Original article

Use of military anti-shock trousers in resuscitation of acute circulatory failure patients in intensive care unit

Panu Boontoterm[1] and Pusit Feungfoo[2]

[1]Division of Neurosurgery Unit, Department of Surgery and Division of Critical Care Medicine, Department of Medicine; [2] Department of Surgery, Phramongkutklao Hospital

Abstract:

Background: *Military anti-shock trousers (MAST) was used for augment venous return (VR) in combat casualty care. Basically, it improves hemodynamic by increasing mean systemic pressure (Pms), causing an increase in MAP. It is suggested in septic shock patients when pharmacologic venous thromboembolism is contraindicated. There is no study of hemodynamics effect and clinical outcome compared with the flat position in patients with shock during resuscitation.* ***Methods:*** *Randomized, single blind, prospective cohort and comparison study on experimental design. Sixty patients with shock were included in this analysis. Thirty patients were performed MAST by using pneumatic leg compression pressure 40 mmHg during and until finish resuscitation, compared with the flat position and measured for hemodynamic variables immediately after finish resuscitation. The primary outcome was differences in hemodynamic variables and the secondary outcome was mean days in ICU stay.* ***Results:*** *There was no difference in baseline characteristics in hemodynamic variables. MAST significantly increased all hemodynamic variables after resuscitation. Compared to the flat position, MAST significantly increased CO [3.29 (2.64, 3.93) vs. 0.34 (0.26,0.42) L/min, $p < 0.001$], SV [9.87 (8.68, 11.05) vs. 1.91 (1.15, 2.67) L, $p < 0.001$], MAP [7.9 (5.8, 10) vs. 1.67 (0.82, 2.52) mmHg, $p < 0.001$], SVR [26.87 (21.13, 32.6) vs. 11.13 (8.99, 13.27) dyn.s/cm^5, $p < 0.001$], FTc [43.23 (37.15, 49.32) vs. 10.93 (7.96, 13.9), $p < 0.001$], SD [2 (1.76, 2.24) vs. 0.7 (0.57, 0.83), $p < 0.001$] and PV [11.07 (9.41, 12.73) vs. 5.57 (4.27, 6.87), $p < 0.001$], and MAST had significantly less mean days in ICU than the flat position (4±1.29 vs. 6±1.11, $p < 0.001$).* ***Conclusion:*** *In patients with acute circulatory failure, MAST significantly increased all hemodynamic variables during resuscitation and was associated with less mean days in ICU.*

Keywords: ● *Military anti-shock trousers* ● *Mean systemic pressure* ● *Cardiac output* ● *Venous return*

RTA Med J 2022;75(2):97-106.

Received 15 October 2021 Corrected 31 March 2022 Accepted 29 May 2022

Corresponding Author: Panu Boontoterm Division of Neurosurgery Unit, Department of Surgery and Division of Critical Care Medicine, Department of Medicine, Phramongkutklao Hospital, 315 Ratchawithi Road, Phayathai, Bangkok, 10400

นิพนธ์ต้นฉบับ

การศึกษาการใช้ กางเกงรัดขาเพื่อป้องกันภาวะช็อกในทางทหาร ในการรักษาผู้ป่วยที่มีภาวะระบบไหลเวียนโลหิตล้มเหลวในหอผู้ป่วยวิกฤต

ภาณุ บุญต่อเติม[1] และ ภูษิต เฟื่องฟู[2]

[1]หน่วยศัลยกรรมประสาท กองศัลยกรรม และ แผนกเวชบำบัดวิกฤต กองอายุรกรรม [2]กองศัลยกรรม โรงพยาบาลพระมงกุฎเกล้า

