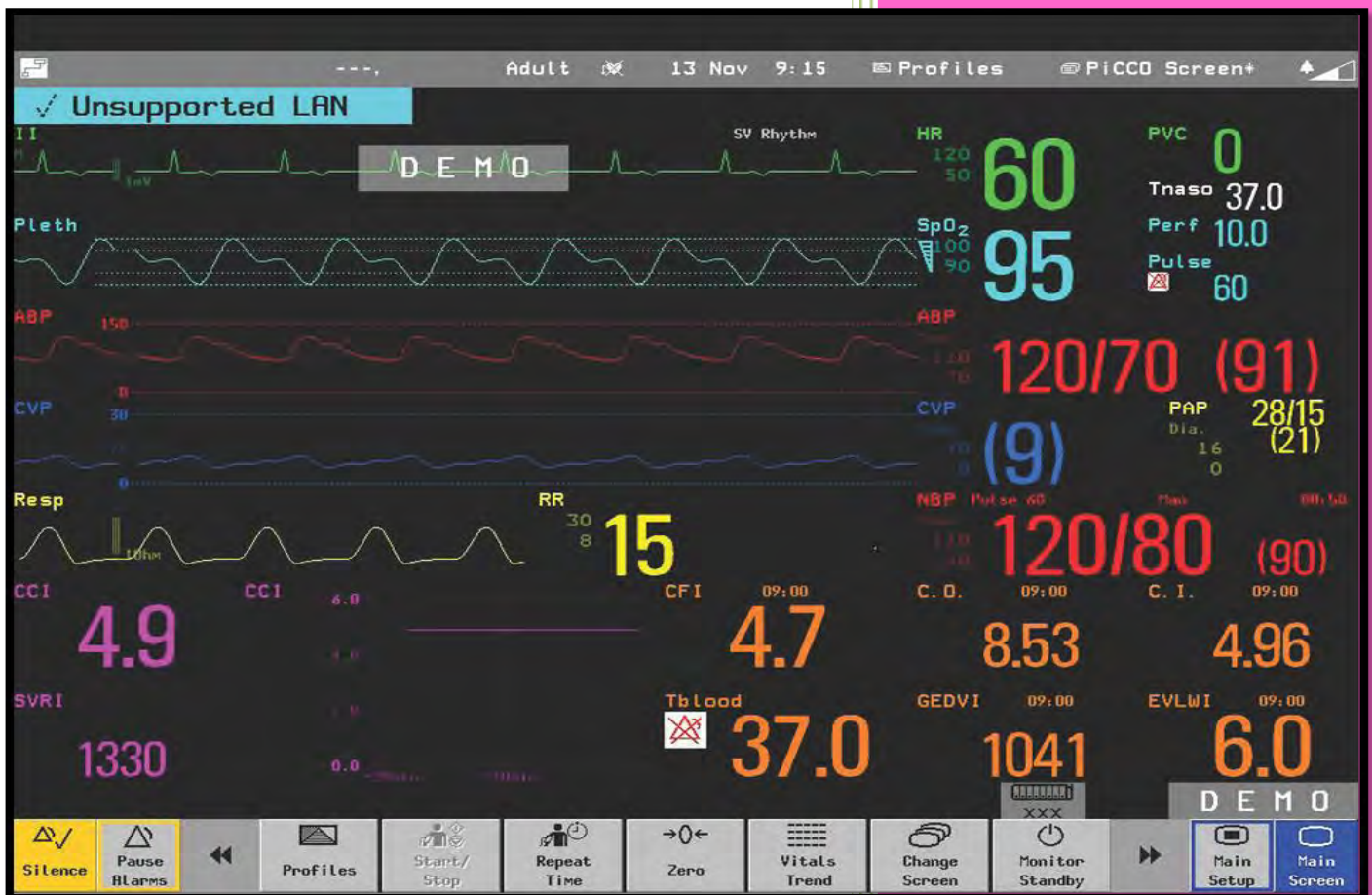


2016

PULSE CONTOUR CARDIAC OUTPUT (PICCO) LEARNING PACKAGE



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INTRODUCTION

PiCCO is an acronym for Pulse Contour Cardiac Output. It enables assessment of the patient's haemodynamic status to guide fluid or vasoactive drug therapy.

PiCCO uses a combination of two techniques for advanced haemodynamic and volumetric monitoring

- Transpulmonary thermodilution
- Pulse contour analysis

The thermodilution technique calculates volumetric measurements of preload and cardiac output.

