BJA Advance Access published March 3, 2015

British Journal of Anaesthesia Page 1 of 8
doi:10.1093/bja/aev001

Comparison of cardiac output measured by oesophageal Doppler ultrasonography or pulse pressure contour wave analysis

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Editor's key points

- Pulse pressure contour wave analysis of cardiac output (PPCO) is a promising monitoring technique.
- PPCO analysed using 9 novel algorithms was compared with oesophageal Doppler monitoring of cardiac output (DCO) in 62 neurosurgical subjects.
- There were significant differences in bias and concordance between PPCO and DCO depending on algorithm and therapeutic interventions.
- Continuous PPCO monitoring with a specific algorithm could offer advantages compared with DCO alone.

Background. Maintaining adequate organ perfusion during high-risk surgery requires continuous monitoring of cardiac output to optimise haemodynamics. Oesophageal Doppler Cardiac Output monitoring (DCO) is commonly used in this context, but has some limitations. Recently, the cardiac output estimated by pulse pressure analysis- (PPCO) was developed. This study evaluated the agreement of cardiac output variations estimated with 9 non-commercial algorithms of PPCO compared with those obtained with DCO.

Methods. High-risk patients undergoing neurosurgery were monitored with invasive blood pressure and DCO. For each patient, 9 PPCO algorithms and DCO were recorded before and at the peak effect for every haemodynamic challenge.

Results. Sixty-two subjects were enrolled; 284 events were recorded, including 134 volume expansions and 150 vasopressor boluses. Among the 9 algorithms tested, the Liljestrand-Zander model led to the smallest bias (0.03 litre min^{-1} [−1.31, +1.38] (0.21 litre min^{-1} [−1.13; 1.54] after volume expansion and −0.13 litre min^{-1} [−1.41, 1.15] after vasopressor use). The corresponding percentage of the concordance was 91% (86% after volume expansion and 94% after vasopressor use). The other algorithms, especially those using the Winkessel concept and the area under the pressure wave, were profoundly affected by the vasopressor.

Conclusions. Among the 9 PPCO algorithms examined, the Liljestrand-Zander model demonstrated the least bias and best limits of agreement, especially after vasopressor use. Using this particular algorithm in association with DCO calibration could represent a valuable option for continuous cardiac output monitoring of high risk patients.

Clinical Trial Registration. Comité d'éthique de la Société de Réanimation de Langue Française No. 11–356.

Keywords: cardiac output; Doppler; pulse wave analyses

Accepted for publication: 17 December 2014

In high risk surgical patients, haemodynamic monitoring is recommended to maintain suitable organ perfusion.[1] Cardiac output is a key cardiovascular parameter and a major determinant of tissue oxygenation.[2] Continuous measurement is preferable to intermittent measurement, especially in the operating theatre when rapid changes in cardiovascular function are often observed. Alternative minimally invasive methods for continuously monitoring cardiac output have then been developed. Two continuous monitors are more frequently used: 1) the oesophageal Doppler method (DCO), and 2) the pulse pressure contour method (PPCO). DCO is accurate in the operating theatre;[3] however, this technique has limitations, including its inability to monitor a continuous signal during surgical haemostasis as a result of electrical interference and lack of access to the mouth in oral surgery and neurosurgery. PPCO is minimally invasive and not operator dependent.

A method of calculating stroke volume from the contour of the arterial pressure curve was first described in 1899.[4] PPCO is based on the hypothesis that the waveform of blood pressure is directly related to the variation in the stroke volume. Many algorithms have been proposed: some make a comparison with a closed hydraulic or electric circuit, such as the

Windkessel concept, and others analyse the area under the systolic portion of the arterial pressure waveform. Algorithm validity has been verified in a variety of patients and circumstances, but performance could be compromised in the presence of haemodynamic instability, cardiac arrhythmias, or other factors that disturb the arterial pressure waveform, particularly during vasopressor use.[5 6] To increase the reliability of PPCO, some commercial systems have calibrated their algorithms using thermodilution.[5] A prototype for continuously monitoring cardiac output was recently introduced (CombiQ®, Deltex Medical, Chichester, Sussex, UK) that combines oesophageal Doppler and PPCO and includes 9 algorithms to estimate cardiac output after calibration using the DCO value according to a study by Sun and colleagues.[7] The present study compared, in patients under general anaesthesia, the agreement of cardiac output measurements obtained using 9 non-commercial algorithms of PPCO with measures of cardiac output obtained using DCO alone used as a reference. We also analysed variations in cardiac output during haemodynamic challenges, including volume expansion or administration of a vasopressor bolus.

Materials and methods

This prospective, non-interventional, non-randomized study was conducted in neurosurgical patients under general anaesthesia, between November 2011 and July 2012, in the Department of Anaesthesiology at Lariboisière University Hospital (Paris, France). This study was approved by the institutional ethics committee (Comité d'éthique de la Société de Réanimation de Langue Française No. 11–356). All subjects gave written informed consent. Haemodynamic monitoring, including invasive blood pressure and DCO, represented the usual care of patients undergoing neurosurgery with reduced cerebral compliance and/or potential bleeding in our institution. The exclusion criteria were age <18 yrs, pregnancy, contraindication to the use of DCO and chronic cardiac arrhythmia.

Study protocol

All subjects were orally premedicated with hydroxyzine (1 mg kg^{-1}) 1 h before surgery. Anaesthesia was induced with propofol and remifentanil target controlled infusion. Tracheal intubation was facilitated with a atracurium 0.5 mg kg^{-1}, and mechanical ventilation used the volume-controlled mode, with tidal volumes of 7 ml kg^{-1} with positive end-expiratory pressure of 5 cm H_2O and a respiratory rate of 12–16 breaths min^{-1} to maintain end tidal CO_2 of approximately 4.7 Kpa.

After induction of anaesthesia, a radial arterial line and DCO probe were inserted. Both were connected to CombiQ® (Deltex Medical Ltd.). DCO values were averaged over 5 cardiac cycles.

Haemodynamic management

Mean arterial pressure (MAP), measured the day before the surgical intervention, was considered to be the MAP of reference (MAPref). According to our standard of care, a decrease in MAP>20% of MAPref led to a therapeutic intervention according to the choice of the physician in charge: including a fluid challenge (250 ml of saline in 10 min) or a bolus of vasopressor. Three different vasopressors were available according to the choice of the physician (bolus of 50 mcg of phenylephrine, 5 mcg of norepinephrine or 9 mg of ephedrine).

Data collection

After zeroing the system to atmospheric pressure, the arterial pressure waveform was carefully checked using a fast flush test to ensure optimal harmonics of the arterial pressure measurement system. The arterial pressure signal was transferred from the bedside monitor to the DCO system using a serial cable. Nine nonproprietary PPCO algorithms built into the CardioQ-Combi software provide continuous cardiac output values. The 9 PPCO algorithms are described in Table 1 and in the Supplementary material. Haemodynamic data were automatically recorded by the monitor every 5 s. Initial calibration of the PPCO was performed using the DCO value before any intervention and after stabilizing heart rate and arterial pressure (<5% variation over a 1-min period). Each therapeutic event was automatically recorded on the monitor using two predefined categories: fluid challenge or vasopressor bolus. The peak effect of the therapeutic action was recorded 5 min after the fluid challenge or at the peak MAP after administration of vasopressor.

Statistical analysis

The results are expressed as mean (SD) or as median (interquartile range [IQR]), depending on normal distribution of the

Table 1 Characteristics study subjects

Characteristics	All subjects (n =62) (%)
Gender (Male/Female)	26 (42)/36 (58)
Age (yrs)	54 [39–65]
BMI (kg m^{-2})	25 [21–29]
American Society of Anesthesiologists Physical Status	
1	11 (18)
2	36 (73)
3	6 (10)
Comorbidities	
History of hypertension	21 (34)
Chronic heart failure	3 (5)
Coronary artery disease	1 (2)
Chronic obstructive pulmonary disease	21 (34)
Diabetes mellitus	5(8)
Type of surgery	
Cerebral tumour	52 (84)
Aneurism	4 (6)
Spine surgery	4 (6)
Other	2 (3)
Duration of surgery (min)	335 [248–440]
Perioperative fluid administration (ml)	3512 [3750–4500]
Perioperative bleeding (ml)	221 [100–363]
Perioperative diuresis (ml)	957 [500–1350]