Whole blood transfusion versus component therapy in adult trauma patients with acute major haemorrhage

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ABSTRACT

Objective In the era of damage control resuscitation of trauma patients with acute major haemorrhage, transfusion practice has evolved to blood component (component therapy) administered in a ratio that closely approximates whole blood (WB). However, there is a paucity of evidence supporting the optimal transfusion strategy in these patients. The primary objective was therefore to establish if there is an improvement in survival at 30 days with the use of WB transfusion compared with blood component therapy in adult trauma patients with acute major haemorrhage.

Methodology A systematic literature search was performed on 15 December 2019 to identify studies comparing WB transfusion with component therapy in adult trauma patients and mortality at 30 days. Studies which did not report mortality were excluded. Methodological quality of included studies was interpreted using the Cochrane risk of bias tool, and rated using the Grading of Recommendations Assessment, Development and Evaluation approach.

Results Search of the databases identified 1885 records, and six studies met the inclusion criteria involving 3255 patients. Of the three studies reporting 30-day mortality (one randomised controlled trial (moderate evidence) and two retrospective (low and very low evidence, respectively)), only one study demonstrated a statistically significant difference between WB and component therapy, and two found no statistical difference. Two retrospective studies reporting in-hospital mortality found no statistical difference in unadjusted mortality, but both reported statistically significant logistic regression analyses demonstrating that those with a WB transfusion strategy were less likely to die.

Conclusion Recognising the limitations of this systematic review relating to the poor-quality evidence and limited number of included trials, it does not provide evidence to support or reject use of WB transfusion compared with component therapy for adult trauma patients with acute major haemorrhage.

PROSPERO registration number CRD42019131406.

BACKGROUND

Death from traumatic injury is a leading cause of life-years lost worldwide. In 2010, there were more deaths from injuries (5.1 million) than HIV-AIDS, tuberculosis and malaria combined (3.8 million). Around 40% of trauma deaths result from uncontrolled haemorrhage with the majority of patients dying within the first 24 hours after injury.

Blood banks were pioneered during the World War I and fresh whole blood (WB) was the preferred product for resuscitating trauma patients in haemorrhagic shock. WB can be transfused fresh within 24 hours of donation, or cold-stored for up to 35 days depending on the additive solution. In military settings, fresh WB remained the preferred product for resuscitating trauma patients with acute major haemorrhage.

Blood component therapy has become the predominant transfusion approach in middle-income and high-income countries as the extension of shelf-life provided a more manageable approach for blood services. This change in transfusion strategy occurred without evidence to compare the efficacy and risks of WB compared with component therapy in patients with acute major haemorrhage. Leucoreduction techniques have since been developed with improved clinical outcomes in non-haemolytic transfusion reactions, disease transmission and HLA alloimmunisation.
Over the last 10 years, damage control resuscitation principles have gained wide acceptance in civilian practice for trauma patients with acute major bleeding, based on prevention and correction of trauma-induced coagulopathy and rapid haemorrhage control. Evidence suggests that trauma-induced coagulopathy is a multifactorial failure of coagulation due to endogenous acute traumatic coagulopathy and dilutional resuscitation-induced coagulopathy.

The damage control resuscitation approach promotes early transfusion of red blood cells, plasma and platelets in a 1:1:1 ratio, rapid surgical control of ongoing bleeding and prevention of acidosis and hypothermia. Hypotensive resuscitation is advocated until bleeding control is achieved. Of note, patients with traumatic brain injury (TBI) are not generally resuscitated with permissive hypotension as they require a higher mean arterial pressure to maintain cerebral perfusion. Damage control resuscitation efforts are focused on minimising the impact of trauma-induced coagulopathy by limiting the use of crystalloid and transfusing blood component in a ratio that closely approximates WB. The United States Tactical Combat Casualty Care guidelines published in 2017 and 2018 advocate the use of WB transfusion. WB contains the individual component in a smaller transfusion volume with increased haematocrit and fibrinogen, reducing the total non-haemostatic, non-oxygen-carrying fluid transfused into a trauma patient. Theoretically, use of WB may correct acute traumatic coagulopathy more efficiently than component therapy due to the simultaneous infusion of platelets and plasma with the red cells, which when administered together may reduce mortality and transfusion requirements.