Pulse contour analysis provides continuous cardiac output and stroke volume variation.

PiCCO requires the insertion of a central venous pressure (CVP) catheter and a thermodilution arterial line. The arterial line can be placed in the axillary, brachial, femoral or radial artery, although radial insertion requires a longer catheter.

PiCCO not only gives information about cardiac output but can give measurements to assess preload, contractility, afterload and extravascular lung water.

Although these measurements are derived from calculations they can be used in combination with clinical assessment.

HAEMODYNAMIC CALCULATIONS: DEFINITIONS

CARDIAC OUTPUT (CO)

- CO is a measurement of cardiac function
- It can be used to assess the degree of cardiac compromise and response to therapies
- It is the amount of blood ejected by the left ventricle per min
- It is determined by heart rate x stroke volume

STROKE VOLUME

- Amount of blood ejected from the heart with each contraction
- Influenced by preload, afterload and contractility

PRELOAD

- Amount of stretch or volume on heart before contraction
- Reflects the volume status of the patient
- The preload that provides optimal cardiac output varies from each patient and is dependent on ventricular function

AFTERLOAD

- Resistance the left ventricle must overcome to circulate blood
- Is the impedance to left ventricular contraction, is assessed by measuring systemic vascular resistance (SVR)
- It is the degree of constriction or dilatation of the arterial circulation

CONTRACTILITY

- Is the ability of the myocardial muscle fibres to shorten independent of preload and afterload
- It is the ability of the heart to contract and the force it needs to do so

INDICATIONS FOR PiCCO

- Shock: cardiogenic, hypovolaemic, septic
- Sepsis
- Trauma
- Pulmonary oedema
- Acute lung injury
- Burns
- Any condition that requires assessment of haemodynamic and/ or volumetric function

HOW DOES PiCCO WORK

PiCCO uses a combination of two techniques for advanced haemodynamic and volumetric monitoring

- Transpulmonary thermodilution
 - Pulse contour analysis
- PiCCO is intended for monitoring of haemodynamic variables to aid cardiovascular management and support in critically ill patients with circulatory compromise.⁶
 - The PiCCO system continually estimates the stroke volume from the arterial waveform, using the arterial catheter⁶, following an initial calibration process using thermodilution
 - The initial transpulmonary thermodilution calibrates the parameters & the algorithm is then capable of computing each single stroke volume
 - Provides continuous beat by beat parameters which are obtained from the shape of the arterial pressure wave.
 - The area under the arterial curve during systole, minus the background diastolic area, is assumed to be proportional to the stroke volume. Cardiac output is then derived from the stroke volume and heart rate.
 - PiCCO measures volume status by calculating Intrathoracic Blood Volume (ITBV) and extravascular lung water (EVLW) through transpulmonary thermodilution.⁶
 - An added advantage of PiCCO is the ability to measure EVLW and alert clinicians to early development of pulmonary oedema.⁶
 - Clinical data obtained from PiCCO is used to guide clinical management of the patient through volume loading, volume reduction and use of inotropes/ vasopressors.⁵

TRANSPULMONARY THERMODILUTION

- Injection of cold saline through a CVC.
- Mixes with the blood volume & passes through the R) heart, through the pulmonary vessels & back through the L) heart
- Just after the L) heart the arterial line measures the drop in blood temperature & from this we obtain a Thermodilution Curve
- Using the Stewart-Hamilton Equation the area under this curve = CO

