The Variation of Hemodynamic Parameters Through PiCCO in the Early Stage After Severe Burns

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To investigate early hemodynamics of severely burned patients via PiCCO and to discuss clinical significance of hemodynamic monitoring for burn shock resuscitation, 55 extensive burn patients were enrolled in this retrospective study. The fluid resuscitation was guided according to Chinese General Formula and adjusted with urinary output of 0.5–1.0 ml/h/kg as a resuscitation goal. All patients were diagnosed within a relatively stable condition during burn shock stage, and they received PiCCO monitoring within 6 hours after burn. The preload parameter intrathoracic blood volume index was low at first, then returned to normal. The flow parameter cardiac index and myocardial contractility parameter dPmax were gradually changed from low level in the early stage to high level in the fluid reabsorption stage. The afterload parameter systemic vascular resistance index had completely opposite tendency. The lung-related parameters extravascular lung water index and pulmonary vascular permeability index were roughly in the normal range. The change of cardiac index had a linear regression relationship with dPmax and systemic vascular resistance index but had no significant relationship with intrathoracic blood volume index. Under effective fluid resuscitation, the early hemodynamics after burn is still in dynamically changing status, characterized as transition from low cardiac output (CO)–high vascular resistance in early shock stage to high CO–low vascular resistance in fluid reabsorption stage. CO mainly depends on the myocardial contractility and vascular resistance, but not on the blood volume. Excessive fluid resuscitation cannot get normal CO. The normal value of hemodynamics cannot be used as end point of burn shock resuscitation. Dynamic observation of hemodynamics is of great importance. (J Burn Care Res 2017;XXX:00–00)

To prevent hypovolemia and to ensure effective blood perfusion for major organs are key treatments in the early period of major burns. As well as inadequate resuscitation, excessive fluid infusion is also harmful, which would result in the accumulation of interstitial fluid, pulmonary edema, abdominal compartment syndrome, and deepening of wounds. Also it would prolong hospital staying time and mechanical ventilation time. Apart from that, the mortality rate would be increased.[1–3] The ideal resuscitation is not only to correct the hypovolemia but also not to cause the fluid overload.[4] The conventionally used resuscitation strategy is to calculate the expected fluid volume through fluid replacement formula. It is critical to adjust the actual fluid infusion speed and volume according to the urinary output, vital signs, and so on, to maintain the urinary output in the range of 0.5–1.0 ml/h/kg.[5,6] This above method is effective for most patients to get over the shock stage smoothly. For some special cases, in whom the amount of actual fluid infusion exceeds that of formula estimation, they have had severe edema, their urinary output is still less, and the hemodynamics

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is unstable, indicating noneffective shock resuscitation. Some patients undergo renal, cardiac, or pulmonary insufficiency in the early stage after burn. In these cases, hemodynamic monitoring is particularly important.

Burn shock resuscitation monitoring has developed from conventional monitoring of heart rate, blood pressure, central venous pressure (CVP), and urinary output to the hemodynamic monitoring, such as Swan-Ganz catheter, noninvasive esophageal echo-Doppler (ED), FloTrac/Vigileo, and transcardiopulmonary thermodilution monitoring (pulse index continuous cardiac output [PiCCO]). Hemodynamic parameters can be used to further judge the condition of circulation, so it is helpful to guide the fluid resuscitation. Swan-Ganz catheter is a classical and invasive hemodynamic monitoring method. It would get parameters such as CVP, pulmonary capillary wedge pressure, then calculate systemic vascular resistance (SVR), stroke volume (SV), and obtain cardiac output (CO) through thermodilution method. However, it cannot offer a continuous profile of hemodynamic data and is associated with substantial risks.[7–9] ED is a noninvasive monitoring technique through measuring the aortic diameter and the blood flow velocity precisely, and to obtain multiple hemodynamic parameters in real time, including flow volume parameters—aortic blood flow , CO, SV; myocardial contractility parameter—maximum acceleration at onset of systole (Acc); afterload parameter—total systemic vascular resistance in the artery; and preload parameter—SV/Acc can be calculated.[10] However, ED is hard to perform, and during monitoring phase, the patients should be kept relatively motionless to keep the probe in stable position for effective and continuous bedside monitoring. So sedative is necessary for ED monitoring. Thus, it is not suitable for long-time monitoring. In addition, lung-related parameters could not be obtained by this method.[11] FloTrac/Vigileo is a minimally invasive monitoring, which has a blood flow sensor (FloTrac) connecting to an arterial line and Vigileo monitor. The system provides a display of CO, SV, stroke volume variation, and SVR without requiring external calibration.[12] FloTrac system is less invasive and relatively easy to use, which can provide continuous CO monitoring. However, its accuracy is limited in patients with severe arrhythmia, severe aortic valve regurgitation, and other factors disturbing the arterial waveform.[13] So, it was usually used below narcotism in the operating room. PiCCO is a semi-invasive monitoring technique, which is the combination of thermodilution method and pulse contour analysis method. It could monitor the hemodynamic parameters comprehensively and accurately, including flow parameters, myocardial contractility parameters, preload, and afterload parameters of heart and lung.[14]

