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ORIGINAL RESEARCH

Practical impact of a decision support for goal-directed fluid therapy on protocol adherence: a clinical implementation study in patients undergoing major abdominal surgery

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Abstract

The purpose of this study was to assess the effects of using a real time clinical decision-support system, "Assisted Fluid Management" (AFM), to guide goal-directed fluid therapy (GDFT) during major abdominal surgery. We compared a group of patients managed using the AFM system with a historical cohort of patients (control group) who had been managed using a manual GDFT strategy. Adherence to the protocol was defined as the relative intraoperative time spent with a stroke volume variation (SVV) < 13%. We hypothesised that patients in the AFM group would have more time during surgery with a SVV < 13% compared to the control group. All patients had a radial arterial line connected to a pulse contour analysis monitor and received a 2 ml/kg/h maintenance crystalloid infusion. Additional 250 ml crystalloid boluses were administered whenever measured SVV ≥ 13% in the control group, and when the software suggested a fluid bolus in the AFM group. We compared 46 AFM-guided patients to 38 controls. Patients in the AFM group spent significantly more time during surgery with a SVV < 13% compared to the control group (median 92% [82, 96] vs. 76% [54, 86]; P < 0.0005), and received less fluid overall (1775 ml [1225, 2425] vs. 2350 ml [1825, 3250]; P = 0.010). The incidence of postoperative complications was comparable in the two groups. Implementation of a decision support system for GDFT guidance resulted in a significantly longer period during surgery with a SVV < 13% with a reduced total amount of fluid administered. Trial registration: Clinical Trials.gov (NCT03141411).

Keywords Decision-assisted resuscitation · Cardiac output monitoring · Goal-directed therapy

1 Introduction

Many trials have indicated that goal-directed fluid therapy (GDFT) strategies may benefit high-risk surgical patients [1–9] but these strategies are infrequently implemented [10–12]. It has also been shown that without any goal or protocol for fluid resuscitation, large inter- and intra-provider variability exist and have been correlated with marked variations in patient outcomes [13, 14]. Even under ideal study conditions, strict adherence to GDFT protocols is hampered by the workload and concentration required for consistent implementation [1]. Haemodynamic monitors and protocols alone do not enable optimal fluid titration to be provided consistently to all patients—there must also be appropriate and timely interpretation and intervention.

To address this problem of consistency and protocol adherence, a clinical decision support system, "Assisted Fluid Management" (AFM), has been designed to help ease some of

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the workload associated with GDFT protocol implementation. The AFM system (released on the European market in March 2017) may help increase GDFT protocol adherence while leaving direction and guidance in the hands of the care providers. This system can suggest fluid bolus administration, analyse the effects of the bolus, and continually re-assess the patient for further fluid requirements. The core decision engine of the AFM system is based on algorithm development and validation previously performed by our team [15–21].

In December 2016, after completion of a clinical trial showing benefit of GDFT in our institution [22], we started to use a manual GDFT protocol in appropriate patients guided by the EV1000 monitor (Edwards Lifesciences, Irvine, CA, USA). In late March 2017, our hospital received upgraded firmware for the monitors, which now include the AFM software suite. The goal of this study was to assess the implementation of the new AFM system in a prospective cohort of patients undergoing major abdominal surgery (AFM group), and compare the results with those of a retrospective historical group of patients who were managed using the manual GDFT strategy (control group) before implementation of the new AFM system. We hypothesised that use of the AFM system would result in a higher percentage of time spent during surgery with a stroke volume variation (SVV) < 13% (a standard GDFT recommendation [23], and shown to improve outcomes [8]), compared to patients managed using a manual GDFT strategy.

2 Materials and methods

2.1 Ethics

Ethical approval for this study (Number: P2017/290) was provided by the Ethical Committee of Erasme Hospital, 808 Route de Lennik, 1070 Brussels, Belgium, Chairperson, Prof Jean-Marie Boeynaems on May 24, 2017. The study was registered on May 5, 2017 (PI: Alexandre Joosten) on clinicaltrials.gov (NCT03141411). Patients in the prospectively studied GDFT group provided written informed consent while patient consent was waived by the Erasme Hospital Ethic Committee for the historical group.

This manuscript adhere to the STROBE guidelines (STrengthening the Reporting of OBservational studies in Epidemiology).

