Efficacy of Intraoperative Hemodynamic Optimization Using FloTrac/EV1000 Platform for Early Goal-directed Therapy to Improve Postoperative Outcomes in Patients Undergoing Coronary Artery Bypass Graft with Cardiopulmonary Bypass: A Randomized Controlled Trial

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Research Article

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Abstract

Background: Early goal-directed therapy (EGDT) using the FloTrac system reportedly decreased mortality, morbidity, and length of stay (LOS) in intensive care unit (ICU) and hospital among high-risk patients undergoing non-cardiac surgery. The objective of this study was to evaluate the efficacy of the FloTrac/EV1000 platform for improving postoperative outcomes in cardiac surgery.

Methods: Eighty-six adults undergoing coronary artery bypass graft (CABG) with cardiopulmonary bypass (CPB) were randomized to the EV1000 or Control group. The Control group was managed with standard care to achieve the following goals: mean arterial pressure 65-90 mmHg; central venous pressure 8-12 mmHg; urine output ≥ 0.5 mL/kg/h; oxygen saturation > 95%; and hematocrit 26-30%. The EV1000 group was managed to reach similar goals using information from the FloTrac/EV1000 monitor. The targets were: stroke volume variation (SVV) < 13%; cardiac index (CI) 2.2-4.0 L/min/m^2; stroke volume index (SVI) 33-65 mL/beat/m^2; and systemic vascular resistance index (SVRI) 1600-2500 dynes/s/cm^5/m^2.

Results: The LOS in ICU of the EV1000 group was significantly shorter (mean difference -29.5 h; 95%CI -17.2 to -41.8, $p < 0.001$). The mechanical ventilation time was also shorter in the EV1000 group (mean difference -11.3 h; 95%CI -2.7 to -19.9, $p = 0.011$). The hospital LOS was shorter in the EV1000 group (mean difference -1.1 d; 95%CI -0.1 to -2.1, p =0.038). The EV1000 group received a higher number of inotropic or vasoactive drugs than the Control group in pre-bypass period, but less in post-bypass, postoperative period before transfer to the ICU, and in the ICU. The EV1000 group had less atrial fibrillation with rapid ventricular response, acute respiratory distress syndrome, and acute renal injury.

Conclusions: Compared with standard care, intraoperative hemodynamic optimization using the FloTrac/EV1000 platform for the EGDT protocol in patients undergoing CABG with CPB resulted in shorter ventilator time, shorter ICU and hospital LOS, and fewer postoperative complications. The EV1000 group required more fluid and inotropic or vasoactive drugs in the pre-bypass period to optimize SVV, CI, and SVRI and to maintain the target MAP resulting in better myocardium oxygen supply reflected in fewer drugs required during post-bypass, before transfer to, and in, the ICU.

Trial registration

The study was registered with ClinicalTrials.gov (NCT04292951) on 03/03/2020.

Introduction

Cardiac surgery is a high-risk surgery involving high-risk patients leading to high morbidity and mortality. Recently, operative and postoperative mortality have decreased due to improved patient care; however, the morbidity rate remains substantial [1]. Consequently, 10% of patients who underwent cardiac surgery required prolonged postoperative care due to hemodynamic instability, organ dysfunction, and/or multiorgan failure, leading to an increased cost in intensive care and hospital care [2]. Early goal-directed therapy (EGDT) involves detecting alteration of hemodynamic parameters to guide the intravenous fluid

and inotropic or vasoactive therapy, which leads to manipulation of the cardiac preload, contractility, and afterload so as to achieve predefined goals for balancing tissue oxygen supply with demand [3]. Among high-risk patients undergoing non-cardiac surgery, EGDT has been reported to decrease mortality, morbidity, and length of stay (LOS) in the intensive care unit (ICU) and the hospital [4, 5]. There have only been a few small studies assessing the benefits of EGDT in cardiac surgery [3, 6–9]. A systematic review including all five of the randomized control trials revealed that EGDT was a tool that might reduce morbidity and hospital LOS among patients undergoing cardiac surgery [2].