At our department, PiCCO has been the standard hemodynamic monitoring method for patients with severe burns. The goal of this retrospective study is to describe the inherent tendency of hemodynamics in the first week after severe burns and illustrate clinical significance of hemodynamic parameters for burn shock resuscitation.

PATIENTS AND METHODS

Patients

From December 2012 to December 2015, burned patients with burn size equal to or exceeding 40% total body surface area (TBSA) and received PiCCO monitoring less than or equal to 6 hours after burn in the Department of Burn Surgery in Changhai Hospital were considered for entry into this retrospective study. Those patients clinically diagnosed with unstable condition during burn shock stage were excluded from the study. The investigating protocol was approved by the institutional ethics committee for human study.

Methods

All patients were treated with fluid resuscitation immediately on admission. Liquid resuscitation refers to the Chinese General Formula (expected fluid volume in the first 24 hours = 1.5 ml [electrolyte and colloidal solution] × burn area [%] × weight [kg] + 2000 ml [glucose solution], expected fluid volume in the second 24 hours = 0.75 ml [electrolyte and colloidal solution] × burn area [%] × weight [kg] + 2000 ml [glucose solution], with the 2:1 ratio of Ringer's solution to colloid solution). The speed of fluid replacement and actual volume of infused solution were adjusted to maintain the urinary output in the range of 0.5 to 1.0 ml/kg/h.

Simple debridement of wounds and fasciotomy was undertaken when the systemic conditions of patients were stable. Patients were given tracheotomy and mechanical ventilation if necessary. Fiberoptic bronchoscopy was performed in patients with inhalation injury. Low dose of sedatives were given conventionally to keep the patients quiet and awake and reinforced when incoordination of patients with ventilator and painful performances. The first escharectomy and skin grafting was undertaken within 4 to 6 days after burn. PiCCO was also used as intraoperative monitoring of hemodynamics, but the value of hemodynamic data from the start of anesthesia to 2 hours after its end was excluded from this study. Other therapeutic measures included antimicrobial agents against infection, gastric mucosal protection, nutritional support, and so on.

PiCCO Monitoring

All patients had a central venous line and an arterial (mostly femoral artery) access placed on initial admission. Transpulmonary thermodilution measurements were performed using the Pulsiocath 3- or 4-French thermistor-tipped catheters (Pulsion Medical Systems, Munich, Germany). To determine hemodynamic parameters, 10 ml of cooled saline solution (0–6°C) were injected into central venous catheter. Injections were manual and not coordinated with the respiratory cycle. Measurement procedures of each patient were performed every 12 hours after injury. Each procedure consisted of three injections via the venous access, and all saline boluses were administered within a maximum time span of 10 minutes. Results were calculated as the mean of these three consecutive measurements, including the flow parameter (cardiac index [CI]), myocardial contractility parameter (dPmax), preload parameter (intrathoracic blood volume index [ITBVI]), afterload parameter (systemic vascular resistance index [SVRI]), and lung-related parameters (extravascular lung water index [EVLWI] and pulmonary vascular permeability index [PVPI]).

Statistical Analysis

Continuous variables are presented as means ± SDs. Categorical data were summarized as absolute frequencies and percentages. To test the influence of time on the hemodynamic variables, a two-way analysis of variance was performed to determine the statistical significance. When a difference was detected, post hoc analysis was performed using the Dunnett *T* test. Multiple linear regression analysis with CI as dependent variable and ITBVI, SVRI, dPmax, EVLWI, and PVPI as independent variables was undertaken to evaluate the role of myocardial contractility, preload, afterload, and lung-related parameters on the variation of CI during burn shock resuscitation. In all cases, P values < .05 were considered statistically significant.

