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Blood Pressure Measurement Compared Between Oscillometric Blood Pressure Monitoring and Gold Standard Intra-Arterial Blood Pressure Monitoring in Adult Shock Resuscitation Patients

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ABSTRACT

Aim: This study aimed to investigate blood pressure (BP) measurement compared between oscillometric blood pressure (OBP) monitoring and gold standard intra-arterial blood pressure (IBP) monitoring in adult shock resuscitation patients

Study design: Single-center prospective observational study

Materials and Methods: Patients with circulatory shock who were admitted to the medical intensive care unit were prospectively enrolled during 2018-2019. Demographic and clinical data were recorded, and OBP and IBP data were compared.

Results: A total of 82 patients were included. The average age was 66.7 years, and 52.4% were male. The most common cause of shock was septic shock (87.8%). Overall, there was good correlation between OBP and IBP with correlation coefficients of 0.85, 0.85, and 0.78 for systolic BP (SBP), mean arterial pressure (MAP), and diastolic BP (DBP), respectively. SBP and MAP measured by IBP were higher, while the DBP was lower, than the BP readings derived from the mean of the IBP and OBP monitoring methods. The correlation between methods was lower among patients with a MAP <65 mmHg (r=0.55, 0.33, and 0.47 for SBP, DBP, and MAP, respectively).

Conclusions: Among overall patients, BP readings between the two monitoring methods were well correlated; however, SBP and MAP measured by OBP were higher than those measured by IBP in patients with a MAP <65 mmHg. Thus, IBP should be used in adult shock patients with a MAP <65 mmHg to ensure accurate shock diagnosis, and to ensure accurate BP monitoring during shock resuscitation.

Clinical trial registered with https://www.thaiclinicaltrials.org/ (TCTR20220217006), date of registration: 14 February 2022. This is a retrospective registration.

Keywords: Blood pressure, monitoring, non-invasive, invasive, oscillometric, shock resuscitation

Introduction

Circulatory shock is a serious condition that is characterized by hemodynamic instability, and that is associated with organ dysfunction and a high rate of mortality. Circulatory shock affects approximately one-third of all patients admitted to the intensive care unit (ICU) (1). This condition is considered a medical emergency that requires intensive monitoring and aggressive treatment to prevent unfavorable outcomes. Accurate hemodynamic monitoring provides an accurate assessment of the pathophysiology of shock, and helps to guide shock resuscitation. Rapid and accurate resuscitation will accelerate shock reversal, which will result in reduced morbidity and mortality (2-6).

Continuous blood pressure (BP) monitoring is an essentially important hemodynamic monitoring method that is employed during shock resuscitation. Continuous BP monitoring is an accurate, real-time blood pressure monitoring method that allows physicians to appropriately adjust a patient's shock resuscitation medications and interventions. Several shock management guidelines recommend invasive blood pressure monitoring via an arterial line during shock therapy (2,3,5,6). These recommendations are based on the belief that BP directly measured via an arterial line is more accurate than BP measured by a non-invasive method. However, invasive blood pressure (IBP) monitoring requires insertion of an arterial line that may associate with complications, including hemorrhage, vascular insufficiency, pseudoaneurysm, thrombosis, embolization, nerve injury, infection, insertion site hematoma, arterial compromise, and limb ischemia (7-9).

Furthermore, invasive BP monitoring requires ICU admission, so it is not available during the initial phase of shock resuscitation when a patient first arrives at the hospital, or when a patient is in the general medical ward (10).

In routine medical practice, an oscillatory blood pressure (OBP) measuring device is used to monitor blood pressure in the Emergency Department and in the general medical ward. OBP measurement is obtained by measuring a series of small pressure pulses while the blood pressure cuff is inflated and being deflated. When the cuff is inflated, the patient's artery is occluded. As the cuff is gradually deflated, blood is allowed to flow through the vessel, which creates small oscillation waves via the expansions and contractions of the arterial wall. These small oscillation waves are detected and measured by the OBP device. Systolic blood pressure (SBP), diastolic blood pressure (DBP), and mean arterial blood pressure (MAP) are obtained using the device's sophisticated algorithms (11). The accuracy of this BP measurement method for shock resuscitation in adult patients with low mean arterial blood pressure is still being debated (12).

Accordingly, the aim of this study was to investigate BP measurement compared between OBP monitoring and gold standard IBP monitoring in adult shock resuscitation patients.

Materials and Methods

Patients

This single-center prospective observational study was conducted at the Division of Critical Care of the Department of Medicine, Faculty of Medicine, Siriraj Hospital, Mahidol University, Bangkok, Thailand. Patients aged 18 years or older who were diagnosed with circulatory shock and who were admitted to the medical ICU during September 2018 to November 2019 were screened for study eligibility. Shock was defined by the systolic arterial blood pressure < 90 mm Hg or the mean arterial pressure < 70 mm Hg, together with clinical signs of poor tissue perfusion, which included urine output of <0.5 ml per kilogram of body weight per hour, cold and clammy skin, altered mental status or serum lactate > 1.5 mmol per liter. Among those patients, the patients who had already undergone intra-arterial line insertion were eligible for inclusion. Patients with no arterial line insertion, with known peripheral vascular disease, with discrepancy of inter-arm systolic blood pressure difference greater than 20 mmHg, with extreme arm size for which an appropriately sized BP cuff could not be found, and/or unwilling to participate in the study were excluded. The protocol for this study was approved by the Siriraj Institutional Review Board (SIRB) (COA no. Si 575/2018, approval date 14 September 2018), and complied with all of the principles set forth in the 1964 Declaration of Helsinki and all of its subsequent amendments. Written informed consent to participate was obtained from a first-degree relative of each enrolled patient.