บทคัดย่อ

ความเป็นมา *กางเกงรัดขาเพื่อป้องกันภาวะช็อกในทางทหาร (MAST) ช่วยเพิ่มการไหลเวียนโลหิตโดยเพิ่มค่าความดันเฉลี่ยของระบบไหลเวียนโลหิต (Pms) ทำให้เกิดการเพิ่มการไหลเวียนของเลือดดำกลับเข้าสู่หัวใจ นำไปสู่การเพิ่มความดันโลหิต มีคำแนะนำให้ใช้ในผู้ป่วยช็อกเหตุพิษติดเชื้อที่ไม่สามารถให้ยาต้านการแข็งตัวของเลือดเพื่อป้องกันภาวะลิ่มเลือดอุดตัน ปัจจุบันยังไม่มีการศึกษาผลของ MAST โดยการวัดค่าพารามิเตอร์ที่มีความสัมพันธ์กับการไหลเวียนโลหิตและเปรียบเทียบกับการรักษาตามปกติ* ***รูปแบบการวิจัย*** *Randomized, single blind, prospective cohort and comparison study on experimental design* ***วิธีการศึกษา*** *ศึกษาในผู้ป่วย 60 รายโดยแบ่ง 2 กลุ่ม โดยกลุ่มที่ 1 ใช้ MAST ในขณะให้สารน้ำเพื่อแก้ไขภาวะช็อกไปจนสิ้นสุดภาวะช็อกและกลุ่มที่ 2 รักษาตามปกติ วัดค่าพารามิเตอร์ที่มีความสัมพันธ์กับการไหลเวียนโลหิตและนำมาเปรียบเทียบโดยใช้หลักการทางสถิติโดยวัดผลลัพธ์ของการศึกษาเป็นความแตกต่างของค่าพารามิเตอร์ที่มีความสัมพันธ์กับการไหลเวียนโลหิตระหว่างทั้ง 2 กลุ่มและระยะเวลาในการนอนรักษาในหอผู้ป่วยวิกฤต* ***ผลการศึกษา*** *ไม่พบความแตกต่างอย่างมีนัยสำคัญทางสถิติในข้อมูลพื้นฐานค่าพารามิเตอร์ที่มีความสัมพันธ์กับการไหลเวียนโลหิตของผู้ป่วยทั้ง 2 กลุ่มและการใช้ MAST ช่วยเพิ่มค่าพารามิเตอร์ที่มีความสัมพันธ์กับการไหลเวียนโลหิตอย่างมีนัยสำคัญได้แก่ ความดันโลหิต (MAP, SBP, DBP), อัตราการไหลเวียนโลหิตออกจากหัวใจ (CO, FTc), ปริมาตรเลือดที่ไหลออกจากหัวใจ(SV, SD) และ ความต้านทานการไหลเวียนโลหิต (SVR) และเมื่อเปรียบเทียบกับการรักษาตามปกติพบว่า MAST ทำให้มีค่าพารามิเตอร์ที่มีความสัมพันธ์กับการไหลเวียนโลหิตที่มากกว่าอย่างมีนัยสำคัญทางสถิติได้แก่ MAP, SBP, DBP, CO, FTc, SV, SD และ SVR และลดระยะเวลาการนอนในหอผู้ป่วยวิกฤตอย่างมีนัยสำคัญทางสถิติ* ***สรุป*** *ในผู้ป่วยที่มีภาวะระบบไหลเวียนโลหิตล้มเหลว MAST สามารถเพิ่มค่าพารามิเตอร์ที่มีความสัมพันธ์กับการไหลเวียนโลหิตได้มากกว่าการรักษาตามปกติ และ ลดระยะเวลาการนอนในหอผู้ป่วยวิกฤต*

คำสำคัญ: ● *กางเกงรัดขาเพื่อป้องกันภาวะช็อกในทางทหาร* ● *Mean systemic pressure* ● *Cardiac output* ● *Venous return*

เวชสารแพทย์ทหารบก 2565;75(2):97-106.

ได้รับต้นฉบับเมื่อ 15 ตุลาคม 2564 แก้ไขบทความ 31 มีนาคม 2565 ได้ตีพิมพ์เมื่อ 29 พฤษภาคม 2565

ผู้นิพนธ์หลัก : ภาณุ บุญต่อเติม หน่วยศัลยกรรมประสาท กองศัลยกรรม และ แผนกเวชบำบัดวิกฤต กองอายุรกรรม โรงพยาบาลพระมงกุฎเกล้า 315 ถนนราชวิถี แขวงทุ่งพญาไท กรุงเทพมหานคร 10400 Email: sapiens_panu@hotmail.com หมายเลขโทรศัพท์ : 0879128696

