Dry or wet – which is the best for your patient?

Brandstrup B
Department of Surgical Gastroenterology, Bispebjerg University Hospital, Copenhagen, Denmark

Correspondence to: Dr Birgitte Brandstrup, e-mail: bbrandstrup@hotmail.com

ABSTRACT
Perioperative fluid therapy is the subject of much controversy, and the existing evidence seems contradictory. The aim of this paper is to present the (missing) evidence supporting the current standard fluid therapy, as well as the original trials examining the effects of fluid therapy on outcome of surgery.

To emphasise the fluid loss that actually occurs during surgery, the literature examining the evaporation from the abdominal wound, the fluid accumulations in the traumatised tissues, as well as the postulated changes in functional extracellular volume (i.e. the ‘loss to third space’) is briefly presented and critically analysed.

An attempt is made to evaluate all the trials examining the influence of fluid volume on outcome of surgery. The trials of goal-directed fluid therapy can be divided into two categories: the trials that examine the effect of zero fluid balance and the trials examining the effect of giving fluid to a target physiological value measured with either a pulmonary artery catheter or with an ultrasound Doppler device placed in the oesophagus. In addition to the goal-directed trials, the trials examining the effect of fixed volume fluid therapy will be presented. These ‘fixed volume trials’ concern mostly patients undergoing minor surgical procedures in an outpatient surgical setting.

The following conclusions are reached: current fluid therapy is not at all evidence based. The fluid losses that actually occur during surgery are highly overestimated. The perspiration from the surgical wound as well as the fluid accumulated in traumatised tissue is very small in elective surgery. The ‘loss to third space’ is based on flawed methodology and most probably does not exist.

The results of the goal-directed trials examining the effect of fluid therapy guided by a catheter in the pulmonary artery have not been unanimous, and the most exhaustive of these trials including 1 999 patients failed to show any benefit. The trials giving fluid to a maximal stroke volume guided by a Doppler in the oesophagus have several weaknesses, making the results of the trials very difficult to interpret, yet the method seems promising.

The trials focusing on zero fluid balance with the goal of normal body weight have shown that fluid overload with crystalloids causes harm, and avoidance of this fluid overload convincingly improves the outcome. This approach is confirmed by the results of the trials very difficult to interpret, yet the method seems promising.

The aim of this paper is to present the trials investigating the fluid losses that actually occur during surgery as well as the trials investigating the influence of fluid volume on the outcome of surgery. These trials fall into two categories: the trials using physiological goals as endpoint for the fluid therapy, giving either more or less fluid compared with standard fluid therapy, and the trials that compare fixed volumes of fluid.

The reason for this practice goes back to the sixties, where dogs subjected to haemorrhage showed increased survival if resuscitated with crystalloids in amounts exceeding lost blood. At about the same time the so-called loss to third space was claimed to occur during haemorrhagic shock, given a theoretical frame of understanding why the extra fluid was needed. The increased survival among wounded soldiers in Vietnam, where this new resuscitation practice was used for the first time, served as an indirect evidence of its benefits. Research including randomisation of patients (or animals) was only in its early stages, and the new approach that apparently worked so beautifully for soldiers in haemorrhagic shock was expanded to surgical theatres without being tested. Critique was silenced with the finding of a third space loss apparently occurring in patients undergoing gastrointestinal surgery, and possible hypovolaemia if not replaced.

Hypovolaemia leads to impaired tissue perfusion, impaired organ function, organ failure and even death. Fluid overload may, however, be just as harmful as hypovolaemia. Pulmonary oedema has been described as a consequence of fluid overload, also in patients without any known cardiac diseases. Associations between fluid overload and cardiac arrhythmias, pulmonary infections, ARDS, multi-organ failure and death following major surgical procedures have been reported in several papers. Only few clinical randomised trials have, however, examined the effects of fluid volume on outcome of surgery. These trials fall into two categories: the trials using physiological goals as endpoint for the fluid therapy, giving either more or less fluid compared with standard fluid therapy, and the trials that compare fixed volumes of fluid.