Patient baseline information, including age, gender, underlying conditions, current medications, diagnosis that led to this ICU admission, type of circulatory shock, vital signs at ICU admission, and Sequential Organ Failure Assessment (SOFA) and Acute Physiology and Chronic Health Evaluation II (APACHE II) scores within 24 hours after ICU admission were reviewed and recorded. Treatment that patients received during shock resuscitation, including vasopressor type and dosage, and the arterial line insertion site, were extracted and recorded. Twenty-eight-day mortality, ICU mortality, and hospital mortality were also collected and recorded.

Blood pressure measurement

BP measurement was simultaneously performed via both IBP monitoring and OBP monitoring. For invasive BP measurement, the patient's BP was measured via an intra-arterial line. The patient was positioned in the supine position, and the pressure transducer system was leveled and set to zero at the middle of a perpendicular imaginary line from the patient's sternal angle toward the patient's bed (13). For OBP blood pressure measurement, a blood pressure cuff appropriate to the size of the patient's arm was selected (14). Inter-arm BP results were recorded as a baseline measurement. Patients with an inter-arm SBP difference greater than 20 mmHg were excluded per study protocol. SBP, DBP, and MAP were simultaneously obtained from both IBP and OBP measurement. We used Philips Intellivue MP-60 oscillometric monitoring for measure OBP and Philips central monitoring system for measure IBP monitoring. All IBP and OBP measurements made by the blinded observers which were the on-duty ICU nurses. One simultaneous measurement of IBP and OBP values were recorded for each pair comparison. During ICU admission and while the arterial line was in place, multiple pairs of IBP and OBP blood pressure measurements were obtained and categorized according to the 5 stages of shock. The 5 stages of circulatory shock were defined, as follows: stage 1 = early phase of shock with no vasoactive agent; stage 2 = shock during resuscitation with increasing dosages of vasoactive agents; stage 3 = maintain phase of shock with stable dosages of vasoactive agents; stage 4 = shock resolution with decreasing dosages of vasoactive agents; and, stage 5 = out of shock with no vasoactive agent (Figure 1).

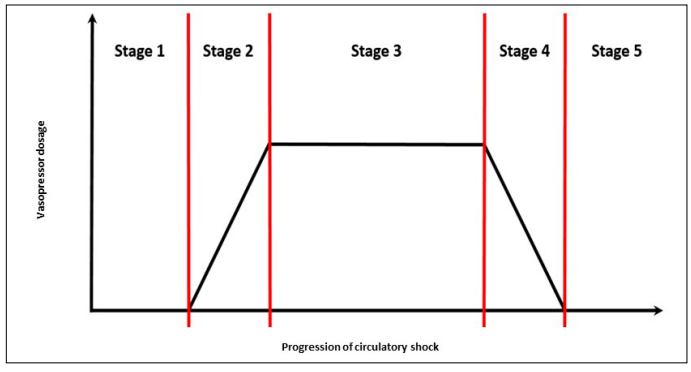

Figure 1. The 5 stages of circulatory shock were defined, as follows: stage 1 = shock with no vasoactive agent; stage 2 = shock with increasing dosages of vasoactive agents; stage 3 = shock with stable dosages of vasoactive agents; stage 4 = shock with decreasing dosages of vasoactive agents; and, stage 5 = out of shock with no vasoactive agent.

Sample size calculation and statistical analysis

The sample size for this study was calculated based on the beta-coefficient for the difference between the non-invasive blood pressure measurement and the invasive radial artery blood pressure measurement from a previous study that compared invasive and concomitant noninvasive blood pressure monitoring during the intraoperative period in noncardiac surgery patients

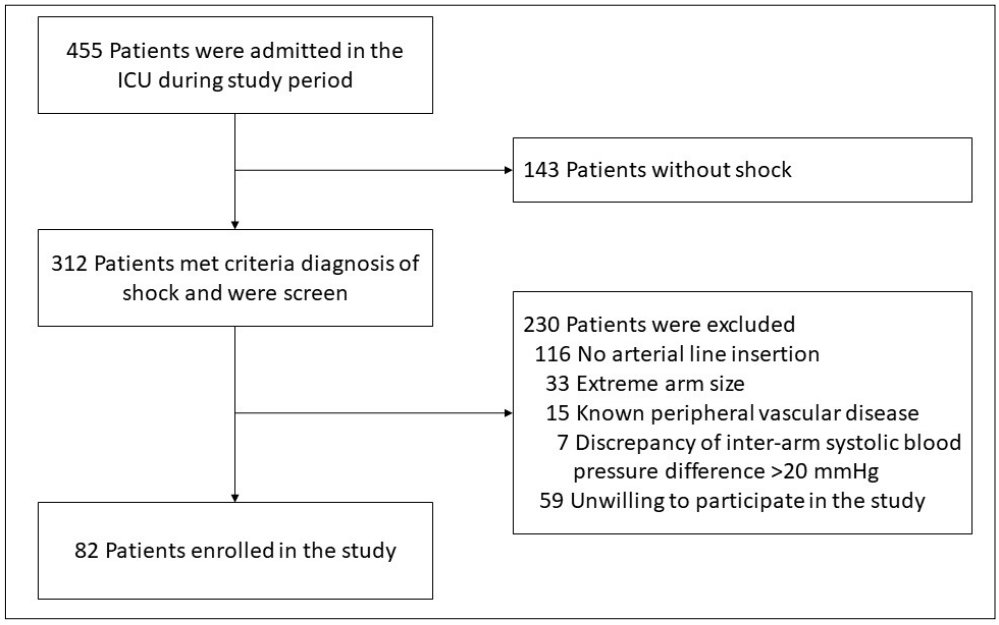

Figure 2. Flow diagram illustrating the screening and enrolment of patients

(15). We used the highest beta-coefficient value of -0.32 for our sample size estimation. With the power of 80% and a two-sided alpha level of 5%, a sample size of 71 pairs of BP measurements was needed for each stage of shock comparison. To compensate for a potential 15% dropout rate for any reason, at least 86 pairs of BP measurements was needed for each stage of shock comparison.