There are many platforms used to define the goals for EGDT (viz., PICCO Plus, FloTrac, esophageal Doppler, and thermodilution pulmonary artery catheter) [2]. Among them, FloTrac constitutes minimally invasive monitoring that needs no calibration. FloTrac is easy to use: just connect it to a radial artery catheter used for direct arterial pressure monitoring. By using a proprietary algorithm for pulse contour analysis, this system can compute stroke volume (SV) from arterial waveform.

The first generation FloTrac was operated with a Vigileo monitor (FloTrac/Vigileo) which provided real-time information on the stroke volume index (SVI), cardiac index (CI), and stroke volume variation (SVV). The systemic vascular resistance index (SVRI) can be acquired intermittently by keying in the central venous pressure (CVP) value. Later generations have been operated with an EV1000 monitor (FloTrac/EV1000) which has an interface connected with a CVP transducer to provide real-time SVRI values updated every 20 s. The EGDT using the FloTrac/Vigileo was reported to reduce postoperative complications and LOS in hospital among high-risk patients undergoing major abdominal surgery [10, 11]. The benefit of this system in cardiac surgery, however, remains inconclusive. A report using FloTrac/Vigileo information for postoperative hemodynamic stabilization in patients who underwent cardiac surgery revealed inconclusive beneficial effects including decreased hospital LOS [3]. A study on the clinical benefit of applying EGDT using the FloTrac/EV1000 in cardiac surgery is needed. We therefore aimed to assess the benefit of applying the FloTrac/EV1000 as a tool for EGDT in this group of patients hypothesizing that EGDT using the FloTrac/EV1000 for hemodynamic optimization during the intraoperative period would reduce morbidity, ICU LOS, and hospital LOS.

The objective of this study was to compare postoperative outcomes between applying EGDT using the FloTrac/EV1000 platform vs. standard care as a tool to manage hemodynamic parameters in patients undergoing coronary artery bypass graft (CABG) with cardiopulmonary bypass (CPB). The primary outcome was a difference in ICU LOS. The secondary outcomes were time of mechanical ventilation in the ICU, hospital LOS, and postoperative complications.

Methods

The current study was approved by the Khon Kaen University Ethics Committee in Human Research (HE611321) and registered at www.ClinicalTrials.gov (NCT04292951) on 03/03/2020. The study was conducted in accordance with Declaration of Helsinki and the ICH GCP.

Written informed consent was obtained from all subjects.

This study was reported according to the CONSORT (Consolidated Standards of Reporting Trials) guidelines.

Our study was a multi-center, prospective randomized double-blind (patient- and assessor-blinded) controlled trial. The sample size calculation was based on ICU LOS (4.9 ± 1.8 d) after cardiac surgery in a previous study [3]. We determined that we needed a sample size of 42 per group to detect a 25% decrease in ICU LOS with an α-value of 0.05, a power (1-ß) of 0.80, and a 20% dropout. Block-of-4 randomization with 1:1 allocation ratio was performed using a computer-generated list kept in sealed opaque envelopes. We included patients of either sex who: 1) were 18 or older who underwent elective CABG with CPB under general anesthesia at Srinagarind Hospital, Khon Kaen University, Khon Kaen, Thailand or Phramongkutklao Hospital, Bangkok, Thailand; and, 2) had an American Society of Anesthesiologists (ASA) classification between II and IV. We excluded patients needing redo surgery, having a contra-indication to central venous cannulation, requiring intra-aortic balloon pump, having ventricular arrhythmias, or having any inability to cooperate. All surgeons and anesthesiologists in the study were qualified personnel for cardiac surgery and anesthesia with > 5 years' experience.