The aims of this paper is to present the trials investigating the fluid losses that actually occur during surgery as well as the trials investigating the influence of fluid volume on the outcome of surgery.

Introduction
Saline or lactated Ringer’s solution has been given in far larger volumes than measured fluid or blood loss, resulting in a weight increase of 4–7 kg in patients undergoing major elective surgery. The reason for this practice goes back to the sixties, where dogs subjected to haemorrhage showed increased survival if resuscitated with crystalloids in amounts exceeding lost blood. At about the same time the so-called loss to third space was claimed to occur during haemorrhagic shock, given a theoretical frame of understanding why the extra fluid was needed. The increased survival among wounded soldiers in Vietnam, where this new resuscitation practice was used for the first time, served as an indirect evidence of its benefits. Research including randomisation of patients (or animals) was only in its early stages, and the new approach that apparently worked so beautifully for soldiers in haemorrhagic shock was expanded to surgical theatres without being tested. Critique was silenced with the finding of a third space loss apparently occurring in patients undergoing gastrointestinal surgery, and possible hypovolaemia if not replaced.

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Basic science: Fluid losses during surgery
Basal fluid requirements
Even though patients are allowed to drink clear fluids until two hours before anaesthesia, preoperative fasting sometimes results in dehydration. A logical approach to determine the volume needed for replacement of the deficit caused by fasting is to ask the patient when and how much he or she has had to drink. The deficit can be replaced with approximately 80 ml/fasting hour.

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Insensible perspiration is not changed during surgery. It is approximately 10 ml/kg/day, with two-thirds lost through the skin and one-third lost through the airways (varying with the humidity of the inhaled air). Ventilation with air of 100% humidity causes a loss from the airways close to zero, while ventilation with dry air causes a loss of 0.5 ml/kg/h.

Surgery causes the release of stress hormones that tend to reduce the excretion of salt and water, thus reducing the urinary output. It has not been shown that a large urinary output can prevent postoperative renal failure, and as long as a small urinary output is not caused by hypovolaemia, but by vasodilatation and low blood pressure, it has not been associated with renal failure.28,29 During surgery a small diuresis can therefore be accepted as long as vasodilatation, and not hypovolaemia, is the cause.

**Perspiration and exudation from the surgical wound**

Perspiration through the surgical wound has been highly overestimated, especially in abdominal surgery, perhaps because it is often confused with the ‘loss to third space’. The evaporative loss from the abdominal wound depends on the size of the incision and the exposure of the intestines, but is independent of the size or the bodyweight of the patient.21 The evaporative losses have been quantified thoroughly, and are as follows: minor incisions with slightly exposed but non-exteriorised viscera cause a loss of 2.1 g/h; moderate incisions with partly exposed but non-exteriorised viscera cause a loss of 8.0 g/h; major incisions with completely exposed and exteriorised viscera cause a loss of 35.2 g/h; and if the exteriorised viscera are wrapped in plastic (as they should be) the evaporative loss is reduced by 87.5%.23 There is no evidence to suggest that the loss from incisions in other anatomical regions is very different.

An exudative loss may occur from the wound in addition to the evaporative loss. This fluid is often lost in the surgical dressings, and its volume based on an estimate. If the exteriorised viscera are placed in a plastic bag the loss can be measured rather accurately. Protein is lost with the exudation, and manipulation of the intestines increases the protein loss.21

**‘Loss to third space’**

The term ‘loss to third space’ is used for a variety of different conditions, and the use of the term needs clarification. It is used to describe the escape of fluid from the circulation to the interstitial space, (“known as the capillary leak syndrome”) often seen in patients having sepsis. It is used to describe the simple fact that intravenous (IV) fluids are leaving the circulation. It is also used to describe the presence of pathological fluid accumulation such as ascites, fluid in the plural cavity, or intra- or extracellular accumulation of blood or oedema fluid. These losses are known as ‘the anatomical third space losses’ 25,26 and may be quantified. A volume of pleural fluid or ascites can be estimated, for example by measuring the loss through drains. Any regeneration of such fluid can be identified by clinical and paraclinical examination with, for example, ultrasound imaging or by measurement of daily bodyweight changes. The fluid sequestered in traumatised tissue is assessed with more difficulty.

