Relative survival benefit and morbidity with fluids in severe sepsis - A network meta-analysis of alternative therapies

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Relative Survival Benefit and Morbidity with Fluids in Severe Sepsis - A Network Meta-Analysis of Alternative Therapies

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Abstract: Background: Fluid resuscitation is widely practiced in intensive care units for the treatment of sepsis. A comparison of the evidence base of different fluids may inform therapeutic choice.

Methods: The risks of mortality and morbidity (the need for renal replacement therapies (RRT)) were assessed in patients with severe sepsis. A network meta-analysis compared trials for crystalloids, albumin and hydroxyethyl starch (HES). A literature search of human randomized clinical trials was conducted in databases, the bibliographies of other recent relevant systematic reviews and data reported at recent conferences. Mortality outcomes and RRT data with the longest follow up period were compared. A Bayesian network meta-analysis assessed the risk of mortality and a pair-wise meta-analysis assessed RRT using crystalloids as the reference treatment.

Results: 13 studies were identified. A fixed-effects meta-analysis of mortality data in the trials demonstrated an odds-ratio (OR) of 0.90 between crystalloids and albumin, 1.25 between crystalloids and HES and 1.40 between albumin and HES. The probability that albumin is associated with the highest survival was 96.4% followed by crystalloid at 3.6%, with a negligible probability for HES. Sub-group analyses demonstrated the robustness of this result to variations in fluid composition, study source and origin of septic shock. A random-effects pairwise comparison for the risk of RRT provided an OR of 1.52 favoring crystalloid over HES.

Conclusion: Fluid therapy with albumin was associated with the highest survival benefit. The higher morbidity with HES may affect mortality and requires consideration by prescribers.

Keywords: Albumin, crystalloid, hydroxyethyl starch, meta-analysis, resuscitation, sepsis, septic shock, severe sepsis.

INTRODUCTION

Sepsis is a systemic, deleterious inflammatory host response to infection. It can evolve to severe sepsis (acute organ dysfunction secondary to documented or suspected infection) and septic shock (severe sepsis plus hypotension not reversed with fluid resuscitation) [1]. Severe sepsis and septic shock are major healthcare problems increasing in incidence [2-6]. Mortality is about 33.3% in the patients with severe sepsis who are hospitalized [7] while treated with the current standard of care in the US. Hypovolemia is a feature of sepsis which is treated with fluids. Among several fluid treatments available for treating sepsis, the first line of treatment is generally crystalloids in a range of formulations [1, 8], followed by colloid if large amounts of crystalloid are administered.

A wide range of colloids are used [9]. They include human albumin solutions which have been used in acute care for decades [10]. Albumin's repertoire of molecular functions includes correction of hypoalbuminaemia [11] and antioxidant properties which are sustained in septic patients [12]. Synthetic colloids include hydroxyethyl starches (HES) which have been used in a range of clinical applications in lieu of albumin [8]. Recent large randomized clinical trials (RCTs) provide insight in determining the efficacy of the fluids and have compared albumin with crystalloid [11, 13, 14] and HES with crystalloid [15-17] but no large head to head randomized controlled trials comparing the two colloids have been reported. Estimates of relative efficacy for all treatments are required to inform clinical decisions, treatment guidelines and economic studies such as cost effectiveness analyses.

A number of meta-analyses have also indicated different mortality and morbidity outcomes with the different drugs [18-23]. None of these standard meta-analytic techniques, which evaluate the relative efficacy of one treatment compared with a single comparator, have compared different colloids or compared crystalloid with albumin. Network meta-analytic techniques have recently been developed that estimate the relative efficacy of any number of different treatments by taking account of the entire network of RCT evidence [24-26]. Given the paucity of head to head trials comparing HES and albumin or comparing crystalloid with both colloids [27, 28], the network method of meta-analysis may inform comparisons between fluid treatments. The present study proposes a network meta-analysis [29] utilizing direct and indirect treatment comparison of randomized trials with common comparators to assess the primary outcome of risk of mortality and a secondary
outcome in the form of a need for renal replacement therapy. Using this approach allowed the inclusion of trials comparing the two colloids, albumin and HES, and concurrent comparison of each colloid with crystalloid.