Analysis for correlation between IBP measurement and OBP measurement was performed using Pearson's correlation coefficient. We compared the two evaluated blood pressure measurements relative to each of the 5 stages of shock, receiving versus not receiving vasopressor, atrial fibrillation versus sinus rhythm, and arterial line insertion via the radial or brachial artery versus the dorsalis pedis artery. A Pearson's correlation coefficient (*r*) greater than 0.7 is considered to reflect a good correlation (16). The degree of agreement between the OBP and IBP methods was evaluated by Bland-Altman plot (17,18). Statistical analysis in this study was performed using SPSS Statistics version 18.0 (SPSS, Inc., Chicago, IL, USA) and STATA version 14.0 (StataCorp LLC, College Station, TX, USA). All continuous variables were tested for normal distribution using Kolmogorov-Smirnov test. Continuous variables that deviated from normal distribution range are shown as median and interquartile range. Continuous variables with normal distribution are shown as mean plus/minus standard deviation. Categorical variables are expressed as number and percentage. A p-value less than 0.05 was considered statistically significant for all tests

Results

A total of 82 patients were included in this study (Figure 2.). There were 43 males (52.4%), and 39 females (47.6%). The mean plus/minus standard deviation age of our study cohort was 66.71±13.95 years. The comorbidities of included patients are shown in Table 1. The leading underlying condition was hypertension (61.0%), followed by diabetes mellitus (35.4%) and chronic kidney disease (22.0%). Nine of 82 patients (11.0%) had atrial fibrillation at the time of study enrollment. The most common cause of circulatory shock was septic shock (87.8%), followed by hypovolemic shock (11.0%) and cardiogenic shock (3.0%). The mean APACHE II score and SOFA score was 29.35±8.26 and 12.15±3.87, respectively. The most frequently used site of arterial cannulation was the radial artery (86.6%), followed by the dorsalis pedis artery (11.0%) and the brachial artery (2.4%) (Table 1).

Table 1. Baseline and clinical characteristics of the study population

Characteristics	Values
Age (years), mean±SD	66.71±13.95
Male gender, n (%)	43 (52.4%)
Female gender, n (%)	39 (47.6%)
Body mass index (kg/m^2), mean±SD	22.63±5.46
Comorbidities, n (%)	
- Hypertension	50 (61.0%)
- Diabetes mellitus	29 (35.4%)
- Chronic kidney disease	18 (22.0%)
- Hematologic malignancy	17 (20.7%)
- Solid organ malignancy	15 (18.7%)
- Stroke	13 (15.9%)
- Coronary artery disease	12 (14.6%)
- Cirrhosis	9 (11.0%)
Type of shock, n (%)	
- Septic shock	72 (87.8%)
- Hypovolemic shock	9 (11.0%)
- Cardiogenic shock	3 (3.7%)
Vasopressor, n (%)	
- Norepinephrine	614 (42.8%)
- Adrenaline	108 (7.5%)
- Dopamine	32 (2.2%)
- Dobutamine	20 (1.4%)
Intra-arterial catheter insertion site, n (%)	
- Radial artery	71 (86.6%)
- Dorsalis pedis artery	9 (11.0%)
- Brachial artery	2 (2.4%)
Outcome, n (%)	
- ICU mortality	24 (29.3%)
- 28-day mortality	27 (32.9%)
- Hospital mortality	43 (52.4%)

