Journal of Clinical Monitoring and Computing
https://doi.org/10.1007/s10877-022-00934-x

ORIGINAL RESEARCH

Bioimpedance spectroscopy fluid analysis in acute high-risk abdominal surgery, a prospective clinician-blinded observational feasibility study

M. Cihoric[1] · **H. Kehlet**[2] · **J. Højlund**[1] · **M. L. Lauritsen**[3] · **K. Kanstrup**[3] · **N. B. Foss**[1]

Received: 30 August 2022 / Accepted: 13 October 2022

Abstract

Objective assessment of fluid status in critical surgical care may help optimize perioperative fluid administration and prevent postoperative fluid retention. We evaluated the feasibility of hydration status and fluid distribution assessment by Bioimpedance spectroscopy Analysis (BIA) in patients undergoing acute high-risk abdominal (AHA) surgery. This observational study included 73 patients undergoing AHA surgery. During the observational period (0–120 h), we registered BIA calculated absolute fluid overload (AFO) and relative fluid overload (RFO), defined as AFO/extracellular water ratio, as well as cumulative fluid balance and weight. Based on RFO values, hydration status was classified into three categories: dehydrated ($RFO < -10\%$), normohydrated ($-10\% \leq RFO \leq +15\%$), overhydrated $RFO > 15\%$. We performed a total of 365 BIA measurements. Preoperative overhydration was found in 16% of patients, increasing to 66% by postoperative day five. The changes in BIA measured AFO correlated with the cumulative fluid balance ($r2 = 0.44$, $p < .001$), and change in weight ($r2 = 0.55$, $p < .0001$). Perioperative overhydration measured with BIA was associated with worse outcome compared to patients with normo- or dehydration. We have demonstrated the feasibility of obtaining perioperative bedside BIA measurements in patients undergoing AHA surgery. BIA measurements correlated with fluid balance, weight changes, and postoperative clinical complications. BIA-assessed fluid status might add helpful information to guide fluid management in patients undergoing AHA surgery.

Keywords Emergency laparotomy · Bioimpedance spectroscopy · Fluid assessment · Fluid overload

1 Introduction

Patients requiring acute high-risk abdominal (AHA) surgery for, e.g., intestinal obstruction and perforated viscus [1, 2] are critically ill, with acute inflammation [3], sepsis, and fluid disturbances [1, 4] secondary to hypovolemia, shock, oedema, ascites, and pleural effusions. These conditions often occur before surgery, making perioperative fluid management a challenging but essential task for anaesthesiologists and surgeons.

Despite progress in the perioperative care of AHA surgery patients [1, 2], the assessment of hydration status and subsequent treatment are still complex and require an in-depth knowledge of body fluid homeostasis. Consequently, volume resuscitation strategies in AHA surgery and critical care are controversial [5–7].

Early fluid expansion is crucial in the resuscitation of patients [8]. Still, too much [9, 10] or too little fluid [11] during and after initial hemodynamic resuscitation can have detrimental consequences with increased morbidity and mortality. Presently, the gold-standard method used to evaluate fluid status is isotope dilution but challenging to perform in critical care patients because of fluid sequestration and abnormal penetration of tracers into cells [12]. Currently, fluid volumes are assessed using different surrogates, including weight, fluid balance, and clinical estimates of oedemas. However, precise body weight may be challenging

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✉ M. Cihoric
mirjana.cihoric.03@regionh.dk

[1] Department of Anaesthesiology and Intensive Care Medicine, Hvidovre University Hospital, Kettegaard allé 30, 2650 Hvidovre, Capital Region of Denmark, Denmark

[2] Section for Surgical Pathophysiology, JMC, Rigshospitalet, Copenhagen, Capital Region of Denmark, Denmark

[3] Gastrounit, Surgical Section, Hvidovre University Hospital, Hvidovre, Capital Region of Denmark, Denmark

to measure in critical patients, and its value may be affected by body composition changes for reasons other than fluid administration [13]. On the other hand, the registration of fluid balance by the difference of inputs and outputs of fluids does not usually consider insensible losses and has shown low accuracy [14, 15], calling for more objective tools [16].

Bioimpedance spectroscopy analysis (BIA) assesses body composition and estimates total and extracellular water volumes based on the tissue's capacity to conduct electrical impulses [17]. BIA detects fluid shifts independent of conventional registration methods, such as weight and cumulative fluid balance,

and is currently recommended for evaluating fluid status in haemodialysis patients [18, 19]. Data regarding BIA use in critically ill patients and septic [20] and burn patients [21, 22] is available but controversial due to mixed results [23, 24]. BIA has not been studied specifically in patients undergoing AHA surgery.

