

Review of fluid resuscitation and massive transfusion protocols from a military perspective

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Abstract

The approach to resuscitation of wounded patients with major haemorrhage has changed dramatically in the last ten years, in part due to recent military experience. The United States military has formulated 'Tactical Combat Casualty Care' guidelines for pre- and early- hospital management, adapting clinical evidence to the military environment. With the exception of fluid management advice, these guidelines are equally applicable to the Australian Defence Force. Emphasis on rapid control of bleeding, with surgery forming part of resuscitation rather than an activity that follows attempts at stabilisation, while sound, challenges traditional clinical and organisational teaching. However, the indications, type, route of administration and endpoints of fluid resuscitation, particularly in the early hospital period, warrant further examination. This review of available evidence makes recommendations in these areas as a stimulus for debate, and ultimately policy development, within the Australian Defence Force.

Introduction

The primary treatment of major haemorrhage is to stop the bleeding. Useful measures include arterial tourniquets, pressure dressings with or without impregnated haemostatic agents, and early damage control surgery. No study has ever found that pre-hospital time spent administering fluid to patients with major haemorrhage is of any benefit. On the contrary, studies convincingly demonstrate either no benefit¹ or harm.^{2,3} Moreover, analysis of timing of deaths and vital signs on admission to hospital suggests that fluid resuscitation of any sort might only benefit less than 2% of wounded patients.^{1,4} Therefore, while there is extensive debate over fluid resuscitation in military trauma, this minimally relevant to the vast majority of patients. Nonetheless, recommendations on fluid resuscitation are frequently sought, and it is incumbent on military physicians to provide the best advice possible.

In this review, we assess current evidence guiding four essential questions (optimal indications, route of administration, type of fluid, and endpoints) related to fluid resuscitation in military

trauma, along with incorporation of fluid resuscitation into the overarching 'damage control resuscitation' concept. We also analyse the recommendations of the US Tactical Combat Casualty Care (TCCC) programme, which provides guidance on these matters for the US military. Our analysis states neither current Australian Defence Force (ADF) policy nor the consensus of Defence Health practitioners, but is presented to stimulate debate to better inform the care of wounded ADF members.

Tactical Combat Casualty Care

The United States military developed the Tactical Combat Casualty Care (TCCC) project to guide battlefield trauma care in 1996, with many revisions of the original guidelines.(5;6) The essence of TCCC is to recognise appropriate trauma care on the battlefield is shaped by the tactical environment. The principles of TCCC are completion of the mission, prevention of further casualties, and lastly the treatment of the casualty.

With respect to major haemorrhage, the initial goal of TCCC treatment is to *obtain haemostasis*. A second critical concept is that prior to definitive control of the haemorrhage, any elevation of the blood pressure leads to *more rapid bleeding* and exsanguination. Fluid resuscitation is only recommended for a systolic blood pressure of <80-85 mmHg, a falling blood pressure, or reduced consciousness without evidence of head injury.(4) In practice, this is *simplified* to only giving fluid resuscitation if the patient is unconscious or does not have a palpable radial pulse. Hetastarch 6% in a balanced salt solution (Hextend; Hospira Pty Ltd, Lake Forest IL, USA), not available in Australia, is the recommended resuscitation fluid for prehospital care. Hetastarch is a carbohydrate molecule into which hydroxyethyl groups have been substituted for some of the glucose molecules. It is distinguished from other substituted starches used for fluid resuscitation, such as Pentastarch, by its average molecular weight and the degree of molar substitution. Hextend is given as a 500ml bolus, repeated once if indicated by level of consciousness or absence of a radial pulse. An intraosseous needle is recommended if an 18 gauge intravenous cannula is not easily inserted.

Hypothermia is prevented using a chemical heating blanket and a heat reflective shell. Early evacuation from the battlefield and early damage control surgery is prioritised. TCCC reflects evidence for limited, if any, prehospital fluid administration, and expert opinion on the demands of the prehospital tactical environment. With the exception of choice of fluid, discussed below, we assess the guidelines a synthesis of current best practice in prehospital haemorrhage control and fluid resuscitation.