Between December 2016 and March 2017, patients equipped with an arterial radial catheter undergoing major abdominal surgery in our institution received GDFT guided by the EV1000 Clinical Platform (Edwards Lifesciences, Irvine, California, USA), which was considered standard of care. These patients represented our historical control group.

Our EV1000 monitor firmware was upgraded in March 23, 2017 to a new version (Version 2.0.0.18) with the AFM algorithm. From May through August 2017, we prospectively enrolled all patients over 18 years of age scheduled for elective major abdominal surgery (open surgery or a combination of laparoscopic and open laparotomy, as per the historical group). Exclusion criteria for both the prospective and historical groups included: under 18 years of age, pregnant, presence of significant valvular disease, cardiac arrhythmias and left ventricular ejection fraction < 30%, or any other contraindications to use of SVV monitoring [24].

2.2 General management protocol in both groups

In all patients, anaesthesia was induced with sufentanil (0.2 µg/kg), propofol (2 mg/kg) and rocuronium (0.6 mg/kg), and was maintained with either sevoflurane or desflurane and sufentanil boluses at the discretion of the anaesthesia team. Adjustments to anaesthetic delivery were made to keep the bispectral index level stable between 40 and 60 using a depth of anaesthesia monitor (BIS monitoring, Covidien, USA). All patients received mechanical ventilation using a volume control mode with tidal volume of 8 ml/kg ideal body weight and a positive end-expiratory pressure of 5 cm H_2O using the Zeus Infinity C700 Anesthesia workstation Machine (Dräger Medical GmbH, Lübeck, Germany). Respiratory rate was adjusted to keep the end tidal CO_2 between 32 and 36 cm H_2O.

Following endotracheal intubation, but before surgical incision, a radial artery catheter was introduced and connected via the Flo-Trac sensor to a minimally-invasive pulse contour analysis monitor (EV1000 Clinical Platform, Edwards Lifesciences, Irvine, USA). Introduction of a central venous catheter was optional.

All patients received a prophylactic dose of appropriate antibiotics and all patients undergoing open abdominal surgery (pancreatectomy, cystectomy, gastrectomy and cancer debulking) received a spinal injection of morphine (250 mcg) before skin incision. Patients undergoing laparoscopic surgery (nephrectomy or colectomy) did not receive spinal morphine. In both groups, if mean arterial pressure (MAP) was < 65 mmHg (despite appropriate BIS value [40–60]) without any fluid bolus being suggested (AFM group) or SVV < 13% (control group), a vasopressor agent was administered (ephedrine or phenylephrine boluses and/or noradrenaline infusion if prolonged hypotension). Additionally, the anaesthesiologist had the option of administering a colloid solution (3% modified gelatin or 6% hydroxyethyl starch 130/0.4 solution) in case of significant blood loss (> 1000 ml) or evidence of haemodynamic instability.

All patients in both groups received a 2 ml/kg/h maintenance infusion of an isotonic balanced crystalloid (Plasmalyte®, Baxter, Belgium). Providers followed the protocol described in "Appendix 1" in the control group or when the software suggested a fluid bolus in the AFM group. The protocol, well accepted by our team [25], uses SVV as the primary trigger to assess a patient's likely fluid responsiveness. If the SVV was 13% or greater, a bolus of 250 ml of crystalloid solution (Plasmalyte®, Baxter, Belgium) was administered over 10 min.

2.3 Assisted Fluid Management

In the prospective AFM group, the AFM system was started following placement of the arterial catheter, but before surgical skin incision. The system has a user-configurable target for SV response after fluid bolus (10, 15 or 20% increase). Although the standard setting was 15%, the target could be individualised for each patient at the discretion of the supervising anaesthesiologist to tailor a more liberal or more conservative strategy. Such changes were noted during data collection.

The AFM software monitors heart rate (HR), MAP, SV and SVV, and makes fluid bolus suggestions based on a customised and previously validated clinical GDFT algorithm [16]. Initially, the system relies on SVV to guide boluses, as did our manual GDFT protocol. Over time, however, the system collects information from each bolus that is administered to the patient, including the overall haemodynamic state before and after each fluid bolus. The system then uses this accumulated information to help guide fluid suggestions based on the patient's history and previous responses.

When the AFM system suggests a fluid bolus, a visual notification is issued. The anaesthesiologist has the option of accepting or rejecting the suggestion. If rejected, the system will enter a quiet period (5 min in the standard setting) and not make other suggestions. If a fluid bolus is accepted, the anaesthesiologist administers 250 ml of crystalloid (Plasmalyte®, Baxter, Belgium), pushes a button to indicate when he/she starts and finishes the bolus and enters the total volume of the bolus given. The system then analyses the patient's response and haemodynamic changes to the bolus, and adds the bolus to the patient's history ("Appendix 2" depicts the AFM interface).

