Pulse Pressure Analysis

M. Cecconi, J. Wilson, and A. Rhodes

II Introduction

Cardiac output monitoring is part of routine practice in the critically ill patient. Recently, there has been increasing interest in continuous cardiac output monitoring, which has seen the development of new devices less invasive than the pulmonary artery catheter (PAC). The insertion of a PAC allows semi-continuous monitoring of cardiac output using the thermodilution technique but these new devices allow continuous monitoring by analyzing the arterial pressure wave. This analysis is known as pulse pressure analysis. This chapter explores the issues associated with pulse pressure analysis and presents the mathematical basis for the devices available.

II From Arterial Pressure to Cardiac Output

Arterial pressure is one of the most commonly monitored variables in critical care medicine; however, arterial pressure is not in itself enough to assess cardiac output. In fact, arterial pressure is the result of a combination of cardiac output and the resistance of the vasculature:

\[ P = CO \times R \]

Where \( P \) = arterial pressure, \( CO \) = cardiac output, and \( R \) = resistance of the vasculature.

It is apparent that the resistance of the vasculature must be known to calculate arterial pressure. Unfortunately, resistance is not constant, but it is possible to relate variations in pressure to variations in stroke volume due to a feature known as compliance. Compliance is the relationship between volume change and pressure change:

\[ C = \Delta V / \Delta P \]

Where \( C \) = compliance, \( \Delta V \) = volume change, and \( \Delta P \) = pressure change.

Therefore, if we know the value of compliance, we can measure the pressure change (\( \Delta P \)) to calculate the volume change (\( \Delta V \)).

\[ \Delta V = C \times \Delta P \]

Compliance in the arterial tree is not a linear function (Fig. 1). Moreover, compliance is not constant for one blood vessel. For instance, vasoconstriction causes arteries to become stiffer and this leads to a decrease in compliance. Vasodilation leads to an increase in compliance (Fig. 2).
Fig. 1. \( \Delta V_{ab} \) and \( \Delta V_{cd} \) have the same value. \( \Delta P_{ab} \) is lower than \( \Delta P_{cd} \). \( C_{ab} \) is then higher than \( C_{cd} \). \( \Delta V \) = change in volume, \( \Delta P \) = change in pressure. \( C \) = compliance

![Figure 1](image1.png)

Fig. 2. Compliance curve can shift to different states and the same change in volume can determine very different changes in pressure. \( C_3, C_1, C_2 \) = compliance respectively for curve 3, 1, 2

![Figure 2](image2.png)

The proximal aorta carries the blood initially pumped from the heart. The aorta is filled according to three forces:
- The force of injection of the blood by the pumping of the heart
- An opposing force dependent on pulsatile inflow (impedance)
- An opposing force depending on the change in volume (compliance).

The peripheral resistance is the force that opposes the blood flow to the periphery. Ideally, these forces should be measured at a site as proximal as possible to the aorta. However, as pulse pressure devices have a low level of invasiveness, they will, by their very nature, record the arterial wave peripherally.

Arterial pressure measured in the periphery is affected by at least three effects:
- The generation of reflection waves in the periphery
- Damping of the arterial pressure measurement system
- Differences in the flow-pressure relationship centrally and peripherally.

Damping is a common problem in clinical practice. The fluid-filled tubes used to measure intravascular pressure form a resonant system that can oscillate. The performance of such a resonant system is determined by the frequency of oscillation and by the damping coefficient.