Stewart Hamilton equation

T_b injection

$$CO_{TDA} = \frac{(T_b - T_i) \cdot V_i \cdot K}{\int \Delta T_b \cdot dt}$$

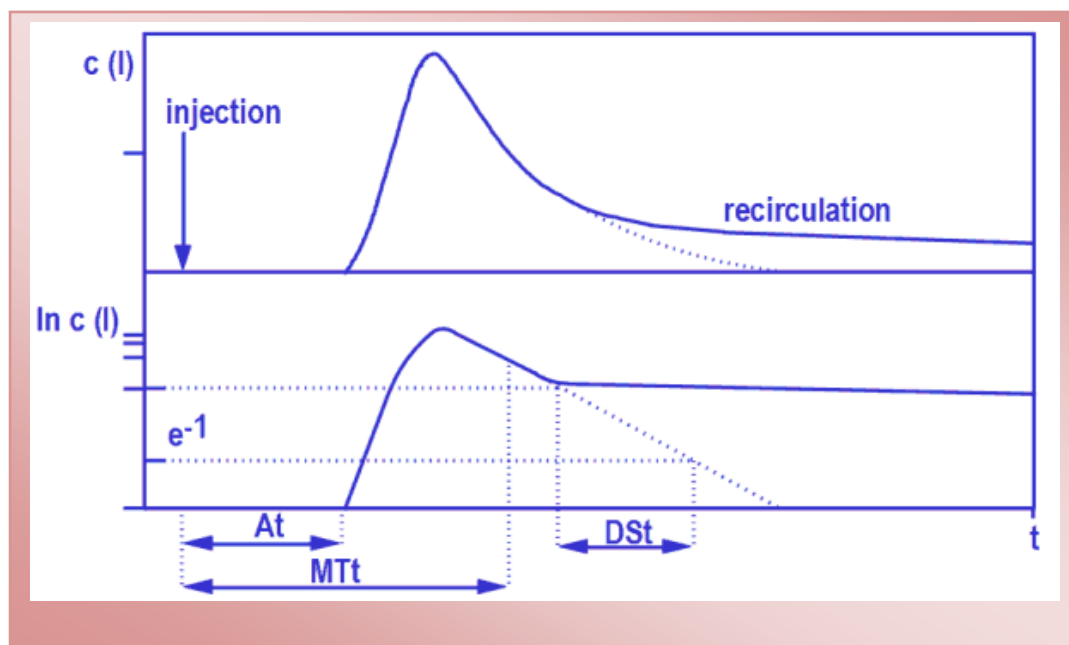
CO Calculation:
→ Area under the
Thermodilution Curve

T_b = Blood temperature
 T_i = Injectate temperature
 V_i = Injectate volume
 $\int \Delta T_b \cdot dt$ = Area under the thermodilution curve
 K = Correction constant, made up of specific weight and specific heat of blood and injectate

Adapted Pulsion Medical 2008

Transpulmonary thermodilution: Volumetric parameters

All volumetric parameters are obtained by advanced analysis of the thermodilution curve: Below shows the graph of change in temp (inverted) against time



Adapted Pulsion Medical

MTt= Mean Transit time: half the indicator has passed the point of injection in the artery
DSt= Down slope time: the exponential time of the down slope curve

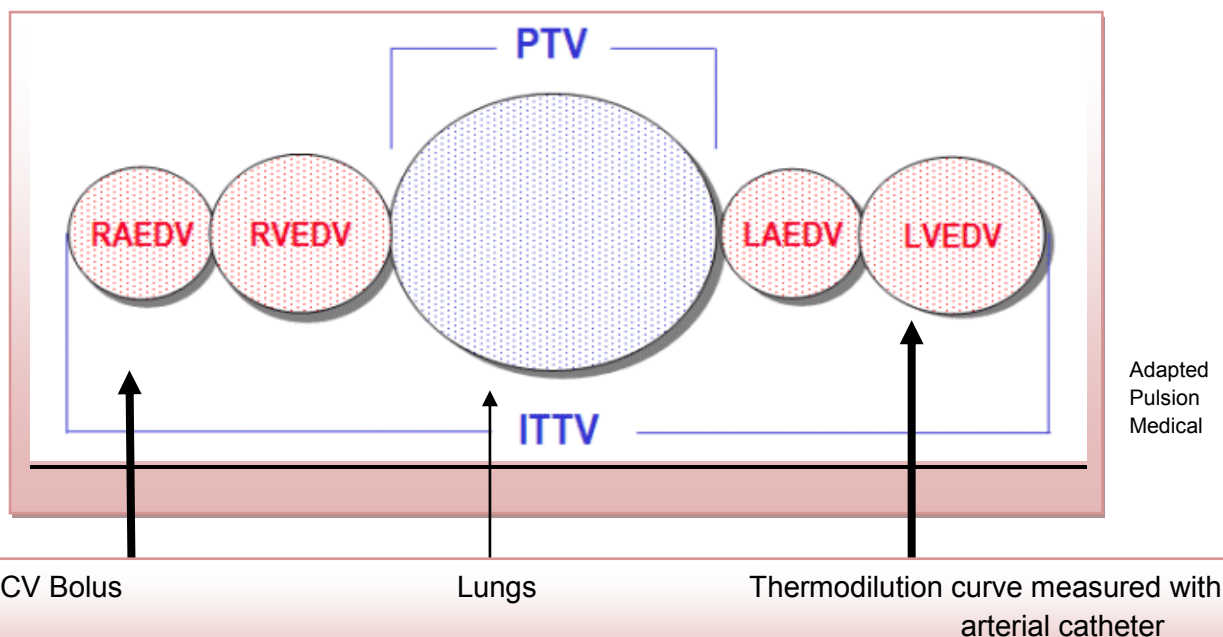
Firstly cardiac output is calculated from the Stewart Hamilton equation i.e. the area under the top graph.