The anaesthesia provider has the option to disregard the fluid bolus suggestion if he or she believes it is contraindicated. The supervising anaesthesiologist can also give a direct bolus, without waiting for a suggestion, if deemed necessary. All these events are recorded by the system for later analysis. For the AFM group, the user's compliance with the system's suggestions was calculated as 100 minus the percentage of occasions when an AFM bolus suggestion was displayed but no action (to accept or to decline) was taken by the anaesthesiologist.

2.4 Outcomes, data collection and analysis

In all patients, we continuously collected (at 20 s intervals) HR, MAP, SV, CO, and SVV values from the EV1000 monitor. We recorded volumes of maintenance crystalloid infusion and GDFT fluid boluses, urine output, estimated blood losses, and use of vasopressors via the anaesthesia information medical records (Innovian®, Draeger). In the AFM group, fluid administration suggested by the AFM system and anaesthesia provider interactions (target set point changes, bolus suggestions accepted and declined, and additional boluses administered) were also recorded by the EV1000.

As a practical clinical implementation study, we included all eligible patients in both the before and after portions of the study without matching, in order to examine the net impact of introduction of the system. Thus, in the historical group, all patients who received GDFT during the data collection period were included; in the prospective group, all patients who received AFM were included.

The primary outcome of the study was the time spent during surgery with a SVV < 13%. Secondary outcomes included volumes of fluid administered, all haemodynamic variables, net fluid balances, incidence of major and minor post-operative complications, and post-anaesthesia care unit (PACU) or intensive care unit (ICU), length of stay (LOS).

2.5 Study power

At the beginning of the prospective data collection period with the AFM system, we calculated that patients undergoing major abdominal surgery with a manual GDFT strategy (control group) spent on average 69 ± 24% of time during surgery with a SVV < 13%. We hypothesised that implementation of the AFM system would increase time-in-target SVV by at least 15% (i.e., 84% time-in-target) compared to the control group. With 38 available patients in the historical GDFT cohort, an a priori power analysis by Monte Carlo simulation for a Mann–Whitney U test indicated that 45 patients would be needed in the AFM group to detect a significant difference with a significance level of 0.05, resulting in a power of 0.81.

2.6 Statistical analysis

Continuous variables are reported as medians [25th, 75th percentiles]. Categorical variables are reported as counts and group percentages. Group comparisons for continuous variables were made using the Mann–Whitney U test. Group comparisons for categorical variables were made using a Chi square or a Fisher exact test when individual cell counts were less than 6. Statistical significance for the primary outcome was set at $p < 0.05$, and for other outcomes at $p < 0.01$. All patients were included in the statistical analysis (intention to treat analysis). Statistical tests were performed with SPSS (IBM Corp, Armonk, NY) or R statistics (http://www.r-project.org).

3 Results

3.1 Baseline characteristics

We prospectively enrolled 46 patients in the AFM group and compared them to the historical group of 38 patients. There were no significant differences in baseline variables between the groups, with the exception of a lower POSSUM physiology score in the AFM than in the control group (Table 1).

3.2 AFM characteristics and anaesthesiologist interaction

The AFM group spent significantly more time during surgery with a SVV < 13% than did the control group (92% [82, 96] vs. 76% [54, 86]; P < 0.001) (Table 2). The lowest time-in-target in this group was 51% in a patient undergoing robotic prostatectomy, but we discovered at the end of the case that not all the fluid being administered was going into the patient; the intravenous infusion had become disconnected and 1.5 l of bolus volume was delivered into the surgical drapes.

The AFM system suggested a total of 245 fluid boluses for the 46 patients with an average of 5.3 ± 3.9 suggestions per patient (Table 3). The number of suggestions ranged from 0 (in three cases) to 18 (in a case lasting 10.4 h). The average duration of surgery was 4.2 ± 2.0 h with a range of 1.6–10.9 h. Normalised to the surgical duration, the average suggestion rate was 1.3 ± 0.7 per hour. Of the 245 fluid boluses suggested by the AFM, seven were declined by the clinician with two suggestions declined in two patients and one suggestion declined in three patients. Of the remaining 238 bolus suggestions that were accepted and performed, 124 (52%) resulted in a scaled[1] SV increase of at least 15% for 500 ml, and 155 (65%) resulted in a scaled SV increase of at least 10% for 500 ml. As a result, the number of non-effective boluses would be 48% (100–52), or 114 boluses.

