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Special Article

SPECIAL ARTICLE

Perioperative fluid management: evidence-based consensus recommendations from the international multidisciplinary PeriOperative Quality Initiative

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Summary

Fluid therapy is an integral component of perioperative management. In light of emerging evidence in this area, the Perioperative Quality Initiative (POQI) convened an international multiprofessional expert meeting to generate evidence-based consensus recommendations for fluid management in patients undergoing surgery. This article provides a summary of the recommendations for perioperative fluid management of surgical patients from the preoperative period until hospital discharge and for all types of elective and emergency surgery, apart from burn injuries and head and neck surgery. Where evidence was lacking, recommendations for future research were generated. Specific recommendations are made for fluid management in elective major noncardiac surgery, cardiopulmonary bypass, thoracic surgery, neurosurgery, minor noncardiac surgery under general anaesthesia, and critical illness. There are ongoing gaps in knowledge resulting in variation in practice and some disagreement with our consensus recommendations. Perioperative fluid management should be individualised, taking into account the type of surgery and important patient factors, including intravascular volume status and acute and chronic comorbidities. Recommendations are made for further research in perioperative fluid management to address important gaps.

Keywords: consensus statement; fluids; fluid management; perioperative medicine; POQI

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Editor's key points

- The Perioperative Quality Initiative international multidisciplinary group aims to establish evidence-based appraisals and generate consensus recommendations for managing patients undergoing surgery to standardise care and direct further research.
- They convened an expert meeting to generate evidence-based consensus recommendations for fluid management in patients undergoing surgery from the preoperative period until hospital discharge for all types of elective and emergency surgery.
- Specific recommendations are made for fluid management in elective major noncardiac surgery, cardiopulmonary bypass, thoracic surgery, neurosurgery, minor noncardiac surgery under general anaesthesia, and critical illness.
- Perioperative fluid management should be individualised, taking into account the type of surgery and important patient factors, including intravascular volume status and acute and chronic comorbidities.

In 2012, more than 312 million surgical operations took place worldwide, which represents a 33.6% increase since 2004.[1] Since then, there have been further increases in the number of surgeries and complexity of procedures. Recent data suggest that more than 20% of patients undergoing major surgery are at high risk of developing a major postoperative complication, including sepsis, acute kidney injury (AKI), acute cardiovascular events, and mortality, resulting in high long-term healthcare needs.[1–4]

Nearly all surgeries require fluid therapy for maintenance or restoration of intravascular volume, correction of electrolyte abnormalities or drug administration. Whilst fluids are considered essential to improve perioperative outcomes, there is increasing evidence that inappropriate fluid management (i.e. unphysiological fluid composition, inappropriate volume, or inadequate rate) is ineffective, costly, and contributes to complications.[5–8] Further, the literature suggests that clinicians' fluid management knowledge is inadequate.[9]

The Perioperative Quality Initiative (POQI) is an international, multidisciplinary nonprofit organisation that aims to establish evidence-based appraisals and generate consensus recommendations for managing patients undergoing surgery to standardise care and direct further research.[10] In 2016, POQI published a framework applicable to the perioperative management of intravenous fluid therapy specifically in patients undergoing elective colorectal surgery within an enhanced recovery pathway.[11] In 2021, a consensus report was published jointly by the POQI and Acute Disease Quality Initiative, which focussed on prevention and management of AKI after surgery.[12] In light of increasing evidence in the field of haemodynamic management and fluid therapy during the perioperative period, new data concerning the benefits and potential harms of fluids and the recent publication of landmark fluid trials, the 11th POQI consensus conference 'Best Practices in Perioperative Medicine' was convened in London, UK, on July 4 and 5, 2023. The aim of the fluid working group was to generate new evidence-based consensus statements for perioperative fluid management of adult patients undergoing surgery.

Methods

A collaborative group of 17 diverse international experts from different healthcare disciplines and backgrounds were invited, including anaesthesia, critical care, perioperative medicine, nephrology, and clinical outcomes research (see Appendix). The panel members were reimbursed for travel, accommodation, and meals but did not receive honoraria. Before the conference, the fluid working group met virtually on five occasions. In the first meeting, they reviewed the previous POQI fluid recommendations[11,12] from 2016 and 2021. Panel members selected the recommendations that were still valid and identified those that needed to be updated based on publication of new fluid trials. We searched PubMed for articles on fluid therapy published between January 1, 2016 (when the previous POQI fluid consensus statements were published) and June 1, 2023 (before the 11th POQI consensus conference was held) using the following MeSH search terms: 'fluid' AND ('major surgery' or 'perioperative' or 'intraoperative'). The search and subsequent bibliographic review were restricted to randomised controlled trials, observational studies, reviews, and meta-analyses published in English. The search identified 329 publications. In addition, we searched ClinicalTrials.gov and the Cochrane database, reviewed the reference lists of articles, and liaised with expert panel members about potential articles. Relevant papers were reviewed by the members of the panel and served to underpin the consensus statements.

