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Edited by
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Preface

Intravenous fluid is a cornerstone in the treatment of the surgical patient. Perioperative management with intravenous fluids is a responsibility of the anesthetist, but many others, including the surgeon, must be oriented in the principles that guide the therapy.

The clinical use of infusion fluids has long been overlooked as a science. One of the main reasons for the neglect is that fluids have not been considered to be drugs. Many of the usual requirements for registration, such as the specification of a therapeutic window and detailed pharmacokinetics, have been overlooked. On the other hand, the experience of the anesthetist is indeed that infusion fluids are drugs. Their appropriate use can be life-saving, while inappropriate use might jeopardize the clinical outcome and even be a threat to the patient's life.

The scattered scientific basis for perioperative fluid therapy has necessitated the development of experience-based "rules-of-thumb" which still play an enormously important role in daily practice. They are usually based on a summation of perceived and measured losses and also include compensation for various factors, such as anesthesia-induced vasodilatation and protein losses due to inflammation.

Alongside the trial-and-error approach and theoretical calculations, scientific methods have been used to find evidence-based guidelines. This has resulted in a marked change over the past decade. The amount of fluid infused has been shown to affect the course of the postoperative follow-up greatly, at least after some types of operation. Another important insight is that guiding fluid therapy by dynamic hemodynamic measures reduces the risk of postoperative complications. A changeover from relying on the pulmonary artery catheter to less invasive and even non-invasive tools for the monitoring of fluid administration is in full swing.

I am extremely proud to welcome contributions from colleagues around the world who are among the highest-ranked researchers in the field of perioperative fluid therapy. I have taken great care to ask researchers and clinicians whom I respect and admire for outstanding contributions to our knowledge about how fluid therapy should be managed. They have written authoritative chapters about subjects in which every anesthetist should be updated when working with patients subjected to common types of surgery.

Each chapter should be read as an independent essay, which means that a topic discussed briefly by one author is often explored in more detail by another. As you will see, the experts take you by the hand and tell you not only what to do, but also why.

Overview of chapter summaries

Section 1: The fluids

Chapter 2. Crystalloid fluids

Robert G. Hahn

Crystalloid electrolyte solutions include isotonic saline, Ringer's lactate, Ringer's acetate, and Plasma-Lyte. In the perioperative period these fluids are used to compensate for anesthesia-induced vasodilatation, small to moderate blood losses, and urinary excretion. Although evaporation consists of electrolyte-free water, such fluid losses are relatively small during short-term surgery and may also be compensated by a crystalloid electrolyte solution.

These fluids expand the plasma volume to a lesser degree than colloid fluids as they hydrate both the plasma and the interstitial fluid space. However, the distribution to the interstitial fluid space takes 25–30 min to be completed, which is probably due to the restriction of fluid movement by the finer filaments in the interstitial gel. The slow distribution gives crystalloid electrolyte solutions a fairly good plasma volume-expanding effect as long as the infusion continues and shortly thereafter.

Isotonic saline is widely used, but has an electrolyte composition that deviates from that of the extracellular fluid ("unbalanced"). This fluid is best reserved for special indications, such as hyponatremia, hypochloremic metabolic alkalosis, and disease states associated with vomiting. Isotonic saline may also be considered in trauma and in children undergoing surgery. Hypertonic saline might be considered in neurosurgery and, possibly, in preoperative emergency care.

Ringer's lactate, Ringer's acetate, and Plasma-Lyte have been formulated to bemore similar to the composition of the ECF ("balanced fluids"). They are the mainstay of fluid administration in the perioperative period and should be used in all situationswhere isotonic saline is not indicated.

Chapter 3. Colloid fluids

Robert G. Hahn

Colloid fluids are crystalloid electrolyte solutions with a macromolecule added that binds water by its colloid osmotic pressure. As macromolecules escape the plasma only with difficulty, the resulting plasma volume expansion is strong and has a duration of many hours. Clinically used colloid fluids include albumin, hydroxyethyl starch, gelatin, and dextran.

The plasma volume expansion shows one-compartment kinetics, which means that colloids, in contrast to crystalloids, have no detectable distribution phase. Marketed fluids are usually composed so that the infused volume expands the plasma volume by the infused amount. Exceptions include rarely used hyperoncotic variants and mixtures with hypertonic saline.

The main indication for colloid fluids is as secondline treatment of hemorrhage. Because of inherent allergenic properties, crystalloid electrolyte fluids should be used when the hemorrhage is small. A changeover to a colloid should be performed only when the crystalloid volume is so large that adverse effects may ensue (mild effects at 3 liters, severe at 6 liters). The only other clinical indication is that dextran can be prescribed to improve microcirculatory flow.

There has been lively debate about clinical use of colloid fluids after studies in septic patients have shown that hydroxyethyl starch increases the need for renal replacement therapy. This problem has not been found in the perioperative setting but the use of starch has still been restricted.

The colloids have defined maximum amounts that can be infused before adverse effects, usually arising from the coagulation system, become a problem.

Chapter 4. Glucose solutions

Robert G. Hahn

Glucose 5% is given after surgery to prevent starvation and to provide free water for hydration of the intracellular fluid space. Glucose is sometimes infused before surgery as well, in particular when surgery is started late during the day, and, in some hospitals, also as a 2.5% solution during the surgical procedure. Glucose infusion has also been used together with insulin to improve outcome in cardiac surgery and in intensive care.