The present study aimed to determine the feasibility of BIA technology measuring pre- to postoperative fluid distribution and, by relating changes in volume status to the net administration of intravenous fluids and changes in weight, to evaluate if BIA measurements yielded plausible results in an acute setting.

Furthermore, we wanted to explore potential correlations between BIA measurements and clinical outcomes.

2 Methods

2.1 Design

We performed a prospective, clinician-blinded, observational study at the department of Anaesthesiology and Intensive Care and the department of Gastrointestinal Surgery at Hvidovre University Hospital, Denmark.

The study was a sub-study of the original research approved by the ethics committee (H-19010653), The Danish Data Protection Agency (VD-2019-121), and registered at clinicaltrials.gov. (NCT03997721). We obtained informed consent from all individual participants included in the study. This study followed STROBE [25] guidelines for reporting observational studies.

2.2 Patients

Inclusion criteria were patients older than 18 years undergoing AHA surgery for intestinal obstruction, perforated viscus, or anastomotic leakage following elective surgery. Exclusion criteria were: (1) other acute abdominal surgeries, e.g., appendectomies, cholecystectomies, internal hernias following gastric bypass, incarcerated hernias without obstruction present, (2) acute reoperations following either elective or acute surgery apart from suspected anastomotic leakage (3) intestinal ischemia (4) intraabdominal bleeding (5) conditions that interfered with making accurate BIA measurements: limb amputation, metallic cardiac or joint prostheses, cardiac pacemakers or stents or decompensated cirrhosis. The observational period started after the patient arrived at the operating theatre and continued for at least 72 h to a maximum of 120 h.

2.3 Setting

We applied a well-established multimodal standardized protocol to patients undergoing AHA surgery [1], following recent NELA guidelines [2], including pre-and intraoperative fluid and hemodynamic management guided by cardiac output, neuraxial anaesthesia, and analgesia.

Subsequent intra- and postoperative treatment were left to the discretion of the treating anaesthesiologist and surgeon, who were not informed about the BIA result, thereby reflecting clinical practice.

2.4 Data collection and management

Demographics, comorbidities information, and surgery details were recorded for each patient. Clinical data (e.g., arterial blood pressure, heart and respiratory rate, and body temperature), laboratory data, and details of hospital course (e.g., use and dosage of vasopressor agents, need for mechanical ventilation, and CRRT) were recorded preoperatively, 6 h after surgery, and on the postoperative day one, three and five. The occurrences of major postoperative complications were assessed according to Clavien Dindo criteria [26], while AKI was based on RIFLE [27] for 30 days after surgery.

Intra- and postoperative daily fluid balance was recorded as the algebraic sum of fluid intake and output per day, not including insensible losses. The cumulative fluid balance was calculated as the algebraic sum of daily fluid balance during the observational period.

2.5 Bioimpedance spectroscopy analysis (BIA) measurements

The assessments of body fluid composition were performed using the Body Composition Monitor device (BCM, Fresenius Medical Care, Germany), preoperatively within 1 h before surgery, 6 h after surgery, on a postoperative day 1,3, and 5 (120 h). BIA assesses body composition and estimates total (TBW) and extracellular water(ECW) volumes based on the tissue's capacity to conduct electrical impulses [17, 28, 29]. The algorithm built into the BCM device calculates the normal hydration status for a given weight, i.e., the expected normal values for ECW, which would result in healthy renal function and a state of normohydration.

The BCM device calculates absolute fluid overload (AFO), which is the difference between expected ECW and the actual measured ECW, expressed in litres; relative fluid overload (RFO), which is absolute fluid overload/ extracellular water ratio (AFO/ECW), expressed in percentages. A negative AFO suggests the patient's underhydration, while a positive one suggests overhydration. Based on RFO values, a patient's hydration status was classified into three categories: dehydrated ($RFO < -10\%$), normohydrated ($-10\% \leq RFO \leq +15\%$), and overhydrated $RFO > 15\%$ [30–33].

According to the manufacturer's indications, patients were placed in a supine position on the hospital bed without touching metal objects, with the angles between the upper limbs and trunk and between the legs at 30 and 45°, respectively. After the skin was cleaned with alcohol, four non-recyclable electrodes were attached: two on the one hand (on the wrist's bony protuberance and just behind the metacarpals) and two on the ipsilateral foot (on the ankle midline, between the medial and lateral malleoli and just behind the metatarsals). We accepted the data quality above 95%; otherwise, we repeated the measures after applying new electrodes. The primary investigator performed all measurements.

