Minimally Invasive Monitoring

Xavier Monnet, MD, PhD[a,b,*], Jean-Louis Teboul, MD, PhD[a,b]

KEYWORDS

• Hemodynamic monitoring • Cardiac output • Arterial pressure
• Pulse contour analysis • Vascular resistance • Thermodilution

KEY POINTS

- The main advantage of pulse contour analysis is to provide a continuous real-time estimation of cardiac output.
- Calibrated pulse contour analysis devices provide a reliable estimation of cardiac output but are invasive and require frequent recalibrations.
- The reliability of devices using uncalibrated pulse contour analysis is low when vascular resistance changes to a large extent. These devices are more suitable for the perioperative setting than for intensive care units.
- Pulse contour analysis of noninvasive tracings of arterial pressure still needs to be improved.

INTRODUCTION

For many years, the measurement of cardiac output in operating rooms and intensive care units could be performed only with the pulmonary artery catheter. The popularity of the pulmonary artery catheter has progressively declined and some alternative techniques have been developed during recent years,[1] mainly because catheters are invasive, cumbersome to set up, and some of the variables it provides can be difficult to measure and interpret appropriately. Among the alternative techniques, arterial pressure waveform analysis infers cardiac output from the systemic arterial pressure curve. Some of these arterial pressure waveform analysis devices only need an arterial catheter for this purpose and can be considered as minimally invasive. Pulse contour analysis was recently developed for arterial curves that are recorded in a noninvasive way.

Conflicts of interest: Professors X. Monnet and J-L. Teboul are members of the medical advisory board of Pulsion Medical Systems.
[a] Medical Intensive Care Unit, Bicêtre Hospital, Paris-Sud University Hospitals, 78, rue du Général Leclerc, F-94270 Le Kremlin-Bicêtre, France; [b] EA4533, Paris-Sud University, 63 rue Gabriel Péri, F-94270 Le Kremlin-Bicêtre, France
* Corresponding author. Service de réanimation médicale, Hôpital de Bicêtre, 78 rue du Général Leclerc, 94 270 Le Kremlin-Bicêtre, France.
E-mail address: xavier.monnet@bct.aphp.fr

Crit Care Clin 31 (2015) 25–42
http://dx.doi.org/10.1016/j.ccc.2014.08.002 criticalcare.theclinics.com
0749-0704/15/$ – see front matter

This article first summarizes the technological principles of pulse contour analysis. In particular, it explains how devices differ in whether or not they need to be calibrated. The literature on the reliability of arterial pressure waveform analysis for estimating cardiac output is reviewed. In addition, the role of such devices with respect to the other hemodynamic monitoring devices is discussed.

PRINCIPLES OF ARTERIAL PRESSURE WAVEFORM ANALYSIS

Two types of device that use arterial pressure waveform analysis have been developed. Some of them (PiCCO by Pulsion Medical Systems, Munich, Germany; LiDCOplus by LiDCO, London, United Kingdom; and VolumeView/EV1000 by Edwards Lifesciences, Irvine, CA) calibrate the pressure waveform analysis with an independent measurement of cardiac output done by transpulmonary dilution. Some other devices (FloTrac/Vigileo by Edwards Lifesciences; LiDCOrapid by LiDCO; MostCare by Vytech Health, Padova, Italy; and ProAQT/Pulsioflex by Pulsion Medical Systems) do not require any calibration for pressure waveform analysis and are minimally invasive because they only require a standard arterial catheter.

This article briefly describes the functioning principle of both kinds of pressure waveform analysis device. However, the precise algorithms used by the devices are not disclosed by the manufacturers.

Calibrated Devices

These devices integrate 2 independent techniques for measuring cardiac output: arterial pressure waveform analysis and transpulmonary dilution (with cold saline for PiCCO and VolumeView/EV1000, and with lithium for LiDCOplus).

PiCCO and VolumeView/EV1000

Principles common to both devices The PiCCO and VolumeView/EV1000 devices use a pressure waveform analysis that is based on the principle that stroke volume is proportional to arterial pulse pressure and inversely proportional to arterial compliance. In the early 1990s, Wesseling and colleagues[2] computed the aortic flow from the systemic arterial pressure in humans. They simulated a 3-element model including the characteristic impedance of the aorta, the arterial compliance, and systemic vascular resistance (Fig. 1). They described for the first time that it is possible to monitor cardiac output continuously from pulse contour analysis.[2]

Based on this principle, all devices estimating cardiac output from pressure waveform analysis record the arterial pressure curve from a peripheral artery and automatically compute cardiac output from it. Overall, for most devices, the analysis is supported by 4 principles:

1. The amplitude of the pressure curve of the aorta is proportional to stroke volume and to a multiplication factor k.
2. k is inversely proportional to the arterial compliance.
3. The arterial pressure at the periphery is different from the arterial pressure at the aortic level (see Fig. 1). This difference is called the pulse wave amplification phenomenon. Because of the reduction of arterial diameter from the aorta to the periphery, the amplitude of the arterial pressure signal increases along the arterial tree.
4. The amplification of pulse along the arterial tree depends on the arterial resistance.

As a result, arterial pressure waveform analysis devices must:

1. Analyze the geometry of the arterial pressure curve signal
2. Estimate the arterial compliance