Providers delivered a total of 10 additional fluid boluses through the system by hand. Seven of these boluses resulted in a scaled[1] SV increase of at least 15% for 500 ml. Interestingly, of the user-initiated boluses, half were given within 60 s of an upcoming AFM suggestion (based on the off-line review of the EV1000 debug logs after the data collection had been completed) or after a suggestion had been made but using the 'user-bolus' option, and half were not associated with an AFM suggestion. The user boluses that *were* associated with a current or pending AFM recommendation had a scaled SV response of 21 [19–23]% while the boluses *not* associated with a current or pending AFM recommendation had a scaled SV response of 10 [8–10.5]% (P = 0.008).

The AFM system settings were set to use the default 15% fluid strategy (i.e., the system would provide bolus suggestions if the anticipated SV increase was 15%) 90% of the time. The fluid strategy was changed to 10% (more liberal) in 10 cases, which accounted for 10% of the cumulative case time. At no point in any of the cases was the fluid strategy set to 20% (more conservative). The time-weighted compliance with AFM suggestions was 97.5% and the per case minimum and maximum compliances were 88 and 100%, respectively. Compliance with the protocol was not tracked in the control group, so no comparison is possible.

3.3 Fluid balances

Patients in the AFM group received significantly smaller amounts of maintenance baseline crystalloid (600 ml [500, 900] vs. 1050 ml [800, 1300]; P < 0.010). Both groups were supposed to receive 2 ml/kg/h baseline, but the control group actually received almost 50% more baseline fluid than this target (3 ml/kg/h), whereas the AFM group was on target at 1.9 ml/kg/h. Patients in the AFM group also received a smaller total amount of fluid (1775 ml [1225, 2425] vs. 2350 ml [1825, 3250]; P = 0.003) and had a less positive fluid balance than the control group (1010 ml [575, 1450] vs. 1725 ml [1100, 2525]; P < 0.001) (Table 2). The fluid balance remained less positive in the AFM than in the control group at the time of discharge from the PACU/ICU (475 ml [–50, 1700] vs. 1675 ml [750, 2300]; P < 0.001) (Table 4).

3.4 Vasopressor use

The percentage of patients receiving any vasopressors (ephedrine-phenylephrine boluses or noradrenaline infusion) was similar between groups. However, the percentage of patients receiving noradrenaline during surgery was significantly higher in the control group than in the AFM group. No inotropes were used in either group (Table 2).

3.5 Clinical outcomes

There was no significant difference between groups in the incidence of postoperative complications, including acute kidney injury. Lengths of stay in the PACU/ICU and hospital were shorter in the AFM than in the control group (Table 4).

4 Discussion

This before-after study provides data from the first use of a computer-implemented algorithmic decision support system to guide fluid administration and assist clinicians in providing consistent GDFT in patients undergoing major abdominal surgery. Its implementation in our institution significantly

[1] The scaled response is calculated as scaled_SV_response = (actual_SV_increase × scaling_factor) where the scaling_factor is a function of the bolus volume delivered.

