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Review

Current views on fluid therapy in the critically ill

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Abstract ***Introduction*** Intravenous (IV) fluids are regularly ordered as part of the ICU routine rather than thoughtfully prescribed with due consideration of the goals of administration, the pharmacokinetics and dynamics of the fluids and potential adverse consequences of fluid administration. ***Methods*** The authors have attempted to summarise current clinical knowledge of IV fluids based on their assessment of the available literature. ***Results*** The review considers the use of IV fluids for resuscitation including "hypotensive" and small volume resuscitation, assessment of fluid responsiveness, systemic effects of IV fluids and the clinical utility of crystalloid or colloid solutions for fluid resuscitation. An approach to maintenance fluid administration in the ICU concludes the review. ***Conclusions*** IV fluids should be carefully prescribed with consideration of the goals of therapy and recognition of potential adverse effects. The role of clear fluids, either crystalloid or colloid is becoming increasingly limited. Blood and blood products are the cornerstone of trauma resuscitation. Resuscitation from sepsis may be better achieved by circulatory manipulation with inotropes and vasopressors rather than generation of markedly positive fluid balances.

Key words colloid · crystalloid · intravenous fluids · maintenance · resuscitation

Introduction

Intravenous (IV) fluids are regularly ordered as part of the ICU routine rather than thoughtfully prescribed with due consideration of the goals of administration, the pharmacokinetics and dynamics of the fluids and potential adverse consequences of fluid administration. However, IV fluids are required for resuscitation from volume deficit, either absolute (hypovolaemic shock) or relative (septic shock). After deficits have been corrected, fluids are still required for nutrition and medication. This review will focus on resuscitation, including rationale, endpoints and fluids used as well as fluids for maintenance in the ICU after initial resuscitation.

Resuscitation

Acute intravascular volume depletion

This is most commonly haemorrhagic but can also result from sepsis causing inappropriate vasodilation. Restoration of circulating blood volume is essential to survival [46].

"Hypotensive" resuscitation

The only reason for delayed resuscitation is a penetrating injury requiring surgical haemostasis, where MAP should be maintained at a maximum of 60 mmHg (palpable radial pulse) and a heart rate of <120. Restoration to pre-injury levels should be delayed until haemostasis has been secured at surgery [36]. Low dose vasopressin (POR-8®) 0.02—0.05 U/kg/hr (5 U [1 amp] in 50 ml or 20 U [4 amps] in 200 ml at 10—30 ml/h) may be used for no more than six

hours while awaiting surgery to minimise clear fluid administration [49].

"Small volume" resuscitation

Hypertonic saline increases intravascular volume by drawing fluid out of the interstitial space. This has the advantage of reducing endothelial and tissue oedema, promoting perfusion. The effect is prolonged by the addition of a colloid, either dextran (Rescue Flow™) or hydroxyl-ethyl starch (Hyper Haes™, only available in Europe) [7].These fluids are best used with haemorrhagic shock after achievement of haemostasis. Use in the prehospital environment cannot be recommended, even with associated traumatic brain injury, after the early termination of a study using prehospital hypertonic saline [6]. During trauma resuscitation an initial bolus of 250 ml should be given as early as possible after achieving haemostasis. The use of these products as the initial fluid bolus in septic patients has theoretical advantages that have yet to be tested. Hypertonic sodium lactate has theoretical advantages and has been studied clinically in postoperative patients [48]. Rapid clearance of lactate results in an extracellular chloride deficit that is replaced from the intracellular space with water, resulting in resolution of cellular oedema, particularly of the endothelium, while augmenting intravascular volume.

Fluid responsiveness

Only half of the ICU patients with hemodynamic instability are able to "respond" to fluid loading [25]. This is explained by the shape of the Frank-Starling curve. On the initial and steep limb of the curve, the stroke volume is highly dependent on preload: administering fluid will actually result in a significant increase in stroke volume. In contrast, if the heart is working on the terminal and flat portion of the Frank-Starling curve, it cannot utilize any preload reserve and fluid administration will not increase significantly stroke volume. Accordingly, predictors of volume responsiveness are mandatory to distinguish between patients who can benefit from fluid and those in whom fluid infusion is without any benefit and hence deleterious.