Introduction

In critically ill patients with sepsis and septic shock, passive leg compression (PLC) is widely used as an alternative method for deep vein thrombosis (DVT) prophylaxis as recommended by surviving sepsis campaign guideline (SSC) 2018 and European Society of Intensive Care Medicine[1]. However, its application has been used for augment venous return (VR) purpose for at least a decade in Military, known as military anti-shock trousers (MAST)[2]. Basically, it improves hemodynamic by increasing mean systemic pressure (Pms), and then augment VR causing an increase in mean arterial pressure (MAP)[2]. Previous studies[3] showed evaluated effects of PLC on augmented flow velocity and volume flow in patients with varicose vein, and PLC significantly increased VR volume up to 106 mL per cycle. In addition, in healthy volunteers it was found that there was an increase in venous volume following thigh cuff pressure[4]. Nowadays, PLC is a method to prevent venous thromboembolism (VTE) in ICU patients[5]. Its mechanisms are increasing fibrinolytic activity and flow of venous return[4]. For PLC and effect on circulatory hemodynamic, there were randomized control trials investigating the use of a leg compression device (LCD) to support mean arterial pressure (MAP) in 45 healthy patients undergoing elective caesarean section under spinal anesthesia. They found that LCD used in conjunction with vasopressor significantly reduced the incidence of a 20% reduction of MAP ($p = 0.004$)[6]. In recent years, there have been growing concerns on the safety of various interventions performed by emergency teams during resuscitation. Fluid infusion during resuscitation has led to worsen clinical outcomes.[7,8] Another resuscitation body position, such as Trendelenburg, was associated with an increase in intracranial pressure. There are no data about the safety and clinical outcome of PLC during resuscitation, and the beneficial effect of PLC performed during resuscitation in ICU is still unknown. We hypothesized that PLC performed at the beginning of resuscitation as MAST will be a safe maneuver and will improve survival compared to patients treated in a flat position (standard way). In this study we did not only demonstrated that PLC can increased VR by increased Pms but we also demonstrated that PLC increased MAP in patients with acute circulatory failure.

Materials and Methods

The objective of this study was to compare changes in hemodynamic related variables following PLC pressure 40 mmHg between MAST and the flat position during and after finish resuscitation. We performed a randomized, single blind, prospective cohort and comparison study on experimental design. Regarding randomization of patients start with PLC pressure 40 mmHg as MAST or flat position, we used a block of four methods by randomize 1:1 ratio by varying the block size and using computer-generated sequence and allocation, single blind by opaque envelopes (concealed with opaque envelopes). Patients were classified to PLC and the flat position as described below.

Participants

Sixty patients in medical and surgical intensive care unit (ICU), Phramongkutklao hospital, Bangkok, Thailand from May 2020 to May 2021 were monitored for invasive arterial blood pressure, peripheral O_2 saturation (SpO_2), esophageal Doppler (CardioQ, Deltex medical, UK) for hemodynamics related variables and electrocardiogram. All patients were measured for cardiac output (CO), stroke volume (SV), systolic blood pressure (SBP), diastolic blood pressure (DBP), mean arterial pressure (MAP), heart rate (HR), systemic vascular resistance (SVR), flow time corrected (FTc), stroke distance (SD), peak velocity (PV), and central venous pressure (CVP) immediately after PLC pressure 40 mmHg as MAST procedures. The inclusion criteria were age of more

than 18-year-old, septic shock (Sepsis-3 criteria) or acute circulatory failure defined as persistent MAP less than 65 mmHg at least 15 min despite adequate volume resuscitation (perform dynamic parameters shows fluid non-responsive) or required vasopressor to maintain MAP more than 65 mmHg, and the exclusion criteria were patients who had contra-indication for esophageal Doppler catheter placement, intolerate to esophageal Doppler probe insertion, coarctation of aorta, bleeding tendency (INR > 2, platelets < 50,000/mL), patients who had received advance mechanical hemodynamic support, valvular heart disease, contraindication for PLC (e.g. leg ulcer or limb amputation), bed ridden more than 1 month before enrollment due to contra-indication for PLC and high risk for DVT, deep vein thrombosis (DVT), peripheral arterial disease (ankle-brachial index < 0.9), pregnancy, muscle atrophy of the leg, pain when performing PLC, and intraabdominal pressure more than 16 mmHg during procedure. Withdrawal criteria were patients who had complications from esophageal Doppler insertion e.g. massive epistaxis, suspected perforation of upper gastrointestinal tract

Hemodynamic monitoring

All patients were monitored for invasive arterial blood pressure, radial arterial catheter, and central venous catheter was linked to a bedside monitor on one side and to a specific transducer (Philips Intellivue Philips MX600, USA) for blood pressure and CVP monitoring. The value of CO, SV, SVR, FTc, SD and PV were estimated with aortic flow from esophageal Doppler (CardioQ, Deltex medical, UK). Sedative and paralytic agents were given based on bedside physician judgements including fentanyl, dexmedetomidine, cisatracurium, and midazolam. Patients were mechanically ventilated using a pressure-control ventilation mode with a tidal volume of 6 to 8 mL/kg of ideal body weight, respiratory rate was adjusted to maintain normocapnia, positive end-expiratory pressure was set between 3 and 6 cm H_2O, inspired oxygen fraction was adjusted to maintain SpO_2 above 94%, and inspiratory/expiratory ratio was 0.5.