Despite changes in transfusion practice in trauma patients, there is a paucity of evidence to guide the optimal transfusion strategy for blood component in trauma. Recent military experience suggests that WB may be the optimum transfusion strategy; however, no systematic review has been conducted to date.

**METHODOLOGY**

We performed a systematic review of studies comparing WB with component therapy in adult trauma patients with acute major haemorrhage. Our primary outcome was survival at 30 days. Secondary outcomes were in-hospital mortality, 24 hours mortality, total volume of transfusion, morbidity including acute respiratory distress syndrome (ARDS), acute kidney injury (AKI), multiple organ dysfunction syndrome (MODS), embolic events and transfusion reactions.

This systematic review was carried out in accordance with the Preferred Reporting Items for Meta-Analyses (PRISMA) guidelines.

Electronic database searching was carried out in line with PRISMA guidelines. PubMed, Web of Science, Cochrane, OVID, Embase and the Transfusion Evidence Library were searched independently by two reviewers (PA and SM) using MESH terms combined with the Boolean operator ‘AND’ (Box 1). The search dates start from the inception of the databases to the search date (15th December 2019). Non-English language papers, abstracts and other non-published data were excluded; abstracts and non-published data were excluded to ensure the included literature had been peer-reviewed.

Titles and abstracts were uploaded to EndNote X7, duplicates were removed and relevant titles were selected by two independent reviewers (PA and SM). Where indicated, full-text papers were reviewed for inclusion or exclusion based on clear criteria (table 1). Reference lists were screened for relevant titles.

Authors of three included studies were contacted to clarify the time point of recorded ‘mortality’ and to request missing data, but no replies were received. For studies deemed relevant by abstract, the full-text report was retrieved and examined further for compliance with the inclusion criteria. There were no relevant unpublished materials or conference abstracts excluded because they lacked a full report, and no disagreements between the two independent reviewers about the inclusion of studies.

Records of each database search were kept, the date, total number of hits, number of duplicates removed, number excluded based on title, number excluded based on abstract and full text for each reviewer. All titles were stored on EndNote X7.

The two reviewers (PA and SM) extracted data independently into Excel. Extracted information included: authors, year, title, country, study design, study setting, time period, number of participants, study population, primary outcome measure, secondary outcome measures, inclusion and exclusion criteria, details of WB transfusion, details of component therapy, mortality at 30 day or in-hospital, mortality at 24 hours (if reported), TBI (if reported) and study conclusions. Information collected for risk of bias assessment for individual study methodology and reporting included: participant selection, participant and allocation concealment, handling of incomplete outcome data and outcome reporting.

Following data extraction, percentage of 30-day or in-hospital mortality was presented. Results from each study were defined as statistically significant if the p value was <0.05. Due to the diversity between the included study populations and interventions, pooling of outcome data for meta-analysis was not performed. Findings are presented narratively.

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**Box 1**

**Electronic database search terms combined with Boolean operator ‘AND’**

**Terms for whole blood**

blood OR blood transfusion OR whole blood OR whole blood transfusion OR blood banks OR blood bank OR blood*

**Terms for component therapy**

blood component transfusion OR component therapy OR blood transfusion OR platelets OR plasma OR red blood cells OR red cells OR erythrocyte transfusion OR packed cell OR simple cell

**Terms for haemorrhagic shock**

exsanguination OR acute haemorrhage OR acute bleeding OR haemorrhagic shock OR haemorrhage OR acute major haemorrhage OR code red

**Terms for adult**

adult

**Terms for trauma patients**

trauma OR polytrauma OR blunt trauma OR penetrating trauma OR wounds OR injuries

**Terms for types of trials**

retrospective OR prospective OR randomised OR randomised controlled OR observational OR cohort studies OR RCT OR randomised*

**Terms for outcomes**

morbidity OR mortality OR multiorgan failure OR organ failure OR sepsis OR transfusion reaction OR adult respiratory distress syndrome OR myocardial infarction OR pulmonary embolus OR renal failure OR volume transfusion OR ARDS OR PE OR MI OR AKI OR acute kidney injury OR acute renal failure OR outcome OR outcomes OR thrombotic events OR immunological reactions
The Grading of Recommendations Assessment, Development and Evaluation (GRADE) approach was used as a systematic method to rate the reliability of evidence from each included study.27 As part of this, limitations of included study designs and execution were assessed using the Cochrane risk of bias tool.28 Heterogeneity between included studies, indirectness and imprecision were assessed. Quality appraisal was carried out by both reviewers (PA and SM) independently. There were no disagreements between the reviewers regarding the risk of bias and GRADE rating.

