Mean Arterial Pressure Should Above 65 mmHg at Vasopressor Weaning — Exploratory Study of Optimal Weaning Blood Pressure for Patients in Intensive Care Unit

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Research

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Abstract

Objective:

Vasopressors are one of the main treatments for severe hypotension or shock, which commonly occurs in intensive care unit (ICU) patients. However, only a few studies have been conducted on the appropriate timing for vasopressor weaning. This study aims to explore the effect of blood pressure at vasopressor weaning on the probability of in-hospital mortality.

Design: Single-center retrospective observational study.

Setting: ICU from Beth Israel Deaconess Medical Center between 2008 and 2019.

Patients: ICU patients who received vasopressor treatment were selected. Patients younger than 18 years old, died before vasopressor weaning or without blood pressure measurement at weaning were excluded. Finally, 8,298 patients were included.

Result: General additive model (GAM) result showed that blood pressures at weaning had “U-shape” non-linear relationship with in-hospital mortality probability. The optimal levels of weaning mean arterial pressure(WMAP), weaning systolic blood pressure(WSBP), and weaning diastolic blood pressure(WDBP) were 85, 120, and 65 mmHg, respectively. Subgroup analysis showed the optimal WMAP, WSBP,WDBP has deviations between diagnoses. The “cut-point” of a lower mortality probability for WMAP was 65 mmHg. ROC curves showed that mean arterial blood pressure as an indicator exhibited the best prediction performance. Cox regression demonstrated that patients with WMAP equal to or higher than 65 mmHg will have 61% lower risk of in-hospital mortality.

Conclusion: WMAP is a powerful indicator for in-hospital mortality, and its value should be greater than 65 mmHg and close to 85 mmHg to reach the highest survival probability for ICU patients after vasopressor treatment.

Introduction

Patients in the intensive care unit (ICU) often suffer from infection-induced sepsis, heart failure, and other organ dysfunction that lead to hypotension or even shock^{1,2}. The probability of septic shock occurring in ICU is approximately 10.4%³, and that of cardiogenic shock in patients with acute myocardial infarction is approximately 7.3%⁴. Fluid resuscitation⁵ and vasopressor usage maintain and restore tissue perfusion in ICU patients⁶. As an essential component of shock management⁷, catecholamines are the most commonly used vasoactive drugs in ICUs, and norepinephrine is the first-line treatment in most clinical situations⁸. Therefore, the rational use of vasopressor can restore the low blood pressure to normal by contracting peripheral blood vessels or increasing cardiac output, thus improving the perfusion and circulation of important organs and effectively reducing the risk of organ damage. During circulatory arrest, vasopressors can immediately increase blood pressure and still function with other treatments⁹.

Blood pressure is one of the important factors of organ perfusion, and its fluctuation guides the clinical treatment of ICU patients. The 2016 Surviving Sepsis Campaign (SSC) guidelines recommended the initial mean arterial pressure (MAP) should be over 65 mmHg for patients with septic shock¹⁰. Another multicenter prospective study on patients with the same condition and receiving resuscitation treatment showed that setting the target mean arterial pressure of 80–85 mm Hg has no effect on the 28-day mortality¹¹. However, the effect of blood pressure level at vasopressor weaning on the survival of ICU patients remains unclear. The present work conducted a retrospective research based on the Medical Information Mart for Intensive Care (MIMIC)-IV database to explore the effect of blood pressure at vasopressor weaning on the mortality of ICU patients.

Materials And Methods

Data source

All data were extracted from MIMIC-IV 0.4 database, a public database that contains over 250,000 electronic admissions medical records from Beth Israel Deaconess Medical Center between 2008 and 2019^{12,13}. The identity features of all patients are obscured and renumbered randomly to protect their privacy. This database contains patient demographic information, measurement ICU, laboratory examination information, and prescription records.

Participants

Among the 524,250 admissions in MIMIC-IV, 64,975 first admissions in ICU were selected, and 12,163 patients who received vasopressor treatment were recruited. Patients who died prior to vasopressor weaning were excluded to ensure that the blood pressure measurement is precedent of the patients' final status (death/discharge). Patients without blood pressure measurement at weaning and those younger than 18 years old were also excluded to ensure the influence of blood pressure on the status. Finally, 8,298 patients were included in the analysis. In subgroup analysis, patients were divided into nine groups according to their diagnosis based on the ICD-9 code (Figure. 1).

