

# Noninvasive haemodynamic monitoring using finger arterial pressure waveforms

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## ABSTRACT

Haemodynamic monitoring may potentially lead to improved quality of care in haemodynamic compromised patients. However, the usefulness of invasive techniques using the pulmonary artery catheter is questioned. Noninvasive techniques which provide data on haemodynamics might provide a good alternative. New techniques have been developed in recent years to monitor cardiac output and other parameters of cardiac performance continuously and noninvasively. Recently, a new technique has become available that assesses these haemodynamic data from finger arterial pressure waveforms obtained noninvasively. Although an invasively derived calibration is still needed to obtain absolute data on cardiac output, relative changes in cardiac output can be accurately monitored using this method. Currently, the device can be used in patients to continuously monitor haemodynamic data and guide therapy. Furthermore, it might have a role in clinical research to noninvasively assess cardiac output, as a surrogate endpoint, before and after interventions. Although this new method seems promising, the clinical value has to be proven.

## KEYWORDS

Blood pressure, cardiac output, heart failure, noninvasive haemodynamic monitoring

## INTRODUCTION

Haemodynamic assessment is of particular importance in the evaluation of haemodynamically compromised patients. Cardiac output is considered one of the most important parameters when assessing the effects of treatment in a patient with haemodynamic instability but measurement

is often precluded by the invasiveness and complexity of the established cardiac output monitoring techniques. Furthermore, although cardiac output seems to be an important parameter in patient management there is no structural evidence that cardiac output measurements improve morbidity and mortality.

In 1970 Swan and Ganz introduced the pulmonary artery catheter<sup>1</sup> and since then measurement of cardiac output by the pulmonary artery catheter and the thermodilution method has become the gold standard against which new methods are compared. Recently, many questions have been raised regarding the safety, validity and adequate clinical response to the physiological parameters measured, and whether outcome is improved or worsened using the pulmonary artery catheter.<sup>2</sup> In heart failure, functional status as a result of pulmonary artery catheter-guided therapy might improve but no clear benefit has been shown on mortality. Thus, no clear benefit has been shown in guiding therapy while invasive monitoring leads to catheter-related adverse events. As a result, usage of the pulmonary artery catheter has decreased.<sup>3</sup>

Although, new strategies for monitoring heart failure patients have been developed in combination with implantable devices<sup>4,5</sup> these techniques have to prove their clinical benefit and are not applicable in patients without a device.

## HAEMODYNAMIC MONITORING USING FINGER ARTERIAL PRESSURE WAVEFORMS

A relatively new method which noninvasively measures blood pulse curves and that was primarily developed to measure blood pressure has recently been further developed to obtain cardiac output measurements (Nexfin<sup>TM</sup>). This monitor measures blood pressure

noninvasively and continuously. Pressure is measured in the finger arteries and consecutively reconstructed to brachial artery values. This methodology builds on the volume clamp technique as proposed by Peñáz<sup>6</sup> and the physiological criteria of Wesseling<sup>7</sup> to calibrate the blood pressure measurement. In 1986, the first commercially available device was introduced. Further development resulted in several devices for specific settings, including space research.<sup>8</sup> The noninvasiveness of the method allows easy access to arterial blood pressure. Methods have been validated in both clinical<sup>9</sup> and research settings.<sup>10-17</sup>