Table 1 Baseline characteristics

	Control-group (N = 38)	AFM-group (N = 46)	p Value
Age (year)	63 [53, 69]	61 [51, 71]	0.86
Male (%)	22 (58%)	27 (59%)	0.94
Weight (kg)	74 [64, 84]	75 [65, 88]	0.73
Height (cm)	170 [162, 176]	171 [164, 180]	0.46
Body surface area (m^2)	1.9 [1.7, 2.0]	1.9 [1.7, 2.0]	0.63
Body mass index (kg/m^2)	25 [23, 28]	25 [22, 29]	0.89
ASA physical status 2	28 (74%)	32 (70%)	0.677
ASA physical status 3	10 (26%)	14 (30%)	
Medications (%)			
Aspirin	6 (16%)	13 (28%)	0.17
Clopidogrel	0 (0%)	0 (0%)	1.0
Other oral anticoagulation	2 (5.3%)	5 (11%)	0.36
β Blocker	10 (26%)	14 (30%)	0.67
Angiotensin-converting-enzyme	7 (18%)	7 (15%)	0.70
Inhibitor	4 (11%)	2 (4%)	0.274
Angiotensin II receptor blocker	3 (7.9%)	4 (8.7%)	1.0
Calcium channel blocker	5 (13%)	8 (17%)	0.59
Diuretics	5 (13%)	12 (26%)	0.142
Statin	4 (11%)	7 (15%)	0.53
Oral hypoglycaemic drugs	4 (11%)	4 (8.7%)	0.50
Comorbidities (%)			
Myocardial infarction	1 (2.6%)	2 (4.3%)	1.0
Coronary artery bypass graft	1 (2.6%)	2 (4.3%)	1.0
Ischemic cardiomyopathy	5 (13%)	3 (6.5%)	0.46
Hypertension	16 (42%)	20 (44%)	0.90
Hyperlipidaemia	5 (13%)	12 (26%)	0.14
Stroke	3 (7.9%)	3 (6.5%)	1.0
Diabetes I	1 (2.6%)	1 (2.2%)	1.0
Diabetes II	8 (21%)	10 (22%)	1.0
Chronic obstructive pulmonary disease	5 (13%)	5 (11%)	0.75
Cirrhosis	0 (0%)	1 (2.2%)	1.0
Type of surgery (%)			
Pancreatectomy	11 (29%)	12 (26%)	0.96
Cystectomy	2 (5.3%)	3 (6.5%)	
Adrenalectomy	2 (5.3%)	2 (4.3%)	
Gastrectomy	5 (13.2%)	5 (11%)	
Debulking	3 (7.9%)	4 (8.7%)	
Nephrectomy[a]	7 (18%)	7 (15%)	
Colectomy[a]	7 (18%)	11 (24%)	
Other surgical procedure[b]	1 (2.6%)	2 (4.3%)	
POSSUM physiology score	17 [15, 20]	16 [13, 18]	**0.033**
POSSUM operative score	11 [9, 14]	11 [9, 13]	0.66
POSSUM-predicted morbidity (%)	28 [16, 45]	20 [15, 30]	0.09
POSSUM-predicted mortality (%)	3.6 [2.5, 6.7]	3.6 [2.6, 5.3]	0.74

Bold values are significant values with a p value < 0.05

Population data are listed as "value (%)" and quantitative data as median [25th, 75th percentiles]. P-value by chi-square for group-wise comparisons where all cell counts ≥ 5, otherwise p-value by Fisher's exact test. P-value for all scalar variables by Mann–Whitney U test. This score, based on objective physiological and operative criteria, can predict morbi-mortality of patients undergoing major surgery. It was calculated using http://www.sfar.org/scores/possum.php

ASA American Society of Anesthesiology physical status, *POSSUM* Physiologic and Operative Severity Score for the enumeration of mortality and morbidity

[a]Procedures performed laparoscopically

[b]Includes unspecified laparotomy ("exploratory" laparotomy) and prostatectomy

Table 2 Intraoperative data

Variables	Control-group (N = 38)	AFM-group (N = 46)	Difference (95% CI)	P-value
Surgery duration (min)	224 [169, 270]	202 [159, 289]		0.41
Anaesthesia duration (min)	286 [252, 340]	263 [211, 361]		0.61
Maintenance crystalloid volume (ml)	1050 [800, 1300]	611 [500, 900]	− 240, − 508	**< 0.0001**
Maintenance crystalloid volume (ml/kg/h)	3.0 [2.6, 3.4]	1.9 [1.8, 2.0]	− 0.94, − 1.3	**< 0.0001**
Goal-directed therapy fluid volume (ml)	1500 [700, 2250]	1125 [750, 1500]		0.381
Total IN (ml)	2350 [1825, 3250]	1775 [1225, 2425]	− 140, − 1060	**0.010**
Urine output (ml)	200 [150, 425]	300 [225, 600]		0.020
Estimated blood loss (ml)	300 [65, 515]	175 [100, 500]		0.80
Total OUT (ml)	600 [300, 925]	650 [400, 1325]		0.35
Fluid balance (ml)	1725 [1100, 2525]	1010 [575, 1450]	− 277, − 1020	**0.00056**
Blood component transfusion (%)				
Packed red blood cell	3 (7.9)	4 (8.7)		1.0
Fresh frozen plasma	0 (0)	1 (2.2)		1.0
Platelets (6–8 units bags)	0 (0)	0 (0)		1.0
Any blood product (%)	3 (7.9)	4 (8.7)		1.0
Ephedrine (%)	21 (55)	30 (65)		0.38
Phenylephrine (%)	0 (0)	4 (8.7)		0.12
Noradrenaline (%)	27 (71)	10 (21)	0.04, 0.30	**< 0.0001**
Any vasopressor used (%)	29 (76)	34 (73)		1.0
HR (beats/min)	70 [63, 78]	73 [67, 78]		0.27
MAP (mmHg)	76 [72, 82]	85 [77, 90]	4.3, 11.2	**< 0.0005**
Stroke volume index (ml/m^2)	38 [33, 43]	40 [35, 44]		0.39
Cardiac index (l/min/m^2)	2.6 [2.2, 3.0]	2.9 [2.4, 3.2]		0.49
SVV (%)	10.4 [9.0, 12.1]	9 [7.7, 9.7]	− 1.0, − 2.9	**< 0.0005**
% Time with a SVV < 13%	76 [54, 86]	92 [82, 96]	7.6, 25	**< 0.0005**
% Time with cardiac index ≥ 2.5 (l/min/m^2)	52 [27, 95]	84 [49, 94]	3.0, 31	**0.029**
% Time with mean arterial pressure > 70 mmHg	77 [60, 89]	90 [75, 96]	4.0, 17	**0.002**

