Original • DOI: 10.2478/rjaic-2021-0001 • RJAIC 2021;28(1);1-9

Romanian Journal of Anesthaesia and Intensive Care

COMPARISON OF GOAL-DIRECTED FLUID THERAPY USING LIDCOrapid SYSTEM WITH REGULAR FLUID THERAPY IN PATIENTS UNDERGOING SPINE SURGERY AS A RANDOMISED CLINICAL TRIAL

Reza Shariat Moharari, Shervin Shahinpour, Farhad Etezadi, Atabak Najafi, Mohammad Reza Khajavi, Pejman Pourfakhr*

Department of Anesthesiology, Tehran University of Medical Sciences, Sina Hospital, Hassan Abad Square, Tehran, Iran

Abstract

Background: *Goal-directed fluid therapy (GDFT) is a new concept to describe the cardiac output (CO) and stroke volume variation to guide intravenous fluid administration during surgery. LiDCOrapid (LiDCO, Cardiac Sensor System, UK Company Regd 2736561, VAT Regd 672475708) is a minimally invasive monitor that estimates the responsiveness of CO versus fluid infusion. We intend to find whether GDFT using the LiDCOrapid system can decrease the volume of intraoperative fluid therapy and facilitate recovery in patients undergoing posterior fusion spine surgeries in comparison to regular fluid therapy.*

Methods: *This study is a randomised clinical trial, and the design was parallel. Inclusion criteria for participants in this study were patients with comorbidities such as diabetes mellitus, hypertension, and ischemic heart disease undergoing spine surgery; exclusion criteria were patients with irregular heart rhythm or severe valvular heart disease. Forty patients with a previous history of medical comorbidities undergoing spine surgery were randomly and evenly assigned to receive either LiDCOrapid guided fluid therapy or regular fluid therapy. The volume of infused fluid was the primary outcome. The amount of bleeding, number of patients who needed packed red blood cell transfusion, base deficit, urine output, days of hospital length of stay and intensive care unit (ICU) admission, and time needed to start eating solids were monitored as secondary outcomes.*

Results: *The volume of infused crystalloid and urinary output in the LiDCO group was significantly lower than that of the control group ($p = .001$). Base deficit at the end of surgery was significantly better in the LiDCO group ($p < .001$). The duration of hospital length of stay in the LiDCO group was significantly shorter ($p = .027$), but the duration of ICU admission was not significantly different between the two groups.*

Conclusion: *Goal-directed fluid therapy using the LiDCOrapid system reduced the volume of intraoperative fluid therapy.*

Keywords

Fluid therapy • stroke volume • spine surgery • LiDCOrapid • hemodynamics

Introduction

The volume of perioperative fluid therapy may have an impact on the surgical outcome of patients. There are significant differences in how much fluid replacement is appropriate during operations among specialists (anaesthesiologist, surgeons, etc.) [1]. Most therapists use clinical endpoints, such as urinary output, mean arterial pressure (MAP), and central venous pressure (CVP) [2]. Goal-directed fluid therapy (GDFT) is a part of enhanced recovery after surgery (ERAS) protocol using some hemodynamic parameters to guide intravenous (IV) fluid administration [3]. Although some studies have focused on GDFT in different surgical procedures, we did not find any study about GDFT in spine surgery using LiDCO hemodynamic monitoring; therefore, the findings of this study are novel in the field of spine surgery. Hypoxia, shock, and multiorgan failure are prevented by keeping the hemodynamic status in the acceptable range [4]. It is believed that GDFT has the potential to reduce the amount of intraoperative fluid administration, the length of hospital stay, and postoperative complications in patients undergoing major and high-risk surgeries. In fact, recent studies have shown a decrease in the duration of hospital length of stay and some other complications [5].

New monitoring systems invented that use stroke volume optimization to adjust fluid therapy [6]. It is known that stroke

*Corresponding author: e-mail: pourfakhr@tums.ac.ir

volume variation (SVV) and pulse pressure variation (PPV) are good predictors of fluid responsiveness in major surgeries [7]. SVV is one of the most frequently used parameters in GDFT that is based on variations of stroke volume during the respiratory cycle. It is shown that SVV reliably determines fluid responsiveness in the prone position [8]. However, it has a higher threshold (15%) than in the supine position (11%) [9]. Many registered systems, such as LiDCO (LiDCO, Cambridge, UK), are available for obtaining cardiac output power from the arterial waveform with their own algorithms. Net power change in one heartbeat depends on the balance between the mass of blood input from stroke volume minus the blood gone to the periphery [7, 10]. In a LiDCO monitoring system, a transfer function relates the peripheral pressures to central pressures. Peripheral pressure is measured directly, and central pressure is calculated with a mathematical method or population data [11, 12]. When the patient is euvolemic and on the plateau of the Frank-Starling curve, further fluid therapy no longer increase the stroke volume more than 10% and will not be beneficial [13].

The beneficial effects of GDFT using the LiDCO system on surgical outcomes have been reported in major surgeries [14], abdominal aortic surgery [15], lower limb arterial surgery [16], and high- and low-risk caesarean section [16, 17]. However, stroke volume optimization had limited benefit in some elective major abdominal surgeries [18, 19]. In this study, we intend to find whether GDFT applied with the LiDCOrapid system compared with regular fluid therapy could improve intraoperative fluid therapy as well as some postoperative outcomes of patients who undergo spine surgeries.

Methods

This randomised clinical trial was performed in Sina Hospital, Tehran, Iran, in 2019−2020. The study was approved by the Ethics Committee of the Tehran University of Medical Sciences (IR.TUMS.MEDICINE.REC.1398.115) and followed the principles of the Declaration of Helsinki. Written informed consent was obtained from all subjects participating in the trial.

The trial was registered at the Iranian Registry of Clinical Trials (IRCT) website (https://www.irct.ir) before patient enrollment on September 28, 2019 (IRCT20190719044274N1).