METHODS

Systematic Review

A literature search of human clinical trials was conducted in PubMed, ClinicalTrials.gov and within the bibliographies of other recent systematic reviews [23, 30]. In addition, data for mortality for treatment and control arms from the Early Albumin Resuscitation for Sepsis and Septic Shock (EARSS) trial [14] and the Albumin Italian Outcomes Study (ALBIOS) trial [31] for albumin in septic shock were extracted from the results reported as referenced. The search terms used were sepsis, septicemia, systemic inflammatory response syndrome, septic shock, fluid therapy, resuscitation, plasma substitute, albumin, serum albumin, starch, hydroxyethyl starch, hetastarch, pentastarch, tetrastarch and mortality. “Crystalloids” was not included in the initial search strategy as all colloid trials have included crystalloid as a control fluid; including “crystalloids” in a subsequent search did not yield any differences or additional studies.

Inclusion Criteria

Only randomized controlled trials based on an intent-to-treat criterion and providing mortality outcomes were included. Trials with all formulations of crystalloids, HES and albumin (see Discussion) comparing two or all three treatments were included. All age groups were included. In trials with multiple endpoints, mortality outcomes after the longest follow up period were used. Only trials which reported specific data for patients with severe sepsis or septic shock were included. Trials which reported such data as a result of a pre-defined sub-group were also included. Only English language publications from 2000 to date were included. In total, 391 studies were extracted of which 13 were chosen to be included in the analysis as shown in Fig. (1). The studies used are listed in Table 1.

Data Extraction and Validity Assessment

The studies were first screened by their titles and abstracts by a reviewer (MB). In the second screening, two reviewers (AF, MB) were involved. In this screening, full texts were reviewed and articles were excluded on the basis of no relevant comparators, not a randomized clinical trial, not an intent-to-treat analysis, no outcomes for only sepsis patients or no mortality results (Fig. 1). The chosen studies were validated, shown in Table 2, for the method of randomization and allocation concealment, blinding, presentation of an intention to treat analysis and loss to follow-up of >5% of patients for the primary outcome [32]. Any discrepancy was resolved by consulting with a third reviewer (SB).

Statistical Methods

The indirect comparison was conducted using the Bayesian method for a binomial likelihood, fixed effects network meta-analysis [29]. The analysis was conducted using OpenBUGS version 3.2.1. This package uses Bayesian Markov chain Monte Carlo Gibbs sampling methods [33]. The program code used is available in NHS Evidence Synthesis documents [29]. As conducted in previous research, [25, 34, 35] non-informative prior distributions were used for all the treatment effects; see program code for more details (Program 1 (d): http://www.nicedsu.org.uk/TS D2%20General%20meta%20analysis%20corrected%20Mar2 013.pdf).

Studies were included using crystalloids as a reference treatment compared to any composition of colloid fluid.
(albumin or HES) treatment in septic patients and head-to-
head trials of colloid fluids; no trials originating from the
group of Joachim Boldt, which have been retracted from the
peer-reviewed literature because of scientific misconduct,
[36] were included.

The choice for fixed or random effect model was made
by assessing model fit using Deviance Information Criteria
(DIC) and heterogeneity between the trials [37]. The
consistency of the model was assessed as described by
National Institute for Health and Clinical Excellence (NICE)
[26].

The Bayesian analysis ranked the treatments and
provided probability of attaining that rank based on the
proportion of Markov chain iterations in which treatment had
the highest probability of lowering risk of mortality. The OR
and corresponding 95% credible intervals were obtained
with 50,000 iterations and convergence was seen at around
15,000 iterations. The 95% credible interval is used to assess
statistical difference between comparators and can be
interpreted as a 95% probability that true mean change falls
within that range. In Bayesian statistical analysis, p-values
are not provided [38].

Secondary Outcome

The secondary outcome was the need for renal
replacement therapy for the 90-day follow up period only.
The trials sourced through the search for mortality data were
reviewed for data relating to RRT. In addition, a specific
search was conducted for RRT within the PubMed database.
The Bayesian, two treatments, pair-wise meta-analysis was
used as this outcome was only reported in HES vs crystalloid
RCTs. The analysis was conducted in OpenBUGS version
3.2.1; see code for details (Program 1 (a) in [37]. Other
adverse events associated with colloids including
hypotension, bleeding and pruritus [39] were considered for
inclusion in the analysis but were not fully reported or were
associated with low incidence (<1%) in the trials chosen.
Hence, analysis was limited to the widely reported issue of
renal dysfunction as assessed through the need for renal
replacement therapy.

