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Goal Directed Fluid Therapy based on Stroke Volume Variation and Oxygen Delivery Index using Electrical Cardiometry in patients undergoing Scoliosis Surgery

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ABSTRACT

Background: The primary outcome was to evaluate whether goal-directed fluid therapy (GDFT) protocol, established on stroke volume variation (SVV) and oxygen delivery index (DO_2I) using electrical cardiometry (EC) monitor, would be effective in reducing perioperative packed red blood cells (RBCs) transfusion, whereas the secondary outcome was to compare the effects of GDFT with liberal fluid therapy (LFT) as regards total amount of fluids transfused, perioperative complications, and postoperative length of ICU and total hospital stay.

Settings and Design: This study was a prospective randomized controlled clinical trial.

Methods: The study was carried out on 48 patients scheduled for scoliosis surgery. Twenty-four patients, whose intraoperative fluid administration was managed with the GDFT protocol, were compared with 24 patients who received a liberal intraoperative fluid therapy.

The proposal and raw data were registered on PACTR as PACTR202007901764021.

Results: Patients in group II received less units of packed RBCs ($P < 0.001$) and a lower volume of intraoperative crystalloids ($P < 0.001$). They had significantly lower serum lactate levels 2 h after induction ($P = 0.033$), at the end of surgery ($P = 0.001$) and 2 h postoperatively ($P < 0.001$) with shorter ICU stay ($P < 0.001$), total hospital length of stay ($P < 0.001$), and faster return of bowel function ($P = 0.005$).

Conclusion:: Application of a GDFT protocol, established o SVV and DO_2I using EC monitor in patients undergoing scoliosis surgery, can lead to reduced packed RBCs transfusions, reduced total crystalloid volume infusions, less postoperative pulmonary complications, shorter ICU, and total hospital stay with faster return of gastrointestinal function.

Abbreviations: GDFT: goal-directed fluid therapy; SVV: stroke volume variation; DO_2I: oxygen delivery index; EC: electrical cardiometry; LFT: liberal fluid therapy; CI: cardiac index; RBCs: red blood cells; CO: cardiac output; IVC: inferior vena cava; CVP: central venous pressure; MAP: mean arterial pressure; CaO_2: arterial oxygen content; UOP: urine output; ASA: American Society of Anesthesiologist; BMI: body mass index; ROC: receiver operating characteristic; AUC: area under the curve; FFP: fresh frozen plasma

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1. Introduction

Major spine surgery entitles a significantly challenging setting in perioperative fluid management due to the significant third space losses, and sometimes, fatal intraoperative blood loss. Also, there may be associated decrease in cardiac output (CO) and inferior vena cava (IVC) outflow because of prone position. [1,2]. Therefore, there is a persistent need to limit intraoperative blood losses and at the same time maintain adequate spinal cord perfusion.

Many spinal surgeries are associated with significant blood loss. Of these are scoliosis surgeries, which have the greatest incidence of intraoperative and postoperative blood transfusion, ranging from 8% to 30%. [3,] Certain criteria as old age, obesity, surgical complexity, and multiple instrumental levels are all associated with more extensive blood loss.

Transfusion of blood products is associated with many complications, including the transmission of bloodborne infection, immunological cross-reactions, thromboembolism, and attenuation of the immune system [4,5]. These complications can lead to longer hospital stays and higher inpatient morbidity and mortality [6,7]. Postoperative transfusion has been demonstrated by several recent, large retrospective studies in the spine and non-spine surgery patients to increase perioperative mortality, morbidity, and overall costs [8,9].

Liberal fluid transfusion includes transfusion of fluids based on mean arterial pressure (MAP) that has to be ≥ 65 mmHg, and urine output (UOP) which should be around 0.5–1 ml/kg/h.