During the meeting, a modified Delphi method was applied whereby the group presented the research questions to the entire POQI panel and received feedback and assistance in refining the questions. In break-out sessions, the group formulated answers to these questions, supported by evidence when available and by expert opinion when no clear evidence was available. Revised statements were presented to the panel four times and re-revised in response to feedback until consensus was achieved. Nonanonymous voting took place during the final panel meeting. Agreement by 85% of votes was determined *a priori* as necessary for approval.

The Grading of Recommendations Assessment, Development and Evaluation (GRADE) system was used to rate the certainty of evidence.[13] Where evidence was lacking and consensus could not be reached, recommendations for future research were generated. Following the meeting, all recommendations were presented at the Evidence Based Perioperative Medicine (EBPOM) 2023 World Congress in London on July 6, 2023, where attendees were invited to participate in an anonymous vote to indicate their agreement or disagreement for each recommendation using the Slido app (https://www.slido.com). To preserve anonymity, we did not document the institutional affiliation or professional category of the respondents.

Here, we summarise the consensus statements and present the results of the anonymous votes of 91 attendees of the Evidence Based Perioperative Medicine (EBPOM) 2023 World Congress on July 6, 2023 (Table 1).

Scope

By consensus, it was decided to generate consensus recommendations for perioperative fluid management of the surgical patient from the preoperative period until the day of hospital discharge for all types of surgery (elective and emergency), apart from burn injuries, reconstructive surgery, and head and neck surgery. All types of fluids were considered,

Table 1 Level of agreement with attendees of World Congress of Prehabilitation Medicine 2023. Participants: doctors, 92%; nurses, 1%; advanced practice providers, 2%; others 4%. CBP, cardiopulmonary bypass; PONV, postoperative nausea and vomiting.

Recommendations	Number of votes	Agreement
We recommend keeping the preoperative fasting time short (2 h for clear fluids) to reduce thirst and prevent preoperative dehydration.	99	93%
We recommend intraoperative administration of an adequate amount of fluid, generally aiming for 1–2 L positive balance by the end of the case.	87	62%
We recommend against the routine use of albumin or synthetic colloid for intraoperative fluid administration.	97	90%
We recommend the use of buffered crystalloid solutions in the absence of hypochloraemia.	90	98%
We recommend the use of buffered crystalloid solutions over 0.9% saline in kidney transplantation.	75	99%
We recommend against routine use of albumin or synthetic colloids for priming the CBP circuit.	46	100%
We recommend against the use of excessive (>30 ml kg^{-1}) ultrafiltration during CBP.	33	94%
We recommend against a positive fluid balance in the first 24 h following lung resection surgery.	60	88%
We recommend against use of albumin in neurosurgical patients.	68	88%
We recommend against use of hypotonic solutions in neurosurgical patients.	89	100%
We recommend the use of 0.9% saline as a first-line fluid therapy in patients with traumatic brain injury.	Not available	–
We recommend against use of albumin in patients with traumatic brain injury.	84	96%
We recommend a mildly positive fluid balance to reduce the incidence of PONV in minor noncardiac surgery.	89	93%
In critical illness:		
We recommend use of buffered crystalloid solutions in the absence of hypochloraemia.	89	98%
We recommend against use of synthetic colloids.	87	97%
We recommend against routine use of albumin.	92	96%
We recommend use of strategies that minimise the risk of fluid accumulation and promote maintenance of intravascular normovolaemia.	90	99%
We recommend against hypervolaemia in patients with subarachnoid haemorrhage.	74	96%

including oral drinks, but use of blood products was considered to be out of scope. It was decided to focus solely on administration of fluids, starting at the time where a decision was made that fluids were indicated. Fluid management during the de-escalation phase where fluid removal could be a priority was considered out of scope. Similarly, assessment of fluid responsiveness and haemodynamic management were not included as these topics were handled by other POQI working groups.[14]

Conceptual model of intraoperative fluid management

The goals of intraoperative fluid administration are to restore and maintain adequate organ and tissue perfusion and facilitate oxygen delivery. Both intravascular hypovolaemia and fluid overload are harmful and associated with organ dysfunction (Fig. 1a and b). Importantly, patients' ability to tolerate fluids varies such that the same type and volume of fluid can have different clinical effects depending on acute and chronic comorbidities. Patients with congestive heart failure, chronic kidney disease, and acute and chronic lung disease, in particular, have 'lower fluid tolerance' and are at higher risk of fluid accumulation (Fig. 1a). Similarly, in patients with severe intravascular hypovolaemia, larger volumes of fluid can be needed to restore euvolaemia and tissue perfusion. To achieve this, fluid administration has to be individualised based on potential planned and unplanned events, including major haemorrhage and cardiac complications, and continuous monitoring and adjustment of fluid therapy is necessary to maintain fluid status in a state of intravascular euvolaemia (Fig. 1b).

Recommendations

The detailed recommendations are as follows.