You have a value for the Cardiac output in volume/per unit interpreting the bottom graph gives you some values (MTt and DSt) in seconds.

The product of volume/unit time x time= volume.

- The product of CO X MTt represents the total volume traversed by the indicator i.e. total volume between site of injection and detection.
- The greater the volume the bolus has to travel through the longer it will take.
- The product of CO x DSt represents the largest individual mixing volume in a series of indicator mixing chambers.

After injection, the indicator passes the following intrathoracic compartments:



ITTV= Intrathoracic thermal volume and is the sum of all the volumes in diagram

PTV= Pulmonary thermal volume

RAEDV= Right atrial end diastolic volume

RVEDV= Right ventricular end diastolic volume

LAEDV= Left atrial end diastolic volume

LVEDV= Left ventricular end diastolic volume

The intrathoracic compartments can be considered as a series of “mixing chambers” for the distribution of the injected indicator (intrathoracic thermal volume).

The largest mixing chamber in this series are the lungs, here the indicator (cold) has its largest distribution volume (largest thermal volume).

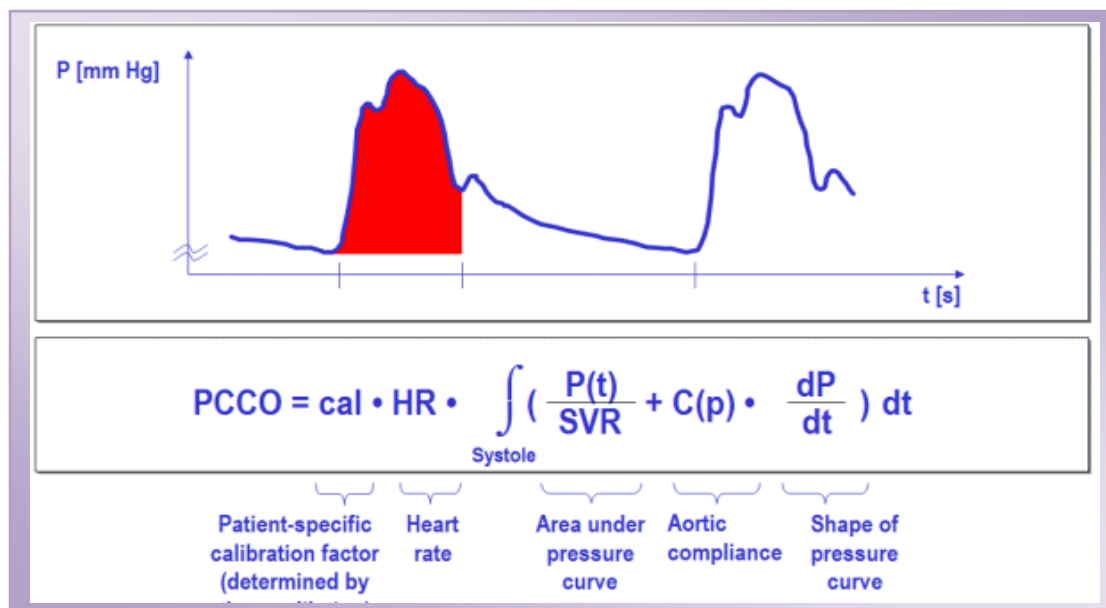
PULSE CONTOUR ANALYSIS: Continuous analysis

- The PiCCO system continually estimates the stroke volume from the arterial waveform, using an arterial catheter.
- Cardiac output is then estimated from the stroke volume and heart rate.
- Provides continuous beat by beat parameters which are obtained from the shape of the arterial pressure wave
- The area under the arterial curve during systole, minus the background diastolic area, is assumed to be proportional to the stroke volume. This means that the stroke volume and thus the cardiac output can be measured beat to beat.
- The initial transpulmonary thermodilution calibrates the parameters & the algorithm is then capable of computing each single stroke volume
- Continuous CO readings are achieved using the area under the systolic part of the curve, a calibration factor (cal) derived from the thermodilution run, the heart rate (HR) and the individual's aortic compliance (which is termed C (p) and characterised by the thermodilution CO and the measured BP).