Precise body weight is difficult to measure both preoperatively and in the postoperative wards in an acute setting, such as with patients undergoing acute high-risk abdominal surgery. However, great effort was put into doing so in the study to be able to compare the findings with bioimpedance measurements. The level of missing data was below 10%.

2.6 Data analysis: Sample size considerations and statistics

To detect a moderate and thereby clinically meaningful correlation ($r = 0.4$) between net perioperative fluid balance and change in fluid overload, a sample of 47 patients was calculated to provide 80% power to discover that the correlation would be significantly different from there being no correlation at the 0.05 level. Sample size considerations were based on association analyses using the Pearson correlation test.

Data are expressed as means ± standard deviations, medians, and interquartile ranges or frequency distributions, as appropriate.

The primary outcome was the correlation of fluid overload measured with BIA on postoperative day 5, both AFO and RFO, and the correlation with cumulative fluid balance. The secondary and exploratory outcome was the correlation between BIA measurements and clinical outcomes. The pre- to postoperative fluid overload changes were evaluated using the Wilcoxon test for a non-gaussian population. Similar exploratory analyses were conducted for all other parameters obtained before and after surgery, as well as in the postoperative period, using paired T-test or Wilcoxon test, depending on the data distribution. The Kruskal–Wallis test was used for comparison between continuous variables, and the chi-square test or Fisher's exact test was used for comparisons between categorical variables.

Spearman's rank correlation coefficient was used to assess the relationship between changes in BIA fluid distribution, cumulative fluid balance, and weight. Statistical analysis was performed using "R" software (R Core Team (2015)).

3 Results

A total of 73 patients were included from 01–06-2019 to 25–02-2021. Since the inclusion period stretched throughout the first Covid-19 wave and the BIA measurements were performed by only one operator, we achieved a low recruitment rate. The main characteristics of the patient population are shown in Table 1.

A total of 365 BIA measurements were performed. Before anaesthesia, 16% of all patients had relative fluid overload (Fig. 1). Simultaneously, AFO increased significantly by 1.77 ± 1.4 L, from 0.68 ± 2.5 L preoperatively to 2.4 L ± 2.7 on postoperative day 1 ($p < 0.0001$), equivalent to a 10% rise in ECW, $p = 0.02$. (Table 2). In contrast, both TBW and ICW only showed non-significant trends toward an increase ($p = 0.430$ and 0.876, respectively). By postoperative day 1, 49% of the cohort were overhydrated ($RFO > 15\%$), and by postoperative day 5, the number had increased to 66.1% (Fig. 1).

The changes in absolute fluid overload measured by BIA on postoperative day five correlated with the 5-day cumulative fluid balance (Fig. 2A and illustrated in Fig. 4) as well as weight change (Fig. 2B) during the first five days after surgery ($r2 = 0.44$, $p < 0.001$ and $r2 = 0.55$, $p < 0.0001$ respectively). Furthermore, change in weight correlated with fluid administration during the perioperative period, $r2 = 0.35$, $p = 0.008$ (Fig. 2C).

Plasma albumin decreased from 30 ± 7 g/L to 27 ± 5 g/L ($p < 0.0001$) and CRP increased from 148 ± 147 mg/dL to 221 ± 121 mg/dL ($p < 0.0001$) pre- to postoperative day 1 (Table 2), as manifested by a significant rise in the capillary leak index ($p < 0.0001$).

We found no significant correlation between the net perioperative (pre- to 6-h postoperative) fluid balance and ICW $r2 = 0.16$, $p = 0.182$ (Fig. 3A). There was a significant correlation between net perioperative fluid balance and change in ECW ($r2 = 0.41$, $p = 0.0003$) (Fig. 3B). Furthermore, there was a significant correlation between change in TBW and net perioperative fluid balance, ($r2 = 0.28$, $p = 0.016$) (Fig. 3C),