Elective major noncardiac surgery

(i) **We recommend keeping preoperative fasting time short (2 h for clear fluids) to reduce thirst and prevent preoperative dehydration.** (Strong recommendation, moderate quality evidence)

Fasting and bowel preparation before surgery can cause intravascular hypovolaemia and trigger thirst and discomfort. A meta-analysis of 38 RCTs and a recent national cohort study of 22 766 anaesthetic procedures concluded that shortening the preoperative fasting time was not associated with increased aspiration risk.[15,16] In addition, several other trials and meta-analyses showed that refraining from mechanical bowel preparation before colorectal surgery was not associated with an increased rate of wound infection or anastomotic leakage.[17–19] The current American and European guidelines encourage that patients scheduled for elective surgery drink

clear fluids (including water, pulp-free juice, and tea or coffee without milk) up to 2 h before surgery.[20,21]

(ii) **We recommend intraoperative administration of an adequate volume of fluid, generally aiming for 1–2 L positive balance by the end of the case.** (Strong recommendation, high-quality evidence)

Observational studies have demonstrated an association between both insufficient and excessive fluid administration during surgery and increased duration of hospital stay and morbidity.[22–24] In patients undergoing colorectal surgery or abdominal aortic aneurysm repair, a 'zero-balance' fluid strategy reduced the number of postoperative complications compared with standard treatment.[25–28] A meta-analysis, including nine RCTs with a total of 801 patients undergoing elective abdominal surgery, confirmed that 'zero-balance' fluid therapy strategy led to a shorter hospital stay (mean difference −3.44 [95% CI −6.33 to −0.54] days; P=0.02) and fewer complications (relative risk [RR] 0.59, 95% CI 0.44 to 0.81; P<0.001) compared with those who received more fluid.[29] However, a large multicentre RCT in 3000 patients undergoing major elective abdominal surgery compared the safety of a stringently restrictive fluid regimen with that of a modestly liberal regimen.[30] Patients assigned to the modestly liberal group had a body weight increase of 1.6 kg compared with 0.3 kg in the zero-balance (restrictive) group within the first 24 h after surgery. Disability-free survival at 1 yr, the primary outcome, was similar in both groups. However, the incidence of AKI was significantly higher in the zero-balance group. Therefore, a mildly positive fluid balance (+1–2 L) by the end of the case should be aimed for to protect kidney function.

(iii) **We recommend against routine use of albumin or synthetic colloid for intraoperative fluid administration.** (Strong recommendation, low quality evidence for albumin and high-quality evidence for synthetic colloids)

Intravenous colloids, including hydroxyethyl starches (HES), dextrans, gelatines, and albumin, contain larger molecules than crystalloids. In terms of volume-sparing effects, the crystalloid to colloid equivalence ratio is ~1:1.3.[31–33] Trials comparing crystalloids *vs* colloids have had conflicting results.[33–37] A subgroup analysis of the multicentre randomised Colloids *vs* Crystalloids for the Resuscitation of the Critically Ill (CRISTAL) trial, including 741 critically ill surgical patients, found no difference in mortality between patients treated with crystalloids *vs* colloids.[34] A meta-analysis of recently published trials showed that use of colloids in surgical patients was not associated with an increased risk of mortality, AKI, or use of renal replacement therapy (RRT).[35,36,38] A recent RCT in 160 patients undergoing major surgery demonstrated that intraoperative administration of HES was associated with a lower occurrence of adverse events compared with use of buffered crystalloids.[37] Follow-up at 1 yr did not show any difference in renal outcomes between the crystalloid and HES groups, but the disability-free survival rate was higher in patients who received HES.[39] Another multicentre trial including 775 patients undergoing major abdominal surgery demonstrated that in patients at risk of postoperative AKI, use of HES for volume replacement therapy compared with 0.9% saline resulted in no significant difference in a composite outcome of major postoperative complications or death within 14 days after surgery. However, use of HES in critically ill patients has been found to be associated with an increased risk of AKI, need for RRT, or death.[31,32,40,41] Considering all these studies and the potential dose–response relationship, the panel recommended not to use HES for volume replacement therapy in surgical patients until new evidence emerges.[42]

In some institutions, albumin is used frequently during major surgery. Potential advantages include maintenance of colloid osmotic pressure and preservation of renal function.[43] In noncardiac surgery, current safety and efficacy data on albumin derive from ICU trials that showed that albumin did not impact renal function or mortality compared with 0.9% saline.[44,45] Another trial including 1818 patients showed no mortality difference between patients with sepsis treated with either crystalloids or albumin.[45] Based on the fact that albumin is more expensive and does not improve patient outcomes, we do not recommend its routine use in surgical patients.