Because of the risk of hyperglycemia, intravenous glucose infusions need to be managed with knowledge, attention, and responsibility. Hyperglycemia promotes wound infection and osmotic diuresis, by which the kidneys lose control of the urine composition. The anesthetist has to consider a four-fold modification in infusion rate of glucose to account for the perioperative change in glucose tolerance. The suitable rate of infusion when a glucose infusion is initiated can be predicted by pharmacokinetic simulation. A control plasma sample taken one hour later shows whether the prediction was correct, and also that plasma glucose will only rise by another 25% if no adjustment of the infusion rate is made.

Glucose solution is contraindicated in acute stroke and not recommended in operations associated with a high risk of perioperative cerebral ischemia, such as carotid artery and cardiopulmonary bypass surgery. Subacute hyponatremia is a postoperative complication that is promoted by infusing >1 liter of plain 5% glucose in the perioperative setting.

Chapter 5. Hypertonic fluids[1]

Eileen M. Bulger

Hypertonic fluids have an osmotic content that is higher than in the body fluids. When this content remains in the extracellular fluid space, such as with saline, the volume effect becomes very powerful owing to osmotic allocation of fluid from the intracellular to the extracellular fluid space. These fluids have also been found to favorably modulate the inflammatory response. The most studied preparations are saline 7.5% with and without a colloid (dextran or hydroxyethyl starch) added.

This chapter reviews the current clinical evidence regarding the use of hypertonic fluids for the early resuscitation of injured patients and for perioperative indications for a variety of procedures. While there is a wealth of preclinical data suggesting potential benefit from this resuscitation strategy, the clinical trial data have failed to show any clear benefit to the prehospital administration of these fluids in trauma patients, and the data for perioperative use is limited. More study is needed to define the best use of these fluids in a variety of patient populations and surgical procedures.

[1] For chapters 5, 12, 13, 15, 16, 20, 21, 25, 28, and 31, summary was compiled by the Editor.

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Chapter 6. Fluids or blood products?

Oliver Habler

Thanks to the impressive anemia tolerance of the human body, red blood cell (RBC) transfusion may often be avoided despite even important blood losses – provided that normovolemia is maintained. While a hemoglobin (Hb) concentration of 60–70 g/l can be considered safe in young, healthy patients, older patients with preexisting cardiopulmonary morbidity should be transfused at Hb 80–100 g/l. Physiological transfusion triggers (e.g. decrease of VO_2, ST-segment depression in the ECG, arrhythmia, continuous increase in catecholamine needs, echocardiographic wall motion disturbancies, lactacidosis) appearing prior to the aforementioned Hb concentrations necessitate immediate RBC transfusion. In the case of unexpected massive blood losses and/or logistic difficulties impeding an immediate start of transfusion, the anemia tolerance of the patient can be effectively increased by several measures (e.g. hyperoxic ventilation, muscular relaxation, or adequate depth of anesthesia).

In cases of dilutional coagulopathy – often reflected by an intraoperatively diffuse bleeding tendency – a differentiated coagulation therapy can either be directed on the basis of viscoelastic coagulation tests (e.g. thromboelastometry/-graphy) or directed empirically by replacing the different components in the order of their developing deficiency (i.e. starting with fibrinogen, followed by factors of the prothrombin complex and platelets). The "global" stabilization of coagulation with fresh frozen plasma requires the application of high volumes and bears the risk of cardiac overload (TACO) and immunological alterations (TRIM).

Section 2: Basic science

Chapter 7. Body volumes and fluid kinetics

Robert G. Hahn

Body fluid volumes can be measured and estimated by using different methods. A key approach is to use a tracer by which the volume of distribution of an injected substance is measured. Useful tracers occupy a specific body fluid space only. Examples are radioactive albumin (plasma volume), iohexol (extracellular fluid space), and deuterium (total body water). The transit time from the site of injection to the site of elimination must be considered when using tracers with a rapid elimination, such as the indocyanine green dye. The volume effect of an infusion fluid can be calculated by applying a tracer method before and after the administration.

Guiding estimates of the sizes of the body volumes can be obtained by bioimpedance measurements and anthropometric equations.

The blood hemoglobin (Hb) concentration is a frequently used endogenous tracer of changes in blood volume. Hb is the inverse of the blood water concentration, and changes in Hb indicate the volume of distribution of the infused fluid volume. Certain assumptions have to be made to convert the Hb dilution to a change in blood volume. Volume kinetics is based on mathematical modeling of Hb changes over time which, together with measurements of the urinary excretion, can be used to analyze and simulate the distribution and elimination of infusion fluids.

Chapter 8. Acid–base issues in fluid therapy

Niels Van Regenmortel and Paul W. G. Elbers

Solutions such as NaCl 0.9% are an established cause of metabolic acidosis. The underlying mechanism, a reduction in plasma strong ion difference, [SID], is comprehensibly explained by the principles of the Stewart approach. Fluid-induced metabolic acidosis can be avoided by the use of so-called balanced solutions that do not cause alterations in plasma [SID]. Many balanced solutions are commercially available, their only drawback being their higher cost. Since NaCl 0.9% remains the first choice of resuscitation fluid in large parts of the world, there remains an important question over whether a large-scale upgrade to balanced solutions should be at hand. There is a lack of high-quality data at the time of writing, but there is increasing evidence that hyperchloremia has a detrimental effect on renal function and has an economic impact of its own. Therefore, until we have more definitive data, the use of balanced solutions in patients who need a relevant amount of fluid therapy seems to be a pragmatic choice.