Table 1 Main characteristics of the study population

Patient characteristics	Entire cohort (n = 73)
Age [years (range)]	63 (22–90)
Sex (female)	34 (46.5)
Height (m)	1.71 ± 9.7
Body Weight (kg)	76.9 ± 20.5
Body Mass Index (kg/m^2)	26 (22–31)
ASA > 2 [n (%)]	27 (36.9)
qSOFA > 1	11 (15.1)
Preoperative acute kidney injury	12 (16.4)
Comorbidities [n (%)]	
Cardiac	21 (28.7)
Pulmonary	9 (12.3)
Renal	6 (8.2)
Cerebrovascular	4 (5.5)
Diabetes	7 (9.6)
Laboratory data at admission	
Arterial pH (unitless)	7.42 (7.34–7.46)
Arterial bicarbonate (mmol/L)	24.4 (22.6–27.3)
Plasma sodium (mmol/L)	137 (135–139)
Plasma potassium (mmol/L)	3.9 (3.6–4.1)
Plasma chloride (mmol/L)	103 ± 6
Plasma creatinine (μmol/L)	82 (65–96)
Haemoglobin (mmol/L)	7.8 ± 1.5
White blood cells (10^3/mL)	10.9 (7.6–16.5)
Intraoperative data	
Intestinal obstruction	27 (37.0)
Perforated viscus	26 (35.6)
Anastomotic leakage	20 (27.4)
Duration of anaesthesia (min)	118 ± 58
Intraoperative fluid administration (mL)	1925 (1550–2780)
Intraoperative fluid balance (mL)	1661 (1387–2284)
Cumulative fluid balance, postoperative day 1–5 (mL)	4009 (949–6780)

Data are expressed as means (SD); medians (IQR) or number (percent) unless otherwise stated

ASA American Society of Anesthesiologists Score, *qSOFA* quick Sequential Organ Failure Assessment score, Cardiac: essential hypertension, atrial fibrillation, previous myocardial injury, heart failure; Pulmonary: asthma, chronic obstructive pulmonary disease, lung fibrosis; Fluid balance: input minus output excl. insensible losses; Cumulative fluid balance: input minus output during the observational period (up to 120 h)

and between change in ICW and change in ECW, ($r2 = 0.35$, $p < 0.001$), (Fig. 3D).

Patient outcomes are shown in Table 3. Patients presenting with RFO > 15% before surgery had a significantly higher incidence of major postoperative complications ($p = 0.007$), length of hospital stay (LOS) (0.026), as well as ICU stay ($p = 0.042$). Postoperative overhydration was significantly associated with incidence of major complications ($p = 0.028$), ICU stay ($p = 0.024$) and increased length of hospital stay ($p = 0.011$).

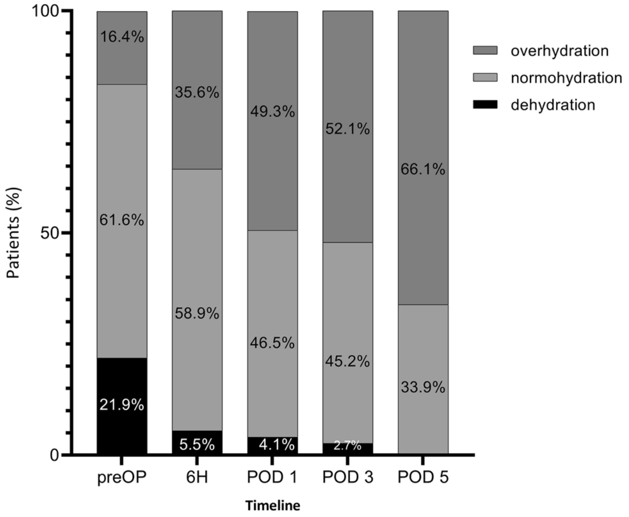

Fig. 1 Distribution of hydration status by Bioimpedance Spectroscopy Analysis in the early perioperative period: dehydration (RFO < − 10%), normohydration (− 10% ≤ RFO ≤ + 15%), overhydration RFO > 15%. *RFO* relative fluid overload

4 Discussion

4.1 Key findings

We conducted an observational, clinician-blinded study to determine the ability of BIA technology to track changes in pre- to postoperative fluid distribution in patients undergoing AHA surgery for intestinal obstruction, perforated viscus, and anastomotic leakage. On initial preoperative BIA assessment, 16% of patients had overhydration, increasing to 66,1% by postoperative day five.

We have shown that directional changes in BIA hydration are consistent with directional changes of the traditional surrogate variables used to assess fluid status, i.e., weight and documented fluid balance.

We have demonstrated the feasibility of performing repeated BIA measurements in AHA surgery patients. Additionally, as an exploratory outcome, peroperative overhydration was found to be associated with poor outcome.