Indications for fluid resuscitation

The goal of fluid resuscitation is to allow sufficient circulating blood volume to deliver oxygen and energy substrates to the cells essential to life, and to remove their products of metabolism. Mechanisms exist to divert circulating blood volume to cells that need it most. For example, renal perfusion is reduced as cardiac output falls, but renal cells suffer little in this process, with less than 1% of trauma patients requiring renal replacement, mostly as a component of late multi-organ failure.(7) Early restoration of a normal circulating blood

volume in major haemorrhage is therefore not required. Furthermore, attempts to do this appear harmful. Replacing each litre of blood lost with three litres of crystalloid makes sense from the relative sizes of the intra- and extravascular fluid compartments,(8) but leads to substantial dilution of the blood constituents, fluid overload with interstitial oedema and the acute respiratory distress syndrome, or 'Da Nang Lung' (named after the town in which many US and allied casualties received treatment during the Vietnam war).(4)

The concept of providing the least possible fluid resuscitation to preserve perfusion to heart, lung and brain has become known as '*hypotensive resuscitation*', as blood pressure measurement is easier than measuring flow to those organs. The benefit of hypotensive resuscitation was first convincingly demonstrated by Bickell et al.(2) in a quasi-randomised controlled trial comparing immediate and delayed fluid resuscitation in 598 adults with penetrating torso injuries. Hospital survival was higher in the delayed resuscitation group (70% vs 62% p=0.04). Patients in the immediate resuscitation group had longer total hospital stays, and there was a non-significant trend towards more complications. The explanation for the differences observed was not empirically explored, but the authors and others hypothesised that restoration of a more 'normal' blood pressure dislodges any clot that may have formed and dilutes coagulation factors, precipitating further haemorrhage.(4) Supporting this, a trend towards more intraoperative blood loss was observed in the immediate resuscitation group. This study brought hypotensive resuscitation into mainstream medical practice.

The study by Bickell et al.(2) is open to a number of criticisms. An alternate day selection method rather than true randomisation was used. This introduced a risk of unmeasured confounding variables – such as one surgical team tending to look after one group more than the other. The authors argued that alternate day allocation was required to avoid delays in initiation of therapy. It is unclear whether the results can be extrapolated to include blunt trauma or pressure injuries from blast. Penetrating trauma is more likely to involve large vessels, in which higher pressure might cause ongoing bleeding, whereas capillary bleeding in blunt trauma may be less affected.

Jackson et al.(9) reviewed hypotensive resuscitation in three groups: penetrating, blunt and head injury. This review included animal as well as human studies, finding the Bickell study(2) the only human study from which conclusions could be drawn. Animal studies consistently showed that excessive crystalloid resuscitation increases the circulating volume and systolic blood pressure, but also increases or restarts bleeding. The evidence supporting hypotensive resuscitation in blunt trauma and head injury is very limited. Thus there is physiological theory (regarding clot disruption and dilutional coagulopathy), evidence from these animal studies, but only one large clinical trial supporting this approach. In the hospital environment, with access to tests of coagulation, lactate, and cardiac output monitoring, the appropriate threshold for fluid resuscitation in trauma patients has never been adequately studied.

Recommendation: Surgical control of bleeding should not be delayed to allow fluid resuscitation.

Route of fluid administration

Rapid circulatory access in trauma cases may be required for fluid resuscitation, analgesia, antibiotics and induction of anaesthesia. Despite the arguments listed in favour of limited fluid resuscitation prior to haemorrhage control, the Early Management of Severe Trauma course (derived from the Advanced Trauma Life Support course(10)) recommends the insertion of large-bore parenteral access devices to allow rapid fluid administration. As discussed, this approach is likely to be more valuable *after* haemorrhage is controlled. Peripheral cannulation is frequently difficult in hypovolaemic shock due to peripheral venous shutdown. Limbs injured by combat wounds, combined with environmental and tactical conditions, may make traditional forearm sites for peripheral venous cannulation unsuitable. Similarly, large 14 gauge cannulae may be impossible to insert. TCCC recognises this, recommending instead 18 gauge cannulae as a compromise between maximal flow rates and ease of insertion.