Chapter 9. Fluids and coagulation

Sibylle A. Kozek-Langenecker

Infusion therapy is essential in intravascular hypovolemia and extravascular fluid deficits. Crystalloid fluids and colloidal volume replacement affect blood coagulation when infused intravenously. Questions remain over whether unspecific dilution and specific side effects of infusion therapy are clinically relevant in patients with and without bleeding manifestations, and whether fluid-induced coagulopathy is a risk factor for anemia, blood transfusion, mortality, and a driver for resource use and costs. In this chapter, pathomechanisms of dilutional coagulopathy and evidence for its clinical relevance in perioperative and critically ill patients are reviewed. Furthermore, medico-legal aspects are discussed. The dose-dependent risk of dilutional coagulopathy differs between colloids (dextran > hetastarch > pentastarch > tetrastarch > gelatins > albumin). Risk awareness includes monitoring for early signs of side effects. With rotational thromboelastometry/thromboelastography not only the deterioration in clot strength can be assessed but also in clot formation and platelet interaction. Fibrinogen concentrate administration may be considered in severe bleeding as well as relevant dilutional coagulopathy. Targeted doses of gelatins and tetrastarches seem to have no proven adverse effect on anemia and allogeneic blood transfusions. Further studies implementing goal-directed volume management and careful definition of triggers for transfusions and alternative therapies are needed.

Chapter 10. Microvascular fluid exchange

Per-Olof Grände and Johan Persson

There is always a continuous leakage of plasma fluid and proteins to the interstitium, called the transcapillary escape rate (TER). The transcapillary escape rate of albumin (TERalb) corresponds to 5–6% of total plasma albumin per hour. Plasma volume is preserved mainly because of recirculation via the lymphatic system and transcapillary absorption. During inflammation and after trauma, TER may increase up to 2–3 times and exceed the recirculation capacity, resulting in hypovolemia, low plasma concentration of proteins, and tissue edema. The present chapter discusses mechanisms controlling microvascular fluid exchange under physiological and pathophysiological conditions, including possible passive and active mechanisms controlling transcapillary fluid exchange. Options to reduce the need for plasma volume expanders while still maintaining an adequate plasma volume are presented. Consequently, this may simultaneously reduce accumulation of fluid and proteins in the interstitium. The effectiveness of available plasma volume expanders is also discussed.

Chapter 11. The glycocalyx layer

Anna Bertram, Klaus Stahl, Jan Hegermann, and Hermann Haller

Endothelial cells cover the inner surface of the vasculature and are essential for vascular homeostasis with regulation of vasodilation and vasoconstriction, permeability, inflammation, and coagulation. The endothelium is not a barren surface but is covered by a thick layer of so-called glycocalyx. The glycocalyx is built of heavily glycosylated proteins such as syndecans which are anchored in the cell membrane, freely associating proteoglycans such as hyaluronidase, and also a multitude of plasma molecules that bind and interact with the proteoglycans.

The glycoproteins collectively organize into the glycocalyx, which plays a vital role in several important vascular functions. It serves as a mechanotransductor mediating information on blood flow and cellular movement to the endothelium, it regulates permeability via its physical properties, it regulates binding of vascular factors to the endothelium, and it is the "habitat" of the resident components of the complement system and the coagulation cascade. In addition, the glycocalyx serves as a sink for small molecules and electrolytes in the plasma and generates chemokine gradients to guide leukocytes to sites of inflammation. The delicate structures of the glycocalyx can be easily disturbed and damaged by acute disease such as sepsis or ischemia, as well as chronic disease such as diabetes or hypertension. The proteoglycans and/or its sugar moieties can be shed by specific enzymes. Novel tools have been developed to better visualize the glycocalyx both *in vitro* and *in vivo*. An understanding and, possibly, a molecular manipulation of the glycocalyx will be important to improve our therapeutic strategies in patients.

Chapter 12. Monitoring of the microcirculation

Atilla Kara, Şakir Akin, and Can Ince

Perioperative fluid management requires comprehensive training and an understanding of the physiology of oxygen transport to tissue. Administration of fluids has a limited window of efficacy. Too little fluid reduces organ perfusion and too much fluid causes organ dysfunction from edema. In addition, isotonic saline carries the danger of hyperchloremia, whereas balanced crystalloid solutions are pragmatic choices of fluid in the majority of perioperative resuscitation settings.

The prime aim of fluid therapy is to improve tissue perfusion so as to provide adequate oxygen to the tissues. Macrohemodynamical parameters and/or surrogates of tissue perfusion do not always correspond to microcirculatory functional states, and especially not in states of inflammation. Even when targets for macrohemodynamics are reached, the microcirculation may still remain damaged and dysfunctional.

Observation of the microcirculation in the perioperative setting provides a more physiologically based approach for fluid therapy by possibly avoiding the unnecessary and inappropriate administration of large volumes of fluids.