The patients were randomized to the EV1000 or Control group. All patients received standard cardiac anesthesia care as per our institution's protocol. The monitors in the operation theater included electrocardiogram, pulse oximeter, non-invasive blood pressure, temperature, capnography, anesthetic gas analyzer, and urine output. The radial artery was cannulated and connected to a pressure transducer in the Control group to measure invasive blood pressure (IBP) or a FloTrac transducer in the EV1000 group to measure IBP as well as SVV, SVI, and CI. The internal jugular vein was cannulated and connected to another pressure transducer in the Control group to measure central venous pressure (CVP) or a pressure transducer connected to the FloTrac transducer in the EV1000 group to measure SVRI. All patients receive fentanyl 2–3 $\mu g \cdot kg^{-1}$ and midazolam 1 mg as a premedication. Propofol 2–3 $mg \cdot kg^{-1}$ or etomidate 0.3 $mg \cdot kg^{-1}$ was used as an induction agent. Endotracheal intubation was facilitated using cis-atracurium 0.2 $mg \cdot kg^{-1}$. Anesthesia was maintained with 50% oxygen in air and 1–2 % sevoflurane or 3–6 % desflurane adjusted to achieve 1 minimum alveolar concentration (MAC) on the monitor to maintain the depth of anesthesia. CPB was initiated after heparin 3–4 $mg \cdot kg^{-1}$ was administered via the CVP catheter with an activated clotting time (ACT) > 480 s, with supplemental doses of 1–2 $mg \cdot kg^{-1}$ to maintain ACT > 400–480 s. Mild hypothermia (32ºC) was maintained during CPB. Cardioplegia solution was infused via an aortic root catheter after aortic cross-clamping. Supplemental cardioplegia was administered at the discretion of the cardiac surgeon. During CPB, mean arterial pressure (MAP) was maintained in the range of 45–75 mmHg. After terminating the CPB, protamine 1 mg per 1 mg of pre-CPB heparin dose was slowly injected to reverse the effect of heparin. All patients were transferred to the ICU and mechanically ventilated. All patients received standard ICU care. The criteria for ventilator weaning and extubation were: good consciousness and motor power, stable cardiovascular status, a PaO_2/FiO_2 ratio ≥ 250 mmHg, and a respiratory rate of 10–25 $times \cdot min^{-1}$. The criteria for ICU discharge were: good consciousness and neurological signs, stable cardiovascular status with no need for inotropic or vasopressor drugs and ICU monitoring, and stable respiratory status with oxygen requirement not more

than 60%. Hospital discharge criteria were: stable cardiovascular and respiratory status, no drain or catheter retained, normal ambulation, no infection or serious complications, wound-stitch removed, and normal diet.

During the intraoperative period, both before and after CPB, the Control group received fluid, inotropic, or vasoactive drugs at the discretion of the attending anesthesiologists to achieve the following goals: MAP 65–90 mmHg; CVP 8–12 mmHg; urine output ≥ 0.5 $mL \cdot kg^{-1} \cdot h^{-1}$; SpO_2 > 95%; and hematocrit 26–30%. Arterial blood gas (ABG) and electrolytes were monitored and corrected hourly. In the EV1000 group, the patients were managed to achieve the similar goals by receiving fluid, inotropic, or vasoactive drugs via the EGDT protocol using information from the FloTrac/EV1000 to achieve the following targets: SVV < 13%; SVI 33–65 $mL \cdot beat^{-1} \cdot m^{-2}$; CI 2.2-4.0 $L \cdot min^{-1} \cdot m^{-2}$; and SVRI 1600-2500 dynes $s^{-1} \cdot cm^{-5} \cdot m^{-2}$. ABG and electrolytes were monitored and corrected in the same manner.

The volume of fluid, amount of inotropic, and vasoactive drugs used during pre-CPB, post-CPB, transfer to the ICU, and in the ICU were recorded. Also recorded were time of mechanical ventilation in the ICU, ICU and hospital LOS, and all complications.

Statistical analysis

Continuous data were tested for Gaussian distribution using the Shapiro-Wilk test. Data with a normal distribution were presented as a mean ± standard deviation (SD) and compared using the unpaired Student's t-test. Data with non-Gaussian distribution were presented as a median (inter-quartile range) and compared using the Mann-Whitney U test. Categorical data were presented as a number (%) and compared using the χ^2 test. The primary outcome was presented as a mean difference with a 95% confidence interval (CI). $P < 0.05$ was considered statistically significant. All data were analyzed using SPSS 16.0 (SPSS Inc., Chicago, IL, USA).

Results

A total of 86 patients were recruited between January 2019 and April 2020 with 44 and 42 patients in the EV1000 and Control group, respectively (Fig. 1). The patient characteristics and clinical data were similar between the two groups except for a higher creatinine, lower sodium, lower postoperative hemoglobin, lower albumin, higher INR, lower postoperative lactate, more crystalloid intake, and more urine output in the EV1000 group (Table 1).

Table 1
Characteristics and clinical data of patients (n = 86)

Variable	EV1000 (n = 44)	Control (n = 42)	*P*-value
Male/female	29 (65.9)/15 (34.1)	30 (71.4)/12 (28.6)	0.581
Number of vessel anastomosis			0.971
2	2 (4.6)	2 (4.8)	
3	21 (47.7)	20 (47.6)	
4	18 (40.9)	16 (38.1)	
5	3 (6.8)	4 (9.5)	
Functional class			0.494
1	1 (2.1)	0	
2	23 (53.2)	26 (76.2)	
3	19 (42.6)	16 (23.8)	
4	1 (2.1)	0	
ASA classification			0.327
2	8 (18.2)	10 (23.8)	
3	34 (77.3)	32 (76.2)	
4	2 (4.5)	0	
Age (y)	64.8 ± 10.0	64.7 ± 8.3	0.960
Body weight (kg)	62.7 ± 13.7	63.7 ± 11.4	0.715
Height (cm)	160.1 ± 7.1	160.9 ± 6.4	0.585
Ejection fraction (%)	55.1 ± 10.7	57.0 ± 13.9	0.478
CKD	11	10	0.898
On hemodialysis	3	0	0.085
Creatinine (mg/dL)			
Preoperative	2.2 ± 2.3	1.3 ± 0.7	0.021

Data are expressed as mean ± SD or number (%)

ASA, American Society of Anesthesiologists; CKD, chronic kidney disease; INR, international normalized ratio; CPB, cardiopulmonary bypass

Variable	EV1000 (n = 44)	Control (n = 42)	*P*-value
Postoperative 0 h	1.8 ± 1.7	1.2 ± 0.6	0.040
Postoperative 6 h	1.9 ± 1.8	1.3 ± 0.7	0.040
Postoperative 12 h	2.2 ± 2.1	1.4 ± 0.7	0.028
Postoperative 24 h	2.1 ± 2.0	1.5 ± 0.7	0.069
Postoperative 48 h	1.9 ± 2.0	1.5 ± 1.0	0.204
Sodium (mEq/L)	135.8 ± 2.6	138.7 ± 3.4	< 0.001
Potassium (mEq/L)	4.3 ± 0.4	4.2 ± 0.4	0.250
Blood sugar (mg/dL)	135.5 ± 33.7	124.3 ± 32.3	0.120
Hemoglobin (g/dL)			
Preoperative	11.6 ± 2.5	12.2 ± 1.7	0.199
Postoperative	10.1 ± 1.1	10.8 ± 1.1	0.004
Albumin (mg/dL)	3.8 ± 0.6	4.2 ± 0.6	0.003
Platelet ($x10^9$/L)	265.0 ± 100.6	240.4 ± 75.2	0.204
INR	1.1 ± 0.1	1.0 ± 0.1	< 0.001
Anesthesia time (min)	420.3 ± 99.8	421.9 ± 87.0	0.937
CPB time (min)	118.4 ± 44.3	119.1 ± 26.4	0.930
Aortic cross-clamp (min)	69.7 ± 22.7	77.9 ± 20.3	0.081
Partial cross-clamp (min)	22.7 ± 3.7	21.5 ± 10.9	0.492
Operation time (min)	360.3 ± 98.2	361.8 ± 81.4	0.939
Lactate (mmol/L)			
Postoperative 0 h	2.3 ± 0.9	3.0 ± 1.8	0.022
Postoperative 24 h	2.6 ± 1.3	3.2 ± 1.9	0.107
Postoperative 48 h	1.5 ± 0.4	2.1 ± 1.9	0.032
Postoperative 72 h	0.9 ± 0.3	1.6 ± 1.6	0.006

Data are expressed as mean ± SD or number (%)

ASA, American Society of Anesthesiologists; CKD, chronic kidney disease; INR, international normalized ratio; CPB, cardiopulmonary bypass

Variable	EV1000 (n = 44)	Control (n = 42)	*P*-value
Crystalloid intake (mL)	2,046.9 ± 743.5	1,736.2 ± 623.4	0.039
Blood loss (mL)	935.7 ± 213.4	968.3 ± 300.8	0.562
Urine output (mL)	1,545.1 ± 980.8	936.1 ± 515.2	< 0.001
Data are expressed as mean ± SD or number (%)			
ASA, American Society of Anesthesiologists; CKD, chronic kidney disease; INR, international normalized ratio; CPB, cardiopulmonary bypass			

The ICU LOS of the EV1000 group was significantly shorter than the Control group (mean difference − 29.5 h; 95%CI -17.2 to -41.8, $p < 0.001$). The mechanical ventilation time was also less in the EV1000 group (mean difference − 11.3 h; 95%CI -2.7 to -19.9, $p = 0.011$). The hospital LOS was shorter in the EV1000 group than the Control group (mean difference − 1.1 d; 95%CI -0.1 to -2.1, p = 0.038) (Table 2).

Table 2
Postoperative outcomes (n = 86)

	EV1000 (n = 44)	Control (n = 42)	Mean difference	95% CI	*P*-value
ICU stay (h)	48.9 ± 11.4	78.4 ± 39.4	-29.5	-17.2 to -41.8	< 0.001
Ventilator time (h)	13.9 ± 7.1	25.2 ± 27.9	-11.3	-2.7 to -19.9	0.011
Hospital stay (d)	9.9 ± 2.0	11.0 ± 2.8	-1.1	-0.1 to -2.1	0.038
Data are expressed as mean ± SD					
ICU, intensive care unit					

The EV1000 group received a higher number of inotropic or vasoactive drugs than the Control group in the pre-bypass period, but required less inotropic or vasoactive drugs in the post-bypass and postoperative period before transfer to the ICU (Table 3). In the ICU, the EV1000 group required less and a shorter duration of inotropic or vasoactive drugs than the Control group (Table 4).

Table 3
Number of drugs required at different stages for each group (n = 86)

	EV1000 (n = 44)	Control (n = 42)	*P*-value
Drug requirement during pre-bypass			< 0.001
0	1 (2.3)	6 (14.3)	
1	6 (13.6)	31 (73.8)	
2	30 (68.2)	5 (11.9)	
3	7 (15.9)	0	
Drug requirement during post-bypass			0.002
0	12 (27.3)	0	
1	20 (45.5)	20 (47.6)	
2	10 (22.7)	20 (47.6)	
3	2 (4.5)	2 (4.8)	
Drug requirement before transfer to ICU			< 0.001
0	27 (61.4)	1 (2.4)	
1	11 (25.0)	22 (52.4)	
2	6 (13.6)	17 (40.5)	
3	0	2 (4.7)	
Data are expressed as number (%)			

Table 4
Duration of inotropic and vasoactive drugs used in ICU

Drug	Immediately at ICU		POD 1–4				
	Postoperative (n)		Postoperative (n)		Postoperative (h)		
	EV1000 (n = 44)	Control (n = 42)	EV1000 (n = 44)	Control (n = 42)	EV1000 (n = 44)	Control (n = 42)	P-value
Epinephrine	1	23	3	21	2 ± 1	16.6 ± 15.0	< 0.001
Norepinephrine	4	7	3	15	5.3 ± 0.6	24.9 ± 18.8	< 0.001
Dobutamine	5	15	12	25	34.8 ± 15.0	50.0 ± 40.6	0.022
Dopamine	7	6	7	10	6.3 ± 1.3	9.3 ± 8.1	0.018
NTG	2	13	14	26	20.8 ± 8.5	28.9 ± 18.8	0.011
Nicardipine	0	0	1	7	6.2 ± 2.0	9.3 ± 4.8	< 0.001
Data are expressed as mean ± SD							

The postoperative complications are presented in Table 5. The EV1000 group had less atrial fibrillation (AF) with rapid ventricular response (RVR), acute respiratory distress syndrome (ARDS), and acute renal injury (AKI) than the Control group.

Table 5
Postoperative complications

	EV1000 (n = 44)	Control (n = 42)	*P*-value
Postoperative complication			
AF with RVR	1	14	< 0.001
VF	0	1	0.303
SVT	0	1	0.303
Cardiogenic shock	0	2	0.143
Post-bypass IABP	0	1	0.303
Reintubation	0	2	0.143
VAP	0	2	0.143
ALI	0	1	0.303
ARDS	0	6	0.009
Post-bypass IABP	0	1	0.303
Sepsis	0	1	0.303
AKI	0	8	0.002
Data are expressed as number			
AF, atrial fibrillation; RVR, rapid ventricular response; VF, ventricular fibrillation; SVT, supraventricular tachycardia; IABP, intra-aortic balloon pump; VAP, ventilator-associated pneumonia; ALI, acute lung injury; ARDS, acute respiratory distress syndrome; AKI, acute kidney injury			

Discussion

The current study reveals that intraoperative hemodynamic optimization using a PGDT-driven protocol via the FloTrac/EV1000 system can decrease ventilator time, reduce ICU and hospital LOS, and lower postoperative complications in patients undergoing CABG with CPB. Patients with ischemic heart disease may experience low cardiac output at different stages during CABG leading to intraoperative hypotension (IOH), which further compromises myocardium oxygen supply, increasing the need for inotropic or vasoactive drugs and leading to postoperative complications. Early recognition and treatment of low cardiac output results in better outcomes [3]. Most anesthesiologists set MAP at between 90–105 mmHg as the principal goal for managing low cardiac output [3]. The MAP, however, does not always represent cardiac output. MAP depends on two factors—viz., cardiac output and systemic vascular resistance (SVR)—while cardiac output relies on preload and contractility. Thus, there are three variables that affect MAP—viz., preload, contractility, and afterload or SVR. A normal MAP can be found in situations of low cardiac

output with a high SVR resulting in tissue hypoperfusion. Treatment of IOH without precise information regarding these three variables may lead to mismanagement which may increase pharmacologic requirement, complications, and ICU and hospital LOS. In EGDT, these three variables are continuously monitored and manipulated to optimize pressure and flow to perfuse body organs resulting in better outcomes.

EGDT applied intraoperatively has been reported to improve postoperative outcomes in non-cardiac major surgery [4, 5], as well as cardiac surgery [2, 12]. There are several means for determining the goals of EGDT—i.e. PICCO Plus, FloTrac, esophageal Doppler, and thermodilution pulmonary artery catheter [2]. We chose a fourth-generation FloTrac with EV1000 to provide the goals for EGDT because this platform is less invasive, easy to use, and can provide continuous real-time data. The EGDT using the FloTrac system in moderate to high-risk cardiac surgery during the postoperative period in the ICU resulted in significantly more extra volume used and a greater number of times inotropic agents were changed. By comparison, in the EGDT group, there was a shorter duration of inotropic agent used, a shorter duration of ventilator support, and a shorter ICU and hospital LOS. The difference between groups has clinical but not statistical significance owing to the small sample size [3].

Our study applied the EGDT protocol from the beginning until the end of the surgery, resulting in similar outcomes with statistical significance. The EV1000 group required more fluid and drug requirements during the pre-bypass period to optimize the SVV, CI, and SVRI according to information from the FloTrac/EV1000 to achieve a target MAP resulting in better myocardium perfusion leading to less drug requirement during post-bypass and before transfer to the ICU. The EV1000 group also required significantly fewer and a shorter duration of inotropic or vasoactive drugs in the ICU, resulting in a shorter requirement for ventilator support, as well as a shorter ICU and hospital LOS. The EV1000 group developed fewer postoperative complications than the Control group which is similar to the previous study [3]. The assumption for fewer complications in the EV1000 group is that tissue perfusion in the EV1000 group was better optimized during the intraoperative period.

The cardiac output measurement agreement between the FloTrac/Vigileo system and the thermodilution technique in cardiac surgery is inconclusive [13–15]. Nevertheless, our study shows that using the FloTrac/EV1000 system in cardiac surgery results in better postoperative clinical outcomes.

Although we did not use the bi-spectral index (BIS) to control anesthesia depth, we used the MAC value to monitor and control depth of anesthesia. The end-tidal concentration of sevoflurane or desflurane was adjusted to achieve 1 MAC for a given age (MAC_{age}) [16] on the monitor. With the additive effect of fentanyl (~ 0.5 MAC) and cisatracurium (~ 0.5 MAC) [17, 18], the total depth of anesthesia was approximately 2 MAC (~ MAC-BAR_{99}) which is optimal.

This study has a few limitations. The attending anesthesiologists could not be blinded. Although we recruited 86 patients from two hospitals in Thailand, the sample size was relatively small, so a multi-

center study with a larger sample size is recommended. The FloTrac/EV1000 platform requires extra cost; however, it reduces ICU and hospital LOS. A cost-effectiveness study regarding this aspect is suggested.

Conclusions

Compared with standard care, intraoperative hemodynamic optimization using the FloTrac/EV1000 platform for EGDT protocol in patients undergoing CABG with CPB resulted in shorter ventilator time, shorter ICU and hospital LOS, and fewer postoperative complications. The EV1000 group required more fluid, and inotropic or vasoactive drugs during the pre-bypass period to optimize SVV, CI, and SVRI, which are needed to maintain the target MAP. The target of MAP yields a better myocardium oxygen supply as reflected in fewer drugs required during the post-bypass period, and before transfer to, and in the ICU.

Abbreviations

EGDT: early goal-directed therapy; LOS: length of stay; ICU: intensive care unit; CABG: coronary artery bypass graft; CPB: cardiopulmonary bypass; MAP: mean arterial pressure; CVP: central venous pressure; SpO_2: oxygen saturation; SVV: stroke volume variation; CI: cardiac index; SVI: stroke volume index; SVRI: systemic vascular resistance index; ICH: International Conference on Harmonization; GCP: Good Clinical Practice; IABP: CONSORT, Consolidated Standards of Reporting Trials; intra-aortic balloon pump; IBP: invasive blood pressure; ACT: activated clotting time; AF: atrial fibrillation; RCR: rapid ventricular response; ARDS: acute respiratory distress syndrome; AKI: acute renal injury; KKU: Khon Kaen University.

Declarations

Ethics approval and consent to participate

The current study was approved by the Khon Kaen University Ethics Committee in Human Research (HE611321). All participants gave written informed consent before being recruited into the study. The study was conducted in accordance with the Declaration of Helsinki and the ICH GCP.

Consent for publication

Not applicable

Availability of data and materials

The datasets used and/or analyzed during the current study available from the corresponding author on reasonable request.

Competing interests

The authors have no competing interests.

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Authors' contribution

ST and TS designed the study, performed the study, conducted the statistical analysis, and wrote the manuscript. KNg, and KNo performed the study and collected data. All authors read and approved the final manuscript.