Static markers of cardiac preload

Considering the Frank-Starling relationship, the response to volume infusion is more likely to occur when the ventricular preload is low than when it is high. Thus, markers of ventricular preload have been first proposed to predict volume responsiveness. However, none of the measures of cardiac preload enables to accurately predict fluid responsiveness: neither the CVP, nor the PAOP, nor the LVEDA can discriminate between responders and non responders to fluid therapy [22]. Indeed, there is not one single curve but several ones relating stroke volume to cardiac preload, depending on the ventricular contractility. Thus a given value of cardiac preload can be associated with the presence of preload reserve in cases of normal cardiac contractility or with the absence of preload reserve in cases of decreased contractility.

Dynamic markers of volume responsiveness

The alternative method for predicting volume responsiveness is simply to induce a change in cardiac preload and to observe the resulting effects on stroke volume or cardiac output or any available surrogate, i.e. to perform a "functional assessment" of the cardiac function [22]. In fact, this is what can be done during a fluid challenge consisting in administration of 300—500 mL colloids or 500—1000 mL crystalloids over 30 mins [47]. Nonetheless, this method can be criticized because repeated infusion of such amounts of fluids could eventually exert adverse effects if there is no preload reserve, especially if pulmonary permeability is increased.

Respiratory variation of hemodynamic signals

Observing the respiratory variation of hemodynamic signals has emerged as an alternative for assessing volume responsiveness without administering fluid. The concept is based on the assumption that the cyclic changes in RV preload induced by mechanical ventilation should result in greater cyclic changes in LV stroke volume when the both ventricles operate on the steep rather than on the flat portion of the Frank-Starling curve, i.e. in case of biventricular preload preserve.

Numerous studies have consistently demonstrated that the magnitude of respiratory variation of surrogates of stroke volume allows predicting fluid responsiveness with accuracy [22]. PPV is the most popular index, since it needs only an arterial catheter to be obtained and since numerous bedside monitors calculate it automatically and displayed its value in real-time. Reliability of PPV to predict fluid responsiveness has been demonstrated in ICU patients when it is calculated from a simple artery catheter [24] or automatically calculated by a simple bedside monitor such as the IntelliVue [9], the PiCCO [17] and the LidCOplus [11] monitors. PPV can also be automatically obtained with the LidCOrapid, Mostcare and Pulsioflex uncalibrated monitors. Non-invasive finger pressure monitors such as the CNAP also allows calculation of a non-invasive PPV, which seems as reliable as PPV to assess fluid responsiveness in critically ill patients [27].

Other markers

The following other surrogates of stroke volume respiratory variation can be used at the bedside:
— Respiratory variation of the pulse contour-derived stroke volume measured by the PiCCO [2] or by the

FloTrac/Vigileo [3] or by the LidCOplus [11].
— respiratory variation of the sub-aortic flow assessed by echocardiography [14] and respiratory variation of the descending aortic blood flow assessed by esophageal Doppler [29].
— other heart-lung interaction indices like respiratory variation of inferior [13] or superior vena cava diameter [45] (echocardiography) have been also validated as accurate predictors of volume responsiveness. Some limitations of heart-lung interaction to detect volume responsiveness must be remembered [22]. First, the predictive value of PPV is lower in case of low than normal tidal volume ventilation and in case of low lung compliance. Thus, in patients with ARDS, the value of PPV is questioned. Second, in cases of spontaneous breathing activity and/or cardiac arrhythmias the beat-to-beat variations in hemodynamic signals is clearly not related to biventricular preload reserve.
— the PLR test. Most critically ill patients experience spontaneous breathing activity during mechanical ventilation since less sedative drugs than in the past are used. In such cases, the PLR test has been proposed as an alternative [31]. Lifting the legs from the horizontal position induces a gravitational transfer of blood from the lower limbs toward the intrathoracic compartment. It significantly increases the right and left cardiac preload supporting the evidence that the volume of blood transferred to the heart during PLR is sufficient for challenging the Frank-Starling curve. The excellent ability of PLR to serve as a test of preload responsiveness was demonstrated in patients with acute circulatory failure [10]. A 10—12% increase in cardiac output or stroke volume during PLR enables to predict fluid responsiveness, even patients with cardiac arrhythmias and/or spontaneous ventilator triggering [30]. However, it is important to monitor the hemodynamic response to PLR with a real-time cardiac output device. In this regard, technologies as echocardiography, esophageal Doppler, PiCCO2, USCOM and FloTrac/Vigileo are suitable for this purpose.The best way to perform the PLR test is to elevate the lower limbs at 45° (automatic bed motion) from the 45° semi-recumbent position rather than from the supine position [31]. This technique has the advantage to mobilize not only the blood contained in the legs but also the blood contained in the splanchnic reservoir, that significantly improves the sensitivity of the PLR test.
— the end-expiratory occlusion test. This test is another alternative for testing fluid responsiveness. During mechanical ventilation, each insufflation interrupts the venous return. In a recent study, we hypothesized that stopping the respiratory cycles during an end-expiratory occlusion could increase the venous return by interrupting the cyclic impediment in venous return and that this could serve for predicting fluid responsiveness [28]. In patients with cardiac arrhythmias or spontaneous triggering of the ventilator, an increase by more than 5% in arterial pulse pressure or in pulse contour-derived cardiac index measured by the $PiCCO_2$ device during a 15-sec end-expiratory occlusion enables to predict fluid responsiveness with a good accuracy. The end-expiratory occlusion test can be used in patients with low lung compliance [26]. This test takes its advantage from its easiness but it cannot be used in patients in whom the spontaneous triggering of the ventilator is sufficient for interrupting the end-expiratory occlusion and, obviously, in non ventilated patients. As for the PLR test, because of its brevity, the end-expiratory occlusion test requires the use of a real-time cardiac output monitor to assess the hemodynamic response. Therefore, except PAC, all the other hemodynamic monitors described above could be suitable.