SD: standard deviation; **ICU:** intensive care unit

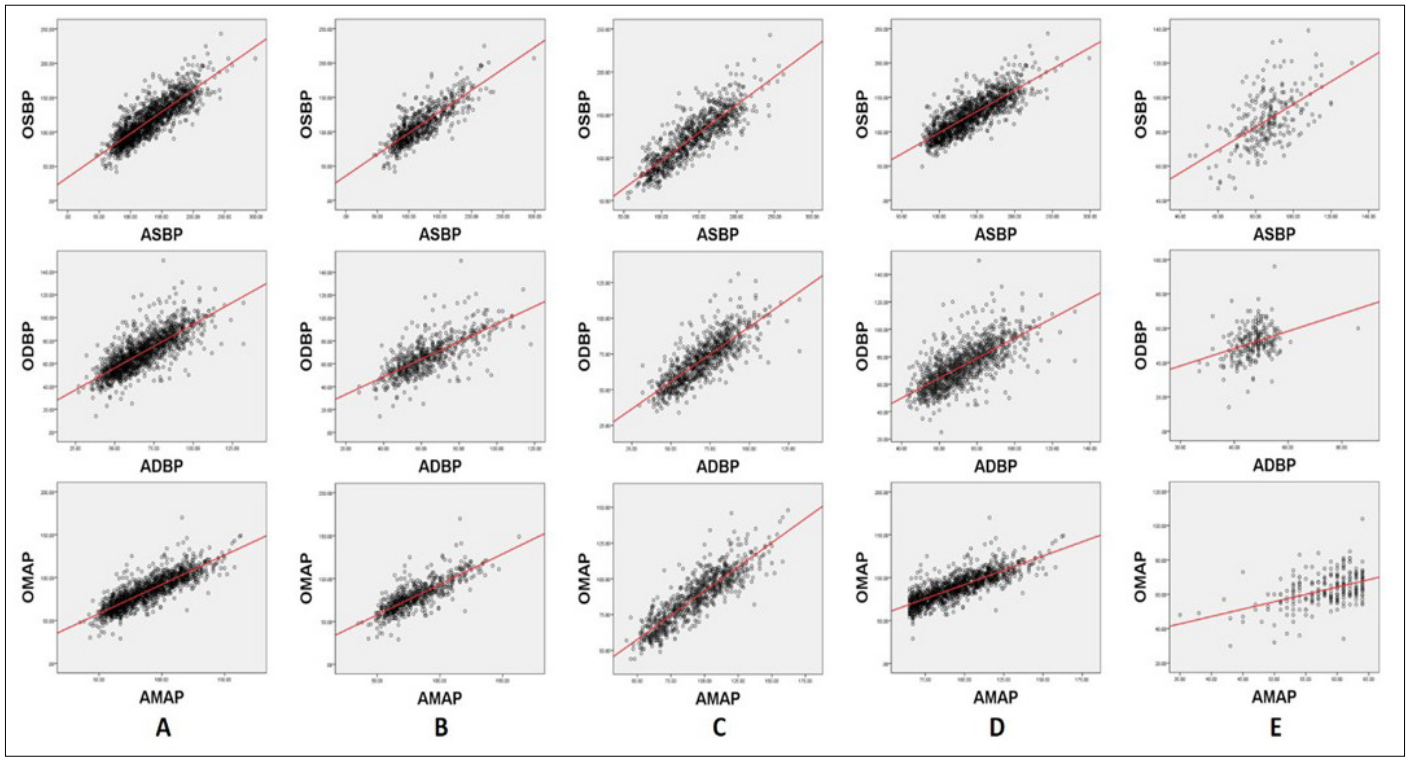

Figure 3. Scatter plots demonstrating the correlation between non-invasive blood pressure measurement via oscillometric method (x-axis) and invasive blood pressure measurement via arterial line (y-axis) in different subgroups (A-E). The subgroups were defined, as follows: panel A = overall patients; panel B = patients with vasopressor; panel C = patients without vasopressor; panel D = patients with a MAP ≥65 mmHg; and, panel E = patients with a MAP

Table 2. Correlation between blood pressure measured by non-invasive method and invasive method for each variable compared among SBP, DBP, and MAP

Variables	Number of BP pairs (%)	Systolic blood pressure				Diastolic blood pressure				Mean arterial pressure			
		r	Mean±SD variation‡	95%CI	p	r	Mean±SD variation‡	95%CI	p	r	Mean±SD variation‡	95%CI	p
Overall	1,435 (100%)	0.85	14.2±0.9	-26.1-55.1	<0.001	0.78	-1.9±11.0	-23.5-19.8	<0.001	0.85	4.1±12.1	-19.6-27.7	<0.001
Site of arterial line													
- Radial/brachial artery	1,091 (76.1%)	0.87	14.0±18.5	-22.3-50.2	<0.001	0.79	-1.6±10.8	-22.7-19.6	<0.001	0.86	4.5±12.0	-19.0-28.1	<0.001
- Dorsalis pedis artery	343 (23.9%)	0.79	14.4±27.1	-38.7-67.5	<0.001	0.75	-2.8±11.7	-25.7-20.1	<0.001	0.84	2.2±11.9	-21.1-25.5	<0.001
Stage of shock													
- Stage 1	113 (7.9%)	0.81	3.7±14.3	-24.3-31.8	<0.001	0.72	-2.6±8.8	-19.9-14.7	<0.001	0.81	-0.7±8.3	-16.9-15.5	<0.001
- Stage 2	202 (14.1%)	0.57	1.3±15.8	-29.7-32.3	<0.001	0.44	-3.3±11.8	-26.5-19.9	<0.001	0.52	-2.0±11.3	-24.1-20.1	<0.001
- Stage 3	288 (20.1%)	0.74	9.2±21.6	-33.2-51.6	<0.001	0.67	-3.6±11.5	-26.3-19.0	<0.001	0.73	1.0±12.2	-22.9-24.9	<0.001
- Stage 4	181 (12.6%)	0.79	18.6±19.1	-18.9-56.1	<0.001	0.71	-2.2±11.9	-25.5-21.1	<0.001	0.78	5.2±11.5	-17.4-27.8	<0.001
- Stage 5	651 (45.4%)	0.80	21.0±20.2	-18.6-60.6	<0.001	0.75	-0.4±10.5	-21.0-20.1	<0.001	0.83	7.8±11.6	-14.8-30.5	<0.001
Vasopressor													
- Did not receive	764 (53.3%)	0.86	18.0±20.2	-21.7-57.6	<0.001	0.81	-0.8±10.1	-20.7-19.0	<0.001	0.88	6.2±11.4	-16.2-28.7	<0.001
- Did receive	671 (46.7%)	0.82	9.1±20.7	-31.4-49.7	<0.001	0.72	-3.2±12.0	-26.8-20.4	<0.001	0.80	1.2±12.3	-23.0-25.3	<0.001
- NE <0.1 mcg/kg/min	361 (25.2%)	0.79	9.6±20.3	-30.3-49.5	<0.001	0.67	-2.7±12.5	-27.2-21.8	<0.001	0.75	1.6±12.8	-23.4-26.7	<0.001
- NE 0.1-0.2 mcg/kg/min	155 (10.8%)	0.84	11.2±21.8	-31.4-53.9	<0.001	0.79	-3.5±9.6	-22.3-15.3	<0.001	0.87	1.1±10.1	-18.7-20.8	<0.001
- NE >0.2 mcg/kg/min	140 (9.8%)	0.89	6.3±19.2	-31.3-44.0	<0.001	0.80	-4.0±12.3	-28.1-20.0	<0.001	0.86	0.1±12.3	-24.1-24.3	<0.001
Blood pressure													
- MAP <65 mmHg	245 (17.1%)	0.55	-0.8±14.0	-28.2-26.7	<0.001	0.33	-4.7±9.3	-23.0-13.4	<0.001	0.47	-4.5±8.5	-21.1-12.1	<0.001
- MAP ≥65 mmHg	1,190 (82.9%)	0.81	17.3±20.7	-23.4-58.0	<0.001	0.72	-1.3±11.3	-23.4-20.8	<0.001	0.80	5.8±11.9	-17.6-29.2	<0.001
Heart rhythm													
- Sinus rhythm	1,169 (81.5%)	0.85	14.6±21.3	-27.2-56.4	<0.001	0.80	-1.5±10.4	-22.0-19.0	<0.001	0.86	4.7±11.9	-18.5-28.0	<0.001
- Atrial fibrillation	266 (18.5%)	0.85	12.4±18.6	-24.1-48.9	<0.001	0.71	-3.5±13.2	-29.4-22.4	<0.001	0.81	1.3±12.5	-23.3-25.9	<0.001