Data collection

Data were downloaded from the Physionet website and extracted by SQL language. Variables contained race, sex, age, marriage status, first care unit, in-ICU weight, length of ICU stay, duration of vasopressor infusion, first measurement of vital signs in ICU (heart rate, respiratory rate, body temperature, oxygen saturation, systolic blood pressure, diastolic blood pressure, and mean arterial pressure), sequential organ failure assessment (SOFA) score, Glasgow Coma Scale (GCS) score, simplified acute physiology score II (SAPS-II), Charlson Comorbidity Index (CCI), blood pressure at vasopressor weaning (systolic [WSBP], diastolic [WDBP], and mean arterial [WMAP]), and diagnosis (sepsis, myocardial infarction, congestive heart failure, cerebrovascular disease, chronic pulmonary disease, diabetes, renal disease, malignant cancer, and severe liver disease).

Statistical analysis

Generalized Additive Model (GAM) is a multivariable regression method widely used in clinical research and other fields¹⁴. Logistic regression-based GAMs were used to analyze the non-linear relationship between hospital mortality and the levels of WSBP, WDBP, and WMAP at weaning. Adjusted variables for GAMs include race, sex, age, marriage status, first care unit, in-ICU weight, length of ICU stay, duration of vasopressor infusion, first measurement of vital signs in ICU, SOFA score, SAPS-II, GCS, and CCI. The non-linear relationship can reflect the Logit $\log[(P(\text{Mortality})/1-P(\text{mortality}))]$ of the probability of mortality in different blood pressure levels and therefore will induce a “cut-point” for different blood pressures. Values above this cut-point indicate that the probability of survival will be higher than the probability of mortality. In addition, the trends of blood pressures also induce optimal levels for WSBP, WDBP, and WMAP with the lowest risk or mortality. Subgroup analysis was also conducted by GAMs to reflect the levels of WSBP, WDBP, and WMAP and their odds of mortality probability in nine diagnosis subgroups: sepsis, myocardial infarct, congestive heart failure, cerebrovascular disease, chronic pulmonary disease, diabetes, renal disease, malignant cancer, and severe liver disease.

The receiver operating characteristic (ROC) curve and area under the curve (AUC) are used to evaluate the prediction power between models by testing their sensitivity and specificity. Models conducted by GAM with indicator (WSBP, WDBP, and WMAP) and models conducted by logistic regression with indicator (WSBP, WDBP, and WMAP) were compared to identify the power between linear and non-linear model with systolic, diastolic, and mean arterial blood pressure as indicators.

All patients were grouped by the “cut-point,” the level of specific blood pressure which had the same probability of mortality and survival, was generated by the GAM model with the best performance of estimation, and analyzed by Cox proportional hazard regression. The outcome is in-hospital mortality, and the independent variable is groups of people. The hazard ratio (HR) and 95%CI were calculated to verify the performance of the “cut-point.”

Data were presented in the interquartile range for continuous variables and in frequencies for categorical variables. The difference between groups was analyzed by Kruskal–Wallis test for continuous and Chi-square test for categorical variables. A two-sided p-value < 0.05 was considered statistically significant. All statistical analyses were conducted by R software.

Result

Among the 8,298 patients, 1,349 (16.3%) died in the hospital. The baseline characteristics between the survival and mortality groups. Significant difference in age, race, length of ICU stay, duration of vasopressor infusion, vital signs except for oxygen saturation, WSBP, WDBP, and WMAP was found between groups. The surviving group had higher blood pressure at first admittance to ICU and vasopressor weaning (Table. 1) .