Once in hospital, better options for large bore intravenous access may be available. A conventional triple-lumen central venous catheter usually has one 16 gauge and two 18 gauge lumens, but the flow that can be achieved is substantially limited by the extra resistance imposed by the 15-20 cm length. The typical internal diameter of a pulmonary artery catheter sheath (figure 1) is 8.5 French, or 2.8mm, which allows flows of 400-800ml/min. An even better option is a temporary dialysis catheter (figure 2), which has two lumens of typically 13.5 French (4.5mm) each. Less likely to kink, flow rates in excess of 1L/min can be achieved without excessive driving pressures.

Central venous access can, however, take time and skill. A better immediate approach is the intraosseous (IO) route (figure 3). Leidel et al.(11) compared success rates and procedure times of IO vs. central venous catheter (CVC) access in adult patients undergoing fluid resuscitation. Success rate on first attempt was 90% for IO versus 60% for CVC insertion, with less time required to obtain IO access (2.3 ± 0.8 min vs. 9.9 min ± 3.7). The IO route is effective in the military environment. Cooper et al.(12) reported a military case series of 16 adults and 10 children in whom 97% of IO needles, including those inserted in-flight (helicopter), functioned effectively. Flow rates through intraosseous needles are determined by the insertion site and whether or not a pressure bag is used. Flows range from 68 to 204 ml/min in the tibial position, (not driven and driven by a pressure bag) and 82-148 ml/min in the humerus,(13) both of which are substantially inferior to that through large-bore central venous access. However, all drugs given IV can be given IO,(14) and it is possible to crossmatch blood and to obtain samples for standard laboratory investigations through the IO route.(15) The technique appears to be safe with few complications if aseptic conditions can be maintained and prolonged infusion times and multiple insertion attempts into the same bone are avoided. The largest case series (of 4270 cases) reported an incidence of osteomyelitis of 0.6%.(16) Therefore, the greatest utility of IO access is in situations when peripheral IV access is impossible, to facilitate administration of drugs and the minimal volumes of fluid recommended prior to control of bleeding, as a bridge to a large volume infusion line.

Recommendation: Emergency prehospital vascular access may be readily achieved by an intraosseous needle when an

intravenous cannula is not possible, if intravenous fluid therapy is indicated. In hospital, large bore central venous access lines should be available and considered for use.

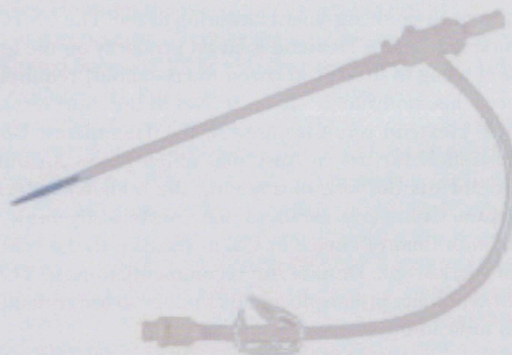


Figure 1 Pulmonary artery catheter sheath. 8.5 French allows flow rates of 400-800 ml/min.

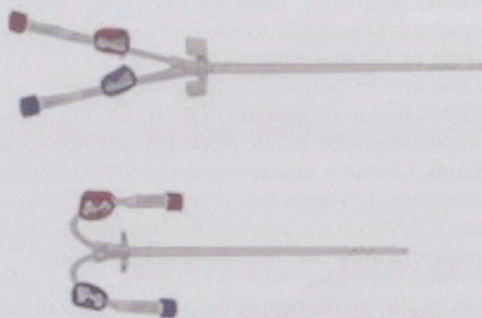


Figure 2 Temporary haemodialysis catheter (Vas-Cath). Two 13.5 French lumens each allow flow rates of >500 ml/min