Bold values are significant values with a p value < 0.05

Qualitative data are listed as "value (%)" and quantitative data as median [25th, 75th percentiles]. Confidence interval is for median group difference.

95% CI 95% confidence interval

Table 3 AFM use

Variable	Min	25th	Median	75th	Max
AFM boluses recommended	0	3	5	6	18
AFM boluses accepted (%)[a]	50	100	100	100	100
AFM boluses declined	0	0	0	0	2
User boluses administered	0	0	0	0	4
AFM session duration (h)	1.6	2.8	3.7	5.1	10.9
AFM boluses recommended per hour	0	0.7	1.3	1.7	3.14
Time-in-target SVV < 13%	51	82	92	96	100
Compliance[b]	88	97	98	99	100

[a]Where at least one bolus was recommended

[b]Compliance = 100 − % of case time when AFM bolus was displayed but no action was taken; i.e., it is a measure of user responsiveness to fluid bolus suggestion

increased time-in-target (SVV < 13%) compared to a manual GDFT strategy. AFM-patients had higher MAP and lower SVV than control patients throughout surgery.

In the prospective study period, only seven out of the 245 AFM-recommended boluses were declined by the anaesthesiologist (3%). Generally, this occurred when the system made a recommendation shortly after a non-effective bolus or when the recommendation occurred with an SVV < 13% (which might occur after the system had "learned" how the patient responded in this SVV region). Clinicians delivered 10 boluses outside AFM suggestions. A review of the engineering data for the AFM system revealed that in four of these boluses, the AFM algorithm had just recommended or would have recommended a bolus in the next minute.

Overall, the AFM group had a significantly higher SVV time-in-target percentage than the control group. Except the described case of the prostatectomy (51% time in target),

Table 4 Postoperative data

Variables	Control-group (N = 38)	AFM-group (N = 46)	Difference (95% CI)	P-value
Fluid balance at exit PACU/ICU (ml)	1675 [750, 2300]	475 [–50, 1700]	− 370, − 1440	**0.00069**
Blood product transfusion[a]	2 (5)	2 (4)		1.0
Major complications (%)				
Patients with any major complications	7 (18)	11 (24)		0.54
Anastomotic leakage	3 (8)	1 (2)		0.32
Peritonitis	3 (8)	1 (2)		0.32
Sepsis	3 (8)	8 (17)		0.33
Wound dehiscence	1 (3)	1 (2)		1.0
Bleeding requiring redo surgery	0 (0)	3 (7)		0.25
Pulmonary embolism	1 (3)	0 (0)		0.45
Pulmonary oedema	0 (0)	1 (2)		1.0
Pneumonia	0 (0)	0 (0)		1.0
Acute coronary syndrome	0 (0)	0 (0)		1.0
Atrial fibrillation/arrhythmia	0 (0)	2 (4)		0.50
Stroke	0 (0)	0 (0)		1.0
Renal replacement therapy	0 (0)	0 (0)		1.0
Reoperation	3 (8)	3 (7)		1.0
30-Day mortality	0 (0)	1 (2)		1.0
Minor complications (%)				
Patients with any minor complications	20 (52)	19 (41)		0.30
Superficial wound infection	1 (2)	2 (4)		1.0
Urinary and other infection	1 (3)	0 (0)		0.45
Paralytic ileus	8 (21)	6 (13)		0.39
Postoperative confusion	1 (3)	4 (9)		0.37
Postoperative nausea and vomiting	11 (29)	12 (26)		0.77
Incidence of acute kidney injury	10 (26)	7 (15)		0.21
KDIGO I	10 (26)	5 (11)		0.088
KDIGO II	0 (0)	2 (4.3)		0.50
KDIGO III	0 (0)	0 (0)		1.0
LOS				
ICU/PACU (h)	20 [18, 20]	13 [4, 18]	− 2.5, − 11.0	**< 0.00001**
Hospital (days)	10 [5, 12]	6 [4, 10]	− 1, − 5	**0.013**
30-Day readmission	7 (18)	5 (11)		0.25

