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Validation of noninvasive pulse contour cardiac output using finger arterial pressure in cardiac surgery patients requiring fluid therapy

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ABSTRACT

Introduction: Nexfin (Edwards Lifesciences, Irvine, CA) allows for noninvasive continuous monitoring of blood pressure (ABP_{NI}) and cardiac output (CO_{NI}) by measuring finger arterial pressure (FAP). To evaluate the accuracy of FAP in measuring ABP_{NI} and CO_{NI} as well as the adequacy of detecting changes in ABP and CO, we compared FAP to intra-arterially measured blood pressure (ABP_{IA}) and transpulmonary thermodilution (CO_{TD}) in postcardiac surgery patients during a fluid challenge (FC).

Methods: Twenty sedated patients post cardiac surgery were included, and 28 FCs were performed. Measurements of ABP and CO were simultaneously collected before and after an FC, and we compared CO and blood pressure.

Results: Finger arterial pressure was obtainable in all patients. When comparing ABP_{NI} with ABP_{IA}, bias was 2.7 mm Hg (limits of agreement [LOA], ±22.2), 4.9 mm Hg (LOA, ±13.6), and 4.2 mm Hg (LOA, ±13.7) for systolic, diastolic, and mean arterial pressure, respectively. Concordance between changes in ABP_{NI} and ABP_{IA} was 100%. Mean bias between CO_{NI} and CO_{TD} was −0.26 (LOA, ±2.2), with a percentage error of 38.9%. Concordance between changes in CO_{NI} vs CO_{TD} and was 100%.

Conclusion: Finger arterial pressure reliably measures ABP and adequately tracks changes in ABP. Although CO_{NI} is not interchangeable with CO_{TD}, it follows changes in CO closely.

1. Introduction

Maintaining adequate tissue perfusion and oxygenation is of paramount importance during anesthesia and in the critical care environment. Establishing an adequate cardiac output (CO) is an essential determinant of this therapeutic goal. Therefore, over the last decade, there has been an increasing interest in the continuous measurement of CO under various clinical conditions. Thermodilution is the clinical criterion standard for CO measurement [1], but this technique requires the placement of a specific intra-arterial or pulmonary artery catheter that might lead to various complications. Therefore, there is a growing need for minimally invasive and continuous CO monitoring. This new technique should meet the desired requirements of accuracy, operator independence, safety, ease of application, and continuous use [2]. Furthermore, a fast continuous method could be beneficial in tracking CO changes as a result of diagnostic maneuvers and interventions. Although a number of methods are available to measure CO noninvasively, none of these techniques answers to all requirements, and therefore, the method of choice will depend on the physician's experience, the patient, and the clinical situation. The Nexfin device (Edwards Lifesciences, Irvine, CA) measures blood pressure and CO continuously and noninvasively by measuring finger arterial pressure (FAP). The device uses a finger cuff to construct an arterial blood pressure waveform using a technique that is based on the volume clamp method developed by Peňaz and the physiocal criteria of Wesseling et al [3,4]. Nexfin CO-TREK is a mathematical model incorporated in the software that calculates beat-to-beat stroke volume using the arterial blood pressure waveform [5]. This combination enables the continuous measurement of blood pressure and CO in a noninvasive manner. With the application of the CO-TREK algorithm, it is also possible to determine the CO off-line using the invasive blood pressure signal measured with an intra-arterial catheter. A small number of studies has been undertaken to assess the accuracy of FAP CO in determining absolute CO levels with varying results [6-8]. However, an important part of hemodynamic optimization is the effect of a given treatment such as fluid expansion. Therefore, we assessed the accuracy of FAP in tracking CO changes after a fluid challenge (FC).

In this study, we compared CO-TREK CO derived from the noninvasive finger blood pressure signal (CO_{NI}) and CO-TREK CO derived from the intra-arterial blood pressure signal (CO_{IA}) with CO derived from transpulmonary thermodilution (CO_{TD}) using PiCCO (Pulsion Medical Systems, Munich, Germany) as the reference method. We also compared FAP blood pressure (ABP_{NI}) to intra-arterially measured blood pressure (ABP_{IA}).

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2. Methods

2.1. Subjects

With the approval of the institutional review board and after obtaining participants' written informed consent, 20 patients admitted to the intensive care unit (ICU) following elective conventional cardiac surgery were studied. Exclusion criteria were cardiac arrhythmias, preoperative inotropic or intra-aortic balloon pump support, and patients requiring emergency or redo cardiac surgery.

2.2. Hemodynamic monitoring

Anaesthesia was according to the institutional protocol at the discretion of the attending anaesthesiologist. A 20 GA right radial intra-arterial catheter (Becton Dickinson and Co, Franklin Lakes, NJ) was introduced before anesthesia induction and connected via standard low compliant tubing to a disposable pressure transducer (Edwards Lifesciences). After induction, a 2-lumen central venous catheter was inserted in the right internal jugular vein for the measurement of central venous pressure. Cardiac output was monitored using the PiCCO monitor and a 5F thermistor-tipped arterial PiCCO catheter inserted in the femoral artery (Pulsion Medical Systems). All pressure monitors were zeroed at the midaxillary line. Signals were recorded simultaneously using a sample rate of 200 Hz and stored on a hard disk.