Calculation of Beat by Beat Pulse Contour Cardiac Output

Rise and fall of the blood pressure curve is also dependent on the patient's individual aortic compliance.

After calibration, the pulse contour Algorithm is able to follow the cardiac output beat by beat.



WHAT DOES PiCCO DO?

From taking three values from the temperature vs. time graph (CO, MTt, DSt) the PiCCO can estimate:

- Cardiac output
- Preload: ITBV
- Degree of Pulmonary oedema: EVLWI

PARAMETERS MEASURED & NORMAL VALUES

Thermodilution Parameters

- CO – Cardiac Output: 4 - 8litres/min
- CI – Cardiac Index : 3- 5litres/min/m₂
- Preload
- GEDI – Global end diastolic index: 680- 800ml/m₂
- ITBVI – Intra thoracic blood volume index: 850-1000ml/m₂
- Pulmonary oedema
- ELWI –Extravascular lung water index: 3-7mls/kg
- PVPI - Pulmonary vascular permeability index: 1.0- 3.0
- Contractility
- CFI - Cardiac function index: 4.5- 6.5%
- GEF - Global ejection fraction: 25- 35%

Pulse contour Parameters

- Flow
- PCC -Pulse contour cardiac output
- ABP - Arterial blood pressure
- HR - Heart rate
- SV - Stroke volume: 50-110mls
- Volume responsiveness
- SVV - Stroke volume variation: <10%
- PPV - Pulse pressure variation
- Afterload
- SVRI - Systemic vascular resistance index: 1700-2400 dyn*s*cm⁻⁵*m²
- Contractility
- Index of left ventricular contractility

PARAMETERS MEASURED: DEFINITIONS

Global End Diastolic Volume (GEDV)

- Is the volume of blood contained in the 4 chambers of the heart

Intrathoracic Blood Volume (ITBV)

- Is the volume of the 4 chambers of the heart plus the blood volume in the pulmonary vessels

Extravascular Lung Water (EVLW)

- Is the amount of water content in the lungs or degree of pulmonary oedema

Stroke Volume Variation (SVV)

- Reflects the sensitivity of the heart to the cyclic changes in cardiac preload induced by mechanical ventilation
- Can predict whether stroke volume will increase with volume expansion

Cardiac Function Index

- The ratio of the index of cardiac output to the index of the GEDV. A measure of how well the CO is doing in relation to its preload.

Global ejection fraction (GEF)

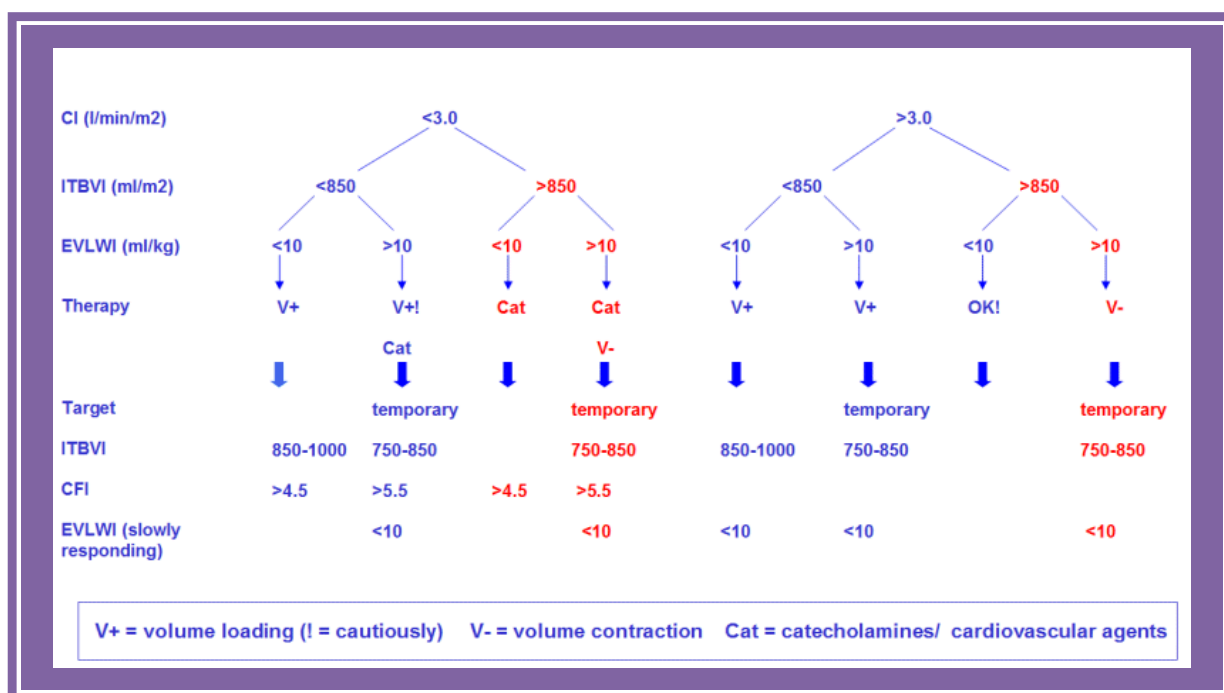
- A % of total blood expelled from the heart every beat to the total amount of blood estimated to be present just prior to ventricular systole.