Sub-group Analysis

Sub-group analyses with different formulations of HES
and albumin were performed, in order to assess recent
conclusions that the drugs behaved as classes with no
therapeutic differences between different compounds [40].
Most of the included RCTs had a population above 60 years
of age. The small trial of Dolecek et al., [11, 41] had a
population between 40-50 years of age. The studies of
Maitland et al. had a much younger population with infants
in two trials [42, 43] and youth in the FEAST trial [13].
Further analysis was performed with patients in different age
groups, as most of the included RCTs had populations of
elderly (> 60 years) patients and also without the inclusion
of the malaria trials of Maitland et al., [13, 42, 43]. All the
trials assessed severe sepsis or septic shock except the trials
of Maitland et al., which were done on patients with malaria
and where the pathophysiology mimics that of sepsis [44].
As two of the largest trials selected - ALBIOS and EARSS -
have only been reported as conference proceedings [14, 31],
a subgroup analysis excluding these two studies was
performed. Further analysis explored outcomes for in-
hospital, 28-day vs 90-day mortality to see the effect of
follow-up period on the mortality outcomes.

RESULTS

Studies Identified

In the literature search, 391 studies were identified. 336
of these were excluded in the first screening. Fig. (1) shows
that 13 studies were finally included in the analysis. As
shown in Fig. (2), there was only one qualifying head-to-
head trial that compared albumin and HES and only one
other small trial that included all three fluid treatments. Out
of the remaining 11 crystalloid controlled trials, 6 were with
HES and rest with albumin. The larger trials included
CHEST, ALBIOS, VISEP, SAFE, EARSS, FEAST and 6S
[11, 13, 14, 16, 17, 31, 45] and all were quite recent studies.
The mortality data were provided for only the sepsis sub-
group but RRT data was presented for all the ICU patients in
the CHEST trial. The trial characteristics are summarized in
Table 1.

Fig. (2). Network diagram of type of fluid used in treatment of
sepsis. Each intervention is a node in the network. The links
between the nodes are trials of the study arms. The numbers
represent number of studies found for each connection. The number
in the center represents the number of trials studying all arms
together.

Choice of Model - Random Effect vs Fixed Effect

The DIC was 182.5 for the random effects model and
180.7 for the fixed effect. The posterior mean of the residual
deviance for random effects model was more than the fixed
effect at 17.2 vs 15.1. The standard deviation with random
effect was also quite small at 0.09 thus exhibiting very low
heterogeneity between trials. These statistical outcomes
indicate that the fixed effect model produced the best fit for
the data [26].