Data from experimental studies show that the oedema of a small bowel anastomosis is not caused by hypovolaemia, but as it was missing from the extracellular space, the term ‘the third space’ was invented to name the still unfound compartment containing the missing fluid. At first, this extensive volume was thought to be sequestered in the intestinal lumen, but this hypothesis was later rejected.32 Another hypothesis that the fluid was sequestered in traumatised tissue could not be confirmed when measuring extracellular volume (ECV) in American soldiers with extensive trauma and severe shock during the armed conflict in Vietnam.33,34 It was believed that this contraction had to be countered by using crystalloids to treat the patient to ‘refill’ the extracellular space during the operation.35

A systematic review of the literature concerning the changes in the ECV during surgery or haemorrhagic shock has recently been published.36 It shows that only trials utilising the labelled sulphate tracer and including the samples collected following 20–30 minutes of equilibration in the calculation of ECV have demonstrated a non-anatomical third space loss. All other studies identified, utilising various different tracers, multiple sampling techniques and longer equilibration times, had not been able to measure a third space loss during surgery or during haemorrhagic shock. Furthermore, it seemed that the use of another tracer, the labelled bromide tracer, led to the opposite finding, i.e. corrected for the blood lost, an expansion of the ECV was found. Thus the results of the ECV measurements seem to be extremely dependent on the utilised tracer and the sampling method.

Still, the loss to third space is replaced with volumes of up to 15 ml/kg/h in the first hour of abdominal surgery, with decreasing volumes in the following hours.55,56 In thoracic or orthopaedic surgery up to 4–7 ml/kg/h is recommended.57,58

**Trials of standard fluid vs less fluid (restricted fluid therapy)**

As seen from the above discussion, current standard fluid therapy is not at all evidence based.

The postoperative weight gain of 3–7 kg in patients undergoing major elective surgery therefore seems to represent a genuine fluid overload. On the basis of this background we performed a clinical randomised assessor-blinded multi-centre trial,39 designed to test the following two hypotheses:

Is standard fluid therapy causing postoperative oedema that may be harmful for tissue healing? Is the same fluid therapy causing cardiopulmonary complications?

Included were 172 ASA group III patients undergoing colorectal resection. They were randomised to a restricted (R) or a standard (S) intra- and postoperative IV fluid regimen. The idea behind the R regimen was that measured fluid loss should be replaced, but both intra- and postoperative fluid overload should be avoided, and the patients kept close to their normal bodyweight. During surgery no preloading of the epidural was given. If the anaesthetist wanted a fluid ‘running’ during induction of anaesthesia, 500 ml of HES was given slowly. This was regarded as an early replacement of expected blood loss, and not preloading of the epidural. Deficit due to fasting was replaced with glucose 5% (IV water), but no fluid was given to replace a third space loss of doubtful existence, and blood loss was replaced on a volume to volume basis with allowance for a maximum of 500 ml extra HES. The zero-balance principle was continued in the recovery room and in the surgical ward. In the absence of pathological fluid accumulations or surgical complications, a bodyweight increase of more than 1 kg was treated with furosemide.

On the day of operation the median IV fluid volume given to the two groups was 2 740 ml in the R group vs 5 388 ml in the S group, and on the first postoperative day 500 ml in the R group vs 1 500 ml in the S group. No significant differences in administered IV fluid volume were observed on postoperative days 2–6. Following 30 days of follow-up, any postoperative complication fulfilling per-protocol defined criteria for diagnosis was registered.

The fluid therapy aiming at zero fluid balance significantly and dramatically reduced the number of patients with postoperative
comlications (p < 0.0001). The number of patients with tissue healing complications and especially the number of patients with cardiopulmonary complications was significantly reduced. The worse the fluid overload, the worse the outcome in a clear dose-response relation. Four patients died in the S group, all from cardiopulmonary complications, with no deaths in the R group. Adverse effects to the restricted regimen were lower diuresis on the day of surgery, and increased aldosterone compared to the patients receiving standard therapy. Renal failure was observed in one case in a patient who developed pneumonia, sepsis, multi-organ failure and subsequently died. This patient was allocated to the S group.