RESULTS

All of our inpatients who had burn size equal to or exceeding 40% TBSA from December 2012 to December 2015 were identified (total 109 patients), of whom 55 patients meeting the criteria were enrolled into the study. Thirty-five patients having received PiCCO monitoring more than 6 hours after burn and 19 patients clinically diagnosed with unstable condition during burn shock stage were excluded from the study. The 55 enrolled burned patients, included 35 men and 20 women, with an average age of 38.07 ± 10.90 years old, burn area of 61.73 ± 10.94% TBSA. The demographics of the patients are listed in Table 1. In the first 24 hours, the infused fluid volume was 2.39 ± 0.22 ml/kg/TBSA%, the infused colloid volume was 0.81 ± 0.07 ml/kg/TBSA%, and the urinary output was 0.59 ± 0.02 ml/h/kg. In the second 24 hours, the infused fluid volume was 1.40 ± 0.13 ml/kg/TBSA%, the infused colloid volume was 0.49 ± 0.06 ml/kg/TBSA%, and the urinary output was 0.72 ± 0.03 ml/h/kg. Patients' urinary output was always maintained in the range of 0.5 to 1.0 ml/h/kg, with warm peripheral extremities, full waveform of finger/toe pulse oxygen, stable heart rate and blood pressure, and no respiratory dysfunction. Thus, these 55 patients were clinically diagnosed with stable condition during burn shock stage.

Cardiac preload: under effective fluid resuscitation, at 12 hours after burn, the preload was still shown as in mildly low-volume state. The average ITBVI was 660.83 ml/m^2, slightly lower than the lowest level of the normal value. At 48 hours after burn, ITBVI returned to normal. At 84 hours after burn, ITBVI was significantly increased compared with that of 12 hours ($P < .05$) and a little bit higher than the highest level of normal value (Figure 1A).

CI: the average CI was 3.23 L/min/m^2 at 12 hours after burn, lower than the lowest level of the normal value, showing low CO. Subsequently, there was a slow rise of CI. At 36 hours after burn, it returned to normal. At 84 hours after burn, it was significantly

Table 1. Demographic and clinical data of critically burned patients

Variables (number = 55)	Number (%) or Mean ± SD
Male	35 (63.64%)
Female	20 (36.36%)
Age (yr)	38.07 ± 10.90
Height (cm)	167.00 ± 7.31
Weight (kg)	61.63 ± 10.14
Mechanism	
Flame	37 (62.27%)
Scald	18 (32.73%)
TBSA burn (%)	61.73 ± 10.94
Length of ICU stay (days)	67.80 ± 46.37

ICU, intensive care unit; *TBSA*, total body surface area.