Bold values are significant values with a p value < 0.05

Outcome data are presented as "value (%)" and/or median [25th–75th percentiles] and difference (95% Confidence interval). P-values are by Mann–Whitney U for scalar data, and by Chi-Square for categorical data. In the event of categories with cell counts of ≤ 5, Fisher's exact test is reported instead. Confidence intervals for scalar data for median group difference

KDIGO kidney disease: improving global outcomes, *ICU* intensive care unit, *PACU* post-anaesthesia care unit

[a]Includes *PRBC* packed red blood cell, *FFP* fresh frozen plasma and platelets

the next two lowest times-in-target (61 and 68%) occurred in patients undergoing laparoscopic surgery in the lateral position and steep reverse Trendelenburg, in whom the SVV may have been unreliable. This may represent a limitation of the AFM algorithm in patients positioned this way.

Importantly, AFM-treated patients did not receive more fluid than control patients to achieve the higher time-in-target; by contrast, they received *less* fluid overall. The significant difference in fluid administration volume was mainly the result of lower maintenance crystalloid volume, with no significant differences in GDFT volumes between groups. One may anticipate that a lower maintenance fluid regimen could have resulted in more fluid boluses, but the opposite was observed, indicating that the AFM system not only maintained lower SVV, but also reduced overall fluid requirements. Moreover, the AFM system could have achieved the primary goal of increased time with SVV < 13% by just fluid overloading all patients (ensuring they were maximally fluid non-responsive in the process), but the reduced overall fluid volume compared to historical practice, despite a higher time in SVV target, argues that this was not the case.

The incidence of postoperative complications was comparable between groups, but PACU/ICU and hospital LOS were shorter in the AFM group than in the control group. Due to the non-randomised nature of this study, it is hard to attribute this result to the differences in fluid balance.

Whether or not increased adherence to a fluid protocol results in improved patient outcomes needs to be studied in a larger prospective, randomised controlled trial (RCT). As there was no enhanced recovery after surgery (ERAS) program in place at our hospital, these results will also need to be explored in hospitals with active ERAS pathways to see whether significant differences in protocol adherence still exist, as at least one study has shown that GDFT and ERAS protocols may not offer independent benefit in terms of LOS or patient outcomes [26].

Fewer patients in the AFM group received noradrenaline. Noradrenaline use was not part of the implementation protocol and no specific instructions were given to providers regarding vasopressor use. Whether the lower vasopressor requirements were related to the less positive fluid balance is an intriguing possibility that should be studied further.

Compliance with the AFM system was excellent (> 97% in more than three-quarters of the patients and > 88% in all patients), indicating that the system was well accepted and that the bolus recommendations were sensible and consistent with provider expectations. Based on the results of this study, the AFM system may enable greater adherence to GDFT principles with minimal additional clinician workload, compared to manual-GDFT.

Our study has several limitations. First, this was not a RCT and the before-after clinical implementation design is not as robust against confounding factors. A prospective RCT would be valuable in assessing the utility of AFM in a centre with active GDFT, especially since the effect of learning contamination bias could be evaluated. A second limitation is that the overall sample size is relatively small, particularly with regards to the complications outcomes. Finally, we did not specifically match patients in the cohorts. Baseline patient characteristics were not statistically significantly different, however, with the exception of the POSSUM physiology score. Thus, while there were no differences in complications between groups, this outcome needs to be interpreted with caution given this difference in baseline POSSUM physiology score.

4.1 Future directions

Our study represents the first clinical evidence that a decision support system for GDFT guidance can increase adherence to a GDFT strategy in patients undergoing abdominal surgery. These findings need confirmation and validation in RCTs and in other institutions and types of surgery.