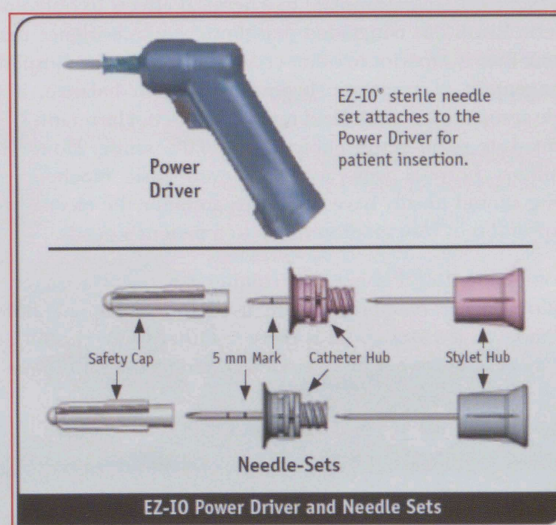


Figure 3 The EZ-IO intraosseous needle insertion device. The 15 gauge needle allows flows of up to 200 ml/min, depending on location

Type of resuscitation fluid

No intravenous fluid used for the resuscitation of patients in haemorrhagic shock has ever been found to produce superior patient-centred outcomes when compared to any other fluid. Each of the available alternatives has at least one theoretical and laboratory end-point argument favouring its use. The US TCCC recommendation for Hextend is based primarily on the lower weight of a bag of fluid (compared to crystalloid) required to produce a haemodynamic effect, at least in the short term.(4) However, Hextend is not licensed by the Therapeutic Goods Administration for use in Australia, which leaves Australian military doctors the task of assessing the available evidence themselves. Crystalloid solutions have historically been the resuscitation fluid of choice in US, in contrast to the colloids used in the Europe. Despite the recommendations of TCCC, half of US military prehospital medics prefer to use crystalloids for this indication.(4)

Crystalloids

Large volumes of 0.9% ('normal') saline produce a hyperchloraemic metabolic acidosis, as noted by Schreiber(17) in his recent review. This may be associated with systemic vasodilation, increased extravascular lung water, and coagulopathy. The most commonly used alternatives, Hartmann's or lactated Ringer's solutions, replace some of the chloride of 0.9% saline with lactate. In the setting of large volume resuscitation of haemorrhagic shock, this can result in transiently increased lactate levels that are not associated with acidosis. Lactate is rapidly converted to bicarbonate by a functioning liver. If hepatic function is impaired, Plasma-Lyte 148 (Baxter, NSW, Australia), which contains gluconate and acetate rather than lactate, may avoid this problem.

Mahler et al.(18) performed a double blinded randomised controlled trial comparing metabolic acidosis in the resuscitation of 52 patients with diabetic ketoacidosis with either normal saline or Plasma-Lyte. Resuscitation with Plasma-Lyte resulted in lower serum chloride and higher bicarbonate levels. McFarlane et al.(19) found similar results in patients following hepatobiliary and pancreatic surgery. However, it may be unwise to extrapolate biochemical effects to outcome benefit. Rizoli(20) concluded that there was no evidence that Plasma-Lyte is superior to other crystalloids for the prehospital management of traumatic hypovolaemia. On balance, if a single resuscitation crystalloid must be chosen, Hartmann's or Plasma-Lyte seem better choices than 0.9% saline. However, a military hospital with access to even basic biochemical testing should ideally have the ability to tailor the electrolyte composition of resuscitation fluids to a patient's needs.

Recommendation: Plasma-Lyte (higher cost) or Hartmann's solution (lower cost) should be used for immediate fluid resuscitation if a crystalloid is chosen. Other fluids should be available for use in hospital, guided by biochemical analysis.