A p-value <0.05 indicates statistical significance
‡:The mean variation was calculated as the average blood pressure measured by invasive method minus the average blood pressure measured by oscillometric method
SBP: systolic blood pressure; **DBP:** diastolic blood pressure; **MAP:** mean arterial pressure; **BP:** blood pressure; **SD:** standard deviation; **CI:** confidence interval; **r:** correlation coefficient; **NE:**Norepinephrine

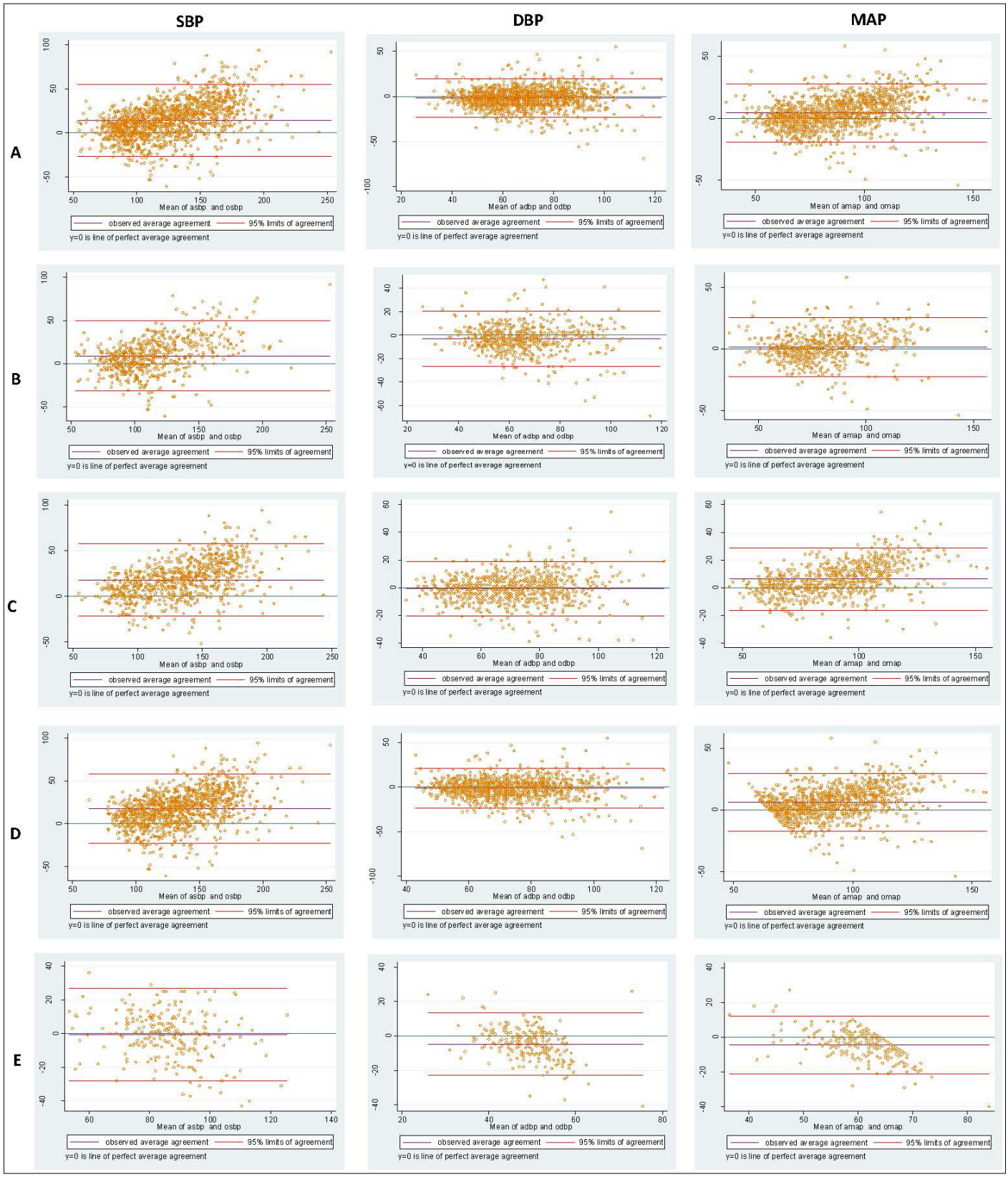

Figure 4. Bland-Altman plots to evaluate for agreement between non-invasive blood pressure measurement via oscillometric method and invasive blood pressure measurement via arterial line in different subgroups (A-E). The subgroups were defined, as follows: panel A = overall patients; panel B = patients with vasopressor; panel C = patients without vasopressor; panel D = patients with a MAP ≥65 mmHg; and, panel E = patients with a MAP <65 mmHg.

SBP: systolic blood pressure; **DBP:** diastolic blood pressure; **MAP:** mean arterial pressure; **OSBP:** oscillometric systolic blood pressure; **ODBP:** oscillometric diastolic blood pressure; **OMAP:** oscillometric mean arterial pressure; **ASBP:** arterial line systolic blood pressure; **ADBP:** arterial line diastolic blood pressure; **AMAP:** arterial line mean arterial pressure; **MAP:** mean arterial pressure

During the study period, a total of 1,435 measured BP pairs were recorded. Among those measured BP pairs 74.8% of the IBP measurements were taken from the radial artery, 23.9% from the dorsalis pedis artery, and 1.3% from the brachial artery. A total of 614 (42.8%) BP pairs were measured when patients were receiving norepinephrine, and 245 (17.1%) BP pairs were measured when patients had a MAP measured by IBP that was lower than 65 mmHg. A total of 266 (18.5%) BP pairs were measured while patients experienced atrial fibrillation. Correlation between BP measured by OBP and IBP for other important variables compared among the SBP, DBP, and MAP subgroups are shown in Table 2.

Overall, there was good correlation between OBP and IBP with correlation coefficients of 0.85, 0.85, and 0.78 for SBP, MAP, and DBP, respectively (Table 2). Scatter plots demonstrating the correlation between the IBP and OBP methods in different subgroups are shown in Figure 3. The degree of agreement between the two BP measurement methods was determined by Bland Altman plot (Figure 4). The results of Bland-Altman analysis showed good overall agreement for SBP, DBP, and MAP between the OBP and IBP measurement methods. The mean variation (defined as the average BP measured by IBP minus the average BP measured by OBP) was highest in the SBP subgroup (14.2±20.9), followed by the MAP subgroup (4.1±12.1) and the DBP subgroup (-1.9±11.0). The SBP and MAP measured by IBP were higher, while the diastolic BP was lower, than the BP readings derived from the mean of the IBP and OBP monitoring methods. The 95% confidence intervals (CI) for the SBP, DBP, and MAP subanalyses were within 2 times the mean variation standard deviation limit. The observed correlation and agreement between the two evaluated BP measurement methods was consistent across all subgroup analyses, including of radial or brachial artery versus dorsalis pedis artery, receiving vasopressor versus not receiving vasopressor, and sinus rhythm versus atrial fibrillation (Table 2).

Concerning the influence of BP level on the correlation and agreement between the OBP and IBP methods, we found good correlation for all BP parameters among patients with a MAP by IBP of equal to or greater than 65 mmHg (r=0.81, 0.72, and 0.80 for SBP, DBP, and MAP, respectively) (Table 2). However, the correlation for those 3 BP parameters was considerably lower among patients with a MAP by IBP lower than 65 mmHg (r=0.55, 0.33, and 0.47 for SBP, DBP, and MAP, respectively). We also observed that the SBP, DBP, and MAP measured by IBP were lower than the BP parameters measured by OBP among patients with a MAP less than 65 mmHg. The mean variation in SBP, DBP, and MAP was -0.8±14.0, -4.7±9.3, and -4.5±8.5 mmHg, respectively. A lower correlation between the two BP measurement methods was also observed during shock resuscitation with uptitration of vasopressor (Table 2).

Discussion

The results of this study showed good correlation between the OBP method and the gold standard IBP method during shock resuscitation. In the overall group, SBP measured by IBP was higher than BP measured by OBP, while DBP was lower. The MAP measured by both methods had a similar value with low discrepancy between methods. However, the correlation between BP measurement methods was weaker when patients had a MAP less than 65 mmHg when compared to the correlation between methods when patients had a MAP equal to or higher than 65 mmHg. Furthermore, among patients who had a MAP by IBP of less than 65 mmHg, the SBP, DBP, and MAP measured by IBP were all lower than those measured by the OBP method. Other factors, including receiving vasopressor, vasopressor dosage, and atrial fibrillation, had no effect on the correlation between the OBP and IBP methods.