When to stop fluid administration?

Fluid administration can be stopped in two circumstances:
— the markers of fluid responsiveness are becoming negative; for example, PPV or SVV have become low or the PLR test has become negative. This means that the patient has become fluid unresponsive and stopping fluid makes sense [43],
— in spite of persistence of positive fluid responsiveness markers, the tolerance of fluid administration is anticipated to be poor if continued. A cumulative positive fluid balance is well recognised as an adverse prognostic indicator in the ICU [5]. One can also take into consideration, an abrupt rise in EVLW (measured by the $PiCCO_2$ or the VolumeView monitor) or in PAOP during the fluid infusion.

What fluid to administer?

What is the place for balanced solutions?

The majority of clinicians mistakenly believe that "pH balanced" intravenous (IV) fluids, when infused into patients, have little effect other than fluid loading. This misconception about "pH balanced" fluids is responsible for much ignorance about the systemic effects of these fluids, especially on acid-base balance, of fluids in common use [21]. A solution of 0.9% "pure" saline (pH=7.0 at 25°C) has similar acid-base effects as that of 0.9% saline equilibrated with atmospheric CO_2 (pH=5.6 at 25°C). It is also a matter of common observation that infusion of 0.9% saline causes metabolic acidosis (mistakenly referred to as hyperchloraemic metabolic acidosis – HCMA). However, until recently, mechanisms of HCMA and other effects of IV fluid administration were poorly understood [20].

The Stewart approach to acid-base physiology can be used to explain many of the effects of electrolyte solutions on systemic pH [21]. Stewart proposed that the acid-base status of a fluid depends upon three independent variables:
— CO_2;
— strong ion difference (SID) which is the difference between the sum of strong cations and strong anions and
— sum of total weak acids (referred to as A_{TOT} by

Stewart); this effect is almost entirely due to plasma albumin (and phosphate, when increased).

Stewart considers H^+ and HCO_3^- as "dependent" variables i.e. variables that have no influence on pH of a solution but are determined by above three independent variables. Unfortunately, for "HCO_3^- centric" clinicians, this approach remains generally unknown. Put simply, in the Stewart approach, when SID narrows (either because of a decrease in sum of cations relative to sum of anions or increase in sum of anions relative to sum of cations), metabolic acidosis follows due to hydrolysis of water; converse being true when the sums of cations and/or anions move in the opposite directions. Dilution of A_{TOT} results in a mild but significant metabolic alkalosis (due to dilution of "weak" acid); conversely, an increase in A_{TOT} (e.g. albumin infusion) results in metabolic acidosis [32].