Patients

Inclusion criteria for participants in this study were patients with comorbidities such as diabetes mellitus, hypertension, and ischemic heart disease undergoing spine surgery.

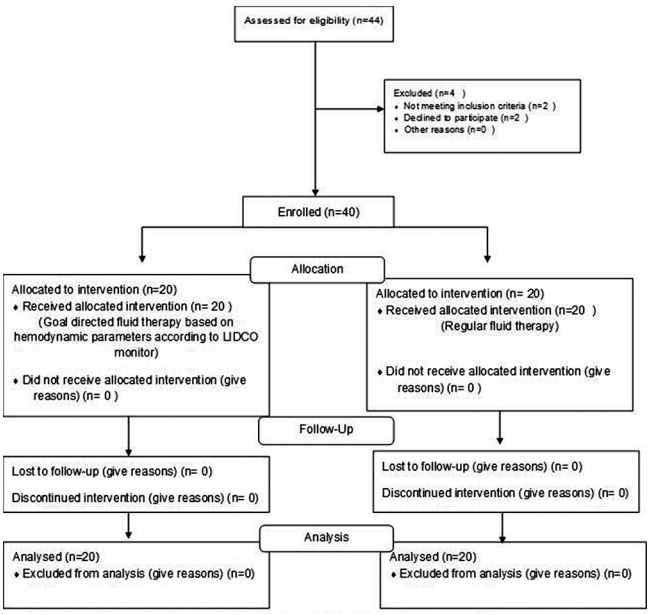

Figure 1. CONSORT flow diagram showing the flow of patients through each stage of study.

A total of 40 patients undergoing lumbar spine fusion surgery (more than two fusions) in the prone position were enrolled in the study.

Exclusion criteria were patients with irregular heart rhythm or severe valvular heart disease (as these could affect the accuracy of the LiDCO device). Patients were randomly and evenly assigned to receive the LiDCOrapid system (LiDCO group) or regular fluid therapy (control group), each group with 20 patients (Figure 1). Patients' clinical data, such as comorbidities and the American Society of Anesthesiologists (ASA) physical status, were recorded. Random allocation was used in this study. Randomisation was based on a block size of 4. A random allocation sequence was performed by the Research Development Centre at Sina Hospital.

Preoperative data

Patients fasted for 6 hours. Before entering the operating room, they did not receive IV fluids. After entering the operating room, blood pressure, heart rate, and oxygen saturation (SpO2) were measured and recorded. Two IV lines were established using an 18-gauge cannula for each patient. Central venous access in the right jugular vein and arterial (radial) catheterization were provided for all patients after induction of anaesthesia. Central venous access in the right jugular vein provided the source for central venous pressure (CVP) in the LiDCOrapid system. SVV was acquired online from the LiDCOrapid system after calibration with

lithium for cardiac output. In both groups hemodynamic variables—noninvasive blood pressure, heart rate, MAP, cardiac output, cardiac index, stroke volume, systemic vascular resistance (SVR), and SVV—were monitored, and the quantity of fluids infused was recorded.

Anaesthesia

An invasive arterial pressure kit or LiDCOrapid system was used to monitor these parameters in control and LiDCOrapid patients, respectively. Bispectral index (BIS) and end-tidal carbon dioxide (EtCO2) monitoring were also applied to all patients. The target BIS range for appropriate depth of anaesthesia was between 40 and 60. During the measurements of hemodynamic parameters, ventilator settings remained unchanged. For both groups standard anaesthesia induction was done using IV fentanyl, midazolam, propofol, and atracurium. Maintenance of anaesthesia was accomplished with total intravenous anaesthesia (TIVA) using titration of remifentanil (0.25−0.5 μg/kg/min) and propofol (0.025−0.075 mg/kg/min) to keep BIS in the appropriate range and MAP > 65 mmHg [20]. The ventilation parameters were adjusted to keep the EtCO2 between 35 and 40 mmHg.

Just after general anaesthesia induction and intubation, the infusion of basal crystalloid (ringer lactate) started at 4 mL/kg/h for all patients. Intraoperative neuromonitoring was also used, and there was no need for a neuromuscular blocking agent. Air-warming blankets and fluid-warming devices were used to keep the esophageal temperature between 36°C and 37.5°C. All patients received ondansetron (4 mg) for postoperative nausea and vomiting (PONV) prophylaxis at the end of surgery. Patients received IV acetaminophen (Apotel) as an analgesic at the end of surgery.

In the LiDCOrapid group, basal crystalloid infusion was initiated at 4 mL/kg/h. Crystalloid administration was then guided by SVV. If SVV was < 15%, the basal infusion was continued. If SVV was > 15%, rapid crystalloid infusion (250 mL free in 5 minutes) was administered to reach SVV < 15%, which has been suggested by previous studies [21] (Figure 2). Patients underwent serial