DVT screening

The provider physician performed a screening of DVT in all patients who enrolled in this study with bedside ultrasound.

Interventions

PLC pressure 40 mmHg as MAST was performed immediately after acute circulatory failure at ICU and was maintained until the end of resuscitation. The procedure was to set the sleeves inflate pressure 40 mmHg then keep maximal effect occurs during resuscitation.

Statistical analysis

The primary outcome was differences in hemodynamics related variables between PLC and the flat position during and after finish resuscitation, and the secondary outcome was survival at hospital admission and mean days in ICU stay between the two groups. We did a randomized, single blind, prospective cohort, and comparison study on experimental design of PLC pressure 40 mmHg as MAST during and until the end of resuscitation, sample size estimation showed that at least 30 patients[6] in PLC group were required to evaluate their ability and to compare the difference. Results were expressed as mean±SD if the data were normally distributed, or median and interquartile range (IQR) if not. Hemodynamic related variables were compared between MAST and the flat position during and after finish resuscitation using the independent-t test, paired t-test, Fisher's exact test, Pearson's correlation, and repeated measure ANOVA test. A *p*-value of less than 0.05 was considered to be statistically significant. Statistical analysis was performed using SPSS version 23.0.

Ethics approval and consent to participate

Institutional Review Board Royal Thai Army Medical Department Ethics Committee approved this study

on March 4, 2020. Research no. R177h/62 followed Council for International Organization of Medical Science (CIOMS) Guidelines 2012 and Good Clinical Practice of International Conference on Harmonization statement no.IRBRTA 292/2563.

Results

Patients characteristics

During the study period, there were 60 patients with acute circulatory failure included in our analysis. Half of the patients were performed PLC as MAST. All patients were measured for cardiac output (CO), stroke volume (SV), systolic blood pressure (SBP), diastolic blood pressure (DBP), mean arterial pressure (MAP), heart rate (HR), systemic vascular resistance (SVR), flow time corrected (FTc), stroke distance (SD), peak velocity (PV), and central venous pressure (CVP) immediately after procedures. Most of the patients were female (57%) with an average age of 67 years. The most frequent coexisting disease was hypertension. And the most frequent etiology of shock was septic shock (Table 1).

Table 1 Demographic data of 60 patients with acute circulatory failure.

Variables	n = 60
Male, n (%)	26 (43.3)
Age (year)	67 ± 13
BMI (kg/m^2)	22.5 ± 3
Co-morbidity, n (%)	
Hypertension	31 (51.6)
Dyslipidemia	10 (16.7)
Diabetes mellitus	22 (36.7)
Chronic kidney disease	12 (20)
Chronic liver disease	11 (18.3)
Coronary artery disease	4 (6.7)
Other diseases	21 (35)
IV fluid (mL)	1675 ± 538
Norepinephrine (mcg/kg/min)	0.26 ± 0.26
Fentanyl (mcg/hr)	58.0 ± 28.3
Fever	20 (66.7)
APACHE II Score	13.73 ± 1.88
RASS score	-0.2 ± 1.1
Type of shock, n (%)	
Septic	50 (83.3)
Hypovolemic	10 (16.7)

Clinical outcomes data

There was no significant difference in baseline characteristic between the two groups of patients in sex, BMI (kg/m^2), coexisting diseases, APACHE II score, received intravenous fluid, fever, dosage of fentanyl, DBP on admission, CVP, CO, SV, SVR, HR, FTc, SD and PV on admission, and type of shock. The details of the survival outcomes were analyzed between the two groups. No significant difference in survival at hospital admission was found [24(80%) vs. 19(63%), $p = 0.152$] but MAST had significantly less mean days in ICU than the flat position (4±1.29 vs. 6±1.11, $p < 0.001$). (Table 2) Hemodynamic changes during MAST and hemodynamic variables in post MAST and the flat position after finish resuscitation are shown in table 2, with the evolution of CO, SV, SBP, DBP, MAP, HR, SVR, FTc, SD, PV, and CVP immediately after finish resuscitation.