Changes in CO_2 do not affect plasma pH due to fluid infusion (as there is no effect on SID or ATOT). IV crystalloids do not contain any ions contributing to A_{TOT}. Infusion of crystalloid will thus cause a metabolic alkalosis by diluting ATOT. This alkalotic effect may be modified by effect on SID which, in turn, depends upon the electrolyte composition of the crystalloid in question. Thus crystalloids with a zero SID (0.9% saline being a very good example, as well as fluids without electrolytes, such as mannitol and 5% dextrose) will differentially alter Na+ and Cl- content of plasma resulting in a narrowing of SID and thus result in a metabolic acidosis (despite dilution of A_{TOT}). Stewart did not calculated that a SID of about 24 is required to have a "neutral" effect on systemic acid-base balance [32]. Among commercially available fluids, Hartmann's solution (effective SID 27) comes closest to this "ideal fluid". However, these commercial preparations depend upon in vivo metabolism of incorporated anion component (lactate in case of Hartmann's). Albumin and gelatin based colloids (Gelofusine®, Haemaccel®) contain A_{TOT} and thus do not cause dilution of A_{TOT}. These solutions have a variable effect on SID whereas starches like Pentaspan and Hydroxyethyl Starches have a zero SID causing similar problems as with 0.9% saline and other crystalloids with zero SID.

Besides these metabolic effects, high Cl^- containing fluids have been shown to be detrimental to renal circulation [19]. These observations, made initially in animal experiments, have recently been confirmed in healthy human volunteers [41]. High chloride fluid management strategies, based on 0.9% saline reliably cause metabolic acidosis. The effects on systemic pH and renal function may not cause harm in healthy individuals; however, caution is advised in patients at risk (e.g. a diabetic patient having radio-contrast for interventional radiology). Recent research has demonstrated benefits from a restrictive chloride resuscitation strategy [50]. The Stewart approach to acid-base physiology comprehensively elucidates systemic effects of various fluids. This approach emphasises the fact that IV fluids are drugs and have side effects like any other drug; this must be taken into account while prescribing and administering any IV fluid [19].

Crystalloids or colloids?

Initial resuscitation from both haemorrhagic and septic shock can be crystalloid based using a balanced salt solution (e.g. Plasmalyte L™) [46]. Evidence of ongoing intravascular volume depletion (systolic pressure variation, oliguria, persistent hyperlactaemia) is best managed with a colloid solution that will remain intravascular. Depending on underlying cardiac function boluses of 100—300 ml may be given over 30—60 min until the chosen endpoint has been reached [22].

The role of colloids has been called into question over the past decade. Gelatins have a short intravascular persistence and a risk of anaphylactic reactions that limit their usefulness [44]. Hydroxy-ethyl starches (HESs) have variable effects depending on their molecular weight and molar substitution. A detrimental effect on kidney function has mostly been observed for higher molecular weight starches (e.g. MW 200) with higher (≥0.5) molar substitution. Higher molecular weight starches (and some gelatin preparations) seem to cause "osmotic nephritis" like lesions in renal tubular cells [39]. Lower molecular weight (MW 130) and molar substitution (0.4) HES preparations (Voluven®, Venofundin®) were developed to limit adverse effects on clotting and kidney function [35]. However the literature on these agents has failed to show a benefit either in improving haemodynamics or reducing renal dysfunction [8]. Two randomised controlled trials published recently have shown that even lower molecular weight starches show an increased incidence of kidney injury and possibly increased risk of death in septic and mixed ICU populations [34, 37]; the larger of these two trials (CHEST, 2012; n=7000) also did not observe any "haemodynamic advantage" traditionally attributed to colloids.

Current recommendations?

A number of influential intensivists have recommended omission of starches from resuscitation, particularly in septic shock following a recently published meta-analysis [51]. Unfortunately the meta-analysis includes a number of high molecular weight and/or high substitution HES solutions no longer in clinical use. Much of the work on new generation HES solutions with lower molecular weight and less substitution were carried out by Dr. J Boldt, who has been shown to have committed major research fraud [38], necessitating withdrawal of his studies and thus limiting the amount of available evidence for new generation HES solutions.

Most HES solutions have been suspended in 0.9%

saline, where high chlorides are not beneficial. One of the few studies to assess the effect of HES on trauma resuscitation showed no harm from HES 130/0.4 suspended in a balanced crystalloid [18].

Crystalloid administration is not without hazards. Excessive crystalloid administration is associated with generation of oedema of skin, abdominal organs (leading to abdominal compartment syndrome), kidneys (leading to renal compartment syndrome, contributing to acute renal failure), and heart (leading to myocardial dysfunction) [12].