Hand-held videomicroscopy is able to visualize microcirculatory perfusion sublingually. It can be used to monitor the functional state of the microcirculation by assessment and quantification of sublingual microvascular capillary density, and thus to guide fluid therapy. The Cytocam-IDF device might provide the needed clinical platform because of its improved imaging capacity in terms of density and perfusion parameters as well as providing on-line quantification of the microcirculation.

Chapter 13. Pulmonary edema

Göran Hedenstierna, Claes Frostell, and João Batista Borges

Pulmonary edema can be either hydrostatic (cardiac) or high-permeability (non-cardiac). In the first type, therapy should focus on a reduction of hydrostatic pressure. Pain relief and anxiety relief reduces vascular pressures by bringing down sympathetic nervous system drive. Treatment also consists in oxygen supplementation, furosemide, continuous positive airway pressure (CPAP) on a tight-fitting face-mask, and possibly venesection.

High-permeability pulmonary edema implies that the barrier function of the vasculature to larger molecules and cells is no longer intact. The permeability increase leads to a rapid and profound fluid leakage, followed by inflammation and destruction of lung parenchymal structure. Treatment consists of fluid restriction while maintaining adequate organ perfusion. Extracorporeal membrane oxygenation (ECMO) may be used in patients with severe non-cardiac pulmonary edema. Adequate treatment of the primary etiology of the condition is essential.

Resolution of pulmonary edema might include local reabsorption, clearance through the lymphatic system, clearance via the pleural space, or clearance through the airway. Maintaining spontaneous breathing, whenever possible, cannot be over-emphasized. Spontaneous breathing with CPAP both counteracts atelectasis formation in the lung and facilitates the ability to clear secretions with the re-emergence of cough.

Section 3: Techniques

Chapter 14. Invasive hemodynamic monitoring

Jonathan Aron and Maurizio Cecconi

The aim of hemodynamic monitoring is to enable the optimization of cardiac output and therefore improve oxygen delivery to the tissues, avoiding the accumulation of oxygen debt, in the perioperative period. Instigating goal-directed therapy based on validated optimization algorithms has been shown to reduce mortality in highrisk patients and complications in moderate-to high-risk patients.

A number of devices are available to facilitate this goal. The pulmonary artery catheter was the first hemodynamic monitor, but its invasive nature precludes its routine use in today's clinical practice. More recently, devices that continuously analyze the arterial pressure waveform to calculate various flow parameters have been developed and validated. These devices have facilitated the introduction of hemodynamic monitoring to the wider surgical population, providing useful clinical information that enables the judicious use of fluid therapy whilst avoiding hypervolemia.

This chapter explores the role that hemodynamic optimization plays in perioperative care, describes some of the commonly used invasive hemodynamic monitors, and explains how to use the information produced effectively. Used correctly, any monitor can be useful to improve outcome if applied to the right population, at the right time, and with the right strategy.

Chapter 15. Goal-directed fluid therapy

Timothy E. Miller and Tong J. Gan

Perioperative morbidity has been linked to the amount of fluid administered, with both insufficient and excess fluid leading to increased morbidity, resulting in a characteristic U-shaped curve. The challenge for us as clinicians is to keep our patients in the optimal range at all times during the perioperative period. Goal-directed therapy (GDT) is a term that has been used for nearly 30 years to describe methods of optimizing fluid and hemodynamic status. The arrival of a number of minimally invasive cardiac output monitors enables clinicians to guide perioperative volume therapy and cardiocirculatory support.

The most widely used monitor is the esophageal Doppler. There are several others that are able to analyze the arterial waveform to calculate stroke volume and cardiac output, and therefore use the "10% algorithm" in response to a fluid challenge. There are a number of studies that show improved outcomes with GDT-guided fluid optimization, as demonstrated by a faster return in gastrointestinal function, a reduction in postoperative complications, and reduced length of stay. The underlying mechanisms for the success of GDT are thought to relate to avoidance of episodes of hypovolemia, hypoxia, or decreased blood flow that may cause mitochondrial damage and subsequent organ dysfunction.

Chapter 16. Non-invasive guidance of fluid therapy

Maxime Cannesson

Optimization of oxygen delivery to the tissues during surgery cannot be conducted by monitoring arterial pressure alone. Therefore, apart from cardiac output monitoring, functional hemodynamic parameters have been developed. These parameters indicate "preload dependence," which is defined as the ability of the heart to increase stroke volume in response to an increase in preload. The Frank–Starling relationship links preload to stroke volume and presents two distinct parts: a steep portion and a plateau. If the patient is on the steep portion of the Frank–Starling relationship, then an increase in preload (induced by volume expansion) is going to induce an important increase in stroke volume. If the patient is on the plateau of this relationship, then increasing preload will have no effect on stroke volume. The functional hemodynamic parameters rely on cardiopulmonary interactions in patients under general anesthesia and mechanical ventilation and can be obtained invasively from the arterial pressure waveform or non-invasively from the plethysmographic waveform. Here, the effects of positive-pressure ventilation on preload and stroke volume are used to detect fluid responsiveness. If mechanical ventilation induces important respiratory variations in stroke volume (SVV) or in pulse pressure (PPV) it is more likely that the patient is preload-dependent. These dynamic parameters, including passive leg raising, have consistently been shown to be superior to static parameters, such as central venous pressure, for the prediction of fluid responsiveness.