(iv) **We recommend use of buffered crystalloid solutions in the absence of hypochloraemia.** (Weak recommendation, moderate quality evidence)

The composition of 0.9% saline (0.9% NaCl) is an unphysiological fluid that differs from buffered solutions that have

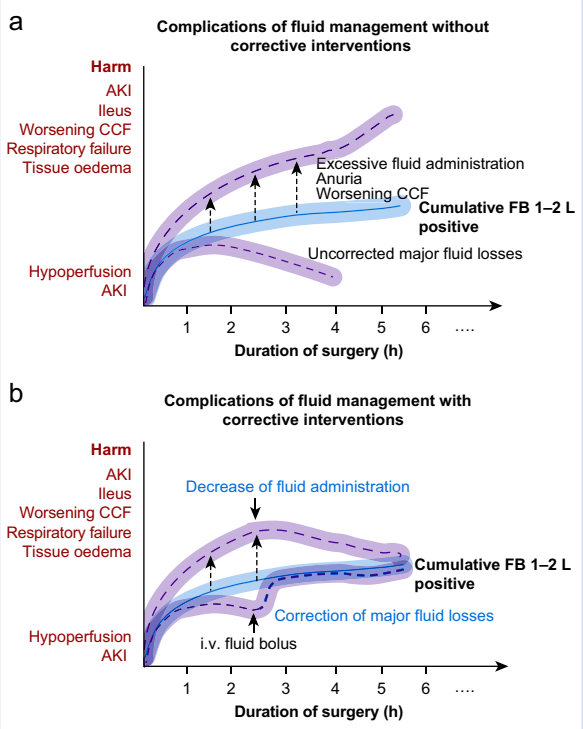

Fig 1. Both intravascular hypovolaemia and fluid overload are harmful and associated with organ dysfunction. A patient's ability to tolerate fluids varies and the same volume of fluid can have different clinical effects depending on acute and chronic comorbidities. High-risk patients have lower fluid tolerance and are at higher risk of fluid accumulation (a). Larger volumes of fluid might be needed to restore euvolaemia and tissue perfusion in patients with severe intravascular hypovolaemia. Fluid therapy needs to be adjusted and individualised to keep the individual fluid status in the 'green zone', that is, in a state of intravascular euvolaemia (b). AKI, acute kidney injury; CCF, congestive cardiac failure; FB, fluid balance.

acid–base balance and an electrolyte composition closer to that of plasma. Administration of large volumes of 0.9% saline can cause hyperchloraemic acidosis, renal vasoconstriction, and AKI.[46–52] A propensity-matched cohort study, including 22 851 patients undergoing noncardiac surgery, showed that hyperchloraemia was present in ~20% of patients and associated with increased 30-day mortality.[53] A registry-based study with more than 30 000 patients undergoing major abdominal surgery showed fewer complications in patients who had received buffered crystalloids compared with those treated with 0.9% saline.[54] The SALT trial, a cluster-randomised, multiple-crossover trial including 974 critically ill patients, concluded that patients who received large volumes of 0.9% saline had a higher rate of major adverse kidney events (MAKE), a composite endpoint consisting of death, need for RRT, and persistent renal dysfunction, compared with patients who received the same amount of buffered fluid.[55] In line with these results, a large trial conducted in 15 802 critically ill patients demonstrated that buffered crystalloids were associated with a lower risk of MAKE than 0.9% saline.[56] Another trial comparing buffered solutions with 0.9% saline in 60 patients undergoing major abdominal surgery was terminated prematurely because of the increased need for vasopressor therapy in the saline group.[57] In contrast, two large recent RCTs including a total of 19 136 patients concluded that use of 0.9% saline did not cause more postoperative complications or increased mortality compared with buffered solutions.[58,59] However, an important limitation of these trials was that the patients only received small amounts of study fluid. Based on the existing evidence and the possible existence of a dose–response relationship between the volume of 0.9% saline and adverse outcomes, buffered intravenous solutions are recommended in the perioperative period.[60]

(v) **We recommend use of buffered crystalloid solutions over 0.9% saline in kidney transplantation.** (Strong recommendation, high-quality evidence)

Kidney transplant recipients are at risk of delayed graft function (DGF), defined as the requirement for dialysis within the first week after transplantation.[61] Delayed graft function is associated with worse outcomes, including an increased risk of acute rejection, graft failure, and death.[62–66] In observational studies, use of buffered crystalloids was associated with a lower risk of DGF compared with 0.9% saline.[67,68] A meta-analysis including six RCTs and a total of 477 patients showed with moderate certainty evidence that buffered crystalloids reduced the risk of hyperchloraemic metabolic acidosis compared with 0.9% saline, but the effects on the risks of hyperkalaemia and DGF were uncertain.[69] A more recent meta-analysis including three additional trials and a matched cohort study demonstrated a lower risk of both hyperkalaemia and acidosis with buffered crystalloids compared with 0.9% saline, but had similar uncertainty regarding the effects on graft function and DGF.[70] A subsequent multicentre trial investigating the association between buffered crystalloids and 0.9% saline and the incidence of DGF in 808 patients showed that among recipients of a deceased donor kidney transplant, buffered crystalloid solutions reduced the incidence of DGF compared with 0.9% saline.[71]

Cardiopulmonary bypass

(i) **We recommend against routine use of albumin or synthetic colloids for priming the cardiopulmonary bypass circuit.** (Strong recommendation, moderate quality evidence)