RESULTS
A summary of the literature search is shown in figure 1. We screened 1551 records after duplicates were removed, and 1477 were excluded by title. Sixty-five records were excluded by abstract and nine full texts were assessed for eligibility. Three full-text articles were excluded as two were review articles, and one did not compare WB with component therapy. A total of six studies, involving 3255 patients, met the inclusion criteria. No ongoing studies or unpublished abstracts were identified at the time of search (15th December 2019).

Included studies
Setting
Three studies were military based in Afghanistan and Iraq involving combat casualties (total n=1211).26 29 30 The other three studies were conducted in the USA with civilian patients (total n=2044).8 25 31 One civilian study included patients aged 15–91 years in their component therapy group.8 All other included patients were aged ≥16 years.

Interventions
The studies incorporated a wide range of transfusion strategies. Each study looked at a transfusion approach involving WB and compared this with component therapy. There was considerable variation in the definition of WB transfusion and component. For example, Cotton et al defined their WB transfusion as leucoreduced, modified WB with the addition of apheresis platelets for every six units.31 Another study defined the WB group as receiving non-leucoreduced, warm fresh WB with red blood cells and plasma.30

Trial design
Two out of the six included studies were prospective: one prospective randomised trial,31 and the other prospective with historical controls.8 The other four studies were retrospective analyses.25 26 29 30

All six studies reported mortality, four as a primary outcome measure25 26 29 30 and two as a secondary outcome measure.8 31 Thirty-day and 24 hours mortality was reported in three studies,29–31 with two others reporting in-hospital mortality,8 25 26 and one reporting mortality with no further detail.8

Three studies reported rates of ARDS,29–31 two reported rates of AKI10 31 two reported rates of MODS29 31 and two reported rates of embolic events.29 30 Transfusion volumes are reported by four studies.8 26 30 31 Three studies reported transfusion reactions.8 26 31

Risk of bias and quality appraisal
Risk of bias interpretation is displayed in table 2. A summary of author judgement is presented in figure 2.

Selection bias was present in all six included studies. Four of these were retrospective with selection bias inherent in design. Selection bias was also present in the prospective, randomised trial resulted due to the lack of an objective scoring system to randomise patients.31 Most studies reported efforts to minimise attrition bias. Only one paper reported significant incomplete outcome data which may bias the result (if the unknown outcomes were poorer in one group), and limits the power to detect a statistical difference.29 Due to important differences between studies in terms of populations, interventions, designs and outcome measures, we did not pool the data for meta-analysis.

Effects of interventions
Primary outcome
Thirty-day mortality is the primary outcome of this systematic review, and three studies reported these data (n=830). Two
### Table 2  Quality of evidence: GRADE rating with Cochrane risk of bias interpretation