Chapter 17. Hemodilution

Philippe van der Linden

Acute normovolemic hemodilution entails the removal of blood either immediately before or shortly after the induction of anesthesia and its simultaneous replacement by an appropriate volume of crystalloids and/or colloids to maintain "isovolemic" conditions. As a result, blood subsequently lost during surgery will contain proportionally fewer red blood cells, thus reducing the loss of autologous erythrocytes. Although still frequently used in some surgical procedures, the real efficacy of acute normovolemic hemodilution in reducing allogeneic blood transfusion remains discussed. The aim of this article is to describe the physiology, limits, and efficacy of acute normovolemic hemodilution.

Chapter 18. The ERAS concept

Katie E. Rollins and Dileep N. Lobo

Optimum perioperative fluid administration as part of an Enhanced Recovery After Surgery (ERAS) program is dependent on a range of factors which are becoming increasingly well documented. Following previous ambiguous terms and definitions for fluid management strategies, appreciation of the importance of "zero balance" (where amount infused equals the amount lost from the body) of both water and salt is increasing, with both over- and underhydration resulting in significantly worse clinical outcomes (in a U-shaped distribution). Excessive fluid loads have a significant negative impact upon outcome. Electrolyte balance, from pre- to postoperative stages, is also now understood to play a key role.

Section 4: The clinical setting

Chapter 19. Spinal anesthesia

Michael F. M. James and Robert A. Dyer

Fluid therapy is widely used in conjunction with spinal anesthesia to minimize hypotensive events. The use of crystalloids for this purpose seems to be only minimally effective, particularly when given prior to the administration of the spinal anesthetic. To be effective, substantial fluid boluses must be administered – of the order of 20 ml/kg – and then preferably as a rapid coload simultaneously with the induction of spinal anesthesia. Several studies and meta-analyses suggest that colloids, either as preload or coload, are more effective than crystalloids andmay result in a smaller volume of fluid loading being required. However, fluids alone, whether crystalloid or colloid, are generally inadequate to prevent or treat significant hypotension associated with spinal anesthesia, and the concomitant use of a vasopressor will frequently be necessary, particularly in obstetrics. The best that can be achieved with optimal fluid therapy is an overall reduction in the total dose of vasopressor required. The best available management of spinal hypotension would appear to be optimal fluid therapy combined with carefully graded administration of the appropriate vasopressor. It is possible that goal-directed fluid therapy, using an appropriate analysis of cardiac performance to assess the response dynamic indices to a fluid challenge, may improve fluid therapy in the future, but, at present, the evidence for this is insufficient to make a firm recommendation.

Chapter 20. Day surgery

Jan Jakobsson

Rapid recovery and a minimum of residual effects are factors of utmost importance when handling the daycase patient. Prolonged preoperative fasting should be avoided. Many countries have adopted revised fasting guidelines that allow patients without risk factors to eat a light meal up to 6 hours and to ingest clear fluids up to 2 hours prior to the induction of anesthesia. Postoperative fatigue can be reduced by fluid intake up to 2–3 hours prior to surgery.

Perioperative intravenous fluid therapy should be instituted on the basis of the case profile. In general, fluid infused during minor surgery may not exert a major effect, but during intermediate surgery, such as laparoscopic cholecystectomy, a liberal fluid program has been shown to improve recovery and reduce postoperative fatigue. Administration of about 1 liter isotonic electrolyte solution to compensate for the fasting, and a further 1 liter during surgery, improves the postoperative course. Liberal fluid administration also reduces the risk for postoperative nausea and the risk vs. benefit seems to be in favor for its routine use in ASA 1–2 patients. The potential benefit in adding dextrose to the intravenous fluid during the early postoperative phase has been assessed, but the benefit seems to be very minor.

Resumption of oral intake, drinking, and eating are traditional variables for the assessment of eligibility for discharge and thus an essential part of day surgery. However, there is no need for patients to drink before discharge; intake of fluid and food should be recommended but not pushed.

Chapter 21. Abdominal surgery

Birgitte Brandstrup

Normal as well as pathological fluid losses should be replaced with a fluid resembling the loss in quantity and quality (electrolyte composition). Elective surgical patients can be allowed to eat until 6 hours and drink up to 2 hours before surgery without increasing the risk of fluid aspiration. Preoperative administration of sugarcontaining fluids, intravenous or by mouth, improves postoperative well-being and muscle strength, and lessens the postoperative insulin resistance. It does not, however, reduce the number of patients with wound- or other complications, length of stay, or mortality. Surgery does not increase the normal fluid and electrolyte losses, but causes perspiration from the abdominal wound that approximately equals the decreased water loss from the lungs because of ventilation with moist air. It is not possible to treat a decrease in blood pressure caused by the use of epidural analgesia with fluid.

The goal of zero fluid balance (formerly called "restrictive") reduces postoperative complications and the risk of death in major abdominal surgery. The goal of zero balance in combination with a goal of nearmaximum stroke volume provides equally good outcome. During outpatient surgical procedures the wellbeing of the patient is improved by giving approximately 1 liter of fluid. The role of glucose-containing fluid in this setting may be beneficial, but the evidence is sparse. "Postoperative restricted fluid therapy," allowing the patients to drink no more than 1,500 ml/day, is not recommended. To measure the body weight is the best way to monitor the postoperative fluid balance. Fluid charts are insufficient.