Figure.2 showed the GAM results of the relationship between Logit $\log[(P(\text{Mortality})/1-P(\text{mortality}))]$ and WSBP, WDBP, and WMAP. For WSBP, the $\log[(P(\text{Mortality})/1-P(\text{mortality}))]$ is less than 0 after the WSBP is greater than 90 mmHg. This finding indicates that the probability of hospital mortality is lower than that of survival when the WSBP is larger than 90 mmHg. The relationship trend also showed that patients with WSBP close to 120 mmHg have the lowest risk of mortality. For WDBP, patients had lower risk of hospital mortality when their WDBP is higher than 50 mmHg, and the WDBP level with the lowest risk was close to 65 mmHg. For WMAP, patients with WMAP higher than 65 mmHg had lower probability of mortality, and the WMAP level with the lowest risk was close to 85 mmHg.

Subgroup analyses revealed the non-linear relationship of WSBP, WDBP, and WMAP with the probability of mortality in patients diagnosed with sepsis, myocardial infarction, congestive heart failure, cerebrovascular disease, chronic pulmonary disease, diabetes, renal disease, malignant cancer, and severe liver disease. The optimal WSBP for survival is close to 120 mmHg in sepsis and diabetes subgroups. The optimal WSBP is higher than 120 mmHg in the myocardial infarction, cerebrovascular disease, renal disease malignant cancer, and severe liver disease subgroups. The optimal WSBP is lower than 120 mmHg in congestive heart failure, chronic pulmonary disease subgroups (Supplemental Digital Content – Figure. 1). The optimal WDBP level is close to 70 mmHg in sepsis, diabetes, renal disease, and severe liver disease subgroups. The optimal WDBP levels are greater than 70 mmHg in other subgroups ((Supplemental Digital Content – Figure. 2). The optimal WMAP level for survival is close to 85 mmHg in sepsis, myocardial infarction, cerebrovascular disease, diabetes, and renal disease subgroups. The optimal WMAP level is lower than 85 mmHg in congestive heart failure subgroups but higher than 85 mmHg in chronic pulmonary disease, malignant cancer, and severe liver disease subgroups ((Supplemental Digital Content – Figure. 3).

The AUC of ROC curves for GAM with WMAP as an indicator was 0.796, which was the highest among the six models (Figure. 3). The result showed that GAM for WMAP has the best performance for the prediction mortality probability in ICU patients, and its generated “cut-point” also had highest accuracy. Patients were grouped by 65 mmHg WMAP. Cox regression results revealed that patients with WMAP higher than 65 mmHg only have 0.39 (95%CI = 0.30,0.38) times risk of hospital mortality compared with patients with WMAP lower than 65 mmHg (Table. 2). Kaplan–Meier curve showed significant difference in the survival between these two groups, and patients with 65 mmHg WMAP have higher survival probability than patients with WMAP lower than 65 mmHg (Figure. 4)

Discussion

Hypotension is a common and extreme syndrome in ICU patients. Shock developing from progressive or persistent hypotension is usually fatal¹⁵. The severity and duration of hypotension are highly related to hypoperfusion and organ dysfunction¹⁶. Vasopressors are commonly used drugs in emergency and critical care units to improve the microcirculation of the organs, increase the effective circulating blood volume, and maintain adequate blood pressure and tissue perfusion¹⁷. However, vasopressors also have many pleiotropic and even adverse effects that are difficult to assess and measure.¹⁸ Vasoconstriction

caused by vasopressors can also impair blood perfusion at the capillary level⁹. Therefore, clinicians must balance the risks of hypotension with the potential adverse effects of vasopressors¹⁹. After hypotension is improved, clinicians must decide on discontinuing vasopressor infusion. However, the current main guidelines do not provide standardized weaning instruction, and the limited research suggested that the optimal WMAP is between 65 mmHg and 70 mmHg²⁰.

WMAp had higher performance for in-hospital mortality prediction in ICU patients than WSBP and WDBP. The logistic based GAM is also more powerful than traditional logistic regression to estimate the probability of mortality based on indicators showing a non-linear relationship with in-hospital mortality probability. Compared with ICU patients with WMAp lower than 65 mmHg, those with WMAp equal or higher than 65 mmHg have 61% lower risk of in-hospital mortality. The result of GAMs revealed that the optimal WMAp, WSBP, and WDBP were 85, 120, and 65 mmHg, respectively. According to the subgroup analysis, patients diagnosed with sepsis, acute myocardial infarction, chronic heart failure, cerebrovascular disease, diabetes, and kidney disease showed similar trends. In patients with chronic lung disease, malignant tumors, and severe liver disease, the optimal WMAp value at weaning is elevated. These results provide reference to achieve the optimal blood pressure levels for shock patients with different diagnoses at weaning for clinical decision-making and treatment strategy.