4.2 Relationship to previous studies

Several studies on critical care and surgical patients have been conducted, with different methods of body composition analysis and mixed results [23]. In this study, we employed bioimpedance spectroscopy using the BCM device, which measures at 50 frequencies and utilizes a unique body composition model for determining fluid overload or overhydration to directly predict TBW, ECW, and ICW. We did not use the gold standard deuterium dilution method to confirm the accuracy of the fat-free TBW assessments provided by the

Table 2 Vital signs and bioimpedance volume status assessment in the pre[a]- and postoperative[b] period

Variables	Preoperative	Postoperative Day 1	Mean difference	P-value (chi square test)
Heart rate (beats/min)	92 ± 21	82 ± 15	− 9 ± 18	< .0001
Systolic blood pressure (mmHg)	141 ± 30	129 ± 24	− 12 ± 31	0.002
Diastolic blood pressure (mmHg)	68 ± 14	67 ± 15	− 2 ± 18	0.469
Plasma albumin (g/L)	30 ± 7	27 ± 5	− 3 ± 5	< .0001
C-reactive protein (mg/dL)	148 ± 147	221 ± 121	72 ± 118	< .0001
Capillary leak index (unitless)	589 ± 614	870 ± 535	281 ± 454	< .0001
TBW (L)	39.8 ± 8.1	41.0 ± 8.1	1.6 ± 8.0	0.140
ICW (L)	21.4 ± 5.0	21.4 ± 5.1	− 0.6 ± 6.0	0.945
ECW (L)	18.3 ± 3.8	20.3 ± 3.7	1.4 ± 4.5	< .01
ECW/ICW ratio	0.87 ± 0.2	1.00 ± 0.2	–	< .001
AFO (L)	0.68 ± 2.5	3.10 ± 2.6	2.4 ± 2.0	< .0001
RFO, median (IQR) (%)	3.1 (− 5.7–11.7)	15.0 (6.9–21.6)	–	< .0001
Patients with FO[c] [n (%)]	12 (16.4)	36 (49.3)	–	< .001

Data are expressed as mean ± SD unless otherwise stated

Capillary leak index: CRP over albumin, multiplied by 100; *TBW* total body water; *ICW* intracellular water, *ECW* extracellular water, *AFO* absolute fluid overload, *RFO* relative fluid overload (percentage of ECW)

[a] Preoperative period: prior to surgery

[b] Postoperative period: Postoperative day 1

[c] FO defined as RFO > 15% of ECW; There was no missing data

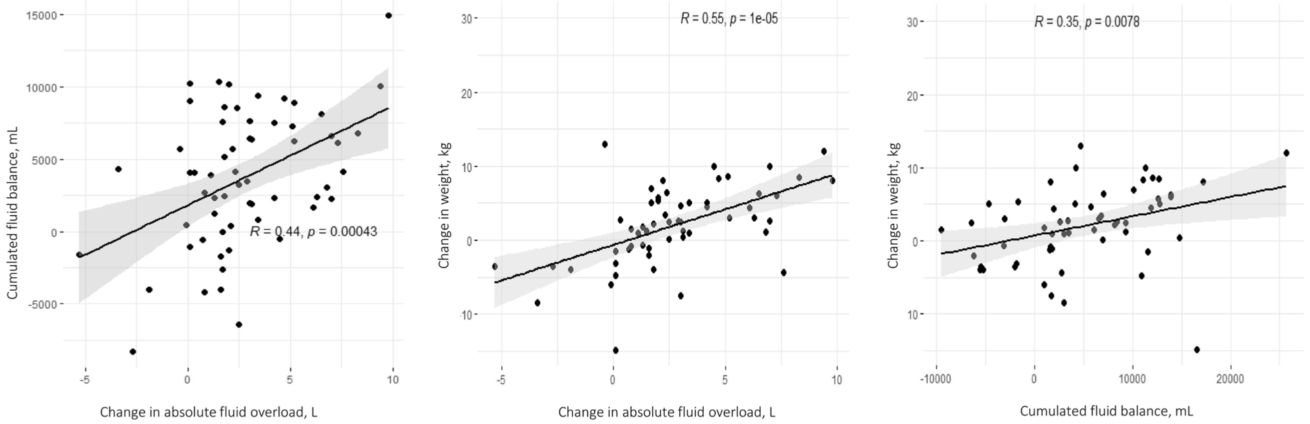

Fig. 2 Relationship between fluid balance, changes in weight, and changes in absolute fluid overload *on postoperative day five* in acute high-risk abdominal surgery: **A** Absolute fluid overload and cumulative fluid balance; **B** Absolute fluid overload and changes in weight; **C** Cumulative fluid balance and changes in weight

BIA technology. However, a study found BIA to be precise in determining fluid compartments [34]. Additionally, the lack of a steady state in critically ill patients and the time taken for equilibration preclude the simultaneous use of gold standard isotopic tracers as a formal validating technique.