Chapter 22. Cardiac surgery

Saqib H. Qureshi and Giovanni Mariscalco

Cardiac surgical patients have altered vascular and immunological factors that dictate short- and long-term clinical outcomes. So far, the evidence does not favor any single choice of fluid therapy. In fact, volume replacement is a determinant of "filling pressures" in isolation but requires a critical balance with other determinants of tissue-oxygen debt such as vasomotor tone, fluid responsiveness, and cardiac contractility. Lastly, none of the available fluid therapies have been assessed for their comparative endothelial homeostatic potential. This leaves a significant knowledge gap and an incentive for researchers, clinicians, and industry to design and test safer and more efficacious choices for clinical use.

Chapter 23. Pediatrics

Robert Sümpelmann and Nils Dennhardt

The main aim of perioperative fluid therapy is to stabilize or normalize the child's homeostasis. Young infants have higher fluid volumes, metabolic rates, and fluid needs than adults. Therefore, short perioperative fasting periods are important to avoid iatrogenic dehydration, ketoacidosis, and misbehavior. Balanced electrolyte solutions with 1–2.5% glucose are favored for intraoperative maintenance infusion. Glucose-free balanced electrolyte solutions should then be added as needed to replace intraoperative fluid deficits or minor blood loss. Hydroxyethyl starch or gelatin solutions are useful in hemodynamically instable patients or those with major blood loss, especially when crystalloids alone are not effective or the patient is at risk of interstitial fluid overload. The monitoring should focus on the maintenance or restoration of a stable tissue perfusion. Also, in non-surgical or postoperative children, balanced electrolyte solutions should be used instead of hypotonic solutions, both with 5% glucose, as recent clinical studies and reviews showed a lower incidence of hyponatremia.

Chapter 24. Obstetric, pulmonary, and geriatric surgery

Kathrine Holte

This chapter focuses on fluid management in obstetric, pulmonary, and geriatric surgery. In obstetrics, the fluid administration debate largely centers on the relevance of fluid infusions to counteract hypotension in conjunction with regional anesthesia administered for pain relief during labor or as anesthesia for Cesarean section, where both colloids and sympathomimetics reduce maternal hypotension. Particular to pulmonary surgery, a positive fluid balance is found to correlate with postoperative lung injury and should be strictly controlled. Elderly patients, while being at increased risk for postoperative complications, may also be more susceptible to perioperative fluid disturbances including preoperative dehydration.

In summary, evidence suggests that fluid management should be individualized and integrated into perioperative care programs. Both insufficient and excessive fluid administration may increase complications, and while determining fluid status is still a challenge, individualized fluid therapy to obtain certain hemodynamic goals may be recommended.

Chapter 25. Transplantations

Laurence Weinberg

Patients with end-stage liver disease have a hyperdynamic resting circulation with high cardiac output states and low systemic vascular resistance and tachycardia. During liver transplantation, this state is amplified. The potential for massive bleeding is common and can result in sudden and catastrophic hypovolemia. Massive blood transfusion results in large volumes of citrated blood being administered. With limited or no hepatic function to metabolize citrate, citrate intoxication can occur, and calcium chloride should be administered when appropriate. Mild to moderate acidosis can be safely tolerated. Albumin is the most common colloid used, while the use of lactate-based crystalloid solutions can result in hyperlactatemia as lactate anions are ineffectively metabolized. Acetate-buffered solutions should be preferred. The most common cause of death in fulminant liver failure is intractable intracranial hypertension from cerebral edema, present in approximately 50–80% of patients with fulminant liver failure. Therefore, permissive hypernatremia and use of hypertonic saline solutions are frequently treatment options in this setting.

Crystalloids are the mainstay and first choice of perioperative fluid intervention in renal transplantation. Conventionally, 0.9% saline is widely advocated because of concerns about hyperkalemia from the balanced/buffered solutions, which all contain potassium. However, this fear has not been confirmed in clinical trials. Hydroxyethyl starch should be avoided owing to increased risk of a delayed graft function.

Chapter 26. Neurosurgery

Hemanshu Prabhakar

Fluid administration is one of the basic components in the management of neurosurgical patients. Despite advances and extensive research in the field of neurosciences, there is still a debate on the ideal fluid. Issues related to adequate volume replacement and effects on the intracranial pressure persist. Studies have demonstrated the harmful effects of colloids over crystalloids. Normal saline has remained a fluid of choice, but there is now emerging evidence that it too is not free from its harmful effects. Hypertonic saline has also been accepted by many practitioners, but its use and administration requires close monitoring and vigilance. There is now growing evidence on the use of balanced solutions for neurosurgical patients. However, this evidence comes from a small number of studies. This chapter tries to briefly cover various clinical situations in neurosciences with respect to fluid administration.

