Abstract

Central venous pressure (CVP) monitoring is used to assess the fluid status of patients in critical care settings. This article explains CVP monitoring, discussing the rationale for its use, the ways CVP can be measured, and the physiological factors that can affect the reliability and validity of CVP measurement. It also discusses the complications associated with CVP monitoring and the nursing responsibilities in relation to this activity.

Keywords

acute care, cardiovascular assessment, central venous pressure, critical care, haemodynamic monitoring, pressure transducer

THE INSERTION OF a central venous catheter (CVC) to measure central venous pressure (CVP) is an invasive method of assessing patients’ fluid status in critical care settings. A CVC is a catheter with a tip that lies within the proximal third of the superior vena cava, the right atrium, or the inferior vena cava. These catheters can be inserted through a peripheral vein or a proximal central vein (Smith and Nolan 2013). CVP can be monitored electronically by connecting the CVC to a cardiac monitor, allowing a transduced waveform to be seen alongside a regularly updated numerical value. This is particularly useful in critical care settings because such patients frequently have a CVC in situ, which can be easily connected to a cardiac monitor to measure CVP. CVP can also be measured manually using a water manometer; however, this method is now rarely used in clinical practice.

This article will discuss the role and value of CVP in clinical practice, while noting that it does not necessarily reflect either intravascular volume status or pressures in the left side of the heart, and so it has limitations in the acute stages of critical illness (Adam et al 2017).

Non-invasive methods for CVP may be used outside of critical care settings, for example by assessing the jugular venous pressure, peripheral venous collapse, and ultrasound visualisation of the inferior vena cava (Bickley 2017).

Critical care settings where CVP monitoring is undertaken include: high dependency units; intensive care units; emergency departments, typically in the resuscitation room; and operating theatres, during major surgical interventions (Department of Health 2000). Cole (2007) suggested that CVP monitoring has also been performed outside of critical care settings, for example in acute wards, because of a shortage of beds in high dependency and intensive care units. However, it should be noted that this is not best practice.

CVP monitoring should only be undertaken by healthcare practitioners who have the appropriate knowledge and skills to do so. The National Confidential Enquiry into Perioperative Deaths (2001) recommended that nursing and medical staff must be trained adequately to undertake CVP monitoring. This is particularly important in acute surgical wards, because it has been demonstrated...
that there is a link between patient deterioration and suboptimal fluid therapy pre-surgery and post-surgery (Foëx and Sear 2004). The Code: Professional Standards of Practice and Behaviour for Nurses and Midwives (Nursing and Midwifery Council (NMC) 2015) requires that nurses must work within their scope of practice at all times. Therefore, if nurses are expected to undertake CVP monitoring, they must have the required skills, knowledge and clinical competence to do so, practising in accordance with the best available evidence.

Rationale for central venous pressure monitoring

CVP monitoring is the measurement of pressure generated in the right atrium, or within the superior vena cava (Gilbert 2015). The CVP equates to the pressure at the end of diastole in the right side of the heart (the right ventricular end-diastolic volume) (Adam et al 2017). This is known as the ‘preload’ and represents the ‘filling pressure’ of blood returning to the right atrium (Woodrow 2002, Magder 2015). The Centre for the Advancement of University Teaching (2005) suggested that in healthy patients, the mean right atrial pressure (estimated CVP) closely resembles the mean left atrial pressure. In turn, during diastole, the left atrial pressure is assumed to equal left ventricular end diastolic pressure, which is thought to reflect left ventricular end diastolic blood volume (Magder 2015). Thus, the patient’s CVP is assumed to reflect left ventricular preload.

CVP monitoring enables cardiovascular assessment and haemodynamic monitoring. It supports clinical decision-making regarding a patient’s fluid status, enabling healthcare practitioners to consider ways of optimising the patient’s blood pressure and mean arterial pressure, with the aim of improving the perfusion and oxygenation of the body’s vital organs (Vincent et al 2011).