<table>
<thead>
<tr>
<th>Study</th>
<th>Design</th>
<th>Initial GRADE</th>
<th>Risk of bias interpretation</th>
<th>GRADE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotton et al</td>
<td>Prospective, randomised trial</td>
<td>High</td>
<td>High*</td>
<td>Moderate ⌂ ⌂ ⌂</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>◄ Selection bias: no objective scoring system to randomise patients.</td>
<td>Serious limitations, downgrade one level.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>◄ Performance bias: due to inadequate concealment of allocations.</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>◄ Detection bias: due to knowledge of the allocated interventions by outcome assessors.</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>◄ Study and clinical personnel unblinded to treatment group.</td>
<td></td>
</tr>
<tr>
<td>Jones and Frazier</td>
<td>Retrospective</td>
<td>Low</td>
<td>High*</td>
<td>Very low ⌂</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>◄ Selection bias: retrospective study.</td>
<td>Serious limitations, down grade one level.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>◄ Reporting bias: due to selective outcome reporting.</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>◄ WB not further qualified.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>◄ Number of products transfused not reported.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>◄ FFP not included.</td>
<td></td>
</tr>
<tr>
<td>Nessen et al</td>
<td>Retrospective analysis of prospectively collected dataset</td>
<td>Low</td>
<td>Unclear†</td>
<td>Low ⌂ ⌂</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>◄ Selection bias: retrospective convenience sample of those teams that had collected data introducing sampling bias.</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>◄ Survival bias: minimised by eliminating patients who died in first hour.</td>
<td></td>
</tr>
<tr>
<td>Perkins et al</td>
<td>Retrospective review</td>
<td>Low</td>
<td>High*</td>
<td>Very low ⌂</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>◄ Selection bias: retrospective study.</td>
<td>Serious limitations, downgrade one level.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>◄ Attrition bias: due to amount of incomplete outcome data, huge loss to follow-up.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>◄ Survival bias.</td>
<td></td>
</tr>
<tr>
<td>Spinella et al</td>
<td>Retrospective</td>
<td>Low</td>
<td>Unclear†</td>
<td>Low ⌂ ⌂</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>◄ Selection bias: retrospective study.</td>
<td>Serious limitations, do not downgrade.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>◄ Survival bias.</td>
<td></td>
</tr>
<tr>
<td>Yazer et al</td>
<td>Prospective, historical controls</td>
<td>Low</td>
<td>High*</td>
<td>Very low ⌂</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>◄ Selection bias: groups produced not directly comparable, significance difference in median age of patients, biased allocation to intervention.</td>
<td>Serious limitations, downgrade one level.</td>
</tr>
</tbody>
</table>

*High: plausible bias that seriously weakens confidence in the results. Crucial limitation for one criterion, or some limitations for multiple criteria, sufficient to lower confidence in the estimate of effect.
†Unclear: plausible bias that raises some doubt about the results.
GRADE, Grading of Recommendations Assessment, Development and Evaluation.

Figure 2  Summary of author judgement—risk of bias.

In-hospital mortality

Two retrospective studies (grade of evidence very low and low) reported in-hospital mortality and found no statistical difference in unadjusted mortality between groups (n=2233).25 26 However, logistic regression analyses of these studies found a statistically lower likelihood of death in patients receiving WB transfusion strategy and blood component therapy.29 31 The third study, a retrospective study by Spinella et al (grade of evidence low) found a statistically significant difference in 30-day mortality between WB transfusion and component therapy (5% vs 18% respectively, p=0.002) (table 3).30