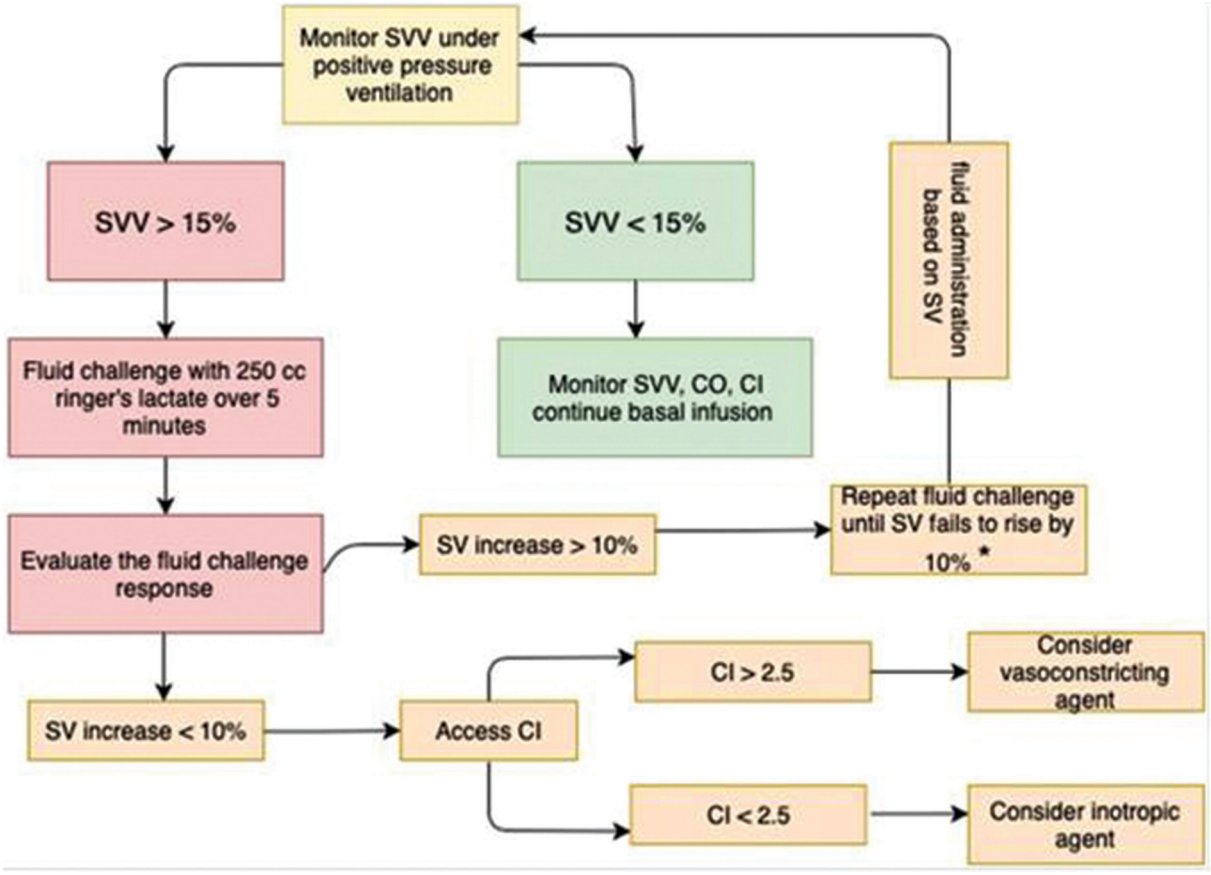

Figure 2. Intraoperative protocol of GDFT in LiDCO group. SVV, stroke volume variation; CO, cardiac output; CI, cardiac index; SV, stroke volume. *If volume loss due to bleeding reaches maximum allowable blood loss (MABL) fluid challange will be stopped and fluid therabhy will be continued with blood transfusion.

arterial blood gases (ABG) sampling, and urine output was evaluated hourly. When the patient reached maximum allowable blood loss (MABL), GDFT continued with packed red blood cells infusion.

In the control group fluid therapy was performed to maintain the heart rate, blood pressure, and CVP in the normal range (MAP > 65 mmHg, heart rate < 100 beats per minute, and CVP 8 to 15 mmHg).

LiDCOrapid system

This device, which is minimally invasive, is designed to help make clinical decisions in hemodynamic monitoring and controlling the amount of fluid administration. The use of LiDCOrapid is feasible in perioperative settings that use PulseCO software. LiDCOrapid with pulse power analysis and arterial waveforms estimates the responsiveness of cardiac output and volume beat by beat [7, 10]. In a LiDCO device, a transfer function relates the peripheral pressures to central pressures. Peripheral pressure is measured directly, and central pressure is calculated with a mathematical method or population data [12]. LiDCOrapid (http://www.lidco.com/product/lidco-rapid/) has the ability to display pressure (MAP, systolic, and diastolic), heart rate, stroke volume, and cardiac output from the beginning of the procedure.

Parameters and outcomes

The primary outcome of this study was the volume of intraoperative fluid administered.

Parameters such as the amount of bleeding, base deficit, urine output, days of hospital length of stay and intensive care unit (ICU) admission, time needed to start eating solids, and amount of packed red blood cells needed for transfusion were all monitored and considered as secondary outcomes. Intraoperative blood loss was quantified by measuring irrigation fluid and weight measurement of surgical sponges.

Statistical analysis

Participants, care providers, and those assessing outcomes were blinded, and they did not know which participant was in which group.

The primary outcome of this study was the volume of intraoperative fluid administered. We determined sample size according to the study by Han et al [22]. Intraoperative fluid in the control group had a standard deviation of 387 mL. We expected a reduction of the mean fluid volume by 400 mL in the LiDCO group, and with an α error of 0.05, and power of 0.8, the calculated sample size per group was 15 patients. In this study we included 20 patients in each group. Quantitative variables with normal and nonnormal distribution were described as mean ± standard deviation and median (interquartile range), respectively. Frequency (%) was used to describe qualitative variables. Qualitative variables were analysed using a chi-square test and continuous quantitative variables with normal distribution using Student's t-test. Quantitative variables with nonnormal distribution were assessed by the Mann-Whitney U test. Normal distribution of variables was assessed based on the Shapiro-Wilk test. All analyses were performed by SPSS software SPSS 20 (Statistical Package for Social Sciences). Statistical significance was considered at $p < .05$.

Table 1: Preoperative characteristics of patients divided into two groups

Group		Control *N* (%)	LiDCO-Rapid *N* (%)	Total *N* (%)	Probability
Sex	Female	11 (55)	11(55)	22 (55)	0.624
	Male	9 (45)	9 (45)	18 (45)	
ASA	I	5 (25)	6 (30)	11 (27.5)	0.500
	II	15 (75)	14 (70)	29 (72.5)	
Hypertension		10 (50)	6 (30)	16 (40)	0.167
Hyperlipidemia		2 (10)	0 (0)	2 (5)	0.244
Diabetes mellitus		5 (25)	2 (10)	7 (17.5)	0.204
Ischemic heart disease		4 (20)	3 (15)	7 (17.5)	0.500
Mitral valve prolapse		0 (0)	1 (5)	1 (2.5)	0.500
Chronic obstructive pulmonary disease		1 (5)	1(5)	2(5)	1.000

ASA, American Society of Anesthesiologists physical status classification.