On the other hand the patients in the S group had lower arterial pH, lower bicarbonate and negative base excess in the postoperative period. No difference between the groups was found regarding intraoperative blood pressure, heart rate or the use of pressor substances. The results of our trial have been confirmed by Nisenovich and colleagues, randomising 150 ASA group I-III patients undergoing various major gastrointestinal procedures. This trial examined the effect of a reduction in the volume of lactated Ringer’s solution as no colloids were given. Patients in the restricted group received 4 ml LR/kg/h compared to the standard group who received a fluid bolus of 10 ml/kg followed by 12 ml LR/kg/h. Blood loss was replaced by diuresis on the day of surgery, and increased heart rate a fluid bolus was given. The fluid volume given on the day of operation was 3 578 ml in the restricted group vs 5 883 ml in the standard group. No difference in the fluid volumes given on postoperative day 1 or 2 was observed.

Again the restricted fluid regimen significantly reduced the number of patients with postoperative complications. Patients in the restricted group had significantly shorter time to first flatus and stool and their hospital stay was significantly reduced. A weakness in the trial is that there was no follow-up after discharge, with the possible consequence that late complications may have been overlooked. The conclusion of these trials are that fluid overload with crystalloids is harmful and should be avoided to improve the clinical outcome.

**Trials of standard fluid vs more fluid**

When trying to estimate the need for IV fluid in patients with possible hypovolemia, it is common to observe the effect of a volume load on central haemodynamic variables such as cardiac index. This strategy is, however, based on two assumptions: that the haodynamic variable is sensitive to variations in cardiac index vs a standard programme. The first drug of choice was fluid, but the administered fluid volumes were not given. The optimisation programme did not reduce postoperative mortality, morbidity or time in hospital, but the use of a PAC had significant adverse effects. Being the most exhaustive trial of the use of a PAC to guide fluid therapy, this trial has been subject to critique. One point of critique is that the goals were not reached in many patients in the intervention group. To the author’s knowledge, no trials of goal-directed fluid therapy monitored with a PAC have been performed after the publication of this trial.

The new method for monitoring is an ultrasound Doppler device placed in the oesophagus. The goal is a stroke volume (SV) close to maximum obtained by repeated boluses of fluid (HES) until the SV increases no more or very little. In the first trials of oesophageal Doppler-guided fluid therapy, the number of patients was small, and in case of low diuresis, low blood pressure, or increased heart rate a fluid bolus was given. The fluid volume given on the day of operation was 3 578 ml in the restricted group vs 5 883 ml in the standard group. No difference in the fluid volumes given on postoperative day 1 or 2 was observed.

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Table 1: Trials including patients undergoing minor surgery in an outpatient setting. The fluid therapy was given as a fixed volume.