Fluid distribution using BIA or other body composition analysis has not previously been measured in patients specifically undergoing AHA surgery. Few studies have focused solely on surgical patients [35] and the perioperative period [36]. Overall, changes in given body composition analysis partially reflect changes in clinical hydration during critical illness. In this study, measured ECW correlated well with administered fluids, while ICW did not (Fig. 3), adding to the method's credibility. However, a recent systematic review questioned the accuracy of measurements due to a lack of gold standards, where numerous studies, like the present, compared measurements with surrogate parameters with significant variability in design [23].

Fluid status and fluid responsiveness are pre-supposed to be closely tied, and dynamic preload changes are considered the gold standard for perioperative fluid management, as opposed to static measures [37, 38]. However, fluid

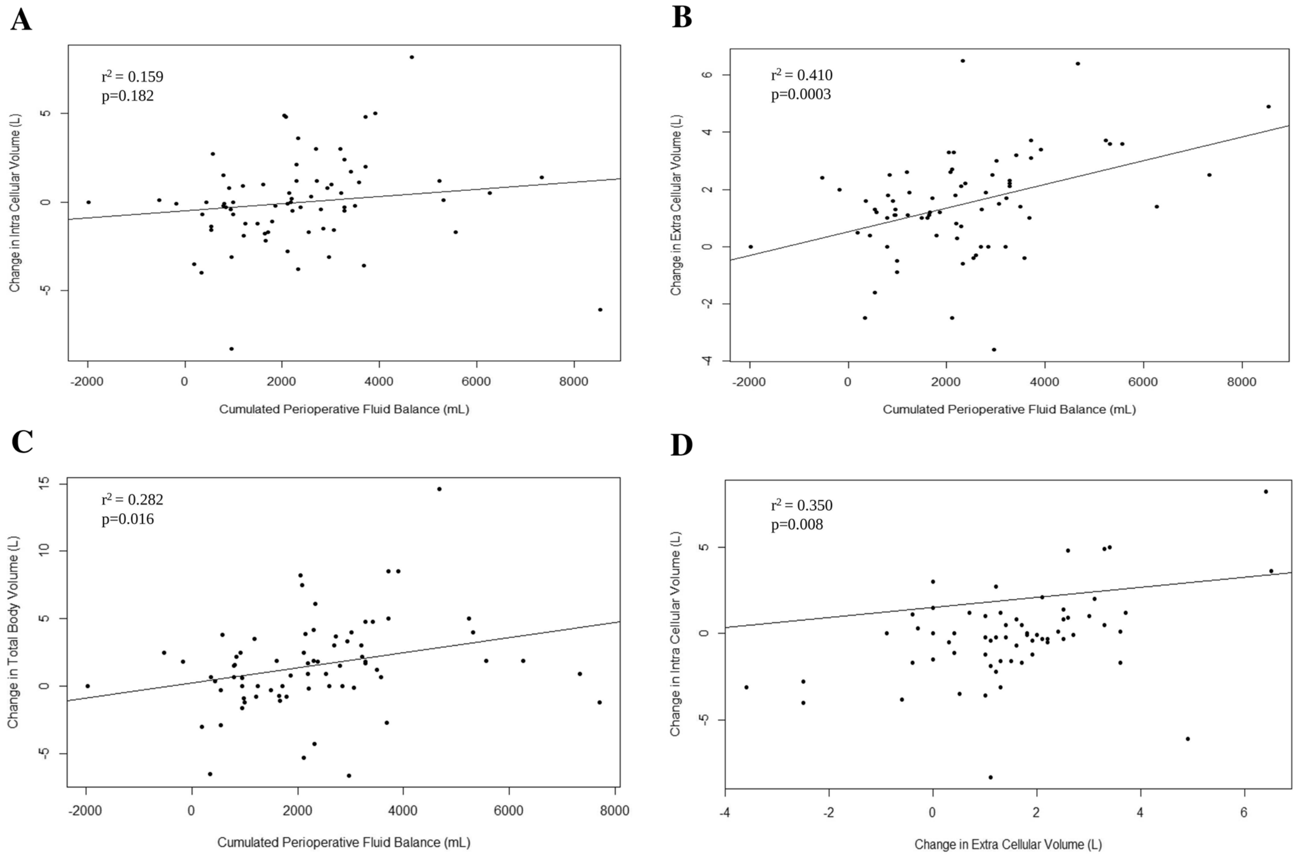

Fig. 3 Associations between pre- to 6 h postoperative changes in volume status and net fluid balance in patients undergoing acute high-risk abdominal surgery. Regression equations are as follows: **A** Change in intra cellular volume; **B** Change in extra cellular volume; **C** Change in total body volume; **D** Change in intra cellular volume and extra cellular volume. Pearson correlation test. R^2 = coefficient of determination