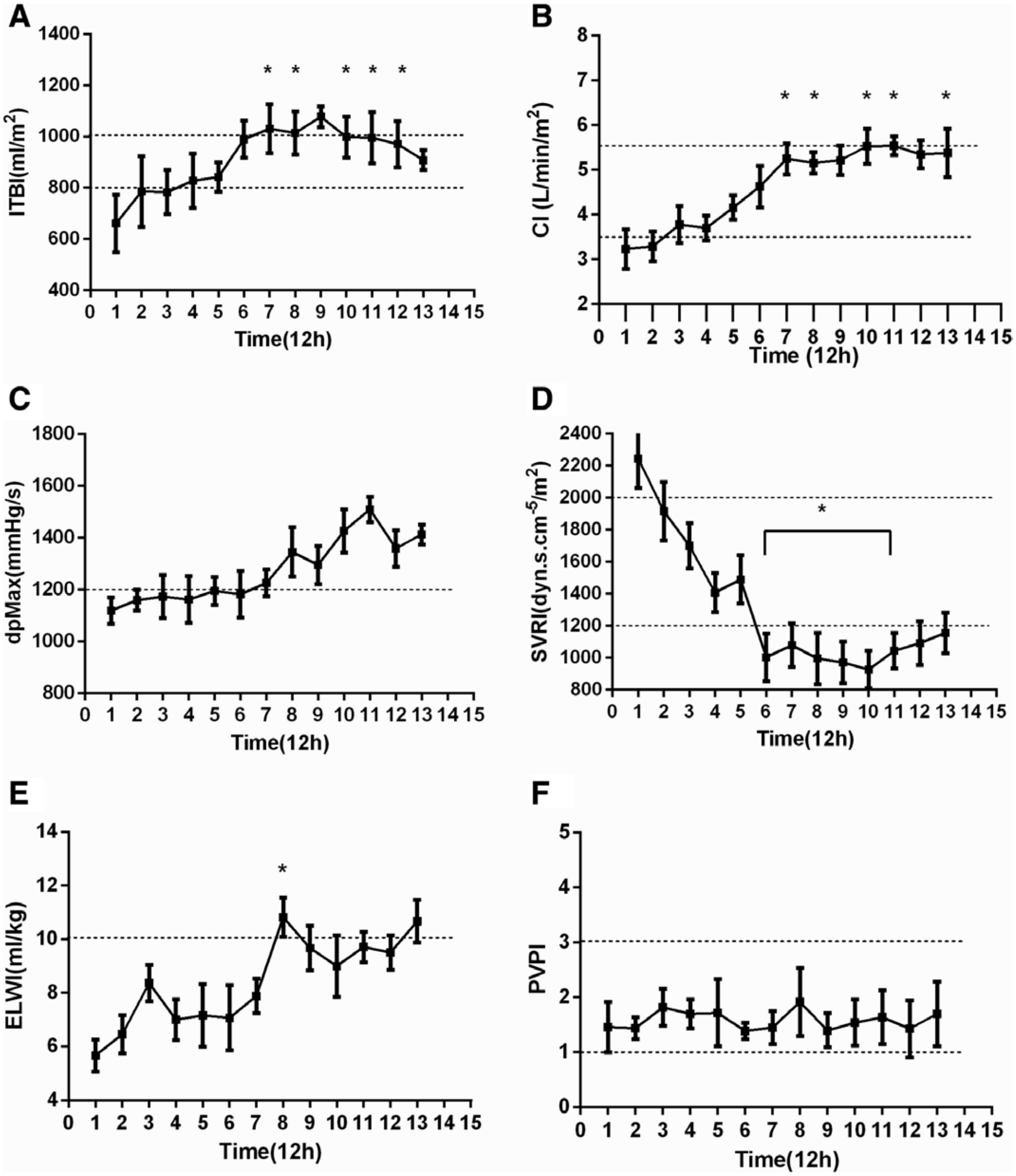

Figure 1. Time profile of hemodynamic parameters from 12 hours to 156 hours after burn. A. Intrathoracic blood volume index. B. Cardiac index. C. Left ventricular systolic index. D. Systemic vascular resistance index. E. Extravascular lung water index. F. Pulmonary vascular permeability index. The dotted lines show the normal range. The normal range of dPmax is 1200 to 2000 mm Hg/s. The normal range of ELWI is <10 ml/kg. *$P < .05$ vs 12 hours. *dPmax*, xxxx; *ELWI*, extravascular lung water index.

increased compared with that of 12 hours ($P < .05$). At 120 hours after burn, it reached the highest level of the normal value and continued to be in a high CO state. CO showed a transition from low output to high output (Figure 1B).

Myocardial contractility: the average dPmax was 1119.16 mm Hg/s at 12 hours after burn, lower than the lowest level of normal value, indicating a state of heart depression. Subsequently, the dPmax increased slowly. At 60 hours after burn, it returned to normal (Figure 1C).

Cardiac afterload: the average SVRI was 2244.67 dyn.s.cm^{-5}/m^2 at 12 hours after burn, higher than the highest level of normal value, indicating a state of high vascular resistance, then gradually decreased. It recovered to normal at 24 hours after burn and significantly decreased at 72 hours compared with 12 hours after burn ($P < .05$). Vascular resistance showed a transition from high resistance to low resistance (Figure 1D).

Lung-related parameters: EVLWI increased slowly after burn, and it was roughly in the normal range (EVLWI < 10 ml/kg; Figure 1E). PVPI was always

Table 2. Multiple linear regression analysis with CI as dependent variable and SVRI, dPmax, ITBVI, EVLWI, PVPI as independent variables

Variables	Standardized Regression Coefficients	T	*P*
SVRI	−0.602	−5.191	.000
dPmax	0.446	3.847	.003
ITBVI	0.389	1.469	.176
EVLWI	0.061	0.360	.727
PVPI	−0.100	−1.179	.269

CI, cardiac index; *dPmax*, xxxx; *EVLWI*, extravascular lung water index; ITBVI, intrathoracic blood volume index; *PVPI*, pulmonary vascular permeability index; *SVRI*, systemic vascular resistance index.

in the normal range and did not change obviously (Figure 1F).