Recent literature supports the need for administration of fluids based on dynamic preload indicators [goal-directed fluid therapy (GDFT)] rather than static

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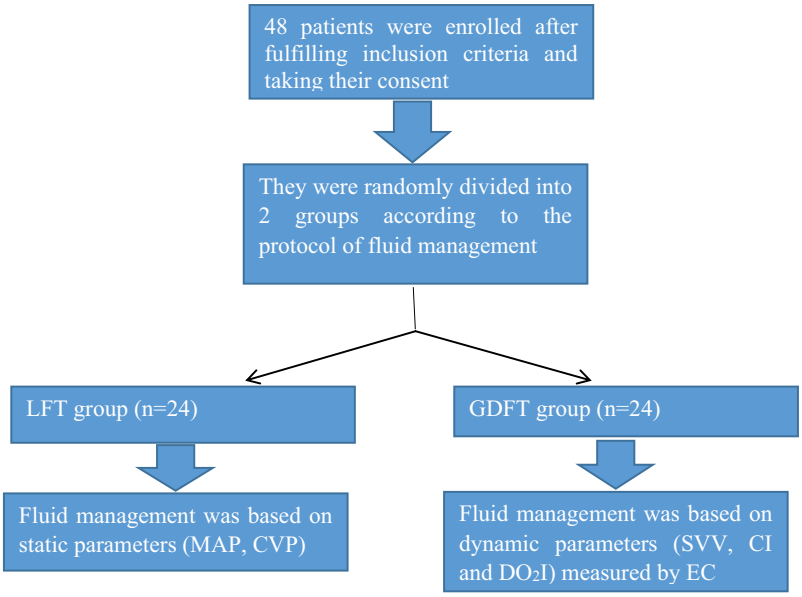

Flow chart of patients.

measurement of central venous pressure (CVP) and MAP [10,11].

Fluid responsiveness, as defined by Paul Marik, is an increase of stroke volume of 10–15% or increase in cardiac index (CI) ≥15% after the patient receives 10 ml/kg of crystalloid over 10–15 minu [12].

Stroke volume variation (SVV) is a dynamic preload parameter. Specific cardiopulmonary interactions under mechanical ventilation cause regularly repeated variations of stroke volume. Beat to beat measurement of SVV has been considered to be a reliable predictor of fluid responsiveness with high sensitivity and specificity in surgical patients. [13]

Low-volume ventilation or the imposition of variable respiratory effort often results in inaccurate SVV values. [14] Therefore, tidal volume should be between 8 and 10 ml/kg ideal body weight before and after a fluid challenge. [14] Also, in the setting of cardiac arrhythmias such as atrial fibrillation or frequent premature ventricular contractions, SVV measurements become inaccurate. [15]

Global oxygen delivery represents the amount of oxygen delivered to the tissues in each minute and can be calculated by the following equation: $DO_2 = CO \times CaO_2$ [16]. Oxygen flux to each tissue bed is not constant throughout the body. The microcirculation responds to altering tissue metabolic demands by varying the regional and local blood flow.

Electrical cardiometry is a method for the noninvasive determination of stroke volume [17], CO, and other hemodynamic parameters in adults, children, and neonates. It has been validated against "gold standard" methods such as thermodilution and is a proprietary method trademarked by Cardiotronic, Inc. [18] It calculates stroke volume [17] by analyzing the maximal rate of change in the resistance of blood flow during systole [19].

Therefore, the main objective of the study was to evaluate the effectiveness of GDFT protocol using electrical cardiometry (EC) monitor in reducing perioperative packed red blood cells (RBCs) transfusion, whereas the secondary objective was to compare the effects of GDFT with liberal fluid therapy (LFT) as regards total volume of crystalloids transfused, perioperative complications, and postoperative length of ICU and total hospital stay.

2. Patients and methods

After complete informed consent and approval from the ethical committee of Alexandria Faculty of Medicine, patients were subjected to complete history taking, physical examination, and routine laboratory investigations at El Hadara University Hospital.

Inclusion criteria were American Society of Anesthesiologist (ASA) status I–II, posterior spine arthrodesis involving at least five vertebral instrumental levels, Age between 15 and 65 years and a planned postoperative ICU admission while exclusion criteria were patients with known heart disease or any cardiac arrhythmia, patients with coagulopathy, and those with abnormal creatinine or liver enzymes.