Secondary outcomes

24 hours mortality

Three studies reported 24 hours mortality (n=830). Two studies found no statistically significant difference in 24 hours mortality between WB transfusion strategy and blood component therapy.29 31; the grade of evidence for these studies was very low.
<table>
<thead>
<tr>
<th>Study</th>
<th>Number of participants</th>
<th>Inclusion criteria</th>
<th>Outcome measures</th>
<th>Whole blood</th>
<th>Component therapy</th>
<th>Results</th>
<th>Quality of the evidence (GRADE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotton et al</td>
<td>107</td>
<td>&gt;18 years of age, highest level trauma activation, active bleeding requiring uncross matched blood.</td>
<td>Primary: 24 hours blood product use. Secondary: 24 hours mortality, 30-day mortality, length of stay, transfusion-associated complications, infections.</td>
<td>mWB (leucoreduced)+aPLT for every 6 units</td>
<td>RBC+plasma+aPLT for every 6 units</td>
<td>No statistical difference in 30-day mortality 22% mWB vs 14% BCT (p=0.26). No statistical difference in 24 hours mortality 11% mWB vs 10% BCT (p=0.83). No statistical difference in 24 hours component use (p=0.462). No other statistical differences between groups in ARDS, AKI, MODS.</td>
<td>Moderate ⊡ ⊡ ⊡</td>
</tr>
<tr>
<td>Perkins et al</td>
<td>369</td>
<td>Trauma patients who required ≥10 units of blood component transfused within first 24 hours and did not receive both FWB and aPLT.</td>
<td>Primary: survival at 24 hours and 30 days. Secondary: rates of ARDS, MODS, infection, embolic events.</td>
<td>FWB (non-leucoreduced)+RBC+FFP+cryo</td>
<td>aPLT+RBC+FFP+cryo</td>
<td>No statistical difference in 30-day mortality 43% FWB vs 40% aPLT (p=0.72). Note a large loss to follow-up (20% FWB vs 37.6% aPLT). No statistical difference in 24 hours mortality 19% FWB vs 16% aPLT group (p=0.52). Higher incidence of ARDS in FWB vs aPLT 18.8% vs 7.4% (p=0.002). No statistical difference in MODS, embolic events. Multivariate regression analysis of FWB vs aPLT 24 hours OR 3.38, 95% CI 0.96 to 11.87 (p=0.06) 30 days HR 1.38, 95% CI 0.77 to 2.47 (p=0.08).</td>
<td>Very low ⊡</td>
</tr>
<tr>
<td>Spinella et al</td>
<td>354</td>
<td>Military combat patients in Afghanistan and Iraq who received at least 1 unit RBC and were treated at a level II or level III hospital. Those receiving both WFWB and aPLT were excluded.</td>
<td>Primary: survival at 24 hours and 30 days. Secondary: blood product administration, adverse effects.</td>
<td>WFWB (non-leucoreduced)+RBC+plasma</td>
<td>aPLT+RBC+plasma</td>
<td>Statistically significant difference for both 24 hours and 30-day mortality 24 hours: WB 4% vs BCT 12% (p=0.01) 30 days: WB 5% vs BCT 18% (p=0.002). Multivariate logistic regression analysis improved 30-day survival in WFWB group vs BCT group OR 12.4, 95% CI 1.8 to 80 (p=0.01). Increased AKI in WB (8%) vs BCT group (3%) (p=0.04). No statistical difference in ARDS or embolic events. Actual blood volume transfused higher in BCT group (5.7 L vs 6.8 L, p=0.03).</td>
<td>Low ⊡ ⊡ ⊡</td>
</tr>
</tbody>
</table>

Continued
<table>
<thead>
<tr>
<th>Study</th>
<th>Number of participants</th>
<th>Inclusion criteria</th>
<th>Outcome measures</th>
<th>Whole blood</th>
<th>Component therapy</th>
<th>Results</th>
<th>Quality of the evidence (GRADE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jones and Frazier  25</td>
<td>1745</td>
<td>Age 18–45 years, ISS &gt;25, required hospital admission, received blood transfusion.</td>
<td>Primary: in-hospital mortality. Secondary: survival ORs.</td>
<td>WB (no additional information available)</td>
<td>RBC+PLT</td>
<td>No statistical difference in mortality 21% WB vs 26% BCT (p=0.27). Logistic regression analysis. BCT patients 3.2 times more likely to die vs WB OR 3.164, 95% CI 1.314 to 7.618 (p=0.01).</td>
<td>Very low ☹ ☺ ☺</td>
</tr>
<tr>
<td>Nessen et al  26</td>
<td>488</td>
<td>Military combat patients in Afghanistan requiring treatment by the six studied US Forward Surgical Teams.</td>
<td>Primary: mortality determined at inpatient discharge. Secondary: mortality between uncross matched and cross-matched blood, number of products transfused.</td>
<td>FWB+RBC+FFP</td>
<td>RBC+FFP</td>
<td>No statistical difference for unadjusted in-hospital mortality between FWB (5.3%) and BCT (8.8%) (p value not reported). FWB were less likely to die vs BCT continuous variable logistic regression analysis OR 0.096, 95% CI 0.02 to 0.53 (p=0.008) stratified propensity score analysis OR 0.11, 95% CI 0.02 to 0.78 (p=0.03). FWB patients received significantly more units of RBC (12.7 vs 4.7, p≤0.001) and FFP (10 vs 2.6, p≤0.001) FWB patients were more likely to receive MBT (52.1% vs 11.6%, p≤0.001). No statistical difference in those who received type specific FWB or uncrossmatched FWB.</td>
<td>Low ☺☺ ☺</td>
</tr>
<tr>
<td>Yazer et al  8</td>
<td>192</td>
<td>Male patients attending a level 1 trauma centre with hypotension secondary to bleeding who received at least 1 unit of WB compared with historical controls.</td>
<td>Primary: haemolysis (haptoglobin used as marker) and transfusion reactions. Secondary: transfusion volumes, mortality rates (no additional information available).</td>
<td>WB (up to 2 unit, leukoreduced)+RBC+plasma+PLT+cryo</td>
<td>RBC+plasma+ PLT+cryo</td>
<td>No statistical difference in mortality (WB 36% vs BCT 28%, p=0.27). No statistical difference between the number of blood products received by each group. Median haptoglobin concentration on post-WB transfusion day 1 was 25.1 mg/dL (normal). No transfusion reactions in the WB group.</td>
<td>Very low ☹ ☺ ☺</td>
</tr>
</tbody>
</table>