| Author       | Surgery                  | No                  | Blinding | Duration | Intervention                        | Fast | Oral fluid | Outcome measures                          | Results                                                                 |
|--------------|--------------------------|---------------------|----------|----------|--------------------------------------|------|------------|-------------------------------------------|-------------------------------------------------------------------------|
| Keane 1986   | Mixed surgery            | 212 pt. 2 gr.       | No       | 18 min.  | Hartman’s solution 1 l + DW 1 l vs. No fluid | ?    | ?          | Dizziness, thirst, nausea, drowsiness, well-being | Fluid reduced thirst, drowsiness Increases well-being, Nausea unchanged |
| Spencer 1988 | Gynaecological surgery   | 100 pt. 2 gr.       | No       | 8 min.   | CSL 1000 ml vs. No fluid              | ?    | ?          | As above                                  | Fluid reduced dizziness and nausea                                     |
| Cook 1990    | Gynaecological Laparoscopy | 75 pt. 3 gr.       | Yes      | 20 min.  | CSL 1400 ml vs. CSL + DW 1400 vs. No fluid | 11-16 h | ?          | As above + overnight stay                  | Fluid reduced dizziness and drowsiness. Hospital stay reduced in DW group |
| Yogendran 1995 | Mixed surgery          | 200 pt. 2 gr.       | Yes      | 28 min.  | Plasmolyte 1215 ml vs. Plasmolyte 164 ml | 8-13 h | ?          | As above                                  | Fluid reduced thirst, dizziness and drowsiness. No effect on nausea.     |
| Elkahim 1998 | Termination of pregnancy | 100 pt. 2 gr.       | Yes      | 12 min.  | CSL 1000 ml vs. No fluid              | 9.66 h | 1.5-2 h    | As above                                  | Fluid reduced nausea and vomiting                                      |
| Bennet 1999  | Dental surgery           | 90 pt. 2 gr.        | Yes      | ?        | Saline 16 ml/kg vs. Saline 1 ml/kg    | 8-13 h | ?          | As above                                  | Fluid reduced dizziness and drowsiness. Nausea unchanged                |
| McCaul 2003  | Gynaecological Laparoscopy | 108 pt. 3 gr.      | Yes      | 22 min.  | CSL 1115 ml vs. CSL + DW 1148 vs. No fluid | 11.5 h | ?          | As above                                  | No significant differences between the groups                           |
| Magner 2004  | Gynaecological Laparoscopy | 141 pt. 2 gr.      | Yes      | 20 min.  | CSL 30 ml/kg vs. CSL 10 ml/kg         | 13 h  | ?          | As above                                  | Fluid reduced nausea and vomiting. No effect on dizziness or thirst.     |
| Chochedri 2006 | Mixed surgery           | 200 pt. 2 gr.       | Yes      | ?        | Saline 20 ml/kg Saline 2 ml/kg        | ?    | ?          | As above                                  | Fluid reduced vomiting and thirst, but not dizziness or nausea          |

CSL = Compound Sodium Lactose, DW = Dextrose in Water 5%, NS = Normal Saline 0.9%, LR = Lactated Ringer’s solution.
volumes given preoperatively, the total volumes given were 3392 ml vs 3500 ml vs 3076 ml with very little volume difference between the groups. Both the trials found that the fluid optimisation programme shortened hospital stay. No difference in morbidity was reported. However, despite the very small number of patients included in the trials, and even though the result of the meta-analysis was not significant, it gave rise to a hypothesis of restricted mortality in the intervention groups. In the trial of Sinclair et al one patient in each group died. In the trial of Venn et al two patients in the control group, six in the CVP group and three in the oesophageal Doppler group died, giving a Peto's odds ratio of 1.44 (95% CI: 0.45–4.65).

The trial including the largest number of patients monitored with the oesophageal Doppler was performed by Wakeling and colleagues.64 They randomised 134 patients to a goal-directed programme vs standard fluid therapy. A basic volume of 3 l was given to each group. The patients were then directed to receive an additional fluid optimisation with Haemaccel® or Gelofusine®. The standard group received 1500 ml of colloid while the Doppler group received 2000 ml. The patients were preoperatively given 1000–2000 ml of Hartmann’s solution, but data on postoperative fluid therapy is not available. A significantly shorter time in hospital and faster return of bowel function were found in the Doppler group. Significantly more patients in the standard group developed complications. The latter, however, is highly dependent on the number of gastrointestinal complications and, unfortunately, the author does not write what they are. Two patients in the standard group vs one in the Doppler group had anastomotic leakage, five vs one had a high output stoma, but the reader is not told what happened to the remaining 27 vs 15 patients registered to have gastrointestinal complications. The power calculation of the trial was performed to show a difference in length of hospital stay, and hence definitions for acceptance of a complication were not made per protocol. Leaving the unknown gastrointestinal complications out, the difference in complications vanishes.

Trials of fixed volume fluid therapy
Nine randomised trials testing the effects of different IV fluid volumes on the outcome of outpatient surgery were found.62–70 The patient was given 392 ml vs 3350 ml vs 3076 ml with very little volume difference between the groups. Both the trials found that the fluid optimisation programme shortened hospital stay. No difference in morbidity was reported. However, despite the very small number of patients included in the trials, and even though the result of the meta-analysis was not significant, it gave rise to a hypothesis of restricted mortality in the intervention groups. In the trial of Sinclair et al one patient in each group died. In the trial of Venn et al two patients in the control group, six in the CVP group and three in the oesophageal Doppler group died, giving a Peto’s odds ratio of 1.44 (95% CI: 0.45–4.65).