Results

Twenty-two patients (55%) were female, and 18 (45%) were male. The mean age of patients was 51.40 years, with a standard deviation of 16.17. The mean body mass index (BMI) of patients was 25.67, with a standard deviation of 2.15. Other characteristics of patients are presented in Table 1. Two groups were not significantly different in preoperative characteristics.

Comparing the intra- and postoperative parameters in two groups

No patient needed inotropic or vasopressor therapy. As shown in Table 2, there was no significant difference in the amount of bleeding during the surgery between the two groups, but the base deficit was significantly better in the LiDCO group ($p < .001$; Figure 3).

Table 2: Comparing the peri- and postsurgical quantitative variables in two groups

	Group	*N*	Mean	Standard deviation	Median	IQR	Probability
Bleeding (cc)	control	20	527.00	273.90	-	-	0.916
	LiDCO	20	517.50	290.47	-	_	
Base excess (mEq/L)	control	20	-8.25	1.94	-	-	<0.001
	LiDCO	20	-4.75	2.22	-	_	
Volume (cc) crystalloid	control	20	1920.00	584.53	-	-	0.001
	LiDCO	20	1332.50	409.19	-	_	
Urine output (cc)	control	20	647.50	211.18	-	-	<0.001
	LiDCO	20	377.50	105.72	-	_	
Hospitalization (day)	control	20	-	-	2	2-3	0.027*
	LiDCO	20	-	-	2	1-2	
ICU admission (day)	control	10	-	-	0.5	0-1	0.087*
	LiDCO	6	-	-	0	0-0.75	
Starting solids (hour)	control	20	-	-	10	8-12	<0.001*
	LiDCO	20	-	-	7	6-7.5	

* Mann-Whitney U test.
ICU, intensive care unit; IQR, interquartile range.

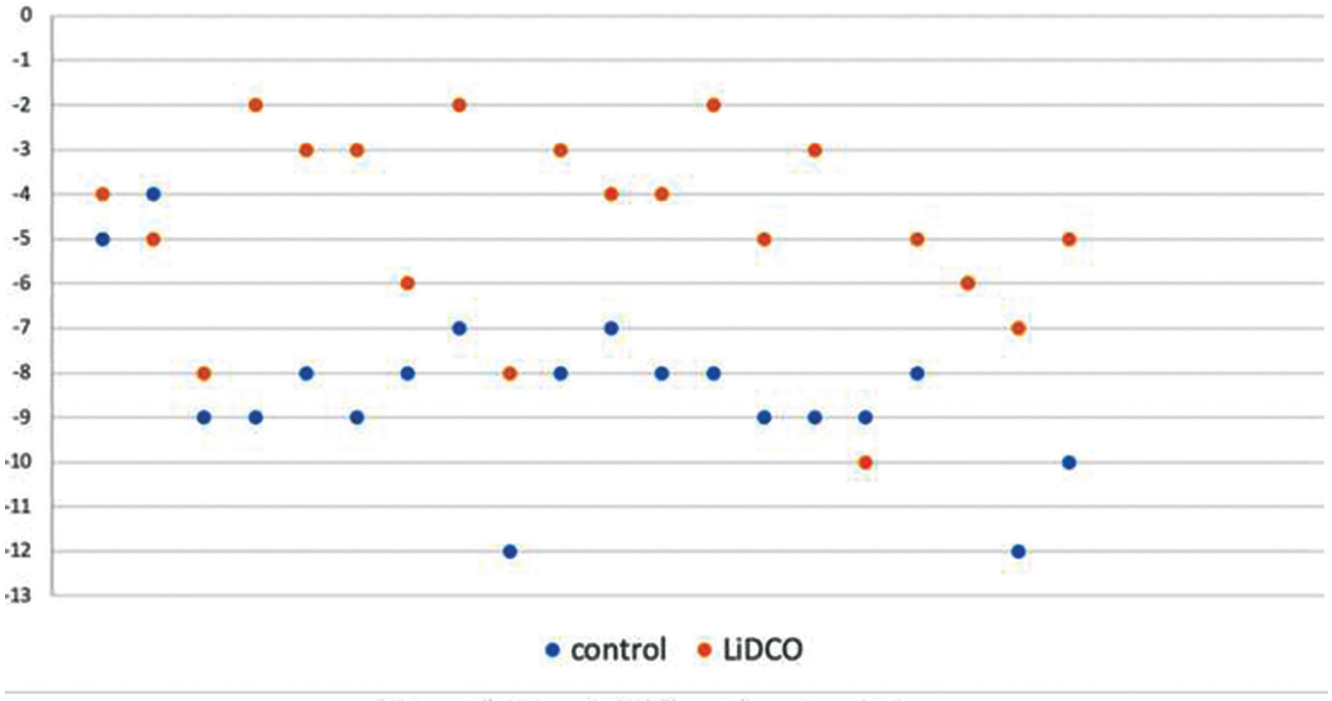

Figure 3. Base deficit (meq/l) values in two groups.

The volumes of injected crystalloid and urinary output in the LiDCO group were also significantly lower than that of the control group (p = .001 and < .001, respectively; Figure 4). However, none of the patients had oliguria or significant increase in serum creatinine. The duration of hospital length of stay in the LiDCO group was significantly lower (p = .027), but the duration of ICU admission was not significantly different in the two groups. Also, eating solids started sooner in the LiDCO group (p < .001).