AKI, acute kidney injury; aPLT, apheresis platelets; ARDS, acute respiratory distress syndrome; BCT, blood component therapy; cryo, cryoprecipitate; FFP, fresh frozen plasma; FWB, fresh whole blood; GRADE, Grading of Recommendations Assessment, Development and Evaluation; ISS, injury severity score; MBT, massive blood transfusion ≥ 10 units; MODS, multiple organ dysfunction syndrome; mWB, modified whole blood; RBC, red blood cells; WB, whole blood; WFWB, warm fresh whole blood.
(retrospective study) and moderate (RCT). A third, retrospective study (n=354, grade of evidence very low) found a statistically significant difference in 24-hours mortality between WB transfusion and blood component therapy (4% vs 12% respectively, p=0.018).36

Acute respiratory distress syndrome
Three studies reported rates of ARDS. Two studies found no statistically significant difference between the two groups,29 31 and one study found a higher incidence of ARDS in the fresh WB group compared with apheresis platelets (aPLT) group (18.8% vs 7.4%, respectively, p=0.002).29

Acute kidney injury
Two studies reported the incidence of AKI. One study found no statistical difference in AKI between those receiving WB and those receiving component therapy.31 One study reported a higher incidence of AKI in the group receiving WB transfusion compared with component therapy (8% vs 3% respectively, p=0.04).30

Multiple organ dysfunction syndrome
Two studies reported rates of MODS. Neither study found a statistically significant difference in MODS between those receiving WB transfusion and those receiving component therapy.29 31

Embolic events
Two studies reported rates of embolic events. Neither study found a statistically significant difference in embolic events between those receiving WB transfusion and those receiving component therapy.29 30

Number of units transfused
Four studies reported volume of units transfused. Two studies found no statistical difference between the number of blood products received by each group.31 One study reported that actual blood volume transfused was higher in component therapy group compared with the WB group (6.8L vs 5.7L respectively, p=0.03).29 One study found that FWB patients received significantly more units of both red blood cells and fresh frozen plasma.26

Transfusion reactions
Three studies reported on transfusion reactions. Two studies reported no transfusion reactions in patients receiving WB transfusion.1 26 One study reported specifically no cases of transfusion-related acute lung injury in either group.31

Subanalysis of patients with TBI
Only one study excluded patients with penetrating head injury and GCS of ≤7.26 One study performed a sensitivity analysis to assess outcomes of patients without severe TBI.31 The authors found that WB significantly reduced transfusion volumes in patients without severe TBI, but there was no statistically significant difference in 30-day mortality (6% WB vs 9% component therapy, p=0.62). This again may represent a type II error as the study was not powered to demonstrate a difference in 30-day mortality. Another study we examined conducted a post hoc analysis excluding patients with TBI, and also found that use of WB significantly reduced the number of red blood cell and platelet transfusions.8

DISCUSSION
This systematic review evaluated current evidence comparing WB transfusion with component therapy in adult trauma patients with acute major haemorrhage. There were only six studies, and overall quality was low. Of the three studies reporting our primary outcome of 30-day mortality (total of 830 patients), two had ratings for grade of evidence of low and very low.29 30 The highest quality evidence for this outcome was an RCT (grade of evidence moderate), which demonstrated no statistical difference in 30-day mortality; however, this study (n=107) was not powered to demonstrate a difference in 30-day mortality as the primary outcome.31 Two observational studies reporting in-hospital mortality (2233 patients) found in logistic regression analyses that patients receiving WB transfusion strategy were less likely to die.25 26 However, both studies suffered from poor quality evidence with grade rated low and very low.