Pulmonary Vascular Permeability Index(PVPI)

- Indication of pulmonary oedema in relation to preload

HOW DO THESE CALCULATIONS GUIDE MANAGEMENT OF THE PATIENT?

The decision tree below from Pulsion Medical is useful in deciding on what therapy to use for the patient.



Preload

- Volume
- GEDV- used to work out if patient is under, over or adequately filled
- GEDV + ITBV more sensitive to preload than standard filling pressures of CVP & PAWP

Contractility

- 2 measurements of contractility: Global Ejection Fraction and Cardiac Function Index
- GEF & CFI which tells us how well heart is contracting & whether the patient needs inotropes

Afterload

- Resistance to ventricular ejection
- Measured by Systemic vascular resistance
- SVR : $MAP - CVP/CO$
- Constrictors or vasodilators

Extravascular Lung Water

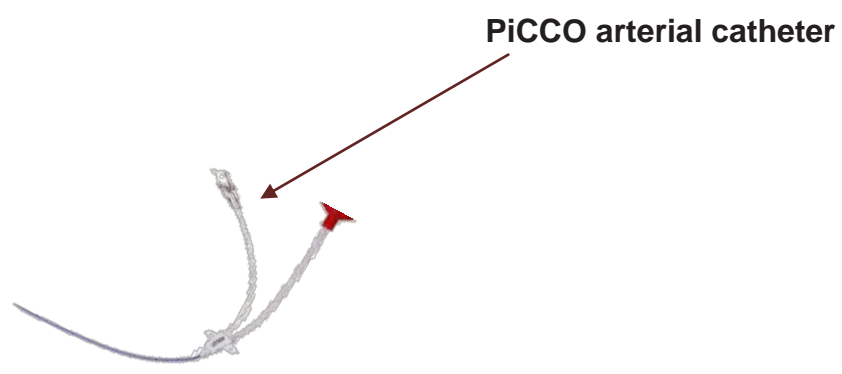
- Indication of fluid overload
- Measures the fluid in the interstitial space outside of the pulmonary blood volume

SET UP

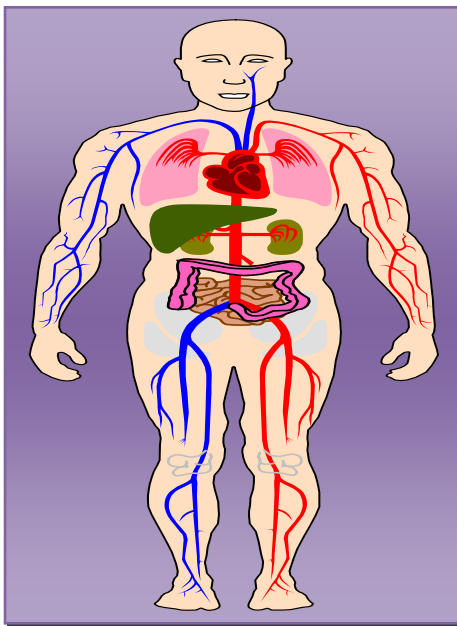
PiCCO requires the insertion of a central venous pressure (CVP) catheter and a thermodilution arterial line. The arterial line can be placed in the axillary, brