Pitfalls of Hemodynamic Monitoring in Patients with Trauma

Richard R. McNeer, MD, PhD[a,b,*], Albert J. Varon, MD, MHPE, FCCM[a,c]

KEYWORDS

- Trauma • Hemodynamic monitoring • Hemorrhagic shock
- Blood pressure measurement • Dynamic response • Natural frequency
- End-tidal carbon dioxide • Assessment of cardiac output

KEY POINTS

- Hypotensive resuscitation imposes additional burdens on the anesthesiologist to maintain adequate blood pressure while also avoiding blood pressure overshoots or sustained hypertension.
- Accuracy and interpretation of blood pressure monitoring in trauma depend on complex interactions between patient physiology and factors intrinsic to measurement devices.
- Oscillometry overestimates systolic blood pressure in hypotensive patients.
- The impact of hemorrhagic shock on reflection wave behavior may limit the reliability or confound interpretation of both noninvasive and invasive blood pressure measurements.
- Adequate dynamic response is required for proper recording of an arterial waveform, and dynamic response requirements increase with tachycardia.
- The only way to determine dynamic response is to conduct a flush test.
- End-tidal CO_2 is correlated with cardiac output; however, this correlation is affected following cardiac or respiratory arrest.

INTRODUCTION

Resuscitation of the patient with trauma with ongoing blood loss has historically been geared toward maintaining normal or higher than normal blood pressure. Investigations of the role of hypotensive resuscitation have been conducted with mixed results.

Funding sources: None.
Conflict of interest: None.

[a] Division of Trauma Anesthesiology, Department of Anesthesiology, University of Miami Miller School of Medicine, PO Box 016370-M820, Miami, FL 33101, USA; [b] Department of Biomedical Engineering, College of Engineering, University of Miami, PO Box 248294, Coral Gables, FL 33146, USA; [c] Ryder Trauma Center at Jackson Memorial Hospital, 1800 NW 10th Avenue, Miami, FL 33136, USA
* Corresponding author. Division of Trauma Anesthesiology, University of Miami Miller School of Medicine, PO Box 016370-M820, Miami, FL 33101.
E-mail address: mcneer@miami.edu

Anesthesiology Clin 31 (2013) 179–194
http://dx.doi.org/10.1016/j.anclin.2012.11.005 anesthesiology.theclinics.com

A review of 52 animal studies of mortality during induced hemorrhage found that hypotensive resuscitation reduced the risk of death.[1] However, in human studies, decreased blood loss and transfusion requirements have only been confirmed in penetrating injury.[2] Other studies[3] are currently in progress and may add evidence to support a paradigm shift in the management of blood pressure in the patient with trauma. It may no longer be sufficient to maintain blood pressure at an adequate level, and added vigilance may be needed to prevent sustained overshoots in blood pressure. It is therefore ironic that the monitoring strategies meant to inform the anesthesiologist of a patient's hemodynamic status are limited in the context of hypotension and the deranged physiology associated with hemorrhagic shock.

This article discusses the complex interplay between alterations in the physiology of a patient with trauma, the monitoring devices engineered to measure these alterations, and interpretation of these data by the anesthesiologist. Focus is placed on the early stages of caring for the patient with trauma before surgical hemostasis is obtained, when hemodynamic assessment must be made quickly and accurately to maintain sufficient cardiac output and blood pressure without exceeding levels that may worsen outcome. Hemodynamic monitoring and resuscitation end points of patients in the period after surgical hemostasis have been reviewed elsewhere[4] and are only mentioned here. For example, monitoring strategies based on arterial pressure waveform variation, venous oxygen saturation ($S\bar{v}O_2$) and central venous oxygen saturation ($ScvO_2$), and laboratory parameters such as base excess and lactate have been, or are increasingly becoming, a part of the trauma anesthesiologist's armamentarium, but it is often not feasible to implement these strategies during the initial, frenetic stages of care. The 3 bread-and-butter monitors heavily relied on during the initial assessment and resuscitation of the unstable patient with trauma are arguably the end-tidal pressure of CO_2 ($PETCO_2$), noninvasive blood pressure (NIBP), and invasive arterial blood pressure (IABP). The underpinnings and limitations of these monitors in the patient with trauma are discussed in reverse order starting with invasive blood pressure, acknowledging that the other two may be the only hemodynamic monitors available before an arterial catheter can be inserted. Wherever possible, figures are included to illustrate important points from the text.

Invasive Blood Pressure Monitoring

When using IABP to guide the management of patients with trauma, it is incumbent on the physician to discern true signal (the physiologic waveform) from artifact (a distorted waveform). The physiologic waveform should be processed with high fidelity to obtain an accurate recording. Several characteristics of the patient with trauma and of the recording device can lead to the generation of distorted (or what appears to be distorted) waveform morphology. Patients with trauma are likely to exhibit tachycardia, hypotension, decreased cardiac output, and high (or occasionally low) systemic vascular resistance (SVR). These derangements in patient physiology can exceed the processing capability of the catheter-tube-transducer (CTT) system used to invasively measure blood pressure. Factors that affect waveform morphology can lead to the display of inaccurate blood pressure values and potentially confound clinical interpretation. Two of the main factors are pulse wave reflection within arterial vasculature and the dynamic response characteristics inherent to the CTT system.

To understand why these factors are important, it is useful to recall that any physiologic waveform is decomposable into several sine waves of varying amplitude, frequency, and phase (**Fig. 1**). The reverse process is also true, and sign waves can be selected and summed to generate a simulated waveform. It takes just 3 sine waves to give a persuasive approximation of the typical arterial waveform.[5] Of the 3 sine waves