Baseline characteristics between the two groups of patients

There was no significant differences in baseline characteristic between the two groups of patients in sex, BMI (kg/m^2), coexisting diseases, APACHE II score, received intravenous fluid, fever, dosage of fentanyl, DBP on admission, CVP, CO, SV, SVR, HR, FTc, SD, and PV on admission, and type of shock. The MAST group was at significantly older age, showed higher blood lactate level on admission and dosage of norepinephrine (NE) than the flat position group, and the MAST group had significantly less SBP, MAP, and mean days in ICU than the flat position. The details of the survival

Table 2 Baseline characteristics comparison between the two patient groups.

Variables	MAST (n = 30)	Flat position (n = 30)	*p*-value
Male, n (%)	14 (46.7%)	12 (40%)	0.602
Age (year)	68.2±9.23	62±10.8	0.020*
BMI (kg/m2)	22.7±3.4	22.0±2.1	0.342
Coexisting diseases, n (%)			
HT	19 (63.3%)	12 (40%)	0.071
DLP	6 (20%)	4 (13.3%)	0.488
DM	10 (33.3%)	8 (26.7%)	0.573
CKD	12 (40%)	10 (33.3%)	0.592
chronic liver disease	4 (13.3)	7 (23.3)	0.317
CAD	3 (10%)	1 (3.3%)	0.301
APACHE II Score	13.6± 1.09	13.9±1.85	0.447
Received IV fluid (mL)	1,652±310.77	1,798±363.58	0.100
Fever	9 (30%)	11 (36.7%)	0.584
Sedation drug			
RASS score			
-3	0 (0%)	6 (20%)	0.042*
-1	10 (33.3%)	12 (40%)	
0	10 (33.3%)	6 (20%)	
1	10 (33.3%)	6 (20%)	
Fentanyl (mcg/hr)	57.7±18.99	56.92±23.3	0.887
SBP on admission (mmHg)	105±10.07	113±10.67	0.004*
DBP on admission (mmHg)	52±5.55	54±4.76	0.139
MAP on admission (mmHg)	68±6.69	72±6.24	0.020*
CVP on admission (mmHg)	7±2.03	7±1.44	1.000
CO on admission (L/min)	4.2±0.73	4.3±0.87	0.630
Stroke volume,SV (mL)	47.7±13.33	48.7±12.95	0.769
SVR (dyn.s/cm^5)on admission	878±185.05	877±105.41	0.980
Blood lactate on admission (mmol/L)	5.2±0.92	4.5±1.61	0.044*
Heart rate on admission (beat/min)	94±23.25	93±16.76	0.849
Type of Shock			
Septic	27 (90%)	24 (80%)	0.278
Hypovolemic	4 (13.3)	6 (20)	0.488
Dose Norepinephrine (μg/kg/min)	0.29±0.19	0.2±0.08	0.022*
Survival at hospital admission	24 (80%)	19 (63.3%)	0.152
Means days in intensive care unit	4±1.29	6±1.11	<0.001*
FTc	270±43.23	276±39.26	0.576
SD	7±2.32	7.3±1.84	0.581
PV	47±7.85	47±7.9	1

Value presented as mean ± SD. or n (%). *P*-value corresponds to Independent-t test and Fisher's exact test.

outcomes were analyzed between the two groups, no significant difference in survival at hospital admission was found [24(80%) vs. 19(63%), $p = 0.152$] but MAST had significantly less mean days in ICU than the flat position (4±1.29 vs. 6±1.11, $p < 0.001$).