Fluid management practices in cardiac surgery are a subject of an ongoing debate.[72–74] Both crystalloids and colloids (albumin or synthetic starch-based colloids) are used during cardiac surgery, including for priming of the cardiopulmonary bypass (CPB) circuit. In a survey that included 124 cardiac surgeons, cardiac anaesthesiologists and perfusionists from the USA, most perfusionists (60%) used crystalloids as the priming solution for the CPB circuit, while about one-third preferred a mixture of 25% albumin and crystalloids.[75] In a similar survey of 133 Canadian cardiac anaesthesiologists and intensivists, 62% of responders reported using albumin in cardiac surgery patients in an attempt to minimise positive fluid balance and avoid fluid overload, yet, more than 90% of responders felt that albumin administration did not reduce the risk of mortality, renal injury, or coagulopathy.[76] The use of synthetic colloids in cardiac surgery has been restricted because of concerns regarding increased bleeding and impaired postoperative kidney function, therefore human albumin is preferred over synthetic colloids in many countries.[77–79] In a recent RCT of 84 patients randomised to receive either a dextran-based CPB prime or Ringer's acetate with mannitol, patients in the dextran group had a lower haemoglobin concentration, platelet count, and fibrinogen concentration, and higher international normalised ratio (INR) and activated partial thromboplastin time, as well as longer clot formation time and a larger reduction in fibrinogen-dependent clot strength after CPB, but there were no significant differences in postoperative bleeding complications.[80]

The effects of albumin on postoperative outcomes after cardiac surgery are conflicting. In a meta-analysis including 21 controlled trials with 1346 patients, priming the CPB circuit with albumin resulted in significantly higher platelet counts after CPB when compared with crystalloids.[81] In contrast, a *post hoc* analysis of 525 patients who participated in the Effect of Fibrinogen Concentrate *vs* Cryoprecipitate on Blood Component Transfusion After Cardiac Surgery (FIBRES) trial showed that use of albumin was not associated with reduced bleeding nor with improved kidney function after surgery.[82] In addition, a RCT comparing 4% albumin, HES, and Ringer's lactate in 240 patients undergoing cardiac surgery with CPB showed no difference in postoperative chest tube drainage. However, the rates of red blood cell (RBC) transfusion and administration of fibrinogen concentrate were significantly higher in the albumin and HES groups. Furthermore, serum creatinine immediately after CPB was significantly higher in the albumin group.[83] The Albumin in Cardiac Surgery (ALBICS) trial randomised 1386 patients to receive either 4% albumin (n=693) or Ringer's acetate (n=693) for CPB priming and intravenous volume replacement intraoperatively and up to 24 h after surgery.[84] There was no significant difference between groups in relation to the primary outcome (a composite of death, myocardial injury, acute heart failure, re-sternotomy, stroke, arrhythmia, bleeding, infection, or AKI); nevertheless, albumin reduced the risk of myocardial injury but significantly increased the risk of major bleeding, re-sternotomy and infection, leading to the conclusion that the use of 4% albumin in cardiac surgery was not recommended. Based on these data, the panel recommends against routine use of albumin or synthetic colloids for priming of the CPB circuit.

(ii) **We recommend against use of excessive (>30 ml kg^{-1}) ultrafiltration during cardiopulmonary bypass.** (Weak recommendation, moderate quality evidence)

Ultrafiltration to remove excessive fluids can be performed during CPB (conventional ultrafiltration) or after the completion of CPB (modified ultrafiltration). Previous studies reported that ultrafiltration resulted in less bleeding and decreased transfusion after CPB. As such, ultrafiltration is recommended in blood conservation guidelines; however, with variable grading strength.[85,86] A meta-analysis of 10 RCTs with a total of 1004 patients concluded that ultrafiltration resulted in less postoperative bleeding and decreased requirement for blood transfusions.[87] A more recent RCT in which 60 adult cardiac surgery patients were randomised to receive modified ultrafiltration or no modified ultrafiltration after separation from CPB demonstrated that patients in the modified ultrafiltration group had lower chest tube output at 48 h after surgery and received less RBC transfusion after surgery, but markers of inflammation, specifically plasma levels of intercellular adhesion molecule and soluble tumour necrosis factor receptor, were significantly higher in the modified ultrafiltration group.[88] Several recent publications have reported that conventional ultrafiltration might be associated with an increased risk of postoperative AKI. A retrospective analysis of 6407 patients undergoing coronary artery bypass graft (CABG) surgery in 21 hospitals in Michigan found that patients exposed to conventional ultrafiltration had a higher adjusted risk of AKI.[89] Similarly, an analysis of a cohort of 1641 consecutive elective cardiac surgery patients showed that after adjustment for age, body mass index, last haematocrit before surgery, CPB duration, and vasoactive-inotropic score, a conventional ultrafiltration volume >32.6 ml kg^{-1} was associated with an increased risk of postoperative AKI.[90] Interestingly, higher conventional ultrafiltration volumes were associated with more allogeneic blood transfusions and longer stay in hospital. Finally, a meta-analysis of seven RCTs with a total of 928 patients and two observational trials with 47 007 patients, concluded that moderate ultrafiltration was associated with significantly fewer RBC transfusions, while conventional ultrafiltration did not demonstrate a similar association.[91] However, conventional ultrafiltration with removal of larger fluid volumes (>2.2 L in a 70-kg patient) was associated with postoperative AKI. Based on these data, the panel recommends against use of excessive (>30 ml kg^{-1}) ultrafiltration during CPB.