5 Conclusion

Implementation of a decision support system for GDFT guidance resulted in a significantly longer period during surgery with a SVV < 13%. Interestingly, the total amount of fluid administered was also substantially reduced.

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Compliance with Ethical Standards

Conflict of interest Alexandre Joosten is a consultant for Edwards Lifesciences (Irvine, CA, USA). Joseph Rinehart is a consultant for Edwards Lifesciences (Irvine, CA, USA) and is also co-founder of Sironis, a compagny developing closed-loop fluid management systems. The other authors declare that they have no conflicts of interest concerning this study.

Appendix 1

See Fig. 1.

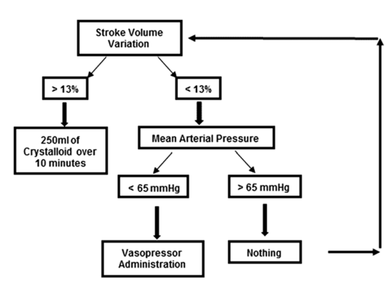

Fig. 1 Goal directed fluid therapy algorithm

Appendix 2

See Fig. 2.

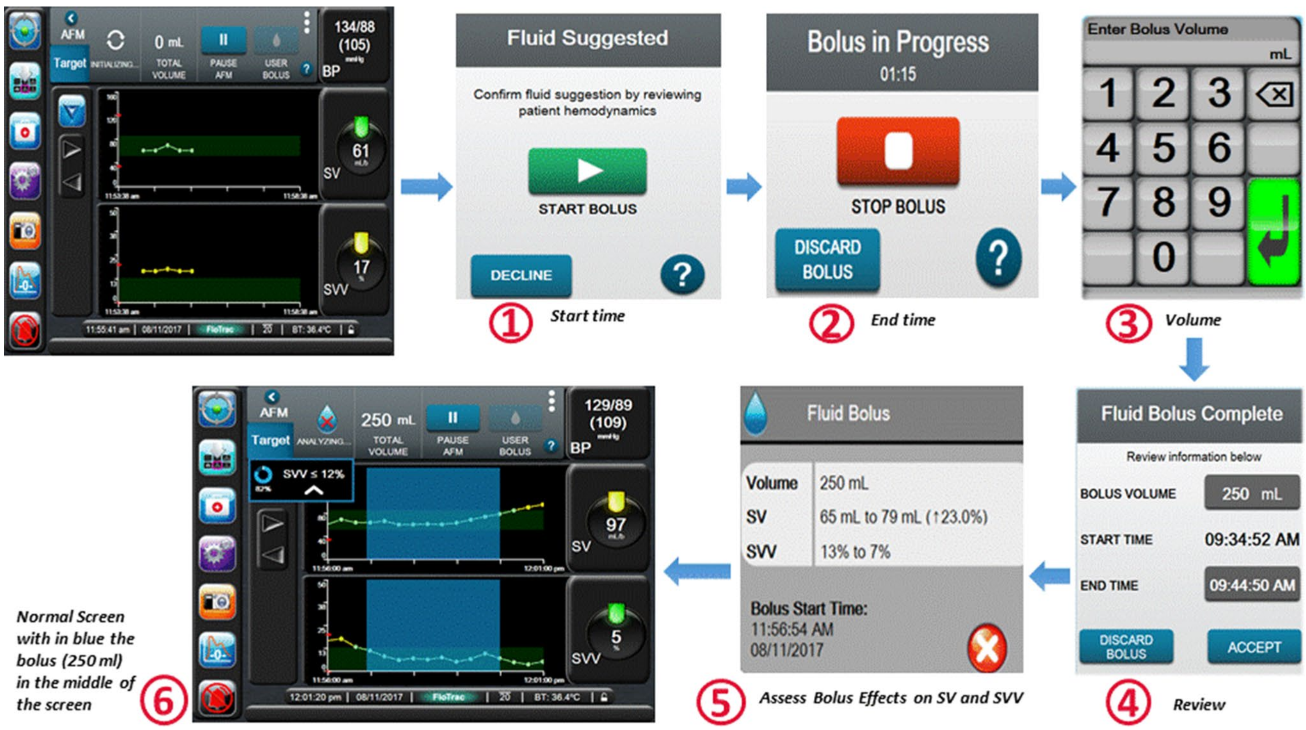

Fig. 2 Depicts the AFM interface

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