Current recommendations for trauma resuscitation emphasise early administration of blood and blood products, with limitation of clear fluid administration, either crystalloid or colloid [4]. A similar approach could be taken in sepsis, where capillary leak with generation of oedema is well recognised.

What to do in chronic intravascular volume depletion?

Medical patients with gradual dehydration over many hours to days as well as those with sepsis will have significant interstitial as well as intravascular volume depletion. The major deficit is crystalloid so resuscitation can be crystalloid based using a balanced salt solution and correcting electrolyte deficiencies as they are identified by regular monitoring [46].

Maintenance fluids

In providing maintenance fluids care should be taken to avoid causing tissue oedema. This requires limitation of crystalloid administration [15].

What about nutrition?

Every attempt should be made to provide nutrition by the enteral route. Clear fluids containing electrolytes and both short chain polysaccharides and peptides are now available for preoperative hydration. These fluids may be given up to two hours prior to elective surgery [1]. After intra-abdominal surgery, a fine-bore feeding tube should be placed in the jejunum from the nose to allow immediate postoperative administration of semi-elemental enteral feed to maintain the integrity of the enterocytes and gut associated lymphoid tissue [16]. Intravenous nutrition may be provided peripherally (5% dextrose) for a maximum of five days post injury. After this period, or earlier with evidence of pre-injury nutritional depletion, if there is absent or inadequate Enteral Nutrition, Parenteral Nutrition – including CHO, lipid and peptides should be provided [23]. Phosphate levels should be checked prior to and after initiation of nutrition, if the period of starvation is longer than 48 hours. The refeeding syndrome is primarily due to acute hypophosphataemia, which is corrected with potassium hydrogen phosphate, replaced as 40 mmol $KHPO_4$ and 2 g $MgSO_4$ in 200 ml saline over four hours, repeated until phosphate levels are normalised [42].

Other fluid requirements

The priority in ICU is maintenance of oxygen delivery (by adequate transfusion) and coagulation (by appropriate use of clotting factors). If any of these products is required clear fluids, either crystalloid or colloid, will not be required, and may be harmful in the presence of endothelial damage as occurs in Acute Lung Injury [33].

Crystalloids are required as vehicles for administration of medication, including antibiotics, sedation and inotropes/vasopressors. The fluid required for the administration of these solutions together with those required for nutrition should not exceed 2 ml/kg/hr. The fluid chosen is usually 0.9% saline but 5% dextrose or Plasmalyte™ may be used if the serum electrolytes require. The solutions infused may also be made more concentrated to limit volume requirements e.g. adrenalin 4—8—16—32 mg; morphine 50—100—200 mg in 200ml/50ml [40]. ICU patients require a goal directed approach to fluid management consisting of two stages: early and rapid correction of volume deficit by liberal fluid administration followed by a restrictive fluid administration strategy to avoid the generation of a positive fluid balance indicative of dangerous organ oedema.

Key messages

Fluids are drugs with indications, contra-indications, harms, benefits and doses. Fluid prescription can, thus, never be routine, but must be considered in the same way as a drug prescription. Haemorrhagic shock should be resuscitated with blood or blood products. Fluids should be restricted prior to achievement of haemostasis and clear fluid minimised to avoid dilutional coagulopathy. Maintenance crystalloid solutions should be limited to 2 ml/kg/hr, including medication, nutrition and line flushes. Every effort should be made to feed enterally as early as possible.