In the studies conducted in military settings, it is reported to take 30–45 min to receive the first unit of WB, introducing survival bias favouring the patient group receiving WB. Rapidly exsanguinating patients may not survive long enough to receive WB. Only one study attempted to minimise this bias by excluding patients who died within the first hour of treatment.26 It is important to note this issue will not be resolved with more retrospective studies.

With WB not currently available in most civilian Western institutions, clinicians have adapted to the use of available component therapy. Interestingly, this practice now resembles reconstituted WB with component therapy transfused in a ratio of 1:1:1, after a multicentre observational study reported a reduction in mortality with higher plasma and platelet ratios.32 This was followed by an RCT demonstrating a trend towards survival in the group receiving 1:1:1 regimen compared with 1:1:2.16 A recent secondary analysis of a multicentre randomised phase III trial reported combined red blood cells and plasma transfusion had the greatest statistical reduction in 30-day mortality (HR 0.28, p≤0.001), compared with plasma or red blood cells or crystalloid alone resuscitation.18 It should however be noted that even between trauma centres there is a significant variation in practice and the regimen used.31

Looking at adverse events between groups, one study (n=354) reported a higher incidence of AKI in the WB group compared with component therapy.30 Another study (n=369) found a higher incidence of ARDS in the FWB group compared with aPLT group.29 Neither study was designed to address these measures as their primary outcome, and therefore may not be powered to demonstrate an accurate difference. Both studies used non-leucoreduced fresh WB. Both AKI and ARDS may be the result of complex immunological mechanisms. A simplified explanation includes inflammation caused by the transfusion of donor white blood cells.30 White blood cells cause inflammation resulting from microvascular damage to the endothelium. In the lungs, this may cause vascular leakage into the alveolar space, resulting in pulmonary oedema and ARDS. Of note, most WB in the low-income and middle-income world is leucoreduced due to risk of infectious diseases such as variant Creutzfeldt-Jakob disease.

The resuscitation end points for patients with TBI differ quite significantly from those with acute major haemorrhage. Patients with TBI require a higher mean arterial pressure to maintain cerebral perfusion pressure and are not generally resuscitated with all damage control resuscitation principles including permissive hypotension. The subanalysis of patients with TBI suggests that if patients with TBI are excluded from analysis...
due to the differing resuscitation goals, there is trend towards WB significantly reducing the transfusion volumes required. However, due to the studies not being powered sufficiently this is an area that requires further research.

Around a quarter to third of trauma patients requiring transfusion are coagulopathic at presentation. Presence of trauma-induced coagulopathy is an independent predictor of mortality. WB is a more concentrated transfusion, reducing the total dilutional, non-haemostatic fluid transfused into a trauma patient. Therefore, WB may be superior compared with component therapy for reversing the effects of trauma-induced coagulopathy. While fresh WB transfusion is becoming increasingly prevalent therapy for reversing the effects of trauma-induced coagulopathy. While fresh WB transfusion is becoming increasingly prevalent, safety testing is time consuming and most importantly fresh WB has a short shelf-life of up to 72 hours. However, there are 19 trauma centres using WB in the USA, and civilian use of WB in the context of trauma and massive transfusion is being studied.

LIMITATIONS
The quality of this systematic review is limited by methodology of the studies it appraises. The papers were mostly retrospective cohort studies with one prospective randomised trial. There was a paucity of high-quality evidence. This systematic review is also limited by the significant heterogeneity of included studies. Both intervention and control groups are not consistent across studies. For example, one study compared leucoreduced modified whole blood (mWB) (no native platelet function), with the addition of one pool of apheresis platelets for every six units of mWB. Another used non-leucoreduced WFWB with red blood cells and plasma. These differences in transfusion protocol, comparison groups and outcome measures across studies meant that data pooling and meta-analysis were not possible.

CONCLUSION
Overall, this systematic review is unable to determine if the use of WB transfusion compared with component therapy improves survival at 30 days in adult trauma patients with acute major haemorrhage based on the evidence identified. However, no reduction in survival was reported with WB transfusion in any of the included studies. Larger prospective, randomised or adaptive trials are required to better understand if WB improves survival. If the use of WB is shown to be superior to component therapy, blood services are more likely to manufacture WB despite the shorter shelf life.

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REFERENCES
Systematic review