Thoracic surgery

(i) **We recommend against a positive fluid balance in the first 24 h following lung resection surgery. (**Weak recommendation, very low-quality evidence)

Liberal administration of intravenous fluids during lung resection surgery can increase extravascular lung water and contribute to formation of pulmonary oedema. It is associated with an increased risk of postoperative acute lung injury and other pulmonary complications (i.e. pneumonia, atelectasis) that can lead to prolonged mechanical ventilation, acute respiratory distress syndrome (ARDS), longer ICU and hospital stay, and mortality rates as high as 50%.[92–94] In a review that included 14 publications considered as best evidence, higher volumes of intravenous fluid were associated with significantly increased risk for postoperative lung injury, leading the authors to recommend intraoperative fluid administration rates of 1–2 ml kg^{-1} h^{-1} and avoidance of a positive intraoperative fluid balance of >1.5 L.[94] A retrospective analysis of 354 patients undergoing lung resection, including 287 lobectomies, showed that administration of higher volumes of intraoperative fluids and blood transfusion were risk factors for postoperative acute lung injury.[95] Patients with postoperative lung injury had a longer ICU and hospital stay, longer duration of mechanical ventilation, and higher postoperative mortality.

In a retrospective analysis of 1442 patients undergoing lung resection or oesophagectomy, the incidence of postoperative AKI was 5.1%.[96] There was no association between restrictive fluid administration and risk for AKI, but intraoperative administration of synthetic colloids was associated with postoperative AKI. Similar results were found in a cohort of 1129 undergoing lung resection surgery.[97] The incidence of postoperative AKI was 5.9%, and intraoperative HES administration was associated with risk of AKI. Other studies have confirmed that restrictive fluid protocols during lung resection surgery result in perioperative oliguria but are not associated with an increased risk of postoperative AKI.[98,99] In a small RCT of 40 patients undergoing lung resection surgery, targeting normovolaemia combined with a protective lung ventilation strategy resulted in no change in extravascular lung water content compared with before surgery.[100] With the use of Enhanced Recovery After Surgery (ERAS) protocols in thoracic surgery patients, there is an increased emphasis on targeting normovolaemia and early renewal of enteral intake after surgery.[101–104] Based on these data, the panel recommends against a positive fluid balance in the first 24 h following lung resection surgery.

Neurosurgery

(i) **We recommend against use of albumin in neurosurgical patients.** (Strong recommendation, moderate quality evidence)

(ii) **We recommend against use of hypotonic solutions in neurosurgical patients.** (Strong recommendation, moderate quality evidence)

(iii) **We recommend use of 0.9% saline as a first-line fluid therapy in patients with traumatic brain injury.** (Weak recommendation, moderate quality evidence)

(iv) **We recommend against use of albumin in patients with traumatic brain injury.** (Strong recommendation, moderate quality evidence)

There is a paucity of data regarding perioperative fluid therapy in neurosurgery and a distinct lack of RCTs. The majority of available data are based on expert opinion, evidence from inadequately powered subgroup analyses of RCTs within the perioperative and ICU settings, or guidance from professional societies. Evidence from fluid studies in emergency cerebral conditions is relevant for clinicians working in perioperative medicine, as patients with acute stroke, subarachnoid haemorrhage (SAH), or acute brain trauma not infrequently require neurosurgical or extracranial surgical interventions.

The primary goal for fluid therapy during neurosurgery is to maintain normal blood volume, optimise cerebral blood flow, and avoid reduction in plasma osmolarity. Both patients undergoing emergency surgery and patients presenting for elective neurosurgical interventions are frequently intravascularly fluid depleted attributable to reduced preoperative fluid intake or perioperative use of osmotic diuretics. The

osmolarity of intravenous fluids administered has a direct impact on movement of water between the plasma and the brain, cerebral water content, and risk of oedema owing to rheological effects.[105] Hypotonic solutions such as Hartmann's or Ringer's lactate are therefore commonly avoided, with a preference for 0.9% saline. Buffered isotonic solutions (such as Plasmalyte®) might be better as they are not associated with hyperchloraemic metabolic acidosis or adverse renal effects.