Consistency of the Model

The assessment showed similar effect sizes and DICs for
the consistency (DIC=180.9) and inconsistency (DIC =
182.9) models in case of the fixed effect analysis. As shown
in Fig. (3), most of the posterior mean deviations of the
individual data points lie around one on the line of equality
suggesting consistency.
<table>
<thead>
<tr>
<th>Study</th>
<th>Population Description</th>
<th>Mean Age (Years)</th>
<th>Treatment Arms</th>
<th>Type of Crystalloid (If Any)</th>
<th>Albumin/ HES Composition</th>
<th>Follow-Up Duration</th>
<th>Crystalloid Deaths/ RRT</th>
<th>Albumin Deaths/ RRT</th>
<th>HES Deaths/ RRT</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALBIOS 2012 [31]</td>
<td>Sepsis or septic shock</td>
<td>66.3- A, 66.3-S</td>
<td>Crystalloid, Albumin</td>
<td>crystalloids</td>
<td>20% A</td>
<td>hospital discharge</td>
<td>342</td>
<td>907</td>
<td>326</td>
</tr>
<tr>
<td>Charpentier et al. (EARSS) 2011 [14]</td>
<td>Septic shock</td>
<td>66 for both</td>
<td>Crystalloid, Albumin</td>
<td>0.9% saline</td>
<td>20% A</td>
<td>28 days</td>
<td>103</td>
<td>393</td>
<td>96</td>
</tr>
<tr>
<td>Finfer S (SAFE study) 2006 [11]</td>
<td>Severe sepsis</td>
<td>58.6- A, 58.5-S</td>
<td>Crystalloid, Albumin</td>
<td>0.9% saline</td>
<td>4% A</td>
<td>28 days</td>
<td>217</td>
<td>615</td>
<td>185</td>
</tr>
<tr>
<td>Maitland 2005 [42]</td>
<td>Children with severe malaria and sepsis as a sub-group</td>
<td>1.6 (for all txs)</td>
<td>Crystalloid, Albumin</td>
<td>0.9% saline</td>
<td>4.5% A</td>
<td>hospital discharge</td>
<td>3</td>
<td>20</td>
<td>4</td>
</tr>
<tr>
<td>Maitland 2005 [43]</td>
<td>Children with severe malaria and moderate or severe metabolic acidosis (sepsis as a sub-group)</td>
<td>2.8 (for all txs)</td>
<td>Crystalloid, Albumin</td>
<td>0.9% saline</td>
<td>4.5% A</td>
<td>hospital discharge</td>
<td>11</td>
<td>61</td>
<td>2</td>
</tr>
<tr>
<td>Maitland K, (FEAST Trial Group) 2011 [13]</td>
<td>Patients with severe febrile illness and impaired perfusion (sepsis as a sub-group)</td>
<td>23-A, 23-S</td>
<td>Crystalloid, Albumin</td>
<td>0.9% saline</td>
<td>5% A</td>
<td>30 days</td>
<td>126</td>
<td>1047</td>
<td>128</td>
</tr>
<tr>
<td>Myburgh (CHEST) 2012 [17]</td>
<td>Adult patients with sepsis (subgroup)</td>
<td>63.1-H, 62.9-S</td>
<td>Crystalloid, HES</td>
<td>0.9% saline</td>
<td>6% H (130/0.4)</td>
<td>90 days</td>
<td>224/196*</td>
<td>958</td>
<td>248/235*</td>
</tr>
<tr>
<td>Brunkhorst (VISEP) 2008 [45]</td>
<td>Patients with severe sepsis</td>
<td>64.9-S, 64.4-H</td>
<td>Crystalloid, HES</td>
<td>ringer's lactate</td>
<td>10% H (200/0.5)</td>
<td>28 days</td>
<td>66</td>
<td>275</td>
<td>70</td>
</tr>
<tr>
<td>Guidet (CRYSTMAS) 2012 [15]</td>
<td>Severe sepsis</td>
<td>65.8-H, 65.9-S</td>
<td>Crystalloid, HES</td>
<td>NaCl fluid</td>
<td>6% H (130/0.4)</td>
<td>28 days</td>
<td>24</td>
<td>96</td>
<td>31</td>
</tr>
<tr>
<td>McIntyre (FINESS) 2008 [46]</td>
<td>Patients with septic shock</td>
<td>63.6-S, 63.1-H</td>
<td>Crystalloid, HES</td>
<td>normal saline</td>
<td>ICU</td>
<td>6/1 28 days</td>
<td>6</td>
<td>19</td>
<td>6</td>
</tr>
<tr>
<td>Perner (6S) 2012 [16]</td>
<td>Patients with severe sepsis</td>
<td>66-H, 67-S</td>
<td>Crystalloid, HES</td>
<td>ringer's acetate</td>
<td>6% H (130/0.4)</td>
<td>28 days</td>
<td>144</td>
<td>400</td>
<td>154</td>
</tr>
<tr>
<td>Dolecek 2009 [41]</td>
<td>Adult patients with severe sepsis</td>
<td>47-A, 43-H</td>
<td>Albumin, HES</td>
<td>6% H (130/0.4), 20% A</td>
<td>28 days</td>
<td>4 30 days</td>
<td>172/65</td>
<td>400</td>
<td>201/87</td>
</tr>
<tr>
<td>Veneman 2004 [27]</td>
<td>Severely ill patients with sepsis and post-surgical patients with systemic inflammatory response syndrome</td>
<td>67-S, 72-A, 68-H</td>
<td>Crystalloid, Albumin, HES</td>
<td>0.9% saline</td>
<td>20% A, 10% H</td>
<td>30 days</td>
<td>5</td>
<td>16</td>
<td>8</td>
</tr>
</tbody>
</table>

*In CHEST 2012 study, RRT is analyzed for all patients in the ICU. Sepsis is a sub-group of those patients. Total ICU patients under crystalloids: 3375, HES:3352.
Baseline Results

The pairwise ORs and their respective 95% credible intervals are presented in Fig. (4). The fixed effect network meta-analysis in the forest plot (Fig. 4) resulted in ORs of 0.90, 1.25 and 1.40 favoring albumin versus crystalloid, crystalloid versus HES and albumin versus HES, respectively. The random effects model showed similar results (0.89 for albumin vs crystalloid, 1.28 for HES vs crystalloid and 1.45 for HES vs albumin). The Frequentist pairwise fixed effect meta-analysis showed an OR of 0.90 favoring albumin versus crystalloid and 1.24 favoring crystalloid over HES. The baseline 95% credible intervals showed no significant statistical differences between the treatments.