Multiple linear regression analysis with CI as the dependent variable and ITBVI, SVRI, dPmax, EVLWI, and PVPI as the independent variables was showed in the Table 2. The results indicated that the change of CI had positive linear regression relation with dPmax (the regression coefficient was 0.446) and negative relation with SVRI (the regression coefficient was −0.602). There was a low correlation between CI and blood volume ITBVI.

DISCUSSION

In the early stage after severe burns, the rapid recovery of circulation volume and the blood perfusion of tissue are critical. The survival rate at burn shock stage has been significantly increased since the application of the burn fluid replacement formulas. With the guidance of these formulas, combined with individualized resuscitation strategy, most extensive burned patients were able to get over burn shock stage smoothly. Nonetheless, some patients still experience shock resuscitation failure. For example, although having received far more than estimated fluid volume of formula and developed severe edema, some patients still had little urinary output and unstable circulation state, or patients got heart or renal failure. Under these circumstances, the circulatory state cannot be reflected by routine indicators, such as urinary output. The development of hemodynamic monitoring devices provides new method for the clinical treatment.

Swan-Ganz catheter was initially applied in the resuscitation of burn shock monitoring in 1978 by Aikawa et al.[15] He found that when the blood pressure and urinary output maintained normal in the burn shock stage, hemodynamics still showed low CO and high vascular resistance. On the basis of his insistence that hemodynamic data were much effective, he believed that resuscitation guided by routine indicators such as urinary output could lead to inadequate fluid volume. Therefore, in order to pursue the normalization of hemodynamic data, the excessive amount of fluid infusion were administered.[2,3,16,17] Holm et al[18] reported that the large quantity of fluid resuscitation during shock stage (6.26 ml/kg/TBSA%) could not get the normal CO and cardiac preload. Excessive fluid replacement would result in severe edema, wound healing delay, infection and multiple organ failure, and finally the increase of mortality rate.[1–3] In fact, Swan-Ganz catheter did not reduce mortality. Therefore, the use of Swan-Ganz catheter in the United States in the past 10 years was significantly reduced.[8] The reason for exaggeration of the role of Swan-Ganz catheter was that clinicians misunderstood the significance of hemodynamic data in burn shock resuscitation.

In 2008, Wang et al[11] used ED to describe the early hemodynamic changes after severe burns. He found that CO, Acc, and SV/Acc were at a low level in the early stage, but increased gradually, while total systemic vascular resistance was at a high level in the early stage, but decreased gradually. Based on his research results, he pointed out that the hemodynamic parameters in early stage after burn were continuously changing. Therefore, Wang et al[11] insisted that pursuit of normalization of the values of hemodynamic data in burn shock stage should be harmful.

PiCCO is an advanced hemodynamic measurement that combines the thermodilution method with pulse contour analysis method. Compared with Swan-Ganz catheter and ED, PiCCO could obtain comprehensive parameters, especially lung-related parameters. Although it is an invasive performance, there is no need to use the right heart catheterization. And the safety has been improved.[19–21] Data from PiCCO haves important significance in clinical application. Continuous measurement of CI and dPmax can reflect the state of cardiac function. ITBVI refers to the sum of pleural intravascular blood and is not affected by the intrathoracic pressure and myocardial compliance parameters, which is a good indicator of cardiac preload, and it is more sensitive than pulmonary capillary wedge pressure and CVP.[22,23] SVRI could reflect the vascular tension, providing guidance for the application of vasoactive drugs. EVLWI and PVPI are two specific indicators to assess and differentiate diagnosis of pulmonary edema. EVLWI can sensitively reflect, quantify the pulmonary effusion content, and predict pulmonary edema in an early stage.[24] EVLWI ≥ 10 ml/kg has been shown to predict progression to acute lung injury and define pulmonary edema.[25]