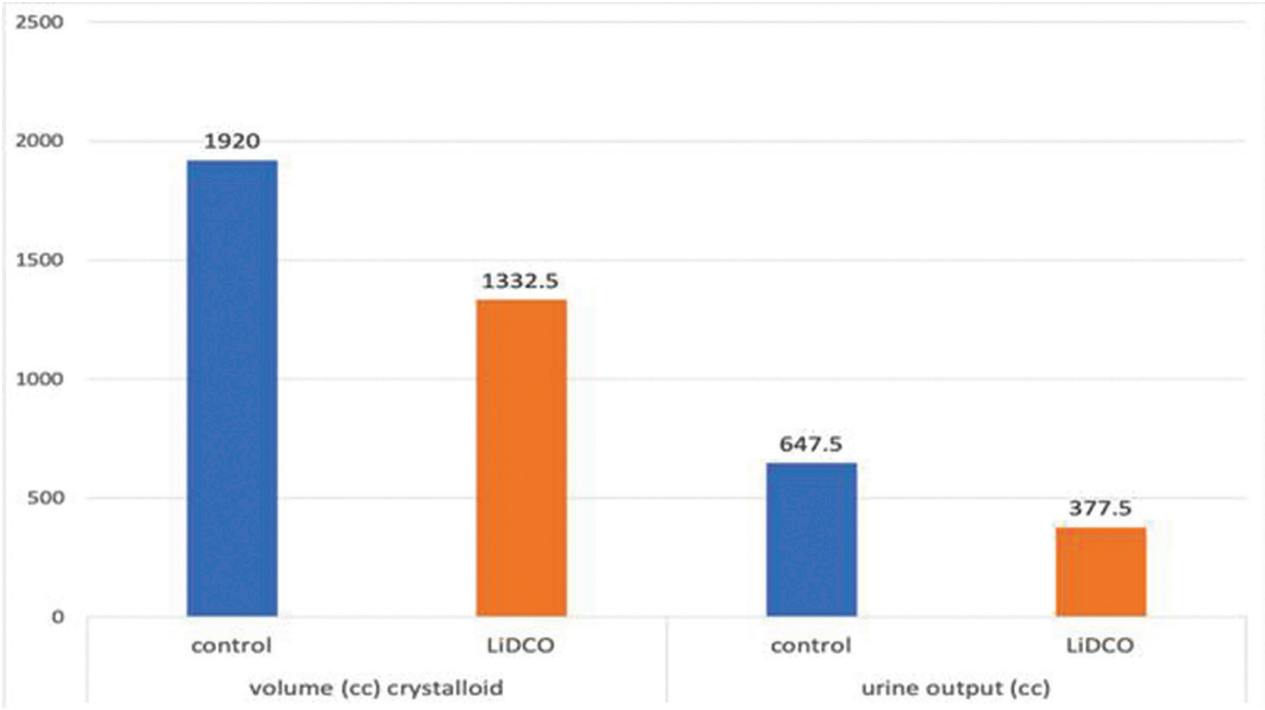

Figure 4. Comparison of injected crystalloid volume urinary and output in two groups.

Table 3: Comparison of peri- and postsurgical complications in two groups of patients

Group	Control *N* (%)	LiDCO-Rapid *N* (%)	Total *N* (%)	Probability
Blood transfusion	2 (10)	3 (15)	5 (12.5)	0.633
Myocardial infarction	0 (0)	0(0)	0 (0)	-
Stroke	0 (0)	0 (0)	0 (0)	-
Pulmonary thromboembolism	0 (0)	0(0)	0 (0)	-
Deep vein thrombosis	1 (5)	0(0)	1 (2.5)	0.3
Pneumonia	1 (5)	1(5)	2 (5)	0.100
Pulmonary edema	0 (0)	0 (0)	0 (0)	-
Urinary tract infection	0 (0)	0(0)	0 (0)	0.1000
Sepsis	0 (0)	0 (0)	0 (0)	-
Acute respiratory distress syndrome	0 (0)	0 (0)	0 (0)	-
Acute renal failure	0 (0)	0 (0)	0 (0)	-
Postsurgical nausea and vomiting	6 (30)	3 (15)	9 (22.5)	0.256
Reintubation	0 (0)	0 (0)	0 (0)	-
Lower extremity nerve defect	0 (0)	0 (0)	0 (0)	-
Total complications	11 (55)	6 (30)	17 (42.5)	0.110

Table 3 shows the number of patients who needed blood transfusion and exhibited other postoperative complications in both control and LiDCO groups. No mortality occurred in this study, and no patient was readmitted within 30 days postsurgery. There was no need of reintubation for any patient during recovery. Blood transfusion was needed in five patients, and the two groups did not differ significantly hereon. No cases of stroke, urinary tract infection, sepsis, acute respiratory disease syndrome, acute renal failure, myocardial infarction, pulmonary thromboembolism, or lower extremity neurologic deficit observed. During the postoperative period, deep vein thrombosis occurred in one patient and pneumonia in two patients; these were not significantly different in the two groups. Six patients in the control group and three patients in the LiDCO group had PONV, and the two groups did not differ significantly.

Discussion

It has been shown that intraoperative GDFT using the LiDCOrapid system resulted in lesser use of intraoperative fluid therapy and also better postoperative outcomes in patients undergoing posterior fusion lumbar spine surgery. Spine surgery patients for whom individualisation of intraoperative fluid management has a possible clinical impact are subject to intraoperative fluid−related complications [23]. SVV as a

functional hemodynamic parameter can be easily achieved by LiDCOrapid [24], and even though it can be affected by the administration of various drugs and changes in vascular tension, it is still known as a useful guide for fluid therapy [22]. The LiDCO system helps in assessing volume responsiveness before fluid administration [25].