To the author's knowledge, this research is the first to study the non-linear relationship between blood pressure at weaning and the risk of in-hospital mortality and discussed the optimal weaning blood pressure. Given its single-center retrospective design, this study has limitations. In addition, the sequence of vasopressors weaning was not considered. Further study is necessary to discover the relationship between blood pressure and mortality risk in specific vasopressor component groups.

Conclusion

WMAp is a more powerful indicator for in-hospital mortality than WSBP and WDP and hence should be prioritized in shock treatment and management. WMAp should be greater than 65 mmHg and close to 85 mmHg to reach the highest survival probability for ICU patients.

Declarations

Ethics approval and consent to participate

No ethics approval was sought for this study, all data were available on the MIMIC-IV database.

Consent for publication

Not applicable.

Availability of data and material

All original data come from MIMIC-IV public database. The data in this article can be reasonably requested from the corresponding author.

Competing interests

The author states that there are no conflicts of interest related to this report.

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Author Contributions

Zichen Wang and Luming Zhang contributed equally to the work. Zichen Wang and Luming Zhang performed statistical analysis, data interpretation. Jun Lyu and Haiyan Yin contributed to the concept organization and study design. Wen Ma contributed to the result explain.

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Not applicable.

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Tables

Table.1 Baseline Characteristics Between Hospital Survival and Hospital Mortality Patients

	Hospital Survival	Hospital Mortality	p-value
	6949	1349	
Age	64.00 (53.00, 75.00)	69.00 (59.00, 80.00)	<0.001
Lenth of ICU Stay(Days)	4.58 (2.35, 9.79)	7.14 (3.58, 12.94)	<0.001
Duration of Vasopressor Infusion(Minutes)	1134.00 (378.00, 2648.00)	2148.00 (703.00, 4904.00)	<0.001
Vital Digns			
Heart Rate(Times/Minute)	84.48 (73.97, 96.96)	88.16 (75.95, 102.94)	<0.001
Respiratory Rate(Times/Minute)	19.31 (17.05, 22.14)	20.61 (17.73, 23.67)	<0.001
Systolic Blood Pressure(mmHg)	82.00 (75.00, 90.00)	80.00 (71.00, 88.00)	<0.001
Diastolic Blood Pressure(mmHg)	43.00 (37.00, 48.00)	41.00 (34.00, 47.00)	<0.001
Mean Arterial Pressure(mmHg)	54.00 (48.00, 60.00)	52.00 (44.00, 59.00)	<0.001
Temperature (°C)	36.85 (36.60, 37.20)	36.75 (36.38, 37.15)	<0.001
Oxygen Saturation(%)	97.32 (95.92, 98.62)	97.21 (95.50, 98.71)	0.021
Sever Score			
GCS	5.00 (4.00, 7.00)	6.00 (4.00, 8.00)	<0.001
SOFA	7.00 (5.00, 10.00)	10.00 (7.00, 12.00)	<0.001
SAPS-II	39.00 (31.00, 47.00)	47.00 (39.00, 58.00)	<0.001
Weaning systolic blood pressure(mmHg)	110.00 (99.00, 123.00)	104.00 (87.00, 120.00)	<0.001
Weaning diastolic blood pressure(mmHg)	58.00 (51.00, 66.00)	53.00 (44.00, 63.00)	<0.001
Weaning Mean arterial pressure(mmHg)	75.33(69.00,83.33)	71.33(60.67,81.00)	<0.001
Race (%)			
White	4692 (67.5)	816 (60.5)	<0.001
Black	714 (10.3)	112 (8.3)	
Others	1543 (22.2)	421 (31.2)	
Marriage Status (%)			
Unmarried	3896 (56.1)	818 (60.6)	0.002
Marride	3053 (43.9)	531 (39.4)	