Ranking of the Treatment

The Bayesian framework ranked the treatments and also assigned a probability to each rank that a treatment can achieve in terms of lowering the risk of mortality. Fig. (5) displays the share of these distributions under each rank. The higher the share in the distribution under a rank, the more likely the treatment will hold that rank. Albumin ranks first 96% of the times versus the other two treatments. The second place is shared in a majority by crystalloid and HES populates mostly the third place. Thus, according to the shares occupied by the treatments, albumin is the most effective treatment followed by crystalloid, and HES is the least effective. The odds-ratio (1.52) for RRT favored

![Fig. (3). Plot of individual mortality data points’ posterior mean deviance contributions for the consistency model (horizontal axis) and the inconsistency model (vertical axis) along with the line of equality. Each data point is expected to have a posterior mean deviance contribution of about 1.0, with higher contributions suggesting a poorly fitting model [26]. Since Maitland et al., [43] and Veneman et al., [27] had data points much higher than 1.0, a sub-group analysis was conducted without the studies of Maitland et al., [13, 42, 43] and another analysis without Veneman et al., [27].](image-url)
crystalloids in comparison to the HES in the random effects Bayesian analysis.

**Sub-Group Results**

Table 3 summarizes the results of sub-group analyses when excluding the trials of Maitland *et al.*, [13, 42, 43], when follow up was for 28days compared to the base case (longest follow-up period), when elderly patients were studied and when different formulations of the colloid solutions were studied. The relative rankings in the survival benefit were not affected in any of the sub-groups (Table 3). In addition, the exclusion of the hitherto not fully published EARSS and ALBIOS trials also did not affect the key outcome.

**DISCUSSION**

The present study found a 96.4% probability that, of the fluid treatments assessed, albumin provides the highest survival benefit in patients with sepsis through lowering the risk of mortality. In this analysis, the longest follow-up mortality data in trials were included. The trials with longer observation periods found more cases of adverse effects such as renal toxicity in patients treated with HES [16, 17, 45]. This finding is augmented by the sub-group analysis in this study, which showed that there is higher risk of mortality in the long term for patients treated with HES.

The recent meta-analyses compared HES either with other colloids or crystalloids in critically ill patients. Gattas *et al.*, [18] concluded that with HES there is a 6%
increase in relative risk of death and a significant 25% increase in relative risk of being treated with RRT. Zarychanski et al., [20] also showed in their analysis that removing the studies by Boldt, there was a clear survival benefit with other control fluids in critically ill patients. Patel et al., [47] conducted a meta-analysis on trials with severe septic patients treated with 6% HES (130/0.4 or 130/0.42). The control fluid showed a higher survival benefit in the 90-day follow up period. Haase et al., [19] found higher rate of RRT and blood transfusion in patients treated with HES 130/0.38-0.45 but no significant difference in risk of death. Delaney et al., [23] compared albumin with any control fluid and found albumin to be superior in reducing the risk of mortality.

The methodology of these routine meta-analyses does not allow the assessment of comparative effectiveness and safety of specific treatments in the absence of direct head to head trials. The present study applied network meta-analysis using a Bayesian approach to compare and rank the different fluid therapies available for severe sepsis so as to inform clinical decision making. This approach has been used to compare therapies in similar circumstances, in areas including pain management, diabetic neuropathy [48] and antifibrinolytic therapy in cardiac surgery [49], and has been shown to be not increase the bias relative to routine meta-analysis [50].

