 days old) and 15 units of ‘old’ (>20 days old) type-specific leucodepleted RBCs available at the time. Despite 8000 injuries being evaluated, of which 3600 were severe, only 24 patients could be randomized and included in the trial, due to the limitation of blood bank inventory. On average, patients included in the trial received 10 units of RBCs. There were no statistically significant differences in post-injury complications between the two groups, which could be due, at least partly, to the limited number of patients studied. However, it is also possible that not only the age of RBCs, but also other factors, contribute to transfusion-associated post-injury infection.

RBC units have a limited shelf-life of around 42 days. Blood banks usually issue the oldest units of RBCs to avoid wastage from expired units. It may seem logical to suggest that fresher RBC units be used for resuscitation of trauma patients with massive blood loss. However, this approach might not be practical in terms of inventory management. A more practical strategy would be to attempt to reduce the amount of RBCs transfused. A prospective randomized controlled trial in critically ill trauma patients (Transfusion Requirements in Critical Care Trial, TRICC) has shown that a restrictive RBC transfusion strategy (haemoglobin concentration 70 g litre\textsuperscript{−1}) appears to be safe.\textsuperscript{41,67}

**The need for haemostatic agents**

Despite significant improvements in resuscitation of trauma patients with haemorrhagic shock, coagulopathy-related bleeding remains a major challenge. The mainstay of
Conclusions

Over recent years, the resuscitation of trauma patients with haemorrhagic shock has improved progressively. Nevertheless, non-surgically correctable bleeding remains a major challenge. Currently, blood component replacement therapy remains the mainstay of coagulopathy-related bleeding. In certain cases, this might fail to control the bleeding resulting in exsanguination. Although RBC transfusion can be life-saving, its negative effects on post-injury outcome have been well documented. Haemostatic agents, which can effectively control bleeding and reduce the amount of RBCs required, may decrease mortality and morbidity in trauma patients but are unlikely to replace blood transfusion completely.

Acknowledgement

We thank Pranee Krailadsiri of Novo Nordisk Health Care, Switzerland, for her assistance in the preparation of the manuscript.

References


Coagulopathy and blood component transfusion in trauma

case of haemostatic treatments that reduce RBC transfusion required in such a setting, might be life-saving, and the use of haemostatic treatments that can be restored by replacement therapy. In some cases, even adequate replacement fails to control the life-threatening bleeding resulting in exsanguination. Alternative haemostatic treatments, which are efficacious in such a setting, might be life-saving, and the use of haemostatic treatments that can be restored by replacement therapy. In certain cases, this might fail to control the bleeding resulting in exsanguination. Although RBC transfusion can be life-saving, its negative effects on post-injury outcome have been well documented. Haemostatic agents, which can effectively control bleeding and reduce the amount of RBCs required, may decrease mortality and morbidity in trauma patients but are unlikely to replace blood transfusion completely.

Conclusions

Over recent years, the resuscitation of trauma patients with haemorrhagic shock has improved progressively. Nevertheless, non-surgically correctable bleeding remains a major challenge. Currently, blood component replacement therapy remains the mainstay of coagulopathy-related bleeding. In certain cases, this might fail to control the bleeding resulting in exsanguination. Although RBC transfusion can be life-saving, its negative effects on post-injury outcome have been well documented. Haemostatic agents, which can effectively control bleeding and reduce the amount of RBCs required, may decrease mortality and morbidity in trauma patients but are unlikely to replace blood transfusion completely.

Acknowledgement

We thank Pranee Krailadsiri of Novo Nordisk Health Care, Switzerland, for her assistance in the preparation of the manuscript.

References

37 Hardy JF, Samama M. Massive transfusion and coagulopathy. TATM 2003; 4: 199–210
47 Hoyt DB. A clinical review of bleeding dilemmas in trauma. Semin Hematol 2004; 41: 40–9
56 Lawson JH, Murphy MP. Challenges for providing effective hemostasis in surgery and trauma. Semin Hematol 2004; 41: 55–64
60 MacLeod J, Lynn M, McKenney MG, Jeroukhimov I, Cohn SM. Predictors of mortality in trauma patients. Am Surg 2004; 70: 805–10


Sauaia A, Moore FA, Moore EE, et al. Multiple organ failure can be predicted as early as 12 h after injury. J Trauma 1998; 45: 291–301


Vamvakas EC, Blachman MA. Delerious clinical effects of transfusion-associated immunomodulation: fact or fiction? Blood 2001; 97: 1180–95

Vamvakas EC, Carven JH. Transfusion and postoperative pneumonia in coronary artery bypass graft surgery: effect of the length of storage of transfused red cells. Transfusion 1999; 39: 701–10


