

Fluid therapy in cardiac surgery patients

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Introduction

This article aims at providing an overview on fluid therapy in cardiac anesthesia in order to support training of anesthetists.

Intraoperative fluid therapy is an integral part of anesthesia management [1, 2]. In an attempt to prevent development of organ damage it is of major importance to ensure adequate fluid and volume supply [3]. Patients who have to undergo cardiac surgery present a major challenge to the anesthetist beyond the problem of fluid therapy: These challenges include specific features of the patients' underlying cardiac disease, complexity of the surgical intervention and, particularly, pathophysiological impact of extracorporeal circulation. During cardiac surgery the patients partly experience extreme conditions like cardiac arrest or deep hypothermia unlike in any other surgical subspecialty.

In the immediate postoperative period, relative insufficiency of blood volume may often occur, in many occasions even absolute insufficiency of blood volume may also be observed. Especially intraoperative use of cardio-pulmonary bypass often induces capillary leakage which may lead to interstitial oedema during concomitant intravasal volume depletion [11]. However, intra- and postoperative hemorrhage as well as administration of diuretics or vasoactive drugs may also cause inadequate blood volume.

Fluid therapy should not only lead to stabilization of macro-circulation, but also of micro-circulation. Micro-circulation especially seems to be affected by different volume substitution fluids. Physiology and pathophysiology of fluid compartments should be accounted for when decision has to be made among different solutions [4].

The main part of body fluids (40% of TBW) can be found within the 75 trillions of body cells and is, in its entire volume, referred to as intracellular space (ICS).

As composition of the individual cell fluids of the different body cells is uniform, the term of 'total compartment' can be applied.

All kinds of fluids outside the cell are part of the so-called extracellular space (ECS), which amounts to approx. 20% of total body water in adults. ECS and ICS mainly differ from each other by the osmotic balance of extracellular sodium ions and intra-cellular potassium ions.

Interstitial (interstitium, 16% of TBW) and intravascular fluid compartments (plasma volume: 4% of TBW, erythrocytes volume in adults 3,5% of TBW) are subsets of the ECS.

Interstitial and intravasal space are separated by a permeable capillary membrane and are interacting constantly. Composition of fluids within interstitium and intravasal space is similar with the exception of a higher protein content in plasma water. This proportion of plasma proteins is responsible for the colloid-osmotic pressure (COP) of approx. 26 - 28 mmHg which prevents intravasal fluid from draining to the interstitium (5 mmHg COP) [5].

Crystalloid solutions

Crystalloid solutions differ from each other due to their osmolality (plasma isotonic, hypertonic or hypotonic) and their amount of electrolytes (full-, 1/3- and 2/3 electrolytes fluids). Balanced full-electrolytes solutions largely correspond to plasma composition. Major characteristics include isotony, an as physiological chloride content as possible and addition of metabolizable anions to avoid dilution acidosis [4]. They rapidly disseminate homogeneously within the entire ECS, i.e. within the intravasal space and the interstitium. They are indispensable to meet physiological maintenance requirements.

Pathological interstitial fluid deficiency is often observed perioperatively which is caused by dehydration or hemorrhage and should be resolved by administration of crystalloid full-electrolytes solutions (Ringer, Ringers' lactate). Due to the fact that crystalloid fluids are disseminated homogeneously throughout the plasma volume (4% of TBW) and interstitium (16% of TBW) a four-fold amount of fluids is needed in comparison to whole blood or colloid plasma substitution in order to achieve the same intravascular volume effect [6]. Therefore, from a certain point of time during crystalloid fluid therapy, there is a risk of interstitial fluid overload, which may lead, for example, to a decrease in arteriolar PaO₂ in case of increasing extravascular lung water [7].

Especially in angloamerican countries, use of isotonic saline is still favoured. However, there is an increased incidence of hyperchloremic acidosis compared to use of ringers solutions [3,8].

According to consensus statements, full-electrolytes infusions should be preferred if crystalloid solutions are to be administered [9].

Hypertonic/hyperosmotic crystalloid solutions

Along with their high concentration of NaCl (7,2%) hyperosmolar and hyperosmolar/hyperoncotic NaCl solutions contain an artificial colloid (e.g. 6% HES 200/0,5). Following fast intravenous infusion rapid mobilization of fluids from interstitium, erythrocytes, and vascular endothelium can be observed. However, volume effect of those solutions is of a very temporary nature, furthermore rapid conventional volume substitution is essential to resolve iatrogenic induced interstitial deficits [4]. Existing data does not allow to make any evidence-based recommendations as to the question whether hypertonic crystalloid solutions or isotonic solutions should be preferred.