Tokarik et al reported findings similar to our study for extensively burned patients [24]. Han et al in a clinical trial used LiDCOrapid in aged patients undergoing hip joint replacement with spinal anaesthesia. They reported more fluids administered in the LiDCO group compared to controls, which contrasts with our results. [22] The disagreement may be due to different protocols of standard fluid therapy and anaesthesiologists' decisions for controls in various centres. Total intraoperative fluid volume has not been different between groups in some other GDFT studies [26, 27]. Michard et al explained that the comparable average amount of fluid between groups might be because some patients, who were fluid responders, received more fluids, and others, who were nonresponders, received less fluid than they would have received with standard fluid therapy. [26] In our study urine output volume was also lower in the LiDCO group, but it was not less than the 0.5 mL/kg/h limit. Recent literature says that even oliguria is common in the perioperative period and is not abnormal without evidence of hypoperfusion [28]. A recent study shows that oliguria and postoperative renal failure may not correlate. However, increased postoperative fluid balance can cause acute kidney injury [29]. We also found that urine output had less variability between patients (smaller standard deviation). Tokarik et al suggested that GDFT by the LiDCO system measures intravascular fluid volume more accurately in comparison to assessing indirectly by urine output. [30] The normal range of base deficit is −2 to +2 mEq/L. Base deficit is a potentially useful indicator of volume deficit and is an important factor in the diagnosis of patients with under-perfused tissues. Metabolic acidosis due to excessive fluid therapy may mask a diagnosis of perfusion deficits. Therefore, avoidance of acid–base alterations by the choice of volume replacement regimen is important. In our study LiDCO patients had a significantly better condition according to base deficit. Observation of more negative base deficit in controls shows metabolic acidosis probably from excessive fluid therapy because intraoperative bleeding was not significantly different between the two groups.

Length of hospital stay, as a postoperative outcome, was significantly less in the LiDCO group. Previous studies reported shorter length of hospital stay by applying GDFT [31, 32], but Bartha et al reported no different length of hospital stay in the GDFT and control groups. [33] Different applied multidisciplinary programs of standard care could be the cause of these different results. All three trials reported less fluid and fewer complications in GDFT patients. Gut edema from excessive fluid therapy can lead to impaired gastrointestinal function and enteral nutrition tolerance [34]. Postoperative pulmonary edema also can be a complication of over fluid therapy and excessive fluid in intravascular space that finally may lead to organ dysfunction, such as pulmonary edema [35]. In this study no patients developed postoperative pulmonary edema. Other postoperative complications were rare and did not show statistically significant differences between the two groups. Habicher et al showed that GDFT in hip revision arthroplasty causes significant reduction in postoperative morbidity [36]. Veelo et al reported a significant decrease in complications as well as decreased ICU length of stay for patients undergoing esophagectomy [37]. Despite the lower total length of hospital stay in our study, we did not find decreased ICU stay in LiDCO patients. Bacchin et al reported reduced ICU length of stay in the GDFT patients, but similar to our results, Benes et al reported reduced hospital, but not ICU length, of stay [9, 38]. Each centre routinely has its own protocols of ICU and ward care, which can cause significantly different lengths of stay. Patients' mobilisation or postoperative care in a ward can also limit and affect the length of the ward stay more than medical fitness to discharge. The criteria for ICU discharge were similar to Bacchin et al [9].

In addition, Jin et al and Cannerson et al have reported reduced morbidities and postoperative complications in high-risk abdominal surgeries and major abdominal procedures, respectively [39, 40]. The number of patients with postoperative nausea and vomiting was also lower in the LiDCO group (6 vs 11 cases), but this difference did not reach the level of significance. Small sample size may have been the cause. PONV prophylaxis was performed in both groups, and the difference is likely due to different strategies of fluid therapy. Han et al, similar to our results, showed fewer complications and better prognosis in the LiDCO patients. They also reported significantly less nausea and vomiting in the LiDCO group [22].

This study has some limitations. For example, there were no significant differences between the study groups in some parameters, such as PONV and days of ICU admission, which may be due to the sample size and lack of precision to detect the differences between these parameters. Another limitation of our study is that, according to our inclusion criteria, all patients are classified as ASA I or II (72.5% ASA II), and this may have affected the length of ICU stay in the current study.

Conclusion

Goal-directed fluid therapy reduced the volume of intraoperative infused fluids. Further multicentre trials with larger sample size evaluating the effectiveness of GDFT and comparing the outcomes with different fluid regimens can help generalize the results of our study.

Acknowledgements

The authors would like to thank the Research Development Centre at Sina Hospital for technical assistance.

Financial support and sponsorship

None.

Conflict of interest: None.

Presentation: None declared.

References

[1] Lilot M, Ehrenfeld JM, Lee C, Harrington B, Cannesson M, Rinehart J. Variability in practice and factors predictive of total crystalloid administration during abdominal surgery: retrospective two-centre analysis. Br J Anaesth 2015; 114(5): 767-76. Epub 2015/01/15. doi: 10.1093/bja/aeu452. PubMed PMID: 25586725

[2] Cecconi M, Hofer C, Teboul JL, Pettila V, Wilkman E, Molnar Z, et al. Fluid challenges in intensive care: the FENICE study--a global inception cohort study. Intensive Care Med 2015; 41(9): 1529-37-Epub 2015/07/15. doi: 10.1007/s00134-015-3850-x. PubMed PMID: 26162676; PubMed Central PMCID: PMCPMC4550653

[3] Hamilton MA, Cecconi M, Rhodes A. A systematic review and meta-analysis on the use of preemptive hemodynamic intervention to improve postoperative outcomes in moderate and high-risk surgical patients. Anesth Analg 2011; 112(6): 1392-402. Epub 2010/10/23. doi: 10.1213/ANE.0b013e3181eeaae5. PubMed PMID: 20966436

[4] Bellamy MC. Wet, dry or something else? Br J Anaesth 2006; 97(6): 755-7. Epub 2006/11/14. doi: 10.1093/bja/ael290. PubMed PMID: 1709872.