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Figures

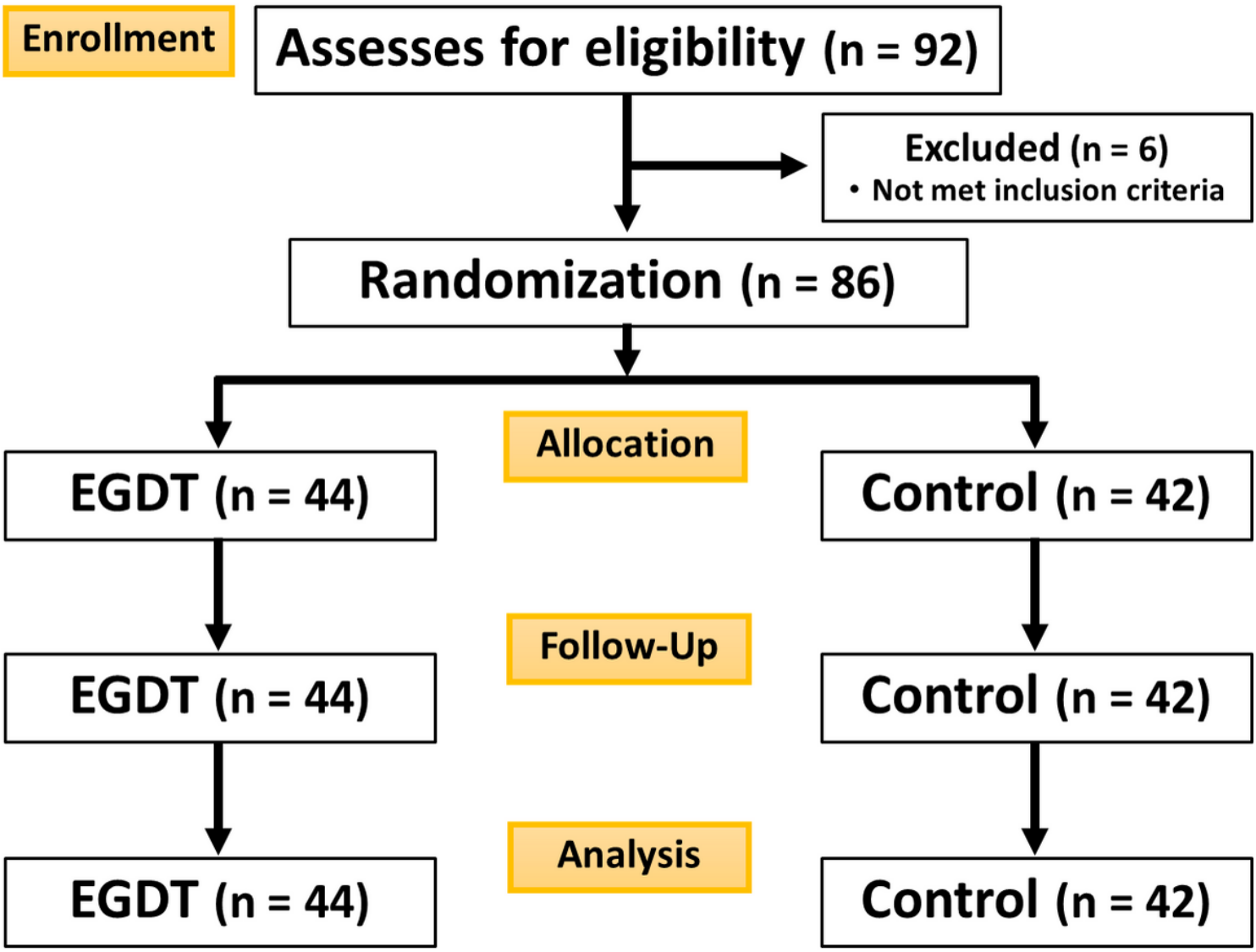

Figure 1

CONSORT diagram of the study. CONSORT, Consolidated Standards of Reporting Trials