Sex (%)			
Male	4013 (57.7)	736 (54.6)	0.033
Female	2936 (42.3)	613 (45.4)	
First Care Unit(%)			
MICU/SICU/TSICU	4860 (69.9)	1053 (78.1)	<0.001
CCU/CVICV	1976 (28.4)	254 (18.8)	
Neuro SICU/PACU	113 (1.6)	42 (3.1)	
Myocardial Infarct (%)			
Not Diagnosed	5492 (79.0)	1054 (78.1)	0.48
Diagnosed	1457 (21.0)	295 (21.9)	
Congestive Heart_Failure (%)			
Not Diagnosed	4388 (63.1)	870 (64.5)	0.364
Diagnosed	2561 (36.9)	479 (35.5)	
Cerebrovascular Disease(%)			
Not Diagnosed	6184 (89.0)	1111 (82.4)	<0.001
Diagnosed	765 (11.0)	238 (17.6)	
Chronic Pulmonary Disease (%)			
Not Diagnosed	5095 (73.3)	968 (71.8)	0.25
Diagnosed	1854 (26.7)	381 (28.2)	
Diabetes (%)			
Not Diagnosed	4867 (70.0)	985 (73.0)	0.031
Diagnosed	2082 (30.0)	364 (27.0)	
Severe Liver Disease (%)			
Not Diagnosed	6556 (94.3)	1211 (89.8)	<0.001
Diagnosed	393 (5.7)	138 (10.2)	
Renal Disease(%)			
Not Diagnosed	5266 (75.8)	991 (73.5)	0.076
Diagnosed	1683 (24.2)	358 (26.5)	
Malignant Cancer (%)			

Not Diagnosed	6179 (88.9)	1125 (83.4)	<0.001
Diagnosed	770 (11.1)	224 (16.6)	
Sepsis (%)			
Not Diagnosed	4088 (58.8)	670 (49.7)	<0.001
Diagnosed	2861 (41.2)	679 (50.3)	

Table.2 Cox Proportional Hazards Regression Result Between Groups with Different Weaning Mean Arterial Blood Pressures

Groups	Non-adjusted		Model 1		Model 2	
	HR(95% CI)	P value	HR(95% CI)	P value	HR(95% CI)	P value
Mean Arterial Pressure After Vasopressor Use						
<65 mm Hg	reference		reference		reference	
≥65 mm Hg	0.31(0.28,0.35)	<0.001	0.34(0.31,0.39)	<0.001	0.39(0.30,0.38)	<0.001

Model1 were adjusted by Race, Sex, Age, Marriage Status, First Care unit, In ICU Weight, Length of ICU Stay, Duration of Vasopressor Infusion, First Measurement of Vital Signs in ICU, SOFA score, SAPS-II, GCS, and CCI.

Model2 were adjusted by co-variables in Model1plus nine diagnoses.

Figures

Figure 1

Inclusion and Exclusion Flowchart of the Study

Figure 2

Relationship Between Probability of In-hospital Mortality and Systolic, Diastolic, and Mean Arterial Blood Pressure at Weaning A2, B2, and C2 are same figures in limited x-axis and y-axis for A1, B1, and C1 to represent the “U-shape” relationship and the optimal blood pressure level. The y-axis is $\log[(\text{P(Mortality)})/1-\text{P(mortality)}]$ and $y=0$ represent the probabilities of in-hospital mortality and survival are equal. Models were adjusted by Race, Sex, Age, Marriage Status, First Care unit, In ICU Weight, Length of ICU Stay, Duration of Vasopressor Infusion, First Measurement of Vital Signs in ICU, SOFA score, SAPS-II, GCS, and CCI.

Figure 3

ROC Curves and AUC Value for Different Models Patients were randomly divided into train cohort (70%) and test cohort (30%). Figure.6 are the ROC curves for test cohort result. Models were adjusted by Race, Sex, Age, Marriage Status, First Care unit, In ICU Weight, Length of ICU Stay, Duration of Vasopressor Infusion, First Measurement of Vital Signs in ICU, SOFA score, SAPS-II, GCS, and CCI.

Figure 4

Kaplan–Meier Curve of Survival Probability for Arterial Pressure Groups The p-value result from Log-rank test. $p < 0.05$ represents the survival between groups are statistically different.

Supplementary Files

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