An underlying presumption in comparing outcomes in different clinical trials through techniques like meta-analysis is that different therapeutic preparations within each arm are biopharmaceutically equivalent. Hence, the different compositions of HES and albumin are assumed to have the same therapeutic effect when compared in meta-analyses such as that in the present study. Crystalloids also form a very broad category with differently formulated solutions. Any differences in formulation, manufacturing method etcetera between different fluids within the same broad class (crystalloids, albumin and HES) are assumed to not affect their therapeutic properties. Equivalent efficacy and safety profiles have been shown for albumin produced by different methods [53]. The most recent HES products have been claimed to be associated with fewer adverse events than earlier products [54] but the outcomes of meta-analysis [30, 55] and recent trials [16,17] have disputed this, and have led the US Food and Drug Administration (FDA) to conclude that in relation to these effects, all HES products behave as a class [40]. This has led the European Medicines Agency to conclude that the negative risk-benefit balance associated with these products justifies the removal of their marketing authorization [56]. Similarly, crystalloid solutions formulated to approximate physiological conditions have been claimed to be therapeutically superior to normal saline [57]. This has not been supported in a systematic review of mortality and morbidity in patients [58]. To test this assumption further, we performed the analysis with different formulations of albumin and HES and obtained similar results. Hence, we propose that the results of previous analyses, [30, 55] and the current study are not affected by any differences in the preparations within each treatment arm.

Similarly, we acknowledge that variability in the patient populations recruited in the individual trials may influence the results of this analysis, although the populations studied, consisting of severe sepsis and septic shock patients, were very similar in terms of age (all populations in the different fluid arms were in the age group 61 to 68) with the exception of the pediatric populations studied in the malaria trials of Maitland et al. We have assessed the effect of variability resulting from patient population, follow up time, product

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**Fig. (5).** Barplots for the ranking probabilities of competing fluid treatments. Horizontal axis is the possible rank of each treatment (from best to worse). The size of each bar corresponds to the probability of each treatment to be at specific rank.
composition and patient age through sub-group analyses which demonstrated no effect on the final result of this study (Table 3), but it is possible that variability in these and other factors may influence the results, as with all meta-analyses.

Our sub-group analysis of trials with 28-day mortality showed a lower risk with HES than our analysis of trials with 90-day mortality outcomes. This suggests that more adverse outcomes from HES ensue after a prolonged period after use, as was shown in both the VISEP [45] and 6S [16] large clinical trials of different generation HES products. A high fraction of HES is taken up and deposited in tissues [59], where its long-term toxic effects on the kidney, liver, and bone marrow [60, 61] may explain the relative time frame of the mortality outcomes. There is a lower risk of mortality with HES and crystalloid in older patients in as assessed through the sub-group analysis in the present study but the relative ranking in survival benefit is not affected. This could be speculatively attributed to a higher incidence of other comorbidities in elderly patients, thus diminishing the difference between the efficacies of the fluid treatments.

All the trials with RRT outcomes had a 90-day follow up period. The indication was severe sepsis or septic shock for all included trials except the CHEST study [17] which assessed all the patients in the ICU setting. Sepsis was a sub-group in the CHEST trial, and the findings of the sub-group have not been published but have been reported (Myburgh J, Presentation at the International Symposium on Intensive Care and Emergency Medicine, Brussels March 2013). The need for RRT in all trials comparing albumin with other fluids did not show any increased risk with albumin, possibly due to albumin’s lack of renal toxicity [62, 63] compared to HES [64].

Direct data on mortality in fluid resuscitation with sepsis, comparing albumin, HES and crystalloids, are minimal and thus the present study may inform therapeutic choice. Moreover, network meta-analysis and indirect comparison is receiving increased acceptance in health care decision making (Pharmaceutical Benefits Advisory Committee in Australia, Canadian Agency for Drugs and Technologies in Health [CADTH], National Institute for Health and Clinical Excellence [NICE] in the UK) [29, 65, 66]. Even when direct evidence is available and conclusive, combining direct and indirect results may yield more refined and precise estimates of the interventions and broaden inference to the population sampled. Network meta-analysis links and maximizes existing information within the network of treatment comparisons [24, 25, 67]. We propose that such an approach should assist policy makers, manufacturers, physicians and patients, when making a choice between fluid-resuscitation treatments.

**CONFLICT OF INTEREST**

Bansal M, Farrugia A and Balboni S provide services to the plasma protein therapeutics industry, which includes the manufacturers of therapies described in this work.

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All the authors were involved in study design. Bansal M contributed to literature review, meta-analysis and
manuscript preparation. Farrugia A contributed to literature review and manuscript preparation, Balboni S was involved in literature and manuscript preparation and Martin G reviewed the manuscript.

**PATIENT CONSENT**

Declared none.

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