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Measurement of blood pressure

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Blood pressure is overwhelmingly the most commonly measured parameter for the assessment of haemodynamic stability. In clinical routine in the operating theatre and in the intensive care unit, blood pressure measurements are usually obtained intermittently and non-invasively using oscillometry (upper-arm cuff method) or continuously and invasively with an arterial catheter. However, both the oscillometric method and arterial catheter-derived blood pressure measurements have potential limitations. A basic technical understanding of these methods is crucial in order to avoid unreliable blood pressure measurements and consequential treatment errors. In the recent years, technologies for continuous non-invasive blood pressure recording such as the volume clamp method or radial artery applanation tonometry have been developed and validated. The question in which patient groups and clinical settings these technologies should be applied to improve patient safety or outcome has not been definitively answered. In critically ill patients and high-risk surgery patients, further improvement of these technologies is needed before they can be recommended for routine clinical use.

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Why and since when do we measure blood pressure?

The first recorded measurement of blood pressure (BP) as a marker of circulation took place in the middle of the 18th century with the experiments of the reverend Stephen Hales in England [1]. He performed direct BP measurements in a horse by inserting a 3-m-high glass tube into an artery and determining the height of the rising blood column. Then he let the horse bleed and repeated the BP measurement. This was performed several times in a row – the BP progressively decreased – until the horse died.

Without a doubt, this physiologic experiment was highly invasive and the applied method impractical for clinical use. Over the course of time, the enthusiastic work and brilliant ideas of a number of great scientists and engineers led to the continuous development of BP measurement devices and BP became the most important vital sign in clinical practice. Nowadays, optimal BP values are targeted during general anaesthesia in the operating theatre, in the treatment of critically ill patients in the intensive care unit (ICU), and for the general prevention of various acute or chronic pathological changes of the human body [2–4]. Retrospective data suggest that a mean BP <55 mmHg, even for a brief duration, increases the risk of acute kidney injury and myocardial injury in patients undergoing general anaesthesia [4], although these findings need to be corroborated prospectively. That said, a prospective randomized controlled trial comparing a mean BP target of 65–70 mmHg to a mean BP target of 80–85 mmHg in septic patients found no difference in the primary outcome although renal replacement therapy was less commonly required in patients with chronic hypertension whose mean BP was maintained at values of ≥80 mmHg [3]. At the same time, several questions concerning BP remain open, for example, the optimal individual BP values during different medical conditions and in different patient groups.

Today, both invasive and non-invasive technologies for BP measurement are available. Understanding the technical basics, advantages, limitations and pitfalls of each method is an essential prerequisite for interpreting BP findings.

The arterial BP waveform

The first device for recording a human pulse wave with a transducer was probably developed in 1855 by the physiologist Karl von Vierordt [5]. A permanent record of pulse curves was obtained by levers on the radial artery and weights to determine the amount of external pressure that was necessary to stop the blood flow in the radial artery. A few years later, Étienne-Jules Marey further developed the method and invented the sphygmograph [6]. The British physician Frederick Akbar Mohamed later described the physiological radial artery BP waveform and laid the foundation for the science of pulse wave analysis (from 1872 to 1884) [7]. Since then, continuous BP recording has progressively improved.

The arterial BP waveform is composed of the different sections of the cardiac cycle. Blood ejection from the left ventricle into the aorta during systole is followed by diastolic distribution of this blood volume towards the periphery. The systolic part of the arterial BP waveform consists of a steep pressure upstroke, peak and decline, representing the phase of left ventricular systolic ejection during the cardiac cycle. The so-called dicrotic notch appears during the downslope of the waveform and is related to aortic valve closure [8]. However, only in cases of direct recording of the waveform from the central aorta, the dicrotic notch agrees timewise with the aortic valve closure while the dicrotic notch of the peripheral arterial BP waveform only approximates the point at which the aortic valve closes and mainly depends on arterial wall properties [9]. The arterial BP waveform then further declines during diastole, finally reaching its lowest point at end diastole.

It is important to keep in mind the effects of physiology and the measurement site (e.g., radial or femoral artery) on its morphological appearance. In fact, three main points must be considered as the fundamental reasons for the waveform to be the shape it is: the closure of the atrioventricular valves, the differences in compliance/stiffness of the artery and wave reflections. These three characteristics together produce the shape of the arterial BP waveform. Because these characteristics differ depending on physiology and age, the arterial BP waveforms differ accordingly. The corresponding differences and similarities have been described in paediatric and elderly patients [5,10]. In the elderly, an increase in the late