[5] Miller TE, Thacker JK, White WD, Mantyh C, Migaly J, Jin J, et al. Reduced length of hospital stay in colorectal surgery after implementation of an enhanced recovery protocol. Anesth Analg 2014 118(5):1052-61. Epub 2014/05/02. doi: 10.1213/ane.0000000000000206. PubMed PMID: 24781574

[6] Miller TE, Roche AM, Gan TJ. Poor adoption of hemodynamic optimization during major surgery: are we practicing substandard care? Anesth Analg 2011; 112(6): 12746- Epub 2011/05/27. doi: 10.1213/ANE.0b013e318218cc4f. PubMed PMID: 21613196

[7] Michard F. in arterial pressure during mechanical ventilation. Anesthesiology 2005; 103(2): 419-28. Epub 2005/07/30. PubMed PMID: 16052125

[8] Biais M, Bernard O, Ha JC, Degryse C, Sztark F. Abilities of pulse pressure variations and stroke volume variations to predict fluid responsiveness in prone position during scoliosis surgery. Br J Anaesth 2010; 104(4): 407-13. Epub 2010/03/02. doi: 10.1093/bja/aeq031. PubMed PMID: 20190260

[9] Bacchin MR, Ceria CM, Giannone S, Ghisi D, Stagni G, Greggi T, et al. Goal-directed fluid therapy based on stroke volume variation in patients undergoing major spine surgery in the prone position: a cohort study. Spine (Phila Pa 1976) 2016;41(18):E1131-7. Epub 2016/04/06. doi: 10.1097/brs.0000000000001601. PubMed PMID: 27046635

[10] Montenij LJ, de Waal EE, Buhre WF. Arterial waveform analysis in anesthesia and critical care. Curr Opin Anaesthesiol 2011; 24(6): 651-6. Epub 2011/11/01. doi: 10.1097/ACO.0b013e32834cd2d9. PubMed PMID: 22036950

[11] Thiele RH, Durieux ME. Arterial waveform analysis for the anesthesiologist: past, present, and future concepts. Anesth Analg 2011; 113(4): 766-76. Epub 2011/09/06. doi: 10.1213/ANE.0b013e31822773ec. PubMed PMID: 21890890

[12] Mehta N, Fernandez-Bustamante A, Seres T. A review of intraoperative goal-directed therapy using arterial waveform analysis for assessment of cardiac output. ScientificWorldJournal 2014; 2014: 702964. Epub 2014/07/06. doi: 10.1155/2014/702964. PubMed PMID: 24987744; PubMed Central PMCID: PMCPMC4058462

[13] Cecconi M, Parsons AK, Rhodes A. What is a fluid challenge? Curr Opin Crit Care 2011; 17(3): 290-5. Epub 2011/04/22. doi: 10.1097/MCC.0b013e32834699cd. PubMed PMID:21508838.

[14] Pearse R, Dawson D, Fawcett J, Rhodes A, Grounds RM, Bennett ED. Early goal-directed therapy after major surgery reduces complications and duration of hospital stay: a randomised, controlled trial [ISRCTN38797445]. Crit Care 2005; 9(6): R687-93. Epub 2005/12/17. doi: 10.1186/cc3887. PubMed PMID: 16356219; PubMed Central PMCID: PMCPMC1414018

[15] Bisgaard J, Gilsaa T, Ronholm E, Toft P. Optimising stroke volume and oxygen delivery in abdominal aortic surgery: a randomised controlled trial. Acta Anaesthesiol Scand 2013; 57(2): 178-88. Epub 2012/08/18. doi: 10.1111/j.1399-6576.2012.02756.x. PubMed PMID: 22897633

[16] Bisgaard J, Gilsaa T, Ronholm E, Toft P. Haemodynamic optimisation in lower limb arterial surgery: room for improvement? Acta Anaesthesiol Scand 2013; 57(2):1 89-98. Epub 2012/09/06. doi: 10.1111/j.1399-6576.2012.02755.x. PubMed PMID: 22946700

[17] Xiao W, Duan QF, Fu WY, Chi XZ, Wang FY, Ma DQ, et al. Goal-directed fluid therapy may improve hemodynamic stability of parturient with hypertensive disorders of pregnancy under combined spinal epidural anesthesia for cesarean delivery and the well-being of newborns. Chin Med J (Engl) 2015; 128(14): 1922-31. Epub 2015/07/15. doi: 10.4103/0366-6999.160546. PubMed PMID: 26168834; PubMed Central PMCID: PMCPMC4717919

[18] Brandstrup B, Svendsen PE, Rasmussen M, Belhage B, Rodt SA, Hansen B, et al. Which goal for fluid therapy during colorectal surgery is followed by the best outcome: near-maximal stroke vol-

ume or zero fluid balance? Br J Anaesth. 2012;109(2):191-9. Epub 2012/06/20. doi: 10.1093/bja/aes163. PubMed PMID: 22710266

[19] Challand C, Struthers R, Sneyd JR, Erasmus PD, Mellor N, Hosie KB, et al. Randomized controlled trial of intraoperative goal-directed fluid therapy in aerobically fit and unfit patients having major colorectal surgery. Br J Anaesth 2012; 108(1): 53-62. Epub 2011/08/30. doi: 10.1093/bja/aer273. PubMed PMID: 21873370

[20] Al-Rifai Z, Mulvey D. Principles of total intravenous anaesthesia: practical aspects of using total intravenous anaesthesia. BJA Education 2016; 16(8): 276-80. doi: 10.1093/bjaed/mkv074

[21] Wu CY, Lee TS, Chan KC, Jeng CS, Cheng YJ. Does targeted pre-load optimisation by stroke volume variation attenuate a reduction in cardiac output in the prone position. Anaesthesia 2012; 67(7): 760-4. Epub 2012/03/29. doi: 10.1111/j.1365-2044.2012.07116.x. PubMed PMID: 22452326

[22] Han G, Liu K, Xue H, Zhao P. Application of LiDCO-Rapid in peri-operative fluid therapy for aged patients undergoing total hip replacement. Int J Clin Exp Med 2016; 9(2): 4473-8.