Patients were randomly categorized, by closed envelope method, into two groups: group I: LFT group, $n = 24$: they received a liberal fluid therapy based on MAP, CVP, and UOP measurements with the goal of keeping MAP ≥ 65 mmHg, CVP ≥ 8 CmH_2O, and UOP > 0.5 ml/kg/h. Group II: GDFT group, $n = 24$: they received fluid therapy according to the SVV and DO_2 I-based protocol as shown in Figure 1.

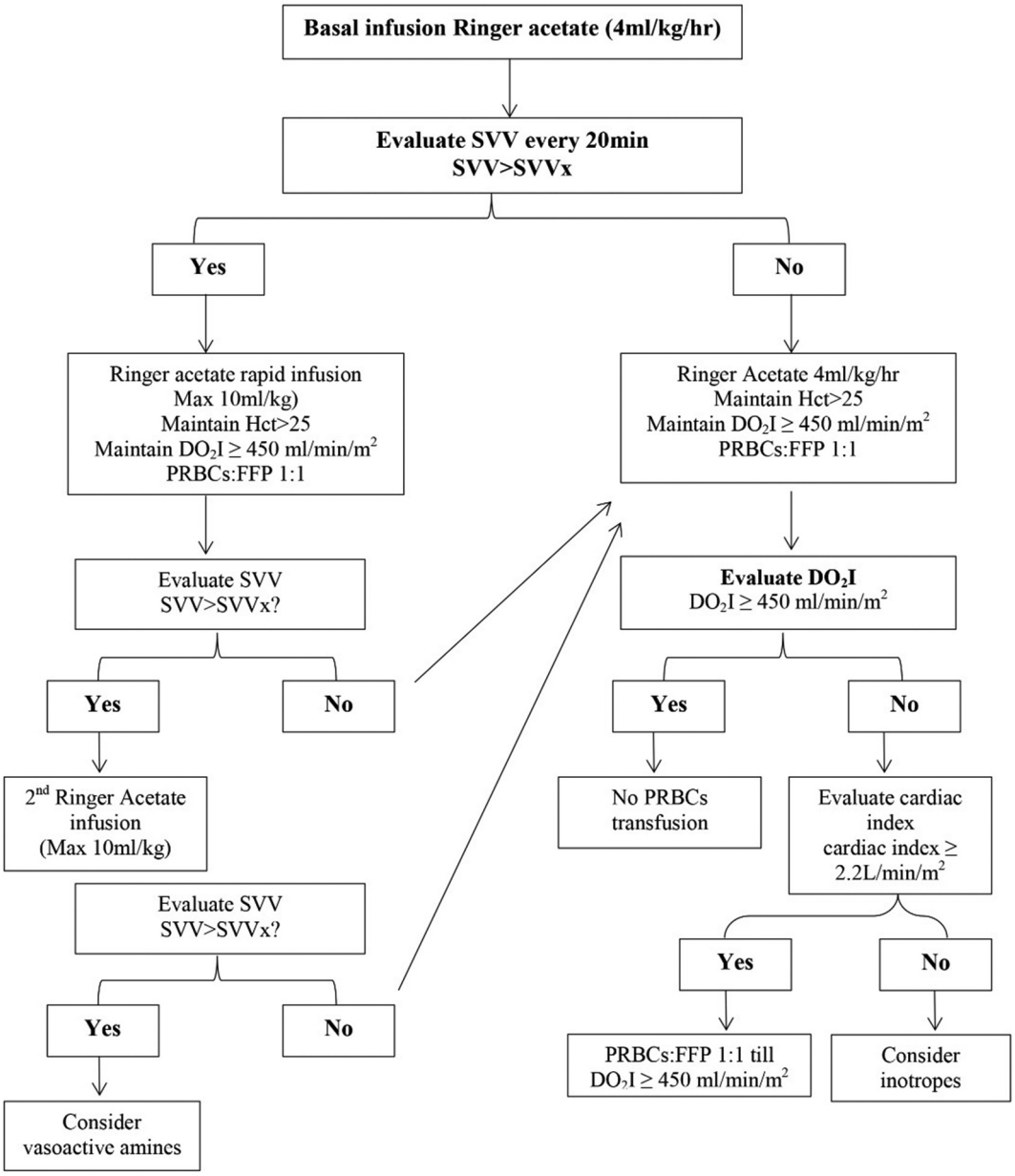

Figure 1. SVV and DO_2I-based protocol. SVVx: the threshold value for crystalloid bolus administration after turning patient to prone position (equals SVV measured at prone position + 20%). [30].

In both groups, EC device, The ICON™ monitor, trademarked by Cardiotronic, Inc., was attached to the patient by four ECG electrodes, two of them were attached to the left side of the neck and the other two electrodes were attached to the left side of the thorax intersecting the mid-axillary line at the level of xiphisternum. [20]

In group I, packed RBCs transfusion was based on maximum allowable blood loss equation where ABL = EBV × (Hi − Hf/Hi) where ABL is allowable blood loss, EBV is expected blood volume, Hi is the initial preoperative hematocrit, and Hf is the final target hematocrit that was set at 24%. Packed RBCs and fresh frozen plasma (FFP) will be transfused in 1:1 ratio.

The variables studied were gender, age, body mass index (BMI), duration of the operation, ASA status, number of instrumental levels, hemodynamic parameters in the form of Invasive MAP, heart rate, pulsed oxygen saturation (SpO_2), CVP, SVV, CI, and oxygen delivery index (DO_2I). Also, total intraoperative infused crystalloid volume, total amount of blood loss and units of intraoperative, and postoperative transfused RBCs and FFP were evaluated.

Serum lactate was measured before induction of anesthesia, 2 hs after induction, at the end of surgery and 2 h postoperatively. Time to return of bowel function, ICU and total hospital length of stay, and any postoperative complications were recorded.

3. Statistical analysis

A sample size of 48 patients was calculated using Epi Info 7 software for sample size calculation and based on 39% of exposed with outcome, to achieve 80% study power and 95% confidence limits. [21]

Data were fed to the computer and analyzed using IBM SPSS software package version 20.0. (Armonk, NY: IBM Corp). Qualitative data were described using number and percent. The Kolmogorov–Smirnov test was used to verify the normality of distribution. Quantitative data were described using range (minimum and maximum), mean, standard deviation, and median. Significance of the obtained results was judged at the 5% level.The used tests were as follows: chi-square test (for categorical variables, to compare between different groups), Fisher's exact (correction for chi-square when more than 20% of the cells have expected count less than 5), Student's *t*-test (for normally distributed quantitative variables, to compare between two studied groups), and Mann–Whitney test (for abnormally distributed quantitative variables, to compare between two studied groups), Pearson coefficient (to correlate between two normally distributed quantitative variables), and receiver operating characteristic (ROC) curve which is generated by plotting sensitivity (TP) on Y axis versus 1-specificity (FP) on X axis at different cutoff values. The area under the ROC curve denotes the diagnostic performance of the test. Area more than 50% gives acceptable performance and area about 100% is the best performance for the test (Figure 2).

Table 1. Demographic data, duration of the operation, ASA status, and number of instrumental levels.

	Group I (n = 24)		Group II (n = 24)			
	No.	%	No.	%	Test of sig.	p
Gender						
Male	9	37.5	8	33.3	χ^2 =	0.763
Female	15	62.5	16	66.7	0.091	
Age (years)						
Mean ± SD	21.08 ± 7.17		21.92 ± 7.73		U =	0.547
Median (min.–max.)	17.50 (15.0–38.0)		19.0 (15.0–43.0)		259.0	
BMI (kg/m^2)						
Min.–max.	20.0–31.0		21.0–31.0		t =	0.956
Mean ± SD	23.98 ± 2.96		24.02 ± 2.24		0.055	
Duration of the operation (min)						
Min.–max.	370.0–440.0		370.0–450.0		0.525	0.602
Min.–max.	396.3 ± 21.43		399.6 ± 22.55			
ASA status						
I	11	45.8	13	54.2	χ^2 = 0.333	0.564
II	13	54.2	11	45.8		
Number of instrumental level						
Min.– max.	6.0–10.0		6.0–10.0		t = 0.592	0.557
Mean ± SD	7.46 ± 1.28		7.25 ± 1.15			

SD: Standard deviation.
χ^2: chi-square test; t: Student's t-test; U: Mann–Whitney test.
p: p value for comparing between the two studied groups.

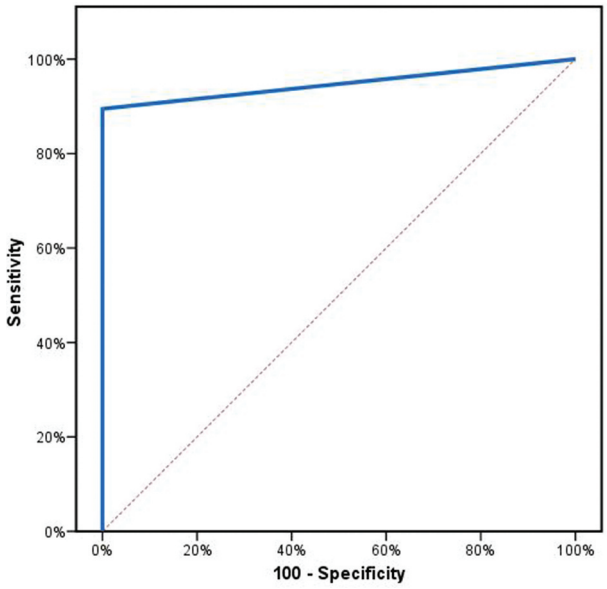

Figure 2. ROC curve for CI (before and after administration of the first fluid bolus to predict associated increase in CI ≥15% (n = 19) in group II.

4. Results

Regarding demographic data, duration of the operation, ASA status, and number of instrumental levels, there was no statistically significant difference between the two groups as shown in Table (1).

Regarding changes in invasive MAP and heart rate, there were no significant changes between the two groups.

A correlation was done between SVV and CI before and after administration of the first, second, and third fluid boluses for each case in group II. There was a statistically significant negative correlation between themas shown in Table (2).

ROC curve was drawn to measure the probability of CI to predict fluid responsiveness after administration of the first fluid bolus for each case in group II.

Increase in CI ≥ 15%, after administration of the first fluid bolus, is considered positive response to fluid bolus. Area under the curve (AUC) was statistically significant (AUC = 0.947, P = 0.003) with 95%

Table 2. Correlation between SVV and CI in group II.

	SVV	
CI	r	p
Before 1	−0.571*	0.004*
Before 2	−0.415*	0.044*
Before 3	−0.683*	<0.001*
After 1	−0.510*	0.011*
After 2	−0.857*	<0.001*
After 3	−0.891*	<0.001*

r: Pearson coefficient. 1: the first fluid bolus administered. 2: the second fluid bolus administered.
*Statistically significant at $p \leq 0.05$. 3: the third fluid bolus administered.

confidence interval between 0.858 and 1.000. The best cutoff value for CI to predict fluid responsiveness after the first fluid bolus was 3.1 l/min/m^2 with high sensitivity (89%) and specificity (100%) as shown in Figure 2. The positive predictive value was 100%, whereas the negative predictive value was 71.4%.

DO_2I was significantly higher in group II at all phases of measurement from 60 min after induction ($P = 0.010$) till the end of surgery ($P < 0.0001$).

Total blood loss was significantly higher in group I where its mean value was 2247.9 ± 158.4 vs. 1447.9 ± 197.5 ml in group II ($P < 0.001$). As regards hemoglobin level, there were no statistically significant changes between the two groups preoperatively (in group I, it ranged from 10.8 to 13.5 g/dl with a mean of 11.88 ± 0.78 g/dl, whereas in group II, it ranged from 10.5 to 13.8 with a mean of 12.13 ± 0.94 g/dl, $P = 0.335$) and at the end of surgery (in group I, it ranged from 8.5 to 10.2 g/dl with a mean of 9.26 ± 0.36 g/dl, whereas in group II, it ranged from 8 to 10.5 with a mean of 9.33 ± 0.7 g/dl, $P = 0.664$). However, it was significantly lower in group I than group II from 60 min (mean 11.18 ± 0.78 vs. 11.73 ± 0.94 g/dl, respectively, $P = 0.034$) till 360 min after induction of anesthesia (mean 8.89 ± 0.44 vs. 9.63 ± 0.70 g/dl, respectively, $P = <0.001$).

By comparing all phases of measurement to preoperative values in both groups; hemoglobin level was significantly lower in all phases in comparison to preoperative values.

Total crystalloid volume (Ringer acetate) infused in group II was significantly lower where its mean value was 3633.3 ± 428.8 vs. 4172.9 ± 482.5 ml in group I ($P < 0.001$). Basal fluid infusion and fluid boluses given to all patients in both groups were in the form of ringer acetate solution in addition to units of packed RBCs and FFP. No hydroxy ethyl starch, albumin, or gelatins were given.

Intraoperative and postoperative units of packed RBCs and FFP transfused were significantly higher in group I as shown in Table 3.

We did not need to give any inotropic support or vasopressors to any patient in the two groups as the target parameters, in both groups, were optimized after the fluid boluses were administered according to the protocol planned for each group.

Blood PH was significantly lower in group I when measured 2 h after induction (mean 7.35 ± 0.01 vs. 7.36 ± 0.01 in group II, $P = 0.033$), at the end of surgery (mean 7.33 ± 0.02 vs. 7.34 ± 0.01 in group II, $P = 0.001$), and 2 h postoperatively (mean 7.32 ± 0.03 vs. 7.35 ± 0.01 in group II, $P < 0.001$). Serum lactate was significantly lower in group II when measured 2 h after induction (mean 1.11 ± 0.12 vs. 1.25 ± 0.14 mmol/l in group I, $P < 0.001$), at the end of surgery (mean 1.15 ± 0.13 vs. 1.76 ± 0.20 mmol/l in group I, $P < 0.001$) and 2 h postoperatively (mean 1.10 ± 0.19 vs. 1.85 ± 0.24 in group I, $P < 0.001$).

Table 3. Comparison between the two studied groups according to total blood loss (ml), intraoperative and postoperative units of packed RBCs and FFP transfused.

	Group I ($n = 24$)	Group II ($n = 24$)	p
Total blood loss (ml)			
Min.–max.	1900.0–2600.0	1200.0–1800.0	<0.001*
Mean ± SD	2247.9 ± 158.4	1447.9 ± 197.5	
Units of packed RBCs transfused			
Intraoperative			
Mean ± SD	3.92 ± 0.65	2.25 ± 0.44	<0.001*
Median (min.–max.)	4.0 (3.0–5.0)	2.0 (2.0–3.0)	
Postoperative			
Mean ± SD	1.25 ± 0.44	0.42 ± .050	<0.001*
Median (min.–max.)	1.0 (1.0–2.0)	0.0 (0.0–1.0)	
Units of FFP transfused			
Intraoperative			
Mean ± SD	5.04 ± 0.91	3.25 ± 0.44	<0.001*
Median (Min.–max.)	5.0 (4.0–7.0)	3.0 (3.0–4.0)	
Postoperative			
Mean ± SD	2.21 ± 0.51	0.42 ± 0.50	<0.001*
Median (Min.–max.)	2.0 (1.0–3.0)	0.0 (0.0–1.0)	

SD: Standard deviation.
p: *p* value for comparing between the two studied groups.
*Statistically significant at $p \leq 0.05$.

The total length of stay in ICU and total hospital length of stay were significantly lower in group II where their median values were 1 and 7 days vs. 2 and 9 days, respectively ($P < 0.001$).

In group I, there was statistically significant positive correlation between serum lactate (measured 2 h postoperatively) and total length of stay in ICU ($r = 0.633$, $P = 0.001$).

Time to return of bowel function was significantly lower in group II where its mean value was 1.0 ± 0.0 day vs. 1.29 ± 0.46 day in group I ($P = 0.005$).

Regarding postoperative complications, incidence of which in group I was higher, though insignificant, than that in group II where two cases were complicated by lung congestion representing 8.3% of the total cases in group I whereas, in group II, no volume-related postoperative complications were reported ($P = 0.489$).

5. Discussion

Despite a great amount of evidence supporting the substantial risk of greater perioperative blood loss during scoliosis surgeries, there is no general agreement to the optimal management of intraoperative fluid administration for these surgical procedures. [2,22,23]

In our study, we found no significant difference between the two groups as regards demographic data, duration of the operation, ASA status, number of instrumental levels, invasive MAP, and heart rate. Insignificant changes in MAP, despite changes in CO, were previously explained by Vincent [24], who concluded that the changes in MAP are dissociated from the changes in CO because of the sympathetic modulation of the arterial tone.

Another important result is the strong negative correlation between ΔSVV and ΔCI before and after administration of fluid boluses in group II. This finding was also suggested by Daniel A Reuter et al. [25], who hypothesized that measuring SVV during mechanical ventilation by continuous arterial pulse contour analysis allows the accurate prediction of changes in CI in response to volume loading.

DO_2I was significantly lower in group I, and this could be explained by the significantly lower hemoglobin because of greater blood loss. Application of GDFT was effective in reducing packed RBCs and FFP transfusion (primary outcome). Hemodynamic optimization and associated reduction in crystalloid and packed RBCs transfusions are closely related as LFT regimen can induce venous congestion, which increases bleeding from the instrumented bone itself. Also, hemodilution lowers the blood hematocrit value, so the transfusion point is reached sooner, and can induce hyper fibrinolytic state and coagulopathy, increasing blood losses even more and creating a vicious loop of fluid overload, excessive bleeding, coagulopathy, and more blood product transfusions.

Reducing the number of transfused RBCs and FFP units is a very striking primary endpoint since transfusion of packed RBCs has been associated with various complications. In agreement with that what has been published by LG Glance et al. [26], who have done a retrospective analysis of the association of blood transfusion and 30-day mortality and morbidity in surgical patients and concluded that intraoperative blood transfusion was associated with a higher risk of mortality and morbidity. Another important result is the significant reduction in the total volume of infused crystalloids in group II. In agreement with that is what has been published by C. Correa et al. [27], who have concluded that SVV-guided GDFT led to less intraoperative volume infusion. Peng et al. [28] have evaluated the effect of SVV-based GDFT on splanchnic organ functions and postoperative complications in orthopedic patients and concluded that GDFT protocol reduced the volume of the required intraoperative infused fluids, maintained intraoperative hemodynamic stability, and improved the perioperative gastrointestinal function.

Blood PH was significantly higher while serum lactate was significantly lower in group II, suggesting that end organ perfusion was significantly superior where GDFT protocol was applied. Prittie et al. [29] have evaluated optimal endpoints of resuscitation and early GDFT and recommended the utilization of serum lactate and blood PH as target endpoints of resuscitation in critically ill patients.

In group I, the incidence of lung congestion, despite insignificant, was 8.3% ($n = 2$) as clinically suspected and then confirmed by lung ultrasound where multiple B lines ($n = 5$) were visualized. The lung congestion was managed by diuretics and non-invasive continuous positive airway pressure and resolved within 12 h after ICU admission.

6. Conclusion

Application of a GDFT protocol, established on SVV and DO_2I using EC monitor in patients undergoing scoliosis surgery, can lead to reduced packed RBCs transfusions, reduced total crystalloid volume infusions, less postoperative pulmonary complications, shorter ICU, and total hospital stay with faster return of bowel function.

7. Limitations

There were several limitations in the present study, being a small-sized, single-center study. ASA scoring of patients included in the study ranged from ASA I–II, which limited the exploitation of CI parameter in establishing inotropic support for those who might be fluid non-responders if higher ASA scores were included as their position on the frank-starling curve might be on the plateau rather than the steep part of the curve.

Disclosure of potential conflicts of interest

No potential conflict of interest was reported by the author(s).

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