Both hypovolaemia and use of hyperosmolar fluids can be detrimental in relation to inadequate cerebral perfusion due to the former or end-organ function due to the latter. The potential beneficial effects of HES on the blood–brain barrier in cerebral ischaemia have not been substantiated beyond *in vitro* modelling; thus, concerns in relation to adverse effects on renal function remain.[106]

The hypothesis of a neuroprotective effect of high-dose human albumin solution in acute ischaemic stroke, based on possible reduction in infarct size and amelioration of cerebral oedema, was not confirmed in RCTs; the ALIAS (Albumin in Acute Ischemic Stroke) part 1 and 2 trials showed no difference in outcomes, yet a six-fold higher rate of pulmonary oedema in albumin-treated patients.[107] In patients with traumatic brain injury (TBI), mortality is higher when albumin is used for resuscitation, and thus the group recommends avoidance of albumin in this clinical setting.[108] Hypervolaemia to improve cerebral perfusion, such as in patients with SAH, not only exacerbates the risk of cerebral oedema but worsens outcomes because of increased extracerebral organ dysfunction, predominantly the lungs.[109] Similar findings have been shown for fluid administration and positive fluid balance in acutely brain-injured patients. A prospective effectiveness study of two observational cohorts (CENTER-TBI in Europe and OzENTER-TBI in Australia) showed higher mortality and worse functional outcomes in patients with higher mean daily fluid balance and fluid intake.[110]

Minor noncardiac surgery under general anaesthesia

(i) **We recommend a mildly positive fluid balance to reduce the incidence of postoperative nausea and vomiting in minor noncardiac surgery.** (Weak recommendation, low-quality evidence)

The incidence of postoperative nausea and vomiting (PONV) is 30% in patients undergoing general surgery and up to 80% in those with risk factors or undergoing particular procedures such as laparoscopic, gynaecologic, cholecystectomy, and bariatric surgery.[111,112] Not only is PONV distressing to patients and a major cause of patient dissatisfaction, it can also impact the risk of postoperative complications such as dehydration, wound dehiscence, electrolyte imbalances, and aspiration.[113] Additionally, PONV is associated with increased costs as a result of unintended hospital admissions.[112] However, there is a paucity of high-level evidence related to PONV in minor noncardiac surgery.

There are many modifiable intraoperative PONV risk factors such as use of nitrous oxide, opioid administration, hypovolaemia, and neuromuscular blocker reversal with neostigmine. Hypovolaemia, for instance, can lead to splanchnic hypoperfusion, which is strongly correlated to PONV (because of an increase in 5-hydroxytryptamine type 3 [5-HT_3] in the intestinal mucosa).[114] Although preemptive risk assessment and subsequent treatment is the cornerstone of mitigating PONV, the effectiveness of antiemetics is variable and a multimodal approach is necessary.[115]

In a retrospective cohort study including 553 adults undergoing elective laparoscopic cholecystectomy, lower amounts of intraoperative intravenous fluids were strongly related to PONV.[116] The researchers reported that an infusion rate of $\geq$2 ml kg^{-1} h^{-1} was adequate for reducing PONV. A retrospective analysis of 38 577 surgeries showed a relationship between intraoperative hypotension and PONV.[117] The adjusted odds for PONV were estimated to be 1.34 times higher (95% CI 1.33–1.35) when a mean arterial pressure (MAP) was <50 mm Hg for at least 1.8 min compared with MAP >50 mm Hg. Patients who experienced PONV received 448 ml more intravenous fluid than those who did not. Importantly, compared with the cohort without PONV, the PONV group included more females, a greater number of inhalation anaesthesia cases, more patients with a history of PONV, more higher-risk surgeries, and increased opioid consumption. Based on these data, the panel recommends a mildly positive fluid balance to reduce the incidence of PONV in minor noncardiac surgery.

Critical illness

(i) **We recommend use of buffered crystalloid solutions in the absence of hypochloraemia.** (Strong recommendation, high-quality evidence)
(ii) **We recommend against use of synthetic colloids.** (Strong recommendation, high-quality evidence)
(iii) **We recommend against routine use of albumin.** (Strong recommendation, high-quality evidence)
(iv) **We recommend use of strategies that minimise the risk of fluid accumulation and promote maintenance of intravascular normovolaemia.** (Weak recommendation, moderate quality evidence)
(v) **We recommend against hypervolaemia in patients with subarachnoid haemorrhage.** (Weak recommendation, moderate quality evidence)

There have been several large interventional trials of crystalloid fluids in the setting of acute and critical illness.[55,56,118,119] As surgical patients form a large proportion of patients in the ICU, some comments and recommendations are included in this statement. In the absence of hypochloraemia, there is evidence to choose a buffered crystalloid solution for fluid therapy in the ICU setting.[120] One probable exception to this recommendation is the setting of TBI, where current data support use of 0.9% saline.[59] However, whether it is the composition (i.e. NaCl concentration) or tonicity that provides the benefit over buffered solutions is unclear. For practical purposes, clinicians caring for patients with TBI or a demonstrably injured brain should choose 0.9% saline as their initial fluid. More research is required to ascertain whether the salt load is important, or whether an isotonic (but buffered) solution might bring equal benefit without the possible subsequent hazard that appears to be associated with large chloride loads.

