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Review

A review of hemodynamic monitoring techniques, methods and devices for the emergency physician

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ABSTRACT

The emergency department (ED) is frequently the doorway to the intensive care unit (ICU) for a significant number of critically ill patients presenting to the hospital. Hemodynamic monitoring (HDM) which is a key component in the effective management of the critically ill patient presenting to the ED, is primarily concerned with assessing the performance of the cardiovascular system and determining the correct therapeutic intervention to optimise end-organ oxygen delivery. The spectrum of hemodynamic monitoring ranges from simple clinical assessment and routine bedside monitoring to point of care ultrasonography and various invasive monitoring devices. The clinician must be aware of the range of available techniques, methods, interventions and technological advances as well as possess a sound approach to basic hemodynamic monitoring prior to selecting the optimal modality. This article comprises an in depth discussion of an approach to hemodynamic monitoring techniques and principles as well as methods of predicting fluid responsiveness as it applies to the ED clinician. We review the role, applicability and validity of various methods and techniques that include; clinical assessment, passive leg raising, blood pressure, finger based monitoring devices, the mini-fluid challenge, the end-expiratory occlusion test, central venous pressure monitoring, the pulmonary artery catheter, ultrasonography, bioreactance and other modern invasive hemodynamic monitoring devices.

Contents

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1. Introduction

Hemodynamic monitoring (HDM) is a key component in the effective management of the critically ill patient. Over the past decade, there have been significant advances in HDM techniques and devices with regards their application in the intensive care unit (ICU) and operating room settings. With the progress and development of emergency medicine globally, an increasing emphasis has been placed on employing accurate diagnostic techniques capable of guiding the early management of the undifferentiated critically ill patient presenting to the emergency department (ED). Coinciding with the turn of the century, there has been increasing emphasis on instituting early management for a number of ED presentations regarded as “time dependent”. Idioms such as the golden hour [1], early-goal-directed-therapy (EGDT) [2], time is muscle [3] and time is brain [4] have been promulgated to emphasize the importance of timely management of trauma, sepsis, ST elevation myocardial infarction and stroke patients presenting to the ED.

Despite the fact that a substantial proportion of individuals undergoing stabilization in the ED resuscitation room ultimately require ongoing care in the ICU setting [5], the applicability and role of various HDM techniques and their application in the ED environment have been poorly defined. Whilst the ED is regarded as the gateway to hospital admission [6], the ED resuscitation room may be regarded as the doorway to the ICU. Good overall patient outcomes are dependent on timely appropriate management of the critically ill patient in the ED. As a result, advanced monitoring and interventional tools which were previously regarded the niche of the ICU and operating room environments, have been introduced to the ED. However, bearing in mind challenges and limitations specific to the ED setting the accuracy, reliability, applicability, invasiveness, cost and user friendliness of available HDM devices must be taken into account prior to implementation [7-9].

At its core, HDM is concerned with two fundamental entities within the human circulatory system, oxygen delivery (DO_2) and oxygen consumption (VO_2) where DO_2 (ml O_2/min) = CO × Hb × 1.34 × SaO_2 and VO_2 (ml O_2/min) = CO × Hb × 1.34 × (SaO_2 − SvO_2). CO = cardiac output in ml/min, Hb = haemoglobin in g/100 ml, SaO_2 = percentage of arterial oxygen saturation and SvO_2 = percentage of mixed venous oxygen saturation [10,11]. An increase in DO_2 is likely in volume-responders whilst non-responders may actually display a drop in DO_2 as a consequence of the hemodilutory effects of volume infusion [12].

In essence, the concept of HDM is primarily concerned with assessing the performance of the cardiovascular system and its ability to deliver sufficient oxygen to meet the metabolic demands of the body [13]. The value of HDM in the ED is threefold in that it is useful in identifying the presence and nature of shock, secondly it guides appropriate therapeutic interventions and finally it provides an assessment tool for response to therapy [14,15]. For HDM to be truly effective in the ED setting various techniques, methods, interventions and technological advances coupled with a sound clinical approach to basic hemodynamic monitoring must be incorporated prior to selecting the optimal modality [8,15]. An understanding of the manner in which the reading is derived, as well as the accuracy of the device in specific clinical scenarios is paramount [16].

In this article the spectrum of haemodynamic monitoring techniques ranging from basic clinical examination to advanced invasive monitoring as well as their practicality and applicability to the ED environment is reviewed.

2. Shock

Shock can be defined as the inadequate delivery and utilization of oxygen at the cellular level. The various categories of shock determining management principles include cardiogenic, hypovolemic, distributive and obstructive subtypes (Table 1) [17]. The goal of intervention following hemodynamic monitoring is to achieve an increase in cardiac output with a subsequent improvement in tissue oxygenation. A sensible management approach would be to identify and treat abnormalities in order of firstly correcting any cardiac rate and rhythm disturbances, then optimising intravascular volume and systemic vascular resistance and finally attending to myocardial pump function and obstruction related disturbances. HDM aims to assess these elements and determine the appropriate choice of therapy (Fig. 1) [18-20].

3. Understanding the role of fluids in light of the frank starling curve

An initial fluid bolus is a frequent reflex response amongst clinicians faced with a victim in circulatory shock. However, as a consequence of shock related microcirculatory and cellular dysfunction, just half the number of individuals receiving a fluid bolus are expected to respond with a corresponding increase in DO_2 (volume responders) and only

Table 1
Description of the 4 categories of shock.

Cardiogenic	Hypovolemic
Dysrhythmias – extreme bradycardia or tachycardia Acute coronary syndrome Acute myocarditis Cardiomyopathies Post traumatic myocardial injury Valvular heart disease	Haemorrhagic, trauma – external hemorrhage, intrathoracic, intraabdominal, pelvis and retroperitoneal, long bones Haemorrhagic, non-trauma – gastrointestinal (UGIB, LGIB), ruptured ectopic pregnancy, ruptured AAA Non-haemorrhagic – diarrhoea, vomiting, heat stroke, excessive sweating
Distributive	**Obstructive**
Neurogenic shock (high spinal cord transection) Anaphylactic shock[b] Septic shock[a]	Tension pneumothorax Pericardial tamponade Pulmonary embolism

[a] Also has an associated 1) hypovolemic component as a result of widespread capillary leak of fluid into the extravascular compartment secondary to cytokine release and loss of the endothelial glycocalyx and 2) cardiogenic component secondary to cytokine mediated myocardial depression.
[b] Also has an associated hypovolemic component as a result of widespread capillary leak of fluid into the extravascular compartment.