Colloid solutions

Colloid plasma solutions are characterized by a high molecular weight (MW) and they only slowly leave the intravascular space through the capillary walls, thereby exerting their osmotic power, the colloid-osmotic pressure (COP), and retaining fluids within the intravascular space. As far as potentially life-threatening hemorrhage is concerned, they are more effective than crystalloid solutions when circulation and oxygen sup-

ply have to be maintained by rapid administration of fluid therapy.

Human albumin

The endogenous colloid, albumin, is characterized by a molecular weight of 69 kDa. It is responsible for 80% of plasma COP and presents as a monodisperse solution, i.e. with uniform molecular size. Furthermore, it is a major transporter for calcium, magnesium and drugs. Fifty percent of total albumin is found outside the intravascular space and is constantly interacting via the lymph system. These solutions which are derived from blood donations are not indicated for primary volume substitution [10].

Artificial colloids are significantly cheaper with equal clinical efficacy (1/10 of the price). There are solutions based on gelatin, dextran and hydroxyethyl starch (HES) which are available in different formulae. They are characterized by their concentration, their median molecular weight (artificial colloids are polydisperse solutions) and their degree of interaction and substitution (in case of HES).

Hydroxyethyl starch (HES)

Hydroxyethyl starch is composed of amylopectine (corn, potatoes) with hydroxyethyl groups added to its glucose groups. In case of normovolemia, intravenously infused starch remains in the vascular bed only for 60 minutes, however, due to hydroxylation, degradation by serum amylases is significantly delayed. The most important feature of HES solution is its degree of substitution (e. g. 0.5; 0.7), the relationship between hydroxyethyl-substituted glucose units and the total number of glucose units. The higher the substitution, the higher is their half-life. Furthermore HES solutions differ from each other by their median molecular weight. For polydisperse solutions, their averaged molecular weight is indicated (70, 130, 200, 260, 280, and 450 kDa), among others determining half-life and volume efficacy of the solution. Concentration of the selected HES solutions (e. g. 3%, 6%, 10%) is the third determinant of intravascular dwelling time and volume efficacy. Depending on their capacity to mobilize water from the interstitium, distinction is made between hypo-oncotic, iso-oncotic and hyperoncotic solutions. Therefore, 6%-HES solution with a median molecular weight of 200 kDa and a degree of

substitution of 0.5 is regarded as iso-oncotic, thus having an 100% volume effect of the amount administered and an intravasal dwelling time of 3 to 4 hours. For this substitution fluid, the maximum dose which is recommended and determined, amounts to 33 ml/kg/day (2 g/kg/day).

Impact on plasmatic and cellular blood coagulation is mainly suspected with use of high molecular (450 kDa) and higher substituted HES solutions (0.7). Formulae which are characterized by 0.5-substituted middle molecular (200 kDa) and low molecular (70 kDa) weight – as mostly used in Europe – show significantly reduced effects. The two HES solutions which are most frequently used in German cardiac surgery are HES 130/0.4 6% and HES 200/0.5 6% [11].

Gelatin

Bovine collagen is the basis for gelatin solutions. Several procedures allow to start with depolymerization of gelatin followed by re-crosslinking of the polypeptid fragments which have been produced [10]. Gelatin is completely metabolized and can be eliminated by the kidneys. Even with slow i.v. infusion, in normovolemic healthy subjects up to 50% of the dosage leave the intravasal space and 70-90% are found in the urine within a few hours. Due to their low molecular weight, intravasal dwelling time in the above mentioned situation is 1 to 2 hours. Gelatin solutions do not influence hemostasis. If major blood losses occur during fluid therapy, this will not only lead to a critical hematocrit, but also to a critical concentration of coagulation factors or even of thrombocytes. This coagulation effect is not due to the fluid substitution solution, but is caused by hemorrhage and ensuing dilution. Gelatin solutions do not impact kidney function and are, therefore, also suitable for use in patients suffering from impaired kidney function. According to the DIVI recommendations [10] gelatin solutions can be adequately used (beyond their use in therapy of moderate volume deficiency shock) for patients at risk of kidney function or coagulation function loss as well as in patients suffering from most severe volume deficiency, in case manufacturer-recommended hemostaseologic and renal dose limitations for HES have been reached.