In yet another trial68 48 patients undergoing knee arthroplasty were randomised to either a restricted or a liberal fluid regimen. The patients in the liberal group received a bolus of 10 ml/kg followed by 30 ml/kg/h, while the patients in the restricted group received no fluid bolus, but 10 ml/kg/h. Adding the fluid volumes given postoperatively to the intraoperative volumes, the total amount of fluid given was 1740 vs 4250 ml lactated Ringer’s solution. In this trial the fluid therapy caused a significant difference in pulmonary function, exercise capacity, postoperative ileus, wellbeing or length of hospital stay. Significant hypercoagulation was found in the liberal fluid group. In the last trial, 32 patients undergoing colonic resection were randomised to either a restricted or a liberal fluid volume.69 The restricted group received a total of 1600 ml of lactated Ringer’s solution and Voluven® while the liberal group received a total of 5000 ml. The restricted group had a transient decrease in pulmonary function in one measurement, but on the second postoperative night the pulmonary function was significantly improved with more oxygen saturation and fewer incidents of desaturation compared to the liberal fluid group. No difference was found in exercise capacity, postoperative ileus, or length of hospital stay. The authors emphasise that in the restricted group three patients suffered anastomotic leakage giving more complications in the restricted group. It may very well be that 1600 ml was too little, especially without a strategy for replacement of lost blood, and that the patients in the restricted group may have suffered from hypovolaemia.

Conclusions
The fluid losses during surgery are very small: The so-called loss to third space most probably does not exist and the evaporation from the surgical wound as well as the oedema formation in traumatised tissue is small during elective surgery. Hence the original ‘restricted fluid regimen’ is not restricted, but merely replaces the fluid actually lost during surgery, avoiding fluid overload with crystalloids. The ‘restricted’ trials have shown a convincing improvement in outcome.

The trials of goal-directed fluid therapy with a Doppler in the oesophagus have shown encouraging but divagating results. The design of the trials has, however, not been optimal. The power calculations have not been performed to show a difference in morbidity, a per-protocol defined hypothesis has not been presented, and demands for the acceptance of complications have not been defined per protocol. In all the trials a ‘standard fluid load’ has been given during the optimisation programme resulting in trials testing the effect of standard fluid load vs even more fluid. Moreover, there has been little control with pre- and postoperative fluid therapy. Because of these shortcomings, it is difficult to draw firm conclusions based on the current literature. Trials using a fixed volume of fluid during minor surgery have confirmed that loss should be replaced and hypovolaemia avoided. In major surgery a fixed volume programme should not be used.

Fluid therapy aiming at zero fluid balance with replacement of loss and resulting in normal bodyweight is recommended.

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References

1. Lang K, Boldt J, Sumter S, Haich G. Collodextr versus crystalline and tissue oxygen tension on patients undergoing major abdominal surgery. Anaesthetist 2001;50:405–9.

2. Lawson JA, Schaefdecker C, Driscoll DF, Benotti PN, Bostian BR. Postoperative fluid overload predicts complications. J Trauma 1999;47:128–34.

3. Loboz DN, Rostock KA, Neil KR, Perkins AG, Rowlands BJ, Allison SP. Effect of salt and water restriction on patient fluid balance during colorectal resection. A randomised controlled trial. Lancet 2002;359:1802–8.

4. Renthner L, Johannsson H, Strouth L. Insensible peritoneal and anaesthesia surgery. Acta Anaesthesiol Scand 1980;24:275–82.

5. Dilling J, Lynch J, Myers R, Butter HC, Moyer C, A bibliography of treatment of hemorrhagic shock. Acta Anaesthesiol Scand 1986;30:561–6.