Differences in CO, SV, SBP, DBP, MAP, HR, SVR, FTc, SD, and PV were compared between MAST and the flat position. Period effect analysis was shown in table 3. Compared to the flat position, MAST significantly increased CO [3.29 (2.64, 3.93) vs. 0.34 (0.26,0.42) L/min, $p = < 0.001$], SV [9.87 (8.68, 11.05) vs. 1.91 (1.15, 2.67) L, $p < 0.001$], SBP [9.87 (8.68, 11.05) vs. 1.91 (1.15, 2.67) mmHg, $p < 0.001$], DBP [10.17 (7.97, 12.37) vs. 1.77 (1.34, 2.19) mmHg, $p < 0.001$], MAP [7.9 (5.8, 10) vs. 1.67 (0.82, 2.52) mmHg, $p < 0.001$], SVR [26.87 (21.13, 32.6) vs. 11.13 (8.99, 13.27) dyn.s/cm^5, $p < 0.001$], FTc [43.23 (37.15, 49.32) vs. 10.93 (7.96, 13.9), $p < 0.001$], SD [2 (1.76, 2.24) vs. 0.7 (0.57, 0.83), $p < 0.001$] and PV [11.07 (9.41, 12.73) vs. 5.57 (4.27, 6.87), $p < 0.001$], but there was no significant difference in HR and blood lactate level pre- and post- procedure between the two groups of patients.

Discussion

This study demonstrated that, in acute circulatory failure patients who were admitted to ICU, after resuscitation the performance of post-MAST changes in CO, SV and MAP is better than the flat position and baseline characteristics of each group were comparable. We evaluated effects of MAST on CO, SV, SBP, DBP, MAP, HR, SVR, FTc, SD, PV, and blood lactate level during and after finish resuscitation. We found that MAST increased CO, SV, SBP, DBP, MAP, SVR, FTc, SD, and PV during and after finish resuscitation from baseline. We also found that compared to the flat position, MAST increased more CO, SV, SBP, DBP, MAP, SVR, FTc, SD, and PV. For peak velocity (PV), it represents preload hemodynamic variables if PV increased. Preload increased that effect on CO, SV, and MAP increased. For stroke distance (SD), it represents stroke volume (SV) if SD increased. SV increased that effect on CO and MAP increased. For flow time corrected (FTc), it represents preload and afterload hemodynamic variables if FTc increased. It means that a decrease in preload or an increase in afterload can be interpreted by a combination with peak velocity (PV). If a normal value of PV showed correlation with a decrease in preload but if a decrease in PV correlated with an increase in afterload. FTc increased that effect on CO and MAP increased. MAST improves hemodynamics in the ICU because European Society of Intensive Care Medicine (ESICM) recommended that PLC is an alternative method to prevent DVT in ICU patients. In this result, MAST was performed more often in cases with worse clinical scenarios as shown in table 2, for example, old ages, less SBP and MAP, and more blood lactate level on admission and dosage of norepinephrine. Comparison to the flat position, baseline characteristics of MAST was at older ages, less SBP and MAP, and more blood lactate level on admission and dosage of norepinephrine than the flat position, and it was suggested that early passive leg compression or use of military anti-shock trousers (MAST) could improve its benefit on survival and have significantly less means days in ICU. Previous studies on its application used MAST for augment venous return (VR) purpose for at least a decade in Military[2] for soldier with hemorrhagic shock in military tactical combat casualty care or in-theater military treatment facility, forward surgical team during care under fire, tactical field care and combat casualty evacuation care[9]. The idea of a transient effect of MAST over time has been described in cases of septic shock patients and is attributed to capillary leak. During acute circulatory failure, to maintained tissue perfusion which could cause more shortened effect of

Table 3 Changes in hemodynamic variables from baseline in MAST and the flat position during and after finish resuscitation.

Variables	MAST	Flat position	Mean change (95%CI)	p-value
CO				
Baseline (Pre)	4.2 ± 0.73	4.3 ± 0.87	-0.1 (-0.51, 0.31)	0.63
Post procedure	7.49 ± 1.48	4.64 ± 0.89	2.85 (2.21, 3.48)	<0.001*
Δ Pre and Post	3.29 (2.64, 3.93)	0.34 (0.26, 0.42)	2.95 (2.31, 3.58)	<0.001*
SV				
Baseline (Pre)	47.7 ± 13.33	48.7 ± 12.95	-1 (-7.79, 5.79)	0.769
Post procedure	57.57 ± 12.87	50.61 ± 12.93	6.96 (0.29, 13.63)	0.041*
Δ Pre and Post	9.87 (8.68, 11.05)	1.91 (1.15, 2.67)	7.96 (6.58, 9.34)	<0.001*
SBP				
Baseline (Pre)	105 ± 10.07	113 ± 10.67	-8 (-13.36, -2.64)	0.004*
Post procedure	117.7 ± 8.55	117.63 ± 9.92	0.07 (-4.72, 4.85)	0.978
Δ Pre and Post	12.7 (10.39, 15.01)	4.63 (3.36, 5.91)	8.07 (5.48, 10.65)	<0.001*
DBP				
Baseline (Pre)	52 ± 5.55	54 ± 4.76	-2 (-4.67, 0.67)	0.139
Post procedure	62.17 ± 8.6	55.77 ± 4.88	6.4 (2.79, 10.01)	0.001*
Δ Pre and Post	10.17 (7.97, 12.37)	1.77 (1.34, 2.19)	8.4 (6.21, 10.59)	<0.001*
MAP				
Baseline (Pre)	68 ± 6.69	72 ± 6.24	-4 (-7.34, -0.66)	0.02*
Post procedure	75.9 ± 9.23	73.67 ± 7	2.23 (-2, 6.47)	0.296
Δ Pre and Post	7.9 (5.8, 10)	1.67 (0.82, 2.52)	6.23 (4.02, 8.45)	<0.001*
HR				
Baseline (Pre)	94 ± 23.25	93 ± 16.76	1 (-9.47, 11.47)	0.849
Post procedure	93.33 ± 23.4	93.2 ± 16.41	0.13 (-10.31, 10.58)	0.98
Δ Pre and Post	-0.67 (-1.16, -0.17)	0.2 (-0.18, 0.58)	-0.87 (-1.48, -0.25)	0.006*
SVR				
Baseline (Pre)	878 ± 185.05	877 ± 105.41	1 (-76.83, 78.83)	0.98
Post procedure	904.87 ± 189.61	888.13 ± 103.94	16.73 (-62.29, 95.76)	0.674
Δ Pre and Post	26.87 (21.13, 32.6)	11.13 (8.99, 13.27)	15.73 (9.74, 21.72)	<0.001*
FTC				
Baseline (Pre)	270 ± 43.23	276 ± 39.26	-6 (-27.34, 15.34)	0.576
Post procedure	313.23 ± 45.06	286.93 ± 37.76	26.3 (4.82, 47.78)	0.017*
Δ Pre and Post	43.23 (37.15, 49.32)	10.93 (7.96, 13.9)	32.3 (25.68, 38.92)	<0.001*
SD				
Baseline (Pre)	7 ± 2.32	7.3 ± 1.84	-0.3 (-1.38, 0.78)	0.581
Post procedure	9 ± 2.32	8 ± 1.97	1 (-0.11, 2.11)	0.077
Δ Pre and Post	2 (1.76, 2.24)	0.7 (0.57, 0.83)	1.3 (1.03, 1.57)	<0.001*
PV				
Baseline (Pre)	47 ± 7.85	47 ± 7.9	0 (-4.07, 4.07)	1
Post procedure	58.07 ± 8.85	52.57 ± 8.45	5.5 (1.03, 9.97)	0.017*
Δ Pre and Post	11.07 (9.41, 12.73)	5.57 (4.27, 6.87)	5.5 (3.44, 7.56)	<0.001*
Lactate				
Baseline (Pre)	5.2 ± 0.92	4.5 ± 1.61	0.7 (0.02, 1.38)	0.044*
Post procedure	4.42 ± 0.83	3.59 ± 1.34	0.83 (0.26, 1.4)	0.006*
Δ Pre and Post	-0.78 (-0.89, -0.67)	-0.91 (-1.17, -0.65)	0.13 (-0.15, 0.41)	0.352

Value presented as mean±SD, and mean change (95%CI). *depicts $p < 0.05$ and compared between baseline vs. each intervention, #depicts $p < 0.05$ and compared between two interventions. *P*-value analyzed using the paired t-test and Independent t test.

MAST on mean systemic pressure (Pms) and cardiac output, optimizing Pms and venous return is a key to improve survival outcomes. In 2007, Griffin M, et al[10] evaluated the augmented flow velocity and volume flow by intermittent pneumatic leg compression in 12 patients with varicose vein. The outcomes were that PLC can increase venous return volume up to 106 ml per cycle. Zadeh FJ, et al[6] conducted an RCT investigation for the use of PLC to support mean arterial pressure (MAP) in 45 healthy patients undergoing elective caesarean section under spinal anesthesia. They found that PLC used in conjunction with vasopressor significantly reduced the incidence of a 20% reduction of MAP (p = 0.004). Christopher RL, et al[3]. investigated an increase in the venous return from unilateral calf when use thigh-cuff pressure in 19 healthy volunteers and found that a median increase in venous volume was 87 mL (65-113 mL). Experimental data supports the distinct hemodynamic effect of PLC combined with volume loading during resuscitation. Volume loading has been associated with a decrease in cerebral perfusion pressure due to the detrimental effect of the increase in right atrial pressure (RAP) in the decompression phase. However, MAST do not seem to alter RAP. Our study confirms many points with previously mentioned studies. Firstly, it was performed in the ICU. Secondly, the goals, therapeutics, and monitoring were similar. Finally, volume expansions from MAST were performed with an approximate quantity of fluid 100 mL. The main limitation of PLC is that it may stimulate sympathetic tone and interfere hemodynamic interpretation in our study. However, using the change of heart rate as a surrogate of sympathetic stimulation, we found that there was no difference in heart rate at any time point on pre- and post- resuscitation. Therefore, we speculated that the effect of sympathetic stimulation during interventions may be minimal.