The normal CVP in a healthy person is 3-6mmHg (Adam et al 2017); however, healthcare practitioners should be aware that this range may vary between texts. In critically ill adult patients, the CVP will be manipulated with intravenous (IV) fluid to assist in optimising perfusion of the vital organs, depending on the patient’s presenting condition – for example when optimising fluid balance in acute kidney failure or when sepsis is suspected (Scales 2010, Rhodes et al 2017). IV fluids are prescribed, generally with a CVP target range, and given in bolus doses and cautiously to achieve the target. The response of the CVP to IV fluids should be monitored and will vary depending on a variety of factors, such as current fluid status and the presence of any degree of heart failure.

While CVP monitoring is beneficial, Kumar et al (2004) and Marik et al (2008) recommended that it should not be used in isolation when assessing fluid status, and should not independently guide fluid resuscitation or fluid management. Alongside CVP monitoring, nurses should also examine non-invasive signs of suboptimal circulating volume to ensure adequate tissue perfusion, including blood pressure, heart rate, capillary refill time and urine output (Bickley 2017). Nonetheless, CVP monitoring continues to be used to support clinical assessment and decision-making for critically ill patients (Vincent et al 2011).

Limitations of central venous pressure monitoring and alternative methods

There are several limitations associated with CVP monitoring. For instance, Marik et al (2008) and Marik and Cavallazzi (2013) stated that CVP does not necessarily predict the response of cardiac output to the administration of a fluid bolus in critically ill patients, while Cole (2008) suggested that several factors can affect CVP, including vessel tone, medicines, heart disease and medical treatments.

Adam et al (2017) advised caution in the use of CVP monitoring, stating that in many critically ill patients, particularly...
those with pulmonary disease or isolated right or left heart dysfunction, the measurement of right atrial pressure does not provide an accurate indication of the function of the left side of the heart. In such cases, other methods should be considered that may provide a more reliable indication of the cardiac haemodynamic parameters of the left side of the heart than CVP. These methods include the Pulse Contour Cardiac Output (PiCCO) system and the Lithium Dilution Cardiac Output (LiDCO) method (Adam et al 2017), or use of the more invasive pulmonary artery catheter.

The PiCCO system is less invasive than a pulmonary artery catheter, and involves the use of a peripheral arterial thermodilution catheter and large-bore peripheral or central venous access. The LiDCO method is also less invasive than the pulmonary artery catheter and requires only an arterial line and a CVC (Adam et al 2017). Because of the risk of arrhythmias, valve damage and ventricular perforation, a pulmonary artery catheter is only used on the rare occasions when arterial access with PiCCO or LiDCO is not possible. However, it remains the gold standard for measuring cardiac output to which all other monitors are compared (Scottish Intensive Care Society 2017).

While the use of CVP monitoring has limitations in clinical practice, it can be a useful part of a wider holistic assessment of the patient. The normal value is wide, therefore it is the trend of the CVP readings that is important in a patient assessment.

**Insertion sites**

A CVC has a single lumen or multiple lumens, providing vascular access for medicines, fluids and monitoring. A Cochrane review by Lai et al (2016) identified that CVCs impregnated with various forms of antimicrobials – either an antiseptic or antibiotics – reduced bloodstream infections by 2%, and are therefore preferable when selecting a suitable catheter. The CVC is inserted by a competent healthcare practitioner – usually an anaesthetist or other medical practitioner – and positioned within the internal jugular vein, subclavian vein or via the femoral vein (Adam et al 2017). It is advanced inside or as close to the right atrium as possible. There is a rationale for each insertion site, so this should be selected based on the individual patient and their condition; for example (Cole 2007):

» Internal jugular vein – this has a high rate of successful insertion. However, occlusion can occur with head movement. The right side is the most commonly used and is considered to have the highest rate of successful insertion.

» Subclavian vein – this has the lowest infection risk, and is said to be the most comfortable for the patient. However, because of its anatomical position below the clavicle, it is associated with a high risk of pneumothorax.

» Femoral vein – this is usually the least frequent site used to insert a CVC. However, this site may be required for patients with acute neurological injuries such as traumatic brain injury, raised intracranial pressure or head trauma, since the femoral vein is furthest away from cerebral blood flow and will therefore not affect intracranial pressure. Pacheco et al’s (2008) study on CVP during cardiac surgery concluded that CVP could be measured accurately in the femoral vein during the immediate post-operative period of heart surgery. However, femoral lines have a high risk of infection, generally as a result of faecal contaminants, sweat and moisture (Cole 2007), and are challenging to maintain, partly because they often have to be covered by a sheet to preserve the patient’s dignity. This creates a risk that any disconnection of the line may not be immediately identified.

**Methods of measuring central venous pressure**

CVP can be measured electronically in mmHg or manually in cmH₂O; however, it is now rare for the manual method to be used in clinical practice. In both methods, the patient should lie flat in the supine position during CVP measurement.
Electronic central venous pressure measurement

Electronic CVP readings are generated by using a pressure transducer, and displayed on a cardiac monitor as a continuous waveform alongside a numerical CVP value. Figure 1 shows CVP monitoring using a pressure transducer.

The equipment required to measure CVP electronically is often assembled in a pre-prepared kit containing the relevant disposable transducer board, tubing to connect the CVC and a three-way tap. A valve port will also be required. It will be necessary to administer IV fluid using a pressure bag to prime the line of the transducer with fluid to ensure it contains no air and is patent. Initially, the transducer requires a pressure bag inflated up to 300mmHg. According to Hignett and Stephens (2006), this pressure will deliver 3-4mL of IV fluid continuously through the system to maintain catheter tip patency and prevent the development of clots in the distal lumen. Either 500mL or 1L of IV fluid – usually 0.9% or 0.45% sodium chloride – should be prescribed and hung on an IV stand. The required size will be specified on the pressure bag. IV fluids should be maintained at more than one quarter bag full to prevent issues such as damp trace, low and/or inaccurate readings, loss of patency, air in the fluid or system and clots around the CVC tip (Hignett and Stephens 2006, Cole 2008). ‘Damp trace’ is the colloquial term for a trace that does not have the clear characteristic elements of the CVP waveform, as a result of disruption of the transduced pressure.

The tubing is attached to the CVC and the cardiac monitor, so that the CVP waveform and numerical value can be displayed. Most cardiac monitors will have a CVP block attachment, and the healthcare practitioner will select ‘CVP’ from the monitor menu and turn the CVP function on. A CVP line will appear on the screen. The healthcare practitioner should ensure that the three-way tap, which is part of the transducer kit and slotted into the transducer board, is positioned in line with the patient’s phlebostatic axis – the midaxillary line at the fourth intercostal space (Figure 2). This is the approximate level of the right atrium and is regarded as the ‘zero’ point above which the CVP is measured. A spirit level is often used to ensure this is achieved.

The healthcare practitioner should then turn the three-way tap to close it to the patient, and open it to air – this may require removing a cap from the three-way tap. They should then press the CVP ‘zero’ button on the cardiac monitor to calibrate the equipment. A flat ‘zero’ line will appear on the monitor after a few seconds. The three-way tap is then reopened to the CVC line and patient. This process of zeroing the CVP maintains an accurate reading. The CVP must be zeroed on the monitor before and after actions that may affect the reading, such as fluid boluses administration, altered inotrope infusions, changes in mechanical ventilation or bed position, and after repositioning the patient (Cole 2008).

The CVP waveform can be selected and labelled on the patient’s cardiac monitor, and have a colour code applied for ease of identification and in line with local policy.

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**Figure 1. Central venous pressure monitoring using a pressure transducer**

Cardiac monitor
Electrocardiogram
Pressure bag
Drip chamber
Roller clamp
Valve port
Central venous catheter
Pressure tubing
Transducer board

[Diagram showing the components of central venous pressure monitoring using a pressure transducer.]
The CVC must be free from any kinks or obstructions to produce a clear and reliable waveform. Figure 3 shows a normal CVP waveform and its characteristic elements.

When selecting a CVC lumen to connect the transducer tubing to, it is advised that the most proximal lumen of the CVC is the most suitable measurement port (Lake et al 2011). This port should be a dedicated CVP transducer line only, which is labelled and dated in accordance with local policy and national guidelines (Loveday et al 2014). Attaching additional fluids to the CVP transducer port will distort the reading. It is advised that the CVC remains in situ for a maximum of seven days, unless infection or inadequate access occurs, in which case the CVC should be changed as soon as possible (The Joint Commission 2013, Loveday et al 2014). This is to reduce the risk of infection, sepsis and thrombus formation. The IV bag and tubing leading to the CVC should be changed every 72-96 hours (Loveday et al 2014), and/or in accordance with local policy and procedures.

**Manual central venous pressure measurement**

Manual CVP measurement is rarely used in clinical practice. It involves the use of a water manometer and a three-way tap, rather than a pressure transducer or cardiac monitor. The manometer consists of an ordinary IV infusion interrupted by a vertical infusion line attached to an IV stand, which runs alongside a tape measure in centimetres. The three-way tap is attached to the vertical manometer tape measure at the 0cm starting point, which is then secured to the IV stand. The CVP is measured by aligning the base of the three-way tap to the phlebostatic axis. A spirit level is often used for alignment. The three-way tap should then be turned off to the patient. The manometer can be carefully filled with saline from the IV fluid bag to just above what the CVP is estimated to be in cmH\textsubscript{2}O. It should be noted that this IV bag is not under pressure, and when CVP is not being measured, it acts as a normal IV infusion to keep the CVC patent. Next, the three-way tap should be opened to the patient. The fluid level inside the manometer will gradually fall until it equals the pressure in the central veins, as a result of gravity. This is the CVP numerical value, which is a single figure rather than a continuous waveform.

When the manometer is not being used, the three-way tap should face north, thus turned off to the vertical manometer and allowing the line to function as a normal IV infusion. When measured manually at the phlebostatic axis, the normal range for CVP is 5-10cmH\textsubscript{2}O (Cole 2008).

**Factors affecting central venous pressure measurement**

The relationship between CVP, cardiac output and the vascular system is complex, making CVP readings complicated to
interpret in relation to general cardiac functioning (Reems and Aumann 2012). To understand this relationship and accurately interpret CVP readings, the healthcare practitioner should continue to gain a wider knowledge of the use of CVP in clinical practice and its role in managing specific conditions such as hypovolaemia, cardiac failure and sepsis.

Factors that affect CVP measurement include: peripheral vasodilation and hypovolaemia, leading to reduced venous return in the vena cava and a decreased CVP; right ventricular failure and hypervolaemia, leading to an increased CVP; tricuspid regurgitation; pulmonary stenosis; and pulmonary hypertension (Woodrow 2011, Adam et al 2017).

There are several other factors that affect the reliability and accuracy of CVP readings. For example, in critical care settings, an important influence is mechanical ventilation. Mechanical ventilation creates a positive pressure in the thorax, leading to increased intrathoracic pressure. This can lead to decreased venous return, which will decrease preload and affect CVP measurement (Hall and McShane 2013).

An additional physiological principle that should be considered is transmural pressure (intracardiac and intrathoracic pressure differences). Factors that might affect the transmural pressure include plural effusion, cardiac tamponade, and increased intra-abdominal pressure. Consequently, transmural pressures may lead to increased CVP readings (Watson and Wilkinson 2012). CVP readings can also be affected by the patient’s body position. While lying flat in the supine position is recommended to ensure consistent readings, healthcare practitioners should be aware that this position may increase venous return, thereby increasing CVP.

Because of the range of factors that can affect CVP, it is essential that a thorough and systematic ABCDE (airway, breathing, circulation, disability, exposure) assessment of the patient is undertaken to provide context for CVP measurements (Resuscitation Council (UK) 2014).

A low CVP reading is indicative of decreased circulating volume, which can be the result of (Rhodes et al 2017):

» Hypovolaemia from active bleeding (haemorrhage).
» Decreased cardiac output.
» Infection such as sepsis.
» Excessive diuresis (polyuria).
» Hyperglycaemia causing osmotic diuresis, diabetes mellitus, diabetic ketoacidosis and hyperosmolar hyperglycaemic state (a serious condition caused by severe hyperglycaemia in type 2 diabetes, with blood glucose levels above 33mmol/L).
» Diabetes insipidus, causing deficiency in antidiuretic hormone.
» Hyperthermia and hypothermia, which have also been noted to increase polyuria.
» Bradycardia-induced decreased cardiac output.
» Certain medicines, including: chemical paralysing agents, such as atracurium besilate; beta-blockers, such as atenolol and bisoprolol fumarate; calcium channel blockers, such as amlodipine; and cardiac glycoside, such as digoxin (British National Formulary 2017).

Complications in relation to central venous pressure monitoring
Complications in relation to CVP monitoring generally occur during insertion, but can also be caused by: inappropriate handling techniques, which increase the risk of CVC infection; inappropriate or insecure caps on the lumens attached to the catheter; leaving any valve ports open, which can result in blood loss; and suboptimal monitoring, for example not maintaining flush bag pressure. Such issues can result in complications such as haemorrhage, air embolism, pneumothorax, catheter displacement, cardiac arrhythmias, and CVC and bloodstream infections (Cole 2008).

The epic2 guidelines (Pratt et al 2007) stated that approximately three in every 1,000 patients admitted to hospital in the UK acquires a bloodstream infection, and that nearly one third of those are related
to central venous access devices, such as CVCs. These guidelines also suggest that severe infections can lead to multiple organ failure and death. Therefore, appropriate hand antisepsis and aseptic non-touch technique are required when using CVCs, including when changing catheter dressings (Loveday et al 2014).

In relation to air emboli, the Royal College of Anaesthetists (2016) published a safety notice following the death of a patient from an air embolism. The coroner’s court reported that the patient had died because a nurse had left the CVC port open, which had resulted in an air embolism and cerebral infarction. It was highlighted that the nurse did not understand the risks of leaving a port open. The Royal College of Nursing (2016) Standards for Infusion Therapy state that under no circumstances should the caps of any ports be left open or exposed.

Nursing responsibilities
Where possible, nurses involved in CVP monitoring should obtain informed consent from the patient for the procedure and provide information about its purpose (NMC 2015). Nurses should ensure that up to 300mmHg pressure is maintained to the transducer pressure bag for it to deliver 3-4mL of 0.9% or 0.45% sodium chloride per hour, to maintain patency and an optimised CVP waveform (Cole 2008). The CVP waveform (Figure 3) must also be observed frequently to identify abnormal trends and initially investigate possible equipment errors (Cole 2008).

Nurses should ensure that the transducer board is secured and is at the correct anatomical position, and that all connections are secure (Cole 2008). It is important that nurses understand that, to maintain an accurate CVP reading, it is crucial to ‘zero’ the CVP before and after fluid boluses are administered, altered inotrope infusions, changes in mechanical ventilation, changes in bed position and after repositioning the patient (Cole 2008).

The nurse should observe the CVC insertion site frequently for signs of infection. If this is suspected, the nurse should be aware that a septic screen should be completed (Loveday et al 2014). Blood cultures can be taken from the CVP line by a competent healthcare practitioner or the nurse could send the CVC tip to the laboratory for microscopy, cultures and sensitivities, in accordance with local policies and procedures. In these cases, advice must be sought from an appropriate healthcare practitioner, such as a senior doctor.

Nurses should adhere to local policies and procedures for CVP monitoring, as well as infection prevention and control procedures (Loveday et al 2014). They should also be aware of the importance of using aseptic non-touch technique when using CVCs and avoiding ‘never events’. According to NHS England (2015), never events are serious incidents that are preventable, and include air embolism as a result of ports not being capped. To avoid the occurrence of never events, national guidance and safety recommendations are available that provide strong systemic protective barriers, which should be implemented in all healthcare organisations.

Conclusion
CVP monitoring in critical care settings is complex and requires nurses to have an understanding of the rationale for its use, as well as its limitations. For nurses to measure, interpret and record CVP accurately, it is important for them to consider the patient’s wider clinical context. A systematic approach to patient assessment should be used to gain a holistic understanding of the numerical data obtained from a CVP measurement. CVP should be monitored in a safe, appropriate environment, and ideally electronically using a pressure transducer and a cardiac monitor, to generate a CVP waveform that can be observed and evaluated. The nurse should ensure that aseptic non-touch technique is used when using CVCs, and that steps are taken to avoid never events. Nurses undertaking CVP monitoring are required to work within their scope of practice, ensuring that they practise in line with the best evidence available, and adhere to local and national guidelines.