Colloids

In Australian practice, the choice of colloid is between Haemaccel (polygeline)(AFT Pharmaceuticals, NSW), Gelofusine (B.Braun, NSW), Albumin (CSL Bioplasma, VIC), and Voluven (hydroxyethyl starch) (Fresenius Kabi, NSW). Notably, while both Hextend and Voluven are hydroxyethyl

starches, their molecular structures are different, which may lead to different adverse effect profiles.

Ogilvie et al.(21) examined the safety and efficacy of Hextend at a Level I trauma centre, with particular focus on the risk of coagulopathy. Over a six month period Hextend was made available for all non-burn patients. At the discretion of the admitting surgeon, 500-1,000 mL of Hextend was administered during initial fluid resuscitation. Initial resuscitation with Hextend was associated with reduced mortality and no obvious coagulopathy. This was the first trial of Hextend in haemodynamically unstable trauma patients and the largest trial to date in any population of surgical patients, but the impact of the findings is diminished because the treatments were not randomised or blinded. Allison et al.(22) studied 45 patients with blunt abdominal trauma randomised to receive either hydroxyethyl starch (Pentaspán, not available in Australia) or Gelofusine in the first 24 hours following hospital admission. Patients in the hydroxyethyl starch group showed fewer instances of posttraumatic capillary leak. There is therefore limited evidence to show that hydroxyethyl starches may be safe and may cause less peripheral oedema than Gelofusine (and by extrapolation, Haemaccel). A recent review by Ogilvie et al.(23) recommended that a randomised, blinded, and adequately powered trial, especially in severely injured penetrating trauma patients, is necessary before these data can be accepted with confidence.

The main risk of gelatins is anaphylaxis, and of starches is renal impairment. A database study of nearly 20 000 patients found the risk of anaphylaxis was 6 times higher for gelatins compared to starch.(24) However, a systematic review of 34 studies involving 2607 patients by Dart et al.(25) found a relative risk of 1.5 for acute kidney injury in patients who had received hydroxyethyl starch when compared with other fluid therapies. There was a relative risk of 1.38 requiring renal replacement therapy. Limited recent studies report third-generation hydroxyethyl starches are safer,(26) but this question is currently the subject of an 8000-patient randomised controlled trial of Voluven vs. 0.9% saline in Australia and New Zealand (the Crystalloid versus HydroxyEthyl Starch (CHEST) study(27)). Recommendations with respect to Voluven, and starches in general, made prior to the results of this trial would be premature.

Recommendation: There is currently insufficient evidence to recommend one colloid over another.

Crystalloids vs. Colloids

The Australasian 6997-patient Saline versus Albumin Fluid Evaluation (SAFE) Study(28) found no difference in 28 day mortality in ICU patients requiring fluid resuscitation randomised to receive either 4% albumin or normal saline. On subgroup analysis there was a strong trend towards increased mortality in the subset of trauma patients with traumatic brain injury receiving albumin,(29) which the authors hypothesised might have been due to exacerbation of vasogenic or cytotoxic cerebral oedema. The SAFE study is the largest ever comparison of crystalloids and colloids for fluid resuscitation. However, only a minority of patients were in haemorrhagic shock at the time of this infusion. Additionally, the findings may be specific to albumin and not extrapolate to gelatins or starches. A Cochrane review(30) of 63 eligible

trials concluded there was no evidence that resuscitation with colloids reduces the risk of death, compared to resuscitation with crystalloids. Similarly, a review by Grocott et al.(31) of the available clinical outcome data found no evidence for relative advantage of crystalloid and colloid fluid therapy, or between the different types of colloid.

The lack of clear evidence demonstrating superiority of crystalloids or colloids leads to a number of conclusions. First, that if there is a difference in outcome, it is unlikely to be large when the therapy is applied to a heterogeneous population. Whether a more targeted approach would allow better outcomes with particular therapies in particular patients remains in question. Second, if logistical considerations are paramount, the possible requirement for less fluid for a similar haemodynamic effect (based both on physiological understanding and also the results of the SAFE study) suggest colloids may be the better choice. However, the logistical concerns around the extra weight of crystalloid may be overstated, as reflected by the continued use of crystalloid by US medics despite TCCC recommendations.(4)

Recommendation: Colloids should not be used for fluid resuscitation unless minimisation of weight carried is an overriding consideration. The weight advantage of colloids is probably overstated.

Hypertonic solutions

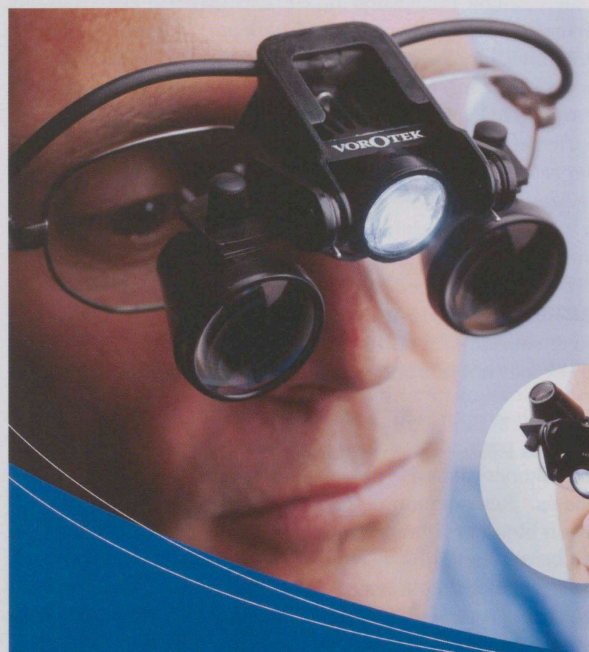
Hypertonic solutions theoretically have a greater ability (per volume infused) to expand blood volume, by recruiting

extracellular fluid into the circulation. Smaller volumes should be required over shorter time periods. The ability to achieve the same effect with less fluid led the US TCCC committee to recommend a 250ml bolus of 7.5% hypertonic saline (in addition to 500ml of Hextend), essentially for reasons of speed and logistics. However, the recommendation was not adopted,(4) at least in part because this fluid was not commercially available in the United States.(32) The effectiveness of hypertonic solutions was explored by Bunn et al.(33) in their review of 14 trials involving 956 participants. Clinical heterogeneity made a pooled meta-analysis inappropriate. However, studies identified in this systematic review did not clearly demonstrate any outcome advantage with hypertonic crystalloid. Hypertonic saline was thought to hold particular advantage for patients with traumatic brain injury, with the hypothesis that brain oedema might be lessened. The definitive study of this concept was performed in 229 patients Melbourne,(34) which found no improvement in neurological function detected at the six month follow up period when compared with conventional fluid resuscitation.

Recommendation: Hypertonic solutions should not be used for fluid resuscitation.

Oxygen-carrying blood substitutes and other experimental fluids

A blood substitute is a synthetic solution that carries oxygen and include substances based on haemoglobin (surface-modified haemoglobin, intramolecular cross-linked haemoglobin and



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polymerised haemoglobin) or perfluorocarbon. There is mixed data on the efficacy and safety of these substitutes. (36;36) Australian experience is limited to case reports, such as that of a Jehovah's Witness requiring transfusion but refusing blood products. (37) 'Pharmacological' resuscitative fluids designed to protect and reduce ischemia-reperfusion are currently being developed. Pyruvate, Na^+/H^+ exchange (NHE) inhibitors, valproic acid, dihydroepiandrosterone (DHEA) (38) and adenosine/lignocaine/hypertonic saline (39) are amongst in the novel agents currently under investigation. However all of these experimental approaches are not licensed for use in Australia and as such beyond the scope of this review.

Recommendation: Blood substitute solutions should not be used outside of experimental protocols

Blood products

The most appropriate resuscitation fluid for massive blood loss is *whole blood*. This simple and obvious statement was appreciated in the 1960s, (4) when there were few alternatives, but fell from popularity when blood suppliers began to separate blood into components in an effort to maximise the use of a limited supply. Until recently, conventional teaching was to give 4 litres of non-blood product resuscitation before considering red cell transfusion, (40) and only after coagulopathy was objectively demonstrated to consider replacement of coagulation factors and platelets. (41) Not surprisingly, this resulted in marked coagulopathy that was difficult to reverse.

Fluid resuscitation in major haemorrhage was revolutionised after the publication of an observational study from a US combat hospital in Iraq. (42) This retrospective cohort study identified 246 patients who had received a massive transfusion (≥ 10 units of red cells in 24 hours). Participants were placed into three groups based on the ratio of plasma to packed red blood cells that they had received: low ratio (1:8 ratio of plasma to packed red blood cells); medium ratio (1:2.5) and high ratio (1:1.4). The higher ratio patients had a significantly lower mortality (65%, 34%, and 19% for low, medium and high ratio groups ($p < 0.001$)) and this effect persisted after adjustment for relevant confounders. Death occurred sooner in the low and medium ratio groups than in the higher ratio group (2,4 and 38 hours respectively). However, as with all observational studies, associations are not proof of causality. The larger number of deaths in the low ratio groups might be due to them receiving less plasma. However, another possible explanation is that, by dying earlier, patients were less likely to have had time to receive plasma. Nonetheless, the findings have been replicated in a study of 467 patients in 16 US civilian trauma centres (43) and in 2746 patients in a single US trauma centre. (44) Given the strength of the association, its replication in other settings, and its biological plausibility, it is now likely there would be insufficient equipoise to perform a randomised controlled trial. The challenge is therefore to identify early patients who will require a massive transfusion, and commence high-ratio plasma (and platelet): packed red cell resuscitation as soon as possible. Minimal volumes of non-blood fluids administered prior to hospital, as recommended in TCCC, facilitate this strategy.

On the basis of observational cohort studies, the age of packed red cells has recently been suggested to influence

patient outcomes. (45) For example, in a cohort of 1813 trauma patients, of patients who received at least six units of packed red cells, the duration for which units had been stored was an independent predictor of higher mortality. (46) The mechanism for this may be lower 2,3 DPG levels, reduced nitric oxide production, increased cell rigidity, transfer of oxygen from recipient to donor red cells, (47) or some other yet to be appreciated factor. However, in the absence of randomised controlled trial evidence, it is not possible to be certain of this hypothesis. The effect of age of transfused red cells is currently the subject of a research programme of the Australian and New Zealand Intensive Care Society Clinical Trials Group.

Recommendation: Patients with massive haemorrhage (expected to require more than 10 units of packed red cells) should receive minimal non-blood resuscitation and early red cells, plasma and platelets (or whole blood) as part of a damage control resuscitation strategy (see below). Non-blood fluid should only be given to maintain consciousness or a palpable radial pulse, as in the TCCC recommendations. Where the likely degree of haemorrhage is less obvious the merits of blood vs. non-blood transfusion are at present less clear. The best strategy may be a combination of titration to laboratory values combined with a bias to early use of blood components in response to ongoing bleeding.

Resuscitation endpoints

As with all pharmacological interventions, achieving the correct 'dose' of fluid resuscitation is likely to be just as important as selecting the optimal resuscitation fluid. This concept is increasingly recognised in elective surgery. For example, Nisanevich et al. (48) compared patients undergoing elective abdominal surgery randomly assigned to receive either liberal (bolus of 10 ml/kg followed by 12 ml/kg/hr) or restrictive (4 ml/kg/hr) volumes of fluid. Complications were fewer in the restrictive group ($p = 0.046$). Patients in the liberal group had a later return of bowel function, and their postoperative hospital stay was longer. Systematic review of similar studies has been limited by highly variable definitions of 'restrictive' and 'liberal' fluid resuscitation strategies, (49) and the question has not yet been subjected to meta-regression analysis. There have been no equivalent studies in trauma patients, who commonly having had a substantial period of pre-resuscitation hypoperfusion, may or may not respond differently to elective surgery patients.

Rather than approach 'resuscitation dose' as a one-size-fits-all question, trauma resuscitation in particular may benefit from fluid volumes tailored to physiological derangements of individual patients. Resuscitation performed in hospital does not have to rely on blood pressure alone as a surrogate for adequacy of the circulation. Eighty-five percent of severely injured patients still have a metabolic acidosis after their blood pressure is normalised. (50) Arterial lactate (50) and urine output are better indices of organ perfusion. Gan et al. (51) studied goal directed fluid management in 100 patients who were to undergo major elective surgery. Patients were randomly assigned to standard care or intraoperative plasma volume expansion guided by cardiac output (measured by oesophageal Doppler), with the goal of maintaining maximal stroke volume. Goal-directed intraoperative fluid administration resulted in earlier return to bowel function, lower incidence of postoperative nausea and vomiting, and decrease in length of postoperative hospital stay. Similarly,

thromboelastography (TEG) has been advocated to allow goal-directed management of coagulopathy in trauma patients.(52) Near infra-red spectroscopy measurement of tissue oxygen saturation is a feasible and theoretically attractive measure of tissue perfusion(53) that clearly identifies patients in severe traumatic shock,(54) but is yet to be subjected to a randomised controlled trial with patient-centred outcomes. Similar promise, awaiting definitive evidence, is held for buccal capnometry,(55) sublingual capillary sidestream dark field imaging(56) and muscle oxygen measurement.(57) Theoretically the most appealing approach is direct imaging of inferior vena cava diameter, myocardial filling and contractility using transthoracic or transoesophageal echocardiography.(58-60) Many of the monitors required to assess these resuscitation endpoints are robust, simple to use, and so amenable to deployment in military hospitals.

Damage Control Surgery and Resuscitation

Discussion of modern fluid resuscitation would be incomplete without mention of damage control resuscitation and surgery. Damage control resuscitation emphasises that surgery forms part of resuscitation, rather than existing as a separate event after the patient is 'resuscitated'. An exsanguinating patient is taken directly to an operating theatre, where monitors are inserted and fluid resuscitation commenced at the same time as the surgical team stops the bleeding. This approach challenges both traditional clinical and organisational thinking. Clinicians were traditionally taught a patient had to be 'resuscitated' before proceeding to the operating theatre. Health planners, particularly in the military, designed systems that took patients to small, non-surgical 'resuscitation' facilities for stabilisation prior to movement to a surgical hospital.

Recommendation: The concept of non-surgical resuscitation of major trauma is outdated and should be abandoned by clinicians and planners alike.

Summary and recommendations

On the basis of the evidence presented, for the fluid resuscitation of ADF trauma patients we recommend:

1. **Battlefield strategy.** The principles of Tactical Combat Casualty Care, including emphasis on haemorrhage control and rapid evacuation for operative management of haemorrhage, are valid. The recommendation for Hextend is currently not appropriate in the Australian context. Hartmann's solution or Plasma-Lyte should be given in 500ml aliquots solely to maintain palpable radial pulse and mentation.
2. **Hospital resuscitation strategy.** Damage control surgery should be performed without delay. A high ratio of plasma with packed red blood cells should be used in the initial resuscitation of patients with anticipated massive (≥ 10 units) haemorrhage. Where crystalloid resuscitation is required, Plasma-Lyte or Hartmann's solution are most likely to be appropriate.
3. **Operative and postoperative fluid management.** Goal directed fluid management should be used when possible, including measurement of clinical (such as urine output), biochemical (such as lactate) and haemodynamic (such as cardiac output) indices.

Conflict of interest statement

Captain Naren and Colonel Royse declare that they have no competing interests in relation to the material in this paper. Lieutenant Colonel Reade is an investigator in the Australian and New Zealand Intensive Care Society Clinical Trials Group trial of Voluven vs. saline (CHEST), but has received no personal or grant support from Fresenius Kabi, the manufacturer of Voluven.

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