responsiveness does not necessarily exclude overhydration. While fluid responsiveness assesses the intravascular status, it does not consider the extravascular space. Since these patients are at significant risk of dyshydration due to, e.g., sepsis, the ability to assess the extravascular space is crucial. Thus, although dynamic parameters such as cardiac output or stroke volume might indicate fluid responsiveness or, indeed, preload dependency, patients could still be severely extravascularly overhydrated. The ability to include these measures in clinical decision-making could facilitate fluid management (Fig. 4).

By using BIA as a support mechanism for the overall fluid status assessment, we have the option of guiding therapy where, while the intravascular fluid treatment takes place, we also take extravascular space into account. Equally as important, we chose to evaluate BIA due to its simplicity and availability in the daily clinical setting. We wanted to explore a tool that can be operated by all personnel, easily implemented, and interpreted even in the surgical ward.

A previous observational study in critically ill patients found that those who were respectively dehydrated, normohydrated, and overhydrated on initial BIA assessment had a subsequent concordant change (positive, neutral, or negative) in cumulative fluid balance [39]. In our study, fluid balance increased throughout the postoperative period, regardless of preoperative BIA assessment. While BIA can assess the intra- and extracellular fluid status, it cannot discern between extravascular and intravascular volume. In healthy subjects, there is an equilibrium among body spaces, whereas patients undergoing AHA surgery have several clinical disorders in body fluid balance induced by inflammatory and surgical stress. This imbalance precipitates hypovolemia, microcirculatory dysfunction, and secondary interstitial oedema, causing systemic hypoperfusion and subsequent overhydration [13]. In this case, BIA measurements might fail to give the clinician a more complete assessment. In patients with intestinal obstruction, a significant amount of fluid is pooled in the bowel. This fluid is not always considered when assessing the overall fluid balance. Thus, BIA measurements could also assist in the comprehensive clinical evaluation of acute surgical patients.

Table 3 Outcome data stratified according to Bioimpedance Spectroscopy fluid distribution during the observational period

Variables Baseline (before surgery)	All (n = 73)	Dehydration (RFO < − 10%) (n = 16)	Normal (− 10% ≤ RFO ≤ + 15%) (n = 45)	Overhydration (RFO > 15%) (n = 12)	P value chi-square test
30-day major postoperative complications, CD > II	29 (39.7)	3 (18.8)	17 (37.7)	9 (75.0)	0.007
Pulmonary complications	8 (10.9)	0 (0.0)	6 (13.3)	2 (12.6)	0.458
Cardiac complications	9 (12.3)	2 (12.5)	5 (11.1)	2 (16.7)	0.052
Acute Kidney Injury, RIFLE	17 (23.3)	3 (18.7)	8 (17.7)	6 (50.0)	0.018
ICU stay	18 (24.6)	1 (6.3)	11 (24.4)	6 (50.0)	0.042
LOS, day, median (IQR)	9 (6–16)	7 (4–13)	9 (6–15)	21 (8–33)	0.026
30-day mortality	9 (12.3)	0 (0.0)	5 (11.1)	4 (33.3)	0.068
Variables Postoperative day 5	All (n = 59)	Dehydration (RFO < − 10%) (n = *3*)	Normal (− 10% ≤ RFO ≤ + 15%) (n = 16)	Overhydration (RFO > 15%) (n = 40)	P value chi-square test
30-day major postoperative complications, CD > II	34 (57.6)	0 (0.0)	8 (50.0)	26 (65.0)	0.028
Pulmonary complications	8 (14.0)	0 (0.0)	1 (6.3)	7 (17.5)	0.427
Cardiac complications	9 (15.3)	0 (0.0)	1 (6.3)	8 (20.0)	0.334
Acute Kidney Injury, RIFLE	16 (27.1)	0 (0.0)	3 (18.8)	13 (32.5)	0.328
ICU stay	17 (28.8)	0 (0.0)	1 (6.3)	16 (40.0)	0.024
LOS, day, median (IQR)	11 (7–18)	–	7 (6–12)	14 (8–23)	0.011
30-day mortality	7 (11.8)	0 (0.0)	1 (6.3)	6 (15.0)	0.031