The findings of our study give rise to concerns about underdetection of shock when using OBP measurement. When patients were in stable condition with a MAP measured by IBP equal to or greater than 65 mmHg, both SBP and MAP measured by OBP were lower than those measured by IBP. These findings are getting along with the results of previous study (19). However, among patients in shock stage with a MAP measured by IBP lower than 65 mmHg, the SBP, DBP, and MAP measured by OBP were higher than those measured by IBP. This could be explained that the blood pressure derived from OBP was the composite of direct intra-arterial hydrostatic pressure and the oscillating wave generated by turbulent flow of intraarterial lumen, while IBP depend mainly on the direct intra-arterial hydrostatic pressure. Among the normal blood pressure range, the turbulent flow component was relatively low, then both IBP and OBP represent the actual intra-arterial hydrostatic pressure, then correlating well each other. In the situation that intra-arterial hydrostatic pressure was lower, the IBP represent the actual blood pressure, but OBP may represent the combination of intra-arterial hydrostatic pressure and the turbulent flow. This effect could result in an inability to diagnose shock or a delayed diagnosis of shock in a significant proportion of patients. This observation was previously mentioned by Meidert, *et al*. who found OBP unable to detect hypotension in up to 64% of patients in the Emergency Department. Those authors reported the MAP measured by OBP to be 13±15 mmHg higher than the MAP measured by IBP method (19). The results of our study confirmed this finding. We found the MAP measured by OBP to be 4.5±8.5 mmHg higher than the MAP measured by IBP. This observation means that patients with a MAP measured by OBP of 65-70 mmHg may actually have a MAP measured by IBP lower than 60-65 mmHg. This information supports the use of invasive BP measurement via an arterial line among patients suspected of being in shock for early and appropriate management.

Regarding the effect of vasopressor administration, especially norepinephrine, on the accuracy of OBP monitoring, information from previous studies reported that despite there were overall strong positive correlations between OBP and IBP, however, the clinically relevant differences in blood pressure were increasing among the patients who received vasoactive agents and inotrope (21-24). Additional data from a previous report showed the intra-radial MAP to be an average of 6.6 mmHg lower than OBP measurement among critically ill patients who received norepinephrine to maintain their blood pressure level (25). Somewhat similarly, our study showed the intra-radial MAP to be an average of 1.2 mmHg higher than the OBP measurement among patients who received norepinephrine.

Concerning the site of arterial line insertion and its effect on the accuracy of BP monitoring, we found radial artery cannulation to be the most commonly used artery for IBP monitoring, followed by the dorsalis pedis artery and brachial artery. Theoretically, blood pressure wave form changes move peripherally along the monitoring site from the central aorta (26). The SBP is higher and the DBP lower; however, the MAP is relatively constant in more peripheral arteries when compared with the central aorta. This increases concerns about the accuracy of invasive blood pressure monitoring derived from the dorsalis pedis artery. The result of our study showed the correlation between OBP and IBP via the dorsalis pedis artery for SBP and DBP measurement to be lower than those measured via the radial artery. Moreover, the mean variation was greater for both SBP and DBP monitoring via the dorsalis pedis artery (compared with non-invasive monitoring) than via the radial artery. The correlation for MAP measured by IBP via the dorsalis pedis or radial artery and the OBP method was comparable with low mean variation in both groups. This finding supports the use of MAP as the target BP guidance parameter for treatment adjustment because this value is the most consistent pressure whether measured by OBP or IBP, and it is not dependent on the arterial cannulation site.

Strengths and Limitations

The strength of this study is that we enrolled a large patient population, and we compared between the two evaluated BP measurement methods for all 5 stages of shock resuscitation. Moreover, we compared between the two evaluated methods for other factors that could influence the accuracy of BP measurement, such as receiving versus not receiving vasopressor, atrial fibrillation versus sinus rhythm, and arterial line insertion via the radial or brachial artery versus the dorsalis pedis artery.

This study also has some mentionable limitations. First, the data included in this study was collected from a single large national tertiary referral center that offers the most sophisticated level of care available in Thailand. As such, our findings may not be immediately generalizable to other care settings. Second, variations in equipment, physician experience, and physician preference may influence the outcomes of shock resuscitation. Third, the study which was referred for sample size calculation was performed in the intra-operative patients which differed from our enrolled critically ill shock patients. Additionally, our study had some potential bias, in term of the blindness of the observer. Although we recorded blood pressure measured by the intensive care nurses who did not aware about the individual patient enrolment status, but during the study period, it was possible that there might be more strictly controlled process of blood pressure measurement by all the on-duty ICU nurses. So these limitations should be considered when clinicians interpret the results of this study, and when they consider adopting the authors' recommendations.

Conclusion

Among overall patients, BP readings between the two monitoring methods were well correlated; however, SBP and MAP measured by OBP were higher than those measured by IBP in patients with a MAP <65 mmHg, Thus, IBP should be used in adult shock patients with a MAP <65 mmHg to ensure accurate diagnosis of shock, and to ensure accurate BP monitoring during shock resuscitation. MAP should be the BP parameter of choice for treatment guidance since it is the most consistent pressure regardless of BP measurement method.

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Availability of Data and Materials

Researchers may contact the corresponding author at surat.ton@mahidol.ac.th for data sharing requests, after approval of a planned analysis protocol. The anonymized participant data will be made available within three months after the publication of the article. The study protocol and statistical analysis plan are available as an appendix.

AUTHOR CONTRIBUTIONS:

Concept: ST, SV; **Design:** ST, SV; **Supervision:** ST, CP; **Resources:** ST, SV, CP; **Materials:** ST, SV, CP; **Data Collection and/or Processing:** ST, SV; **Analysis and/or Interpretation**: ST, SV; **Literature Search:** ST, SV, CP; **Writing Manuscript**: SV, ST, CP; **Critical Review:** SV, ST, CP.