Dextrans

Due to their negative effects on blood coagulation with increased tendency of bleeding and due to an extraordinarily high risk of allergic reactions compared to other colloid volume substitutions, dextrans have been

replaced in clinical practice by other artificial colloid solutions [12]. In Germany, dextrans do not play any role in fluid therapy for cardiac surgery intensive medicine [11].

Clinical preferences in fluid substitution

The German survey by Kastrup and coworkers in 2005 indicates that 63.4% of cardiac surgery intensive care specialists use hydroxyethyl starch as first-choice fluid substitution, followed by crystalloid solutions (21.2%) and gelatin solutions (9.6%) [11].

Blood products are mentioned as first-choice solutions in 1.9% of the questionnaires. As a second-choice fluid, crystalloids (46.8%) are predominantly used, followed by gelatine (23.4%) and hydroxyethyl starch (19.3%). Blood products are used by 6.4% of clinicians as a second-choice substitution solution.

The international survey of the members of the European and French Societies of Intensive Care Medicine which was carried out by the working group of Schortgen et al. [13] demonstrated that 65% of clinicians used a combination of crystalloids and colloids as first-choice fluid substitution followed by singular administration of colloids (18%) and crystalloids (17%). As far as colloids are concerned, starch derivatives have been indicated as first-choice fluid by half of the respondents, followed by gelatin.

Colloid versus crystalloid solutions

Whether colloid or crystalloid solutions should be preferred for fluid substitution is still a matter of debate and needs to be determined. There is a lack of prospective randomized studies with special regard to the cardiac surgical patient population [9].

Risks/Negative events

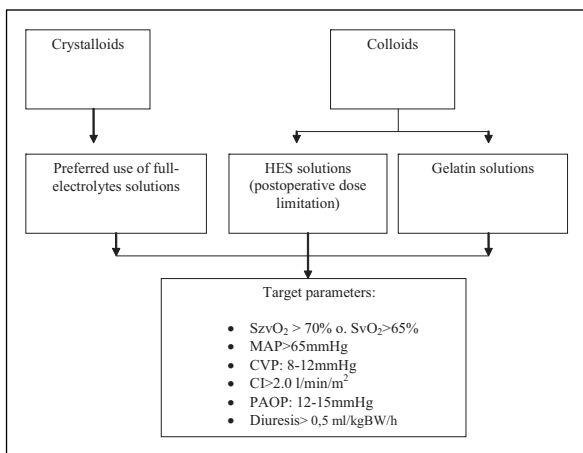
In 2004 security considerations on the use of colloid solutions for fluid therapy have been published by Barron and coworkers [14]. In comparison to the reference solution, albumin, incidence ratio of anaphylactoid reactions was increased four-fold with use of hydroxyethyl starch products and was double with use of dextran products. Compared to albumin, gelatin showed a twelve-fold increase of ratio. The multicenter study which was carried out by Laxanaire and his

working group [15] calculated a 0.33% incidence of anaphylactoid reactions with use of albumin, 0.06% with use of starch products, 0.08% with use of dextran solutions, 0.71% with use of urea-crosslinked gelatin products and 0.14% with use of succinylated gelatin.

Existing data do not provide clear statements on the safety concerning anaphylactoid reactions with use of colloid fluid substitution fluids. Preferential administration of HES products or human albumin may be recommended for clinical use. As far as gelatins are concerned, administration of succinylated products seems to be associated with less risks than use of urea-crosslinked fluids [9].

Algorithm for infusion therapy

The following algorithm corresponds to the guidelines of the German Society of Anesthesiology and Intensive Care Medicine (Deutsche Gesellschaft für Anästhesiologie und Intensivmedizin, DGAI) and the German Society of Thoracic, Cardiac, and Vascular Surgery (Deutsche Gesellschaft für Thorax-, Herz- und Gefäßchirurgie, DGTHG) [9]:



Summary

Fluid therapy in cardiac surgery patients should be managed according to predefined target parameters. In case infusions of crystalloid solutions are applied, full-electrolytes preparations should be preferred. Both, HES and gelatin products – under certain conditions human albumin as well – may be used as colloid solutions. At present, existing literature does not allow to

make a final judgement as to the question whether crystalloid or colloid fluid substitution fluids should be favoured for cardiac surgery. Nevertheless, most German cardiac surgery clinicians use artificial colloid solutions, mainly applying middle-molecular hydroxyethylene starch derivatives, followed by crystalloid solutions.