This study was based on the 7 days' hemodynamic data, through PiCCO, of severely burned patients who were clinically diagnosed with a relatively stable condition during the first week after burn. The results showed that under effective fluid resuscitation, all indices of hemodynamics changed continuously and dynamically in the early stage after burn, which was similar to the results of Wang et al.[11] CI, ITBVI, and dPmax gradually changed from low level in the shock stage to high level in the fluid reabsorption stage and SVRI from high level to low level. There was a dynamic variation from low CO–high vascular resistance in the burn shock stage to high CO–low vascular resistance in the fluid reabsorption stage. Multiple linear regression analysis showed that the changes of CI had a linear regression relationship with dPmax and SVRI, but the relationship between CI and ITBVI was not significant, indicating that excessive fluid infusion could not get the normal CO and was not beneficial to resuscitation.

Therefore, under effective fluid resuscitation, extensive burn patients in shock stage are still in low CO state,[25] which is not mainly due to the lack of blood volume, but the depression of heart function.[26,27] Huang et al[28] defined this phenomenon as "shock heart" and disclosed that before the decrease of blood volume after burn, myocardial blood flow decreased and myocardial injury protein markers elevated. This might be resulted from immediate neuroendocrine response to strong stress of severe burns, as the change of blood vessel permeability does after burn. At this time, the high-vascular resistance might be a protective factor of the body, adapting to the low CO to ensure the tissue perfusion pressure. In this case, emphasis on excessive fluid infusion could not get normal CO[18,29] but would increase the burden on the injured myocardium. Arlati et al[29] published a randomized controlled clinical study in 2007, which showed that compared with the excessive fluid infusion, effective low-volume fluid was very safe, could reduce the damage of organs and tissues, and was beneficial to burn shock resuscitation.

Forty-eight to seventy-two hours after burn, CI is gradually recovered to the high level.[27,30] The possible reason for this might be on the two aspects. First, the myocardial contractile function is gradually recovered. Second, the surge of blood volume due to the arrival of fluid reabsorption stage makes the high CO become inevitable. At this time, the low vascular resistance could adapt to the high CO, so that the blood pressure is not too high. Therefore, in the face of strong stress of severe burns, the blood vessel tension is regulated to adapt to the changes of CO and to maintain perfusion pressure.

The research results showed that EVLWI, PVPI were roughly in the normal range after burn, indicating that these patients did not undergo obvious pulmonary edema. This was consistent with clinical manifestations of the included cases, as there were no cases with respiratory dysfunction enrolled in the study.

The inherent tendency of hemodynamic parameters from low CO–high vascular resistance in the shock stage to high CO–low vascular resistance in the fluid reabsorption stage should be taken as a pathophysiological reaction to severe burn stress. Its clinical significance may be as follows: On the one hand, the normal values of hemodynamics are not appropriate values for burn shock resuscitation. On the other hand, due to the characteristics of continuous and dynamic changes of hemodynamic parameters and their large individual differences for extensive burn patients, it would be difficult to determine the ideal value of hemodynamic parameters for a certain patient at a certain time point. Therefore, hemodynamic data could not take the place of the traditional indicators such as urinary output and should not be used as the end point for burn shock resuscitation.

But dynamic observation of hemodynamic changes is of importance. It can continually supply the value of myocardial contractility, cardiac preload, afterload, and lung water, and follow the tendency of hemodynamics, then help clinician realtimely assess the circulatory response to treatment. So, it is a good assistance to traditional indicators to optimize the clinical decision. Under some special circumstances, such as patients with refractory shock, severe inhalation injury, heart, or kidney dysfunction or those with extreme ages, hemodynamic monitoring will be of great significance.[11]

CONCLUSION

This article investigated the tendency of hemodynamics within the first week after severe burns through PiCCO. The results showed that under effective fluid resuscitation, hemodynamic parameters were still in continuous and dynamic changes in the early period after burn. It was gradually changed from low CO–high vascular resistance in the shock stage to high CO–low vascular resistance in the fluid reabsorption stage, which should be taken as a pathophysiological response to burn stress. CI is mainly dependent on the myocardial contractility and vascular resistance, but not on the blood volume. Excessive fluid resuscitation could not get the normal CO and was not beneficial to resuscitation. The normal value of hemodynamic data should not be used as an end point for burn shock fluid resuscitation. Dynamic monitoring of hemodynamics was more useful in the assistance of clinical treatment.

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