Data are expressed as number (percentage) unless otherwise stated. *CD* Clavien Dindo classification; RIFLE classification of acute kidney injury: ↑ SeCreatinine × 2 or ↓ GFR > 50%, with TD < 0.5 mL/kg/h × 12 h.; *ICU* intensive care unit, *LOS* Length of (hospital) stay

Evidence supports the routine use of BIA as an adjunct to clinical assessment of fluid overload. Considering the incidence of overhydration in the presented cohort, BIA assessment may help physicians optimize fluid administration and diuretic therapy. Still, a specific evaluation of the clinical impact of fluids sequestered in the gut will require further research. BIA could be a valuable additional monitoring technology, as it gives information on the extravascular fluid status, as opposed to the intravascular measures attained by conventional cardiovascular monitoring.

We must also underline that, while AHA surgery patients have similarities with critically ill patients, most of the postoperative period is in the surgical ward and not in the ICU, precluding comparison of care and observation.

4.3 Strengths and limitations

This study has several strengths. This is the first study to evaluate BIA in AHA surgery. Furthermore, by continuing measurements throughout the postoperative period, we could match changes in cumulative fluid balance and weight with corresponding changes in BIA measurements, lending robustness to our study. Our BIA measurements suggest

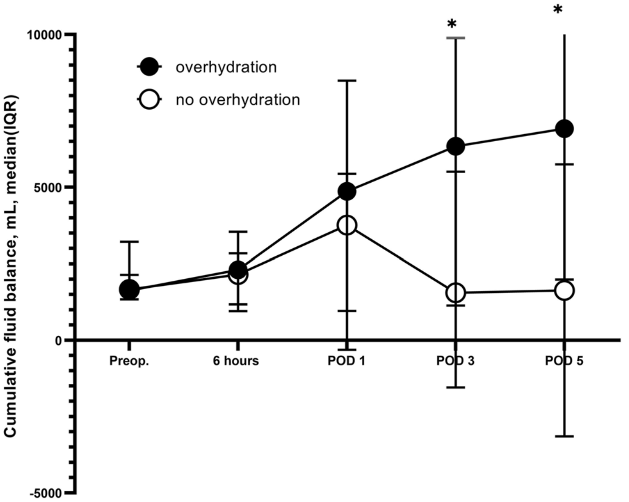

Fig. 4 Association between cumulative fluid balance and Bioimpedance Spectroscopy Analysis measured overhydration, **statistically significant* ($p < .01$): Daily fluid balance was defined as the difference between total input (all fluids, nutrition, blood products, medications) and total output (losses through urinary, gastrointestinal, or other drainage tubes), not including insensible losses). Cumulated fluid balance was calculated as the algebraic sum of daily fluid balance during the observational period; overhydration: Relative fluid overload > 15%

that the administration of intraoperative fluids may increase TBW due to ECW volume expansion without a change in ICW volume, consistent with earlier research [36] and with the physiology.

This study has limitations. It is a single-centre study with all the limitations inherent in such a design. However, we studied a heterogeneous population of AHA surgery patients with > 350 measurements, suggesting a degree of external validity and robustness. This is not an interventional study; therefore, we can make no inferences about BIA's utility in managing fluid balance. However, observational studies such as this are necessary to establish the technique's feasibility, safety, and validity before its application in interventional studies. A prospective interventional study using BIA to guide intra and postoperative fluid administration is the next logical step.

While the BIA measurements mirror the changes in cumulative fluid balance, we acknowledge that the hospital environment may impact the accuracy of BIA measurements. In some circumstances, it was not possible to position the patients in an entirely supine state (e.g., those with aspirate and postoperative abdominal pain), and on occasion, the positioning of the electrodes had to be modified slightly owing to the presence of other devices (e.g., intravenous cannulae). The extensive electrical equipment in the operating room and ICU, including the various monitoring devices and mechanical ventilators, could potentially impact the measured bioimpedance, as could any water in the patient's bed, though to what degree is unknown. However, the fact that BIA still generated reproducible and logical findings supports the applicability of this technology in this environment.

5 Conclusion

Our results suggest that BIA measurements before surgery combined with the postoperative period may add helpful information to future improvements in fluid management in AHA surgery. Whether BIA-guided fluid management can improve clinical outcomes in this challenging population needs to be explored in future interventional studies.

Author contribution All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by MC, NBF, HK, JH, MLL, and KK. The first draft of the manuscript was written by MC and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Funding Funding was provided by Region Hovedstaden.

Declarations

Competing interests The authors declare no competing interests.

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