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References

1. Vincent J-L, De Backer D. Circulatory Shock. N Engl J Med. 2013;369:1726–34. [CrossRef]
2. Cecconi M, De Backer D, Antonelli M, et al. Consensus on circulatory shock and hemodynamic monitoring. Task force of the European Society of Intensive Care Medicine. Intensive Care Med. 2014;40:1795–815. [CrossRef]
3. Egi M, Ogura H, Yatabe T, et al. The Japanese Clinical Practice Guidelines for Management of Sepsis and Septic Shock 2020(J-SSCG 2020). J Intensive Care. 2021;9:53. [CrossRef]
4. Permpikul C, Tongyoo S, Ratanarat R, et al. Impact of septic shock hemodynamic resuscitation guidelines on rapid early volume replacement and reduced mortality. J Med Assoc Thai. 2010;93:S102–9. https://pubmed.ncbi.nlm.nih.gov/20364564/
5. Rhodes A, Evans LE, Alhazzani W, et al. Surviving Sepsis Campaign: International Guidelines for Management of Sepsis and Septic Shock:2016. Crit Care Med. 2017;45:486–552. [CrossRef]
6. Evans L, Rhodes A, Alhazzani W, et al. Surviving Sepsis Campaign: International Guidelines for Management of Sepsis and Septic Shock 2021. Crit Care Med. 2021;49:e1063–143. [CrossRef]
7. Simon EM, Summers SM. Vascular Access Complications. Emerg Med Clin North Am. 2017;35:771–88. [CrossRef]
8. Scheer BV, Perel A, Pfeiffer UJ. Clinical review: Complications and risk factors of peripheral arterial catheters used for haemodynamic monitoring in anaesthesia and intensive care medicine. Crit Care. 2002;6:199. [CrossRef]
9. Tegtmeyer K, Brady G, Lai S, et al. Placement of an Arterial Line. N Engl Med. 2006;354:e13. [CrossRef]
10. Tongyoo S, Viarasilpa T, Permpikul C. The impact of intensive care unit admissions following early resuscitation on the outcome of patients with severe sepsis and septic shock. J Med Assoc Thai. 2014;97:S69–76. https://pubmed.ncbi.nlm.nih.gov/24855845/
11. Alpert BS, Quinn D, Gallick D. Oscillometric blood pressure: a review for clinicians. J Am Soc Hypertens. 2014;8:930–8. [CrossRef]
12. Lakhal K, Ehrmann S, Boulain T. Noninvasive BP Monitoring in the Critically Ill: Time to Abandon the Arterial Catheter? Chest. 2018;153:1023–39. [CrossRef]
13. Saugel B, Kouz K, Meidert AS, et al. How to measure blood pressure using an arterial catheter: a systematic 5-step approach. Crit Care. 2020;24:172. [CrossRef]
14. Lakhal K, Macq C, Ehrmann S, et al. Noninvasive monitoring of blood pressure in the critically ill: reliability according to the cuff site (arm, thigh, or ankle). Crit Care Med. 2012;40:1207–13. [CrossRef]
15. Wax David B, Lin H-M, Leibowitz Andrew B. Invasive and Concomitant Noninvasive Intraoperative Blood Pressure Monitoring: Observed Differences in Measurements and Associated Therapeutic Interventions. Anesthesiology. 2011;115:973–8. [CrossRef]
16. Sarah B, Watters P. Statistics in a Nutshell: A Desktop Quick Reference, Ch. 7. Sebastopol, CA.: O'Reilly Media; 2008. ISBN-13:978-0596510497.
17. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet. 1986;1:307–310. [CrossRef]
18. Doğan NÖ. Bland-Altman analysis: A paradigm to understand correlation and agreement. Turk J Emerg Med. 2018;18:139–41. [CrossRef]
19. Ribezzo S, Spina E, Di Bartolomeo S, et al. Noninvasive techniques for blood pressure measurement are not a reliable alternative to direct measurement: A randomized crossover trial in ICU. ScientificWorldJournal 2014;2014:353628. [CrossRef]
20. Meidert AS, Dolch ME, Mühlbauer K, et al. Oscillometric versus invasive blood pressure measurement in patients with shock: a prospective observational study in the emergency department. J Clin Monit Comput. 2021;35:387–393. [CrossRef]
21. Saherwala AA, Stutzman SE, Osman M, et al. Correlation of Noninvasive Blood Pressure and Invasive Intra-arterial Blood Pressure in Patients Treated with Vasoactive Medications in a Neurocritical Care Unit. Neurocrit Care. 2018;28:265–72. [CrossRef]
22. Rebesco MR, Pinkston MC, Smyrnios NA, et al. A Comparison of Non-Invasive Blood Pressure Measurement Strategies with Intra-Arterial Measurement. Prehosp Disaster Med. 2020;35:516–23. [CrossRef]
23. Babadağ K, Zaybak A. Comparing Intra-Arterial, Auscultatory, and Oscillometric Measurement Methods for Arterial Blood Pressure. Florence Nightingale J Nurs. 2021;29:194–202. [CrossRef]
24. Kaur B, Kaur S, Yaddanapudi LN, et al. Comparison between invasive and noninvasive blood pressure measurements in critically ill patients receiving inotropes. Blood Press Monit. 2019;24:24–9. [CrossRef]
25. Pytte M, Dybwik K, Sexton J, et al. Oscillometric brachial mean artery pressures are higher than intra-radial mean artery pressures in intensive care unit patients receiving norepinephrine. Acta Anaesthesiol Scand. 2006;50:718–21. [CrossRef]
26. Arnal D, Garutti I, Perez-Peña J, et al. Radial to femoral arterial blood pressure differences during liver transplantation. Anaesthesia. 2005;60:766–71. [CrossRef]