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References

1. Awad S, Soni DN: What's new in perioperative nutritional support? Curr Opin Anesthesiol 2011;24:339—348
2. Berkenstadt H, Margalit N, Hadani M, et al. Anesth Analg 2001;92:984—989
3. Biais M, Nouette-Gaulain K, Cottenceau V, et al. Uncalibrated pulse contour-derived stroke volume variation predicts fluid responsiveness in mechanically ventilated patients undergoing liver transplantation. Br J Anaesth 2008;101:761—768
4. Bonanno FG: Hemorrhagic shock: The "physiology approach". J Emerg Trauma Shock. 2012;5(4):285—295
5. Boyd JH, Forbes J, Nakada TA, Walley KR, Russell JA: Fluid resuscitation in septic shock: A positive fluid balance and elevated central venous pressure are associated with increased mortality. Crit Care Med 2011;39:259—265
6. Bulger EM, May S, Brasl KJ, et al. Out-of-Hospital Hypertonic Resuscitation Following Severe Traumatic Brain Injury: A Randomized control trial. J Am Med Assoc 2010;304:1455—1464
7. Bulger EM: 7.5% Saline and 7.5% Saline/6% Dextran for Hypovolemic Shock. J Trauma 2011;70:S27—29
8. Bunkhorst FM, Engel C, Bloos F et al. Intensive insulin therapy and pentastarch resuscitation in severe sepsis. N Eng J Med 2008;358:125—139
9. Cannesson M, Slieker J, Desebbe O, et al. The ability of a novel algorithm for automatic estimation of the respiratory variations in arterial pulse pressure to monitor fluid responsiveness in the operating room. Anesth Analg 2008;106:1195—1200
10. Cavallaro F, Sandroni C, Marano C, et al. Diagnostic accuracy of passive leg raising for prediction of fluid responsiveness in adults: systematic review and meta-analysis of clinical studies. Intensive Care Med 2010;36:1475—1483
11. Cecconi M, Monti G, Hamilton MA, et al. Efficacy of functional hemodynamic parameters in predicting fluid responsiveness with pulse power analysis in surgical patients. Minerva Anestesiol 2012;78:527—533
12. Cordemans C, De Laet I, Van Regenmortel N, et al. Fluid management in critically ill patients: the role of extravascular lung water, abdominal hypertension, capillary leak, and fluid balance. Ann Intens Care 2012;2:S1—12
13. Feissel M, Michard F, Faller JP, et al. The respiratory variation in inferior vena cava diameter as a guide to fluid therapy. Intensive Care Med 2004;30:1834—1837
14. Feissel M, Michard F, Mangin I, et al. Respiratory changes in aortic blood velocity as an indicator of fluid responsiveness in ventilated patients with septic shock. Chest 2001;119:867—873
15. Hahn RG: Volume Kinetics for Infusion Fluids. Anesthesiol 2010;113:470—481
16. Hodgson RE: Enterocyte protection – a new goal in ICU nutrition. South Af J Crit Care 2007;23:6—8
17. Hofer CK, Müller SM, Furrer L, et al. Stroke volume and pulse pressure variation for prediction of fluid responsiveness in patients undergoing off-pump coronary artery bypass grafting. Chest 2005;128:848—854
18. James MFM, Michell WL, Joubert IA, et al. Resuscitation with hydroxyethyl starch improves renal function and lactate clearance in penetrating trauma in a randomized controlled study: the FIRST trial (Fluids in Resuscitation of Severe Trauma). Br J Anaesth 2011;107:693—702
19. Kishen R, Blakeley S: Can the choice of resuscitation fluid adversely affect renal function in the critically ill? In: Nayyar V, Srinivas S, Kishen R, Peter JV (eds). Critical Care Update 2009. Jaypee Publishers, Delhi 2010 (available from the author)
20. Kishen R, Honoré P: Acid-base physiology in the 3rd millennium: Bedside utility of Stewart approach. Ann Intensive Care 2013 (in press)
21. Kishen R: The Trouble with Bicarbonate! : http://www.theiaforum.org/Article_Folder/Stewart-Approach-Acid-Base-Disorders.pdf
22. Marik PE, Monnet X, Teboul JL: Hemodynamic parameters to guide fluid therapy. Ann Intensive Care 2011;1:1
23. Marik PE: Maximizing Efficacy from parenteral nutrition in critical care: appropriate patient populations, Supplemental Parenteral Nutrition, Glucose Control, Parenteral Glutamine, and Alternative Fat Sources. Curr Gastroenterol Rep 2007;9:345—353
24. Michard F, Boussat S, Chemla D, et al. Relation between respiratory changes in arterial pulse pressure and fluid responsiveness in septic patients with acute circulatory failure. Am J Respir Crit Care Med 2000;162:134—138
25. Michard F, Teboul JL: Predicting fluid responsiveness in ICU patients: a critical analysis of the evidence. Chest 2002; 121:2000—2008
26. Monnet X, Bleibtreu A, Ferré A, et al. Passive leg-raising and end-expiratory occlusion tests perform better than pulse pressure variation in patients with low respiratory system compliance. Crit Care Med 2012;40:152—157
27. Monnet X, Dres M, Ferré A, et al. Prediction of fluid responsiveness by a continuous non-invasive assessment of arterial pressure in critically ill patients: comparison with four other dynamic indices. Br J Anaesth 2012;109:330—338
28. Monnet X, Osman D, Ridel C, et al. Predicting volume responsiveness by using the end-expiratory occlusion in mechanically ventilated intensive care unit patients. Crit Care Med 2009;37:951—956
29. Monnet X, Rienzo M, Osman D, et al. Esophageal Doppler monitoring predicts fluid responsiveness in critically ill ventilated patients. Intensive Care Med 2005;31:1195—1201
30. Monnet X, Rienzo M, Osman D, et al. Passive leg raising predicts fluid responsiveness in the critically ill. Crit Care Med 2006;34:1402—1407
31. Monnet X, Teboul JL: Passive leg raising. Intensive Care Med 2008;34:659—663
32. Morgan TJ: Clinical review: The meaning of acid-base abnormalities in the intensive care unit – effects of fluid administration. Crit Care 2004;9:204—211
33. Murphy CV, Schramm GE, Doherty JA, et al. The importance of fluid management in acute lung injury secondary to septic shock. Chest. 2009;136(1):102—109
34. Myburgh JA, Finfer S, Bellomo R et al. Hydroxyethyl starch or saline for fluid resuscitation in intensive care. N Eng J Med 2012.doi:10.1056/NEJMoa1209759
35. Niemi TT, Miyashita R, Yamakage M: Colloid solutions: a clinical update. J Anesth 2010;24:913—925
36. Pepe PE, Dutton RP, Fowler RL: Preoperative resuscitation of the trauma patient. Curr Opin Anesthesiol 2008;21:216—221
37. Perner A, Haase N, Guttormsen AB et al. Hydroxyethyl starch versus Ringer's acetate in sepsis. N Eng J Med 2012;367:124—134
38. Reinhart K, Takala J: Hydroxyethyl Starches: What Do We Still Know? Anesth Analg March 2011;112:507—551
39. Roche AM, James MFM: Colloids and crystalloids: does it matter to the kidney? Curr Opin Crit Care 2009;15:520—524
40. Shum HP, Lee FMH, Chan KC, Yan WW: Interaction between fluid balance and disease severity on patient outcome in the critically ill. J Crit Care 2011;26:613—619
41. Simon TP, Schuerholz T, Huter L et al. Impairment of renal function using hyperoncotic colloids in a two hit model of shock: a prospective randomised study. Crit Care 2012;16:R16.doi:10:1186/cc11161
42. Skipper A: Refeeding syndrome or refeeding hypophosphatemia: a systematic review of cases. Nutrit Clin Prac 2012;27:34—40
43. Teboul JL, Monnet X: Detecting volume responsiveness and unresponsiveness in intensive care unit patients: two different problems, only one solution. Crit Care 2009;13:175
44. Thomas-Rueddel DO, Vlasakov V, Reinhart K, et al. Safety of gelatin for volume resuscitation—a systematic review and meta-analysis. Intens Care Med 2012;38:1134—1142