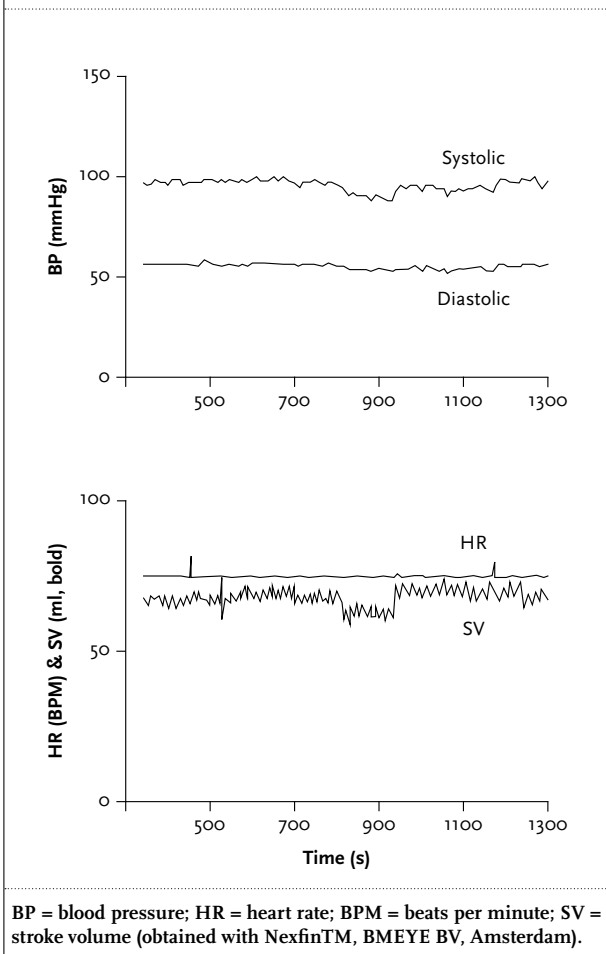
The pressure wave is further used as input to a dedicated algorithm to calculate stroke volume and cardiac output.<sup>18-20</sup> The original concept of the pulse contour method for estimation of beat-to-beat stroke volume was described by Frank in 1899.<sup>21</sup> Wesseling *et al.* further developed this method (Wesseling's cZ method).<sup>18</sup> Wesseling's method relates cardiac output to the area under the systolic portion of the arterial pressure wave ( $A_{sys}$ ). Dividing  $A_{sys}$  by aortic impedance provides a measure of stroke volume. In this

model the mean arterial pressure is used to correct the pressure-dependent nonlinear changes in cross sectional area of the aorta. The heart rate is used to correct for pressure reflections from the periphery. The corrections for arterial pressure and heart rate are age dependent which is taken into account. This method has been further developed using the input of noninvasive finger arterial pressure waveforms. Other parameters which can be assessed are heart rate, total peripheral resistance and maximum  $dP/dt$ .

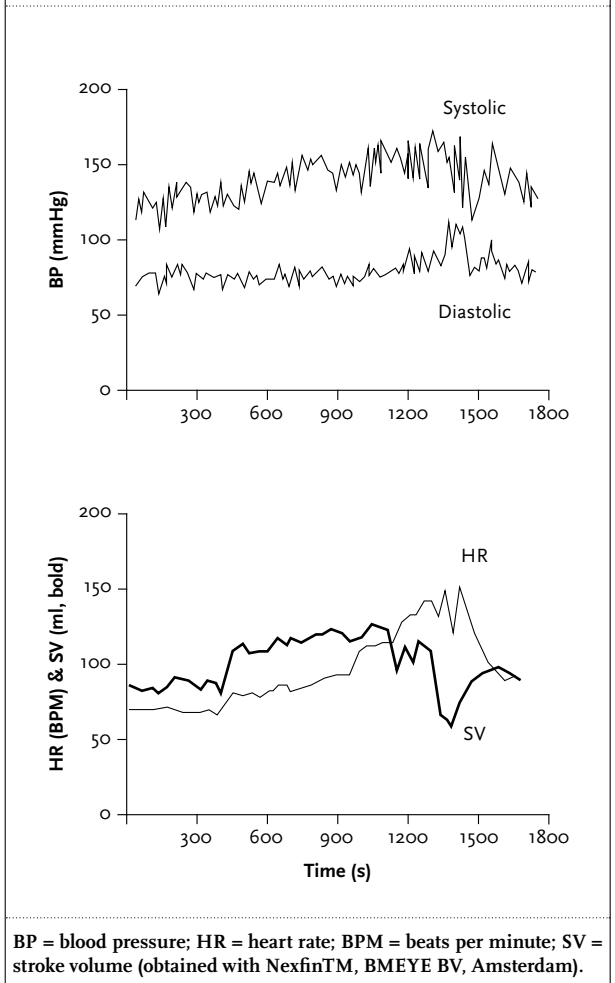
*Figure 1* shows an example of optimising cardiac resynchronisation therapy in a patient aged 56 years with systolic heart failure due to ischaemic heart disease. Beat-to-beat stroke volume and blood pressure were measured using the advanced developments of Wesseling's cZ method while changes in atrioventricular delay were made and an optimal setting was found. *Figure 2* shows the possibility to perform measurement during exercise.