2.3. Finger arterial pressure CO monitoring

Finger arterial pressure is a device for noninvasive and continuous measurement of blood pressure using a finger cuff. A photoplethysmograph mounted inside the finger cuff detects changes in finger arterial diameter. Using a fast pneumatic system, the diameter of the finger artery can be held at a constant level by rapidly varying the pressure in the finger cuff air bladder. This is called the volume clamp method. If the artery is clamped at the correct diameter, the pressure in the air bladder is identical to the pressure inside the artery, and finger arterial pressure is measured. The correct arterial diameter is determined at regular intervals during a blood pressure measurement, by a physiological calibration called physiocal [9]. Nexfin applies a waveform and level correction methodology to reconstruct finger arterial pressure to the arterial pressure waveform at brachial artery level [10].

Finger arterial pressure calculates beat-to-beat stroke volume by dividing the area under the systolic portion of the arterial pressure curve by the aortic input impedance [11]. The value of this aortic input impedance is determined from a 3-element Windkessel model described by Westerhof et al [12]. In this model, the nonlinear effect of mean pressure as well as the influence of the patient's age, height, weight, and sex on aortic mechanical properties is incorporated. The algorithm that converts finger arterial waveform to CO is called CO-TREK.

The noninvasive arterial signal (ABP_{NI}) and CO (CO_{NI}) were obtained using an appropriate size finger cuff applied to the midphalanx of the left middle or index finger according to guidelines provided by the manufacturer. The finger with the cuff was positioned at the midaxillary line, and the finger was checked regularly for signs of tissue hypoxia.

To determine whether inaccuracies in the predictive value of the noninvasive finger signal were caused by the noninvasive character of the measurement or were caused by inaccuracies in the CO-TREK algorithm itself, we also calculated CO using the stored intra-arterial blood pressure signal (CO_{IA}). The CO_{IA} was calculated off-line using the CO-TREK algorithm, and we compared this with CO_{TD}.

2.4. Study design

After surgery, patients were admitted to the intensive care unit (ICU) and sedated with midazolam. Finger arterial pressure recording started immediately after arrival at the ICU. FAP measurement was considered adequate if physiocal occurred at intervals longer than 30 seconds. The intra-arterial pressure measurement was checked for quality by visually inspecting the waveform and performing fast slush test. If, at the discretion of the attending intensive care physician, an FC was indicated, a transpulmonary thermodilution measurement was performed by 3 injections of 15 mL of ice-cold saline through the central venous catheter before the FC (T1) and 5 minutes after completion of FC (T2). If a difference of more than 20% occurred between the 3 thermodilution measurements, injection was repeated. Criterion for an FC was presence of a mean arterial pressure below 70 mm Hg. To evaluate the clinical effect of the FC, another thermodilution measurement was performed 30 minutes after completion of the FC if the clinical situation permitted, for example, patient still fully sedated, no change in inotropic medication, and others (T3). The FC was performed by infusing 6 mL per kg ideal body weight of a 130/0.4 6% hydroxyethyl starch solution (Fresenius Kabi, Bad Homburg, the Netherlands) over a period of 15 minutes. Simultaneous data of CO_{TD}, CO_{NI}, ABP_{NI}, and ABP_{IA} were collected throughout the postoperative period in the ICU until the patient was extubated according to local standard operating procedures.

2.5. Statistical analysis

To compare CO_{NI} and CO_{IA} to CO_{TD}, we averaged a 20-second time interval of the noninvasive finger measurement and intra-arterial measurement and compared it with the simultaneously performed CO_{TD}. This interval was chosen to evade periods of physiocal, which occurs at regular intervals during a FAP measurement. The same time intervals were used to compare ABP_{NI} to ABP_{IA}. Hemodynamic parameters were reported as mean $\pm$ SD. The Kolmogorov-Smirnov test was used to test the normality of the distribution. To assess agreement (bias and limits of agreement [LOA]) between the invasive and noninvasive derived parameters Bland-Altman analysis was used, which was corrected for repeated measurements in 1 subject [13,14]. The mean percentage error was assessed using the Critchley and Critchley method [15]. In addition, we defined an agreement tolerability interval ratio using a tolerability interval of 4 L/min (4-8 L/min) [16]. To assess the hemodynamic change that occurred, we compared a time point to the hemodynamic measurement taken earlier, that is, T1 to T2 and T2 to T3. For assessing the trending ability of CO_{TD}, we determined concordance using a 4-quadrant plot. Changes in blood pressure and CO smaller than 5% were not considered clinically relevant and therefore excluded. Hereafter, we constructed a polar plot of CO changes among consecutive time points described by Critchley et al [17,18]. Influence of temperature and use of vasoactive drugs on bias were checked using the Student *t* test. Statistical analyses were carried out using GraphPad Prism version 5.01 (GraphPad software, Inc, La Jolla, CA). Assuming an SD of 1.33 L/min [7], we needed a minimum of 69 simultaneous measurements to achieve a confidence interval of 0.25 L/min. Assuming we would perform 4 measurements in each subject, we included 20 patients.

3. Results

Twenty patients were included in the study. In all patients, a sufficient quality FAP waveform was obtained. There were no signs of tissue hypoxia distal to the finger cuff, and no adverse events were noted. Twenty-eight FCs were performed in 19 patients. One patient did not receive an FC. Because of technical difficulties intra-arterial blood pressure, recording failed in 4 patients, which led to 66 pairs of CO_{NI} and CO_{TD} and 54 pairs of ABP and CO_{NI}, CO_{IA} and CO_{TD} data.