There are two large trials suggesting a hazard signal associated with use of synthetic colloids in the ICU, and thus we recommend against their use.[31,32] In contrast, regarding albumin use, we recommend against their *routine* use, accepting that there might be certain circumstances where clinicians feel some colloidal supplementation could be beneficial.[33] The data are mixed regarding albumin in the ICU, and this is an

Table 2 Research POQI research recommendations. PONV, postoperative nausea and vomiting; POQI, PeriOperative Quality Initiative; RCT, randomised controlled trial.

- The role of albumin administration during major surgery needs to be further investigated.
- The impact of synthetic colloids on kidney function in the perioperative setting needs to be further investigated.
- Additional studies are needed to determine the parameters that guide individualised fluid management during major surgery.
- The most effective and safe fluid strategy to avoid PONV after nonmajor surgery needs to be further investigated.
- Additional RCTs are needed to guide perioperative fluid therapy in neurosurgery.
- Studies in patients with brain injury are required to ascertain whether the benefit of 0.9% saline is due to the salt load or whether an isotonic (but buffered) solution may result in similar benefits without the possible subsequent hazard associated with large chloride loads.

area where more research will be helpful. The panel felt that given the cost imbalance, the burden of proof lies with the proponents of albumin to demonstrate a benefit, rather than with the opponents to make the case against its use, before routine use can be recommended.

Fluid volume overload and fluid accumulation have clearly been shown to be associated with adverse outcomes in the ICU setting, and a policy of minimising this is recommended whenever possible.[121,122] Sometimes it is not possible to avoid, in which case attention should turn to an emphasis on volume clearance as soon as possible. Lastly, in patients with SAH, there are data suggesting that hypervolaemia is not helpful.[123]

Research agenda

Despite progress and new trials, many uncertainties remain. Table 2 summarises key areas for future research related to perioperative fluid management.

Strengths and limitations

We used a well-established modified Delphi process combining literature review with expert interpretation. The practical consensus statements and recommendations focus on important clinical areas where variation in clinical practice exists. The methodology did not include a formal systematic review or meta-analysis of the literature. The diverse group of experts was carefully selected to be from a variety of professional groups, institution types, and locations. However, a limitation for this set of recommendations is that it was not possible to include experts from all subspecialties of anaesthesia for which recommendations were made (e.g. no neurosurgeon), and the panel did not include lay members, patients, or representatives of the target population (i.e. patients who receive fluid therapy during surgery). Therefore, there remains some risk of bias.

We did not formally document iterations of statements and recommendations during the review and revision process in the working group and plenary (whole-group) sessions. We used the GRADE framework but did not formally document the process of agreeing on the classification of the strength of recommendations and the quality of evidence. We highlight areas of uncertainty or persisting discord in the explanatory text and rationale. Whilst voting by attendees of the Evidence Based Perioperative Medicine (EBPOM) 2023 World Congress cannot be considered formal expert peer review, it is an interesting and novel methodological development to explore the response of a large informed and interested audience to developing recommendations by an expert group. In this regard, the voting was conducted anonymously to minimise bias associated with public declaration of views in front of peers.

Conclusions

Perioperative fluid management should be individualised, taking into account the type of surgery and important patient factors, including intravascular volume status and acute and chronic comorbidities. Our recommendations are intended to guide clinical decision making. We acknowledge that there are ongoing gaps in knowledge resulting in variation in practice and some disagreement with our consensus recommendations (Table 1). Thus, further research in perioperative fluid management is urgently needed.

Authors' contributions

All authors contributed equally to the literature review, development of statements, and writing of the manuscript. The final manuscript was approved by all authors.

Declarations of interest

Declarations for all members of the 11th POQI meeting

MO has received research funding from Baxter Healthcare, Biomerieux, and LaJolla Pharma. JR has received consulting fees from Octapharma and Avania Medical. AZ has received consulting fees from Astute-Biomerieux, Baxter, Bayer, Novartis, Guard Therapeutics, AM Pharma, Paion, Fresenius, research funding from Astute-Biomerieux, Fresenius, Baxter, and speaker's fees from Astute-Biomerieux, Fresenius, and Baxter. ADS has served as a consultant for Novartis, Alexion, AM Pharma, Renibus, and Retia. TJG has received honoraria from Edwards and Medtronic. ME has received an honorarium for lecturing for Edwards Lifesciences and grant funding from the National Institute for Health and Care Research UK. NF is a consultant for Edwards Lifesciences. LGF has received research support from Baxter, Ortho Clinical, and Sphingotec, and honoraria from Baxter, Fresenius, Sphingotec, and Exthera. GK has received honoraria and travel expenses from Edwards Lifesciences. TEM is a consultant for Philips and Retia Medical. VMB has received honoraria from Edwards Lifesciences. JR received consulting fees from Octapharma. BS is an editor of the *British Journal of Anaesthesia*, and has received grants and honoraria from Edwards Lifesciences, Philips Medizin Systeme Boeblingen, research grants and honoraria from Baxter, honoraria from GE Healthcare, CNSystems Medizintechnik, Maquet Critical Care, Getinge, Pulsion Medical

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Appendix

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