Limitations

This study had some limitations. Firstly, CO was monitored by esophageal Doppler. This technology is operator-dependent, and the angle of the probe must be steady, otherwise data acquisition might be inaccurate. Secondly, this study had small sample size and most of the patients received mechanical ventilation, so the findings cannot be extrapolated to spontaneous breathing. Thirdly, our study was conducted in a single center and confined only in patients with acute circulatory failure, our findings may not be generalizable in usual critically ill patients who did not need circulatory support. Fourthly, many exclusion criteria were used. Finally, MAST may stimulate sympathetic tone and interfere hemodynamic interpretation in our study. However, using the change of heart rate as a surrogate of sympathetic stimulation, we found that there was no difference in heart rate at any time point. Therefore, we speculated that the effect of sympathetic stimulation during interventions may be minimal.

Conclusions

In patients with acute circulatory failure, MAST significantly increased CO, SV, SBP, DBP, MAP, SVR, FTc, SD, and PV during resuscitation from baseline. We also found that, compared to the flat position, MAST increased more CO, SV, SBP, DBP, MAP, SVR, FTc, SD, and PV. MAST during resuscitation had significantly less mean days in ICU. However, its accuracy needs to be confirmed in further study.

References

1. *Levy MM, Evans LE, Rhodes A. The Surviving Sepsis Campaign Bundle: 2018 update. Intensive Care Med. 2018;44(6):925-8.*
2. *Lateef F, Kelvin T. Military anti-shock garment: Historical relic or a device with unrealized potential? J Emerg Trauma Shock. 2008;1(2):63-9.*
3. *Lattimer CR, Kalodiki E, Azzam M, Geroulakos G. Pneumatic thigh compression reduces calf volume and augments the venous return. Phlebology. 2015;30(5):316-22.*
4. *Chen AH, Frangos SG, Kilaru S, Sumpio BE. Intermittent pneumatic compression devices -- physiological mechanisms of action. Eur J Vasc Endovasc Surg. 2001;21(5):383-92.*
5. *Rhodes A, Evans LE, Alhazzani W, Levy MM, Antonelli M, Ferrer R, et al. Surviving sepsis campaign: International guidelines for management of sepsis and septic shock: 2016. Intensive Care Med. 2017;43(3):304-77.*
6. *Zadeh FJ, Alqozat M, Zadeh RA. Sequential compression pump effect on hypotension due to spinal anesthesia for cesarean section: A double blind clinical trial. Electron Physician. 2017; 9(5): 4419-24.*
7. *Bernard SA, Smith K, Finn J, Hein C, Grantham H, Bray JE, et al. Induction of therapeutic hypothermia during out-of-hospital cardiac arrest using a rapid infusion of cold saline: the RINSE trial (Rapid Infusion of Cold Normal Saline). Circulation. 2016;134(11):797-805.*
8. *Kim F, Nichol G, Maynard C, Hallstrom A, Kudenchuk PJ, Rea T, et al. Effect of prehospital induction of mild hypothermia on survival and neurological status among adults with cardiac arrest: a randomized clinical trial. JAMA. 2014;311(1):45-52.*
9. *Butler FK Jr, Blackbourne LH. Battlefield trauma care then and now: a decade of Tactical Combat Casualty Care. J Trauma Acute Care Surg. 2012;73(6 Suppl 5):S395-402.*
10. *Griffin M, Kakkos SK, Geroulakos G, Nicolaides AN. Comparison of three intermittent pneumatic compression systems in patients with varicose veins. Int Angiol. 2007;26(2):158-64.*