Chapter 27. Intensive care

Alena Lira and Michael R. Pinsky

Fluid infusions are an essential part of the management of the critically ill, and include maintenance fluids to replace insensible loss and resuscitation efforts to restore blood volume. This chapter is on fluid resuscitation. Fluid administration is a vital component of resuscitation therapy, with the aim being to restore cardiovascular sufficiency. Initial resuscitation aims to restore a minimal mean arterial pressure and cardiac output compatible with immediate survival. This is often associated with emergency surgery and associated lifesaving procedures. Then, optimization aims to rapidly restore organ perfusion and oxygenation before irreversible ischemic damage occurs. Stabilization balances fluid infusion rate with risks of volume overload, and finally de-escalation promotes polyuria as excess interstitial fluid is refilled into the circulation. There is no apparent survival benefit of colloids over crystalloids. Hydroxyethyl starch solutions have deleterious effects in certain patient populations, for example in sepsis. Balanced salt solutions are superior to normal saline. Further fluid resuscitation should be guided by the patient's need for increased blood flow and by their volumeresponsiveness.

Chapter 28. Severe sepsis and septic shock

Palle Toft and Else Tønnesen

Sepsis is a systemic disorder with a protean clinical picture and a complex pathogenesis characterized by the release of both pro- and anti-inflammatory elements. The organ dysfunction and organ failure occurring in the early phase of severe sepsis are believed to result from an excessive inflammatory response. Degradation or destruction of the glycocalyx layer causes transudation of fluid from the vascular space into extravascular tissue. Such capillary leakage makes the patient hypovolemic and promotes a generalized edema in the lungs, heart, gut, brain, and other tissues, which impairs organ function and sometimes causes excessive weight gain. Early, aggressive goal-directed therapy (EGDT) based on the protocol by Rivers *et al.* from 2001 stresses that adequate volume replacement is a cornerstone in management, as restoration of flow is a key component in avoiding tissue ischemia or reperfusion injury. It is the speed with which septic patients are fluid resuscitated that makes the difference. Deep general anesthesia should be avoided and noradrenaline might be needed to prevent circulatory shock before sufficient amounts of fluid have been administered.

Survival improves from EGDT only if optimization is instituted before organ failure is manifested. Most patients require continuous aggressive fluid resuscitation during the first 24 hours of management. In the later course of the disease, between 2 and 7 days, a more restricted fluid management strategy should be instituted. Not all patients who are “fluid responders” should automatically receive fluids.

Chapter 29. Hypovolemic shock

Niels H. Secher and Johannes J. van Lieshout

Hypovolemic shock is a response to a reduced central blood volume (CBV) whatever its cause – hemorrhage, passive head-up tilt, or other cause – and follows three phases. The first comprises a reduction of CBV initially with reflex increase in heart rate (HR) to approximately 90 bpm and maintained blood pressure (BP) by increased vascular resistance. In the second phase, which corresponds to a reduction of the CBV by about 30%, a Bezold-Jarisch-like reflex ceases sympathetic activity, although plasma adrenaline continues to increase, and together with vagal activation enhances coagulation competence. At this stage of progressive CBV the HR decreases, eventually to extremely low values. In the third phase, BP remains low while HR increases to more than 100 bpm.

To treat hypovolemia, volume substitution can be directed to establish maximal values for stroke volume, cardiac output, or venous oxygen saturation. These variables do not increase when CBV is enhanced in supine healthy humans, and thereby define “normovolemia.” The patient’s bed can be tilted head-down, and if the mentioned variables then increase significantly, the patient is in need of volume. If not, a volume deficit does not explain the patient’s condition. Plasma atrial natriuretic peptide (ANP) also decreases in response to a reduced CBV, and to maintain plasma ANP during major surgery requires a 2.5-liter surplus volume of lactated Ringer’s solution. With recording of deviations in central cardiovascular variables, the blood volume can be maintained within 100 ml and provide a comfortable margin to the deficit that affects BP and regional blood flow.

Chapter 30. Uncontrolled hemorrhage

Robert G. Hahn

Fluid therapy in hemorrhage strives to restore hemodynamic function and tissue perfusion. However, these goals are not appropriate when there is an injury to a large blood vessel and the hemorrhage has not been stopped surgically (uncontrolled hemorrhage). Clinical situations in which this is the case include penetrating trauma, ruptured aortic aneurysm, and gastric bleeding. Numerous animal experiments in pigs and rats have shown that the low-flow, low-pressure state characterizing serious hemorrhage promotes coagulation, even if a large blood vessel is injured. An immature blood clot is easilywashedaway if the blood flow rate and the arterial pressure is normalized by infusion fluids. Vigorous fluid therapy then increases both the blood loss and the mortality. The road to optimal survival is to infuse less fluid at lower speed (half volume at half speed is suggested) and aim at a systolic arterial pressure of 90 mmHg. In this situation, the strategy is only to prevent progressive acidosis and irreversible shock. A deviation from normal hemodynamics should be accepted until the source of bleeding has been treated surgically. A sudden drop in arterial pressure during ongoing fluid resuscitation suggests that rebleeding is occurring, and the infusion rate should then be further reduced. There is an unfortunate lack of clinical studies showing that the fluid strategy that has been successful in animal experiments pertains also to humans. However, it is widely accepted in emergency departments and trauma hospitals to resuscitate trauma patients to a lower-than-usual systolic pressure (hypotensive resuscitation).

Chapter 31. Burns

Folke Sjöberg

The purpose of fluid treatment for burn-injured patients is to maintain organ perfusion despite major leakage of fluid from the intravascular space. The leakage is due to a sharp reduction of the pressure in the interstitial fluid space (negative imbibition pressure) and an increase of the vascular permeability. Most of the fluid loss due to the first factor takes place within the first 3–4 hours and the bulk of loss from the second factor within 12 hours after the burn.