6. Shires T, Brown FT, Cantzor PG, Summervill N. Distribution changes in extra cellular fluid during acute hemorrhagic shock. Surg Forum 1990;41:115–7.

7. Shires T, Williams J, Brown F. Acute changes in extracellular fluids associated with major surgical procedures. Ann Surg 1991;154:893–3.

8. Cooperman P. Intravenous fluids in the operative and postoperative period. A review of 40 cases. Ann Surg 1970;172:889–91.

9. Steen L, Bratza J, Morsitte M, Lu P, Wel MH, Shelton H. Pulmonary edema during volume infusion. Circulation 1975;52:489–95.

10. Arai IF. Fatal postoperative pulmonary edema. Pathogenesis and literature review. Pathol Res Pract 1989;185:166–74.

11. Mills M. The clinical syndrome. J Trauma 1968;8:651–5.

12. Simons RL, Heisterkamp BH CA, Mossey RV, Doty DH. Post resuscitative blood volumes in combat casualties. Surg Gynecol Obstet 1990;181:1293–201.

13. Steen L, Bratza J, Cavallienes J, Lu Z, Pech ML, Shelton H. Pulmonary edema during fluid resuscitation in human volunteers. Acta Anaesthesiol Scand 1980;24:275–82.

14. Bennett-Guerrero E, Feierman DE, Barclay GR, Parides MK, Sheiner PA, Mythen MG, et al. Preoperative and intraoperative predictor of postoperative morbidity, poor graft function, and early death in 100 patients undergoing liver transplantation. Arch Surg 2001;136:1177–83.

15. Calligaris KB, Lerner EB, Deaton HI, Dondi N, Dondi N, Simons RL. Intraoperative urinary output does not predict postoperative renal function in patients undergoing abdominal aortic revascularization. Surgery 1994;105:707–11.

16. Prato ED, Blodgett AB, Hines RE. Intravenous fluid administration and urine output during radical neck surgery. Head Neck 1993;15:208–15.

17. Lamke LO, Nielsen GE, Reithner HL. Water loss by evaporation from the skin. J Appl Physiol 1961;16:59–69.

18. Alpert RA, Roizen MF, Hamilton WK, Stoney RJ, Ehrenfeld WK, Poler SM, et al. Fluid management during volume infusion. Circulation 1975;52:483–9.

19. Patel RL, Townsend ER, Fountain SW. Elective pneumonectomy: Factors associated with poor graft function and early surgical failure. J Thorac Cardiovasc Surg 1976;71:914–20.

20. Holte K, Jensen P, Khelet H. Physiologic effects of intravenous fluid administration. Acta Anaesthesiol Scand 1998;42:216–9.

21. Beall AC, Johnson PC, Shirkey AL, Crosthwait RW, Cooley DA, DeBakey ME. Results of open-heart surgery for valvular disease. Ann Surg 1959;150:202–13.

22. Carrico CJ, Coln CD, Shires GT. Salt administration during surgery. Surg Forum 1959;10:277–9.

23. Gumpert JRW, Zollinger RM, Moore FD. Extracellular fluid volume changes during volume infusion. Anesth Analg 1973;52:48–52.

24. Shippy CR, Appel PL, Shoemaker WC. Reliability of clinical monitoring to assess fluid status. Anesthesiology 1982;57:6–10.

25. Steen L, Bratza J, Cavallienes J, Lu Z, Pech ML, Shelton H. Pulmonary edema during volume infusion. Circulation 1975;52:489–95.

26. Arai IF. Fatal postoperative pulmonary edema. Pathogenesis and literature review. Pathol Res Pract 1989;185:166–74.

27. Alpert RA, Roizen MF, Hamilton WK, Stoney RJ, Ehrenfeld WK, Poler SM, et al. Fluid management during volume infusion. Circulation 1975;52:483–9.

28. Gumpert JRW, Zollinger RM, Moore FD. Extracellular fluid volume changes during volume infusion. Anesth Analg 1973;52:48–52.

29. Shippy CR, Appel PL, Shoemaker WC. Reliability of clinical monitoring to assess fluid status. Anesthesiology 1982;57:6–10.