45. Vieillard-Baron A, Chergui K, Rabiller A, et al. Superior vena caval collapsibility as a gauge of volume status in ventilated septic patients. Intensive Care Med 2004;30:1734—1739
46. Vincent JL, Ince C, Bakker J: Circulatory shock - an update: a tribute to Professor Max Harry Weil. Crit Care 2012;16:239
47. Vincent JL, Weil MH: Fluid challenge revisited. Crit Care Med 2006;34:1333—1337
48. Wagner F, Radermacher P, Morimatsu H: Hypertonic lactate solutions: a new horizon for fluid resuscitation? Intens Care Med 2008;34:1749—1751
49. Wenzel V, Raab H: Arginine vasopressin: a promising rescue drug in the treatment of uncontrolled haemorrhagic shock. Best Prac Res Clin Anaesthesiol 2008;22:299—316
50. Yunos NM, Bellomo R, Hegarty C, et al. Association between a chloride-liberal vs chloride-restrictive intravenous fluid administration strategy and kidney injury in critically ill adults. J Am Med Assoc 2012;308:1566—1572
51. Zarychanski R, Abou-Setta AM, Turgeon AF, et al. Association of hydroxyethyl starch administration with mortality and acute kidney injury in critically ill patients requiring volume resuscitation: a systematic review and meta-analysis. J Am Med Assoc 2013;309:678—688