[23] Shoemaker WC, Appel PL, Kram HB, Waxman K, Lee TS. Prospective trial of supranormal values of survivors as therapeutic goals in high-risk surgical patients. Chest 1988; 94(6): 1176-86. Epub 1988/12/01. doi: 10.1378/chest.94.6.1176. PubMed PMID: 3191758

[24] Tokarik M, Sjoberg F, Balik M, Pafcuga I, Broz L. Fluid therapy LiDCO controlled trial-optimization of volume resuscitation of extensively burned patients through noninvasive continuous real-time hemodynamic monitoring LiDCO. J Burn Care Res 2013; 34(5): 537-42. Epub 2013/03/21. doi: 10.1097/BCR.0b013e318278197e. PubMed PMID: 23511280

[25] Pinsky MR, Payen D. Functional hemodynamic monitoring. Crit Care 2005; 9(6): 566-72. Epub 2005/12/17. doi: 10.1186/cc3927. PubMed PMID: 16356240; PubMed Central PMCID: PMCPMC1414021

[26] Michard F, Giglio MT, Brienza N. Perioperative goal-directed therapy with uncalibrated pulse contour methods: impact on fluid management and postoperative outcome. Br J Anaesth 2017;119(1):22-30. Epub 2017/06/13. doi: 10.1093/bja/aex138. PubMed PMID: 28605442

[27] Calvo-Vecino JM, Ripolles-Melchor J, Mythen MG, Casans-Frances R, Balik A, Artacho JP, et al. Effect of goal-directed haemodynamic therapy on postoperative complications in low-moderate risk surgical patients: a multicentre randomised controlled trial (FEDORA trial). Br J Anaesth 2018; 120(4): 734-44. Epub 2018/03/27. doi: 10.1016/j.bja.2017.12.018. PubMed PMID: 29576114

[28] Kunst G, Ostermann M. Intraoperative permissive oliguria: how much is too much? Br J Anaesth 2017; 119(6): 1075-7. doi: https://doi.org/10.1093/bja/aex387

[29] Kambhampati G, Ross EA, Alsabbagh MM, Asmar A, Pakkivenkata U, Ejaz NI, et al. Perioperative fluid balance and acute kidney injury. J Clin Exp Nephrol 2012; 16(5): 730-8. doi: 10.1007/s10157-012-0623-5

[30] Davis JW, Shackford SR, Mackersie RC, Hoyt DB. Base deficit as a guide to volume resuscitation. J Trauma 1988; 28(10): 1464-7. Epub 1988/10/01. PubMed PMID: 3172306

[31] Venn R, Steele A, Richardson P, Poloniecki J, Grounds M, Newman P. Randomized controlled trial to investigate influence of the fluid challenge on duration of hospital stay and perioperative morbidity in patients with hip fractures. Br J Anaesth. 2002;88(1):65-71. Epub 2002/03/08. doi: 10.1093/bja/88.1.65. PubMed PMID: 11881887

[32] Sinclair S, James S, Singer M. Intraoperative intravascular volume optimisation and length of hospital stay after repair of proximal femoral fracture: randomised controlled trial. BMJ 1997; 315(7113): 909-12. Epub 1997/11/15. doi: 10.1136/bmj.315.7113.909. PubMed PMID: 9361539; PubMed Central PMCID: PMCPMC2127619

[33] Bartha E, Arfwedson C, Imnell A, Fernlund ME, Andersson LE, Kalman S. Randomized controlled trial of goal-directed haemodynamic treatment in patients with proximal femoral fracture. BJA 2012; 110(4): 545-53. doi: 10.1093/bja/aes468

[34] Lobo DN, Bostock KA, Neal KR, Perkins AC, Rowlands BJ, Allison SP. Effect of salt and water balance on recovery of gastrointestinal function after elective colonic resection: a randomised controlled trial. Lancet 2002; 359(9320): 1812-8. doi: https://doi.org/10.1016/S0140-6736(02)08711-1

[35] Reid F, Lobo DN, Williams RN, Rowlands BJ, Allison SP. (Ab)normal saline and physiological Hartmann's solution: a randomized double-blind crossover study. Clin Sci (Lond) 2003; 104(1): 17-24. Epub 2003/01/10. doi: 10.1042/. PubMed PMID: 12519083

[36] Habicher M, Balzer F, Mezger V, Niclas J, Müller M, Perka C, et al. Implementation of goal-directed fluid therapy during hip revision arthroplasty: a matched cohort study. Perioper Med (Lond) 2016; 5: 31. Epub 2016/12/22. doi: 10.1186/s13741-016-0056-x. PubMed PMID: 27999663; PubMed Central PMCID: PMCPMC5154150

[37] Veelo DP, van Berge Henegouwen MI, Ouwehand KS, Geerts BF, Anderegg MC, van Dieren S, et al. Effect of goal-directed therapy on outcome after esophageal surgery: a quality improvement study. PLoS One 2017; 12(3): E0172806. Epub 2017/03/03. doi: 10.1371/journal.pone.0172806. PubMed PMID: 28253353; PubMed Central PMCID: PMCPMC5333843

[38] Benes J, Chytra I, Altmann P, Hluchy M, Kasal E, Svitak R, et al. Intraoperative fluid optimization using stroke volume variation in high risk surgical patients: results of prospective randomized study. Crit Care 2010; 14(3): R118-R. Epub 2010/06/16. doi: 10.1186/cc9070. PubMed PMID: 20553586

[39] Jin J, Min S, Liu D, Liu L, Lv B. Clinical and economic impact of goal-directed fluid therapy during elective gastrointestinal surgery. Perioperative Medicine 2018; 7(1): 22. doi: 10.1186/s13741-018-0102-y

[40] Cannesson M, Ramsingh D, Rinehart J, Demirjian A, Vu T, Vakharia S, et al. Perioperative goal-directed therapy and postoperative outcomes in patients undergoing high-risk abdominal surgery: a historical-prospective, comparative effectiveness study. Crit Care 2015; 19: 261. Epub 2015/06/20. doi: 10.1186/s13054-015-0945-2. PubMed PMID: 26088649; PubMed Central PMCID: PMCPMC4512146