The formula for plasma volume support most widely used today is the "Parkland" strategy, in which 2–4 ml of buffered Ringer's solution is administered per total body surface area % per kilogram body weight. Half of the calculated volume is given during the first 8 hours after the burn and the other half during the subsequent 16 hours. A colloid rescue strategy should come into play when the fluid volumes provided are very large, and is adequate after 8–12 hours post-burn.

The patient should be in a state of controlled hypovolemia. The combined use of urine output (aim 30–50 ml/h), mean arterial pressure, and the mental state of the patient is gold standard when guiding the fluid therapy. The use of central circulatory parameters increases the risk of fluid overload and does not improve the outcome. The maximal tissue edema reaches a maximum between the first 24 and 48 hours post-burn, and thereafter the added fluid volume is excreted as an ongoing process over 7–10 days.

Chapter 32. Trauma

Joshua D. Person and John B. Holcomb

In the United States, injury is the leading cause of death among individuals between the ages of 1 and 44 years, and the third leading cause of death overall. Approximately 20% to 40% of trauma deaths occurring after hospital admission are related to massive hemorrhage and are therefore potentially preventable with rapid hemorrhage control and improved resuscitation techniques. Over the past decade, the treatment of this population has transitioned into a damage control strategy with the development of resuscitation strategies that emphasize permissive hypotension, limited crystalloid administration, early balanced blood product transfusion, and rapid hemorrhage control. This resuscitation approach initially attempts to replicate whole blood transfusion, utilizing an empiric 1:1:1 ratio of plasma:platelets:red blood cells, and then transitions, when bleeding slows, to a goal-directed approach to reverse coagulopathy based on viscoelastic assays. Traditional resuscitation strategies with crystalloid fluids are appropriate for the minimally injured patient who presents without shock or ongoing bleeding. This chapter will focus on the assessment and resuscitation of seriously injured trauma patients who present with ongoing blood loss and hemorrhagic shock.

Chapter 33. Absorption of irrigating fluid

Robert G. Hahn

Absorption of irrigating fluid can occur in endoscopic surgeries. The complication is best known from transurethral prostatic resection and transcervical endometrial resection. When monopolar electrocautery is used, the irrigation is performed with electrolytefree fluid containing glycine, or mannitol or sorbitol. With bipolar electrocautery the irrigating fluid is usually isotonic saline. Incidence data on fluid absorption and associated adverse effects show great variation, but absorption in excess of 1 liter usually occurs in 5% to 10% of the operations and causes symptoms in 2–3 patients per 100 operations.

The pathophysiology of the complications arising from absorption of electrolyte-free irrigating fluids is complex. Symptoms can be related to metabolic toxicity, cerebral edema, and circulatory effects caused by rapid massive fluid overload. Available data on absorption of isotonic saline suggest that symptoms are likely when the volume exceeds 2 liters.

Ethanol monitoring is the most viable of the methods suggested for monitoring of fluid absorption in clinical practice. By using an irrigating fluid that contains 1% of ethanol, updated information about fluid absorption can be obtained at any time perioperatively by letting the patient breathe into a hand-held alcolmeter.

Treatment of massive fluid absorption is supportive with regard to ventilation, hemodynamics, and well-being. Hypertonic saline is indicated when electrolyte-free fluids are used, while diuretics should be withheld until the hemodynamic situation has been stabilized. In contrast, absorption of isotonic saline should (logically) be treated with diuretics as saline does not cause osmotic diuresis and is not distributed to the intracellular space.

Chapter 34. Adverse effects of infusion fluids

Robert G. Hahn

Adverse effects may arise if an infusion fluid diverges from the body fluids with respect to osmolality or temperature. Coagulation becomes impaired when the fluid induced hemodilution is approximately 40%. Infusion of 2–3 liters of crystalloid fluid prolongs the gastrointestinal recovery time, while 6–7 liters promotes poor wound healing, pulmonary edema, and pneumonia. In abdominal surgery, suture insufficiency and sepsis become more common. However, a liberal fluid program in the postoperative period probably does not increase the number of complications.

Isotonic saline probably shares these adverse effects with the balanced crystalloid fluids, but adds on a tendency to metabolic acidosis and slight impairment of the kidney function (−10%). Glucose solutions may induce hyperglycemia and post-infusion rebound hypoglycemia. Glucose 5% without electrolytes increases the risk of postoperative subacute hyponatremia.

Adverse effects associated with colloid fluids include anaphylactic reactions, which occur in approximately 1 out of 500 infusions. To reduce this problem when dextran is used, pretreatment with a hapten inhibitor (dextran 1 kDa) should be employed. Hyperoncotic colloid solutions may cause pre-renal anuria in dehydrated patients. The indications for hydroxyethyl starch have been limited, owing to impairment of kidney function in severely ill patients.

Edema from a colloid is most clearly associated with inflammation-induced acceleration of the capillary escape rate. A factor promoting peripheral edema from crystalloid fluids is that volume expansion negatively affects the viscoelastic properties of the interstitial fluid gel. The slow excretion of crystalloid fluid during anesthesia and surgery also contributes to the development of edema.