The derived parameters might be used in the assessment and management of patients with (acute) haemodynamic changes.

**Figure 1.** Optimisation of AV delay with cardiac resynchronisation therapy using noninvasively derived stroke volume



**Figure 2.** Noninvasive haemodynamic parameters during exercise in a patient with heart failure



## DISCUSSION AND CONCLUSION

Parameters of cardiac performance can be obtained continuously and noninvasively using finger arterial pressure waveforms. These parameters can be assessed during interventions in rest and during exercise.

At this moment alternative techniques that can continuously and noninvasively monitor cardiac output in the conscious patient are scarce. Extensive descriptions of invasive and noninvasive methods to assess cardiac output can be found in a recent review.<sup>22</sup> Other pulse contour techniques exist but these are still invasive using an (radial) arterial input curve.<sup>23</sup> With transthoracic echocardiography, cardiac output can be obtained, but continuous monitoring is time consuming and beat-to-beat monitoring is not possible. Another noninvasive method for continuous cardiac output monitoring is oesophageal Doppler monitoring using a probe inserted in the oesophagus.<sup>24</sup> However, the technique can only be applied for continuous haemodynamic monitoring in sedated and mechanically ventilated patients, which applies for transoesophageal echocardiography as well. Another possible true noninvasive alternative might be impedance cardiography. This technique uses four pairs of electrodes placed on the thorax and neck and a set of ECG leads. High frequency, low amplitude alternating currents are transmitted after which thoracic impedance can be measured. Changes in thoracic impedance are related to fluid changes in the thorax and this way stroke volume can be assessed. An extensive description of impedance cardiography can be found in the review by Mathews and Singh.<sup>25</sup> This technique seems ideal for continuous online and intermittent cardiac output monitoring. In heart failure the technique may be hampered by thoracic fluid and therefore haemodynamic data could be less reliable.

Relative changes in cardiac output can be accurately monitored noninvasively with data obtained from the finger arterial pressure waveforms. However, an invasively derived calibration of cardiac output is needed to obtain more reliable *absolute* data on cardiac output. Besides being noninvasive, easy and fast assessment (first data within one minute) of haemodynamic parameters on a beat-to-beat basis is allowed. Blood pressure, cardiac output and dP/dt can be assessed noninvasively by this new monitor. These parameters can be assessed continuously and might be used in clinical practice to guide patient treatment. Potential areas where noninvasively obtained haemodynamic parameters might be used are guiding of inotropic and cardiac pacing therapy, dialysis and perioperative management. However, in most clinical situations no or scarce evidence exists on which parameters are the best to monitor and how this should influence therapeutic decisions leading to improved morbidity and mortality. The advantage of

intensive noninvasive monitoring during sepsis seems obvious. Even so, the possibility to prevent infections using noninvasive monitoring during haemodynamic disturbances in acute heart failure and perioperative management is clear.

This new monitor could be used in physiological research and in clinical research to noninvasively assess changes in cardiac output as a surrogate endpoint. Although accuracy and reproducibility have been investigated in some small trials, these should be further assessed thoroughly in various patient groups in different clinical conditions before this technique can be widely used. Moreover, further development to obtain absolute values of cardiac output without invasive calibration might give a substantial added value to the method. Finally, the usefulness in clinical practice has to be investigated in trials to assess applicability and effects on patient management. The new monitor is not hampered by the safety concerns of invasive monitoring and seems to be a promising technique that may be useful both in clinical research and in patient management.

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