References

1. Gombotz H, Rumpold-Seitlinger F. Volumenersatz in der Herzchirurgie. In: Bold J (Hrsg.) Volumenersatztherapie (S. 187-204). Stuttgart: Georg Thieme Verlag, 2001
2. Zickmann B. Kardiochirurgie. In: Kochs E, Krier C, Buzello W, HA Adams (Hrsg.) Anästhesiologie. AINS Band 1 (S. 1090-1136). Stuttgart: Georg Thieme Verlag, 2001
3. Stephens R, Mythen M. Optimizing intraoperative fluid therapy. *Current Opinion in Anaesthesiology* 2003; 16: 385-392
4. Adams HA. Volumen und Flüssigkeitsersatz – Physiologie, Pharmakologie und klinischer Einsatz. *Anästh Intensivmed* 2007; 48: 448-60
5. Guyton AC, Hall JE. The Kidneys and body fluids. In: Guyton AC, Hall JE (Eds.) *Textbook of medical physiology* (9. ed., pp. 297-312). Philadelphia: WB Saunders Company, 1996
6. Rackow EC, Falk JL, Fein IA, Siegel JS, Packman MI, Haupt MT, Kaufmann BS, Putnam D. Fluid resuscitation in circulatory shock: a comparison of the cardiorespiratory effects of albumin, hetastarch, and saline solutions in patients with hypovolemic and septic shock. *Crit Care Med* 1983; 11: 839-850
7. Boldt J, Kling B, Bormann B von, Hempelmann G. Präoperative normovolämische Hämodilution in der Herzchirurgie. Pulmonale Veränderungen bei Anwendung neuer Techniken. *Anästhesist* 1989; 38: 294-301
8. Waters JH, Gottlieb A, Schoenwald P, Popovich MJ, Sprung J, Nelson DR. Normal saline versus lactated Ringer's solution for intraoperative fluid management in patients undergoing abdominal aortic aneurysm repair: an outcome study. *Anesth Analg* 2001; 93: 817-22
9. Carl M, Alms A, Braun J, Dongas A, Erb J, Goetz A, Gopfert M, Gogarten W, Grosse J, Heller A, Heringlake M, Kastrup M, Kroner A, Loer S, Marggraf G, Markewitz A, Reuter M, Schmitt DV, Schirmer U, Wiesenack C, Zwissler B, Spies C; German Society for Thoracic and Cardiovascular Surgery; German Society of Anaesthesiology and Intensive Care Medicine. Guidelines for intensive care in cardiac surgery patients: haemodynamic monitoring and cardio-circulatory treatment guidelines of the German Society for Thoracic and Cardiovascular Surgery and the German Society of Anaesthesiology and Intensive Care Medicine *Thorac Cardiovasc Surg* 2007; 55:130-48
10. Adams H, Baumann G, Cascorbi I et al. Zur Diagnostik und Therapie der Schockformen. Empfehlungen der interdisziplinären Arbeitsgruppe Schock der DIVI - Teil II: Hypovolämischer Schock. *Anästh Intensivmed* 2005; 42: 96-109
11. Kastrup M, Markewitz A, Spies C, Carl M, Erb J, Grosse J, Schirmer U. Current practice of hemodynamic monitoring and vasopressor and inotropic therapy in post-operative cardiac surgery patients in Germany: results from a postal survey. *Acta Anaesthesiol Scand* 2007; 51: 347-58

12. Boldt J. Volume therapy in the intensive care patient – we are still confused, but. *Intensive Care Med* 2000; 26: 1181-92
13. Schortgen F, Deye N, Brochard L. Preferred plasma volume expanders for critically ill patients: results of an international survey. *Intensive Care Med* 2004; 30: 2222-9
14. Barron ME, Wilkes MM, Navickis RJ. A systematic review of the comparative safety of colloids. *Arch Surg* 2004; 139: 552-63
15. Laxenaire MC, Charpentier C, Feldman L. [Anaphylactoid reactions to colloid plasma substitutes: incidence, risk factors, mechanisms. A French multicenter prospective study]. *Ann Fr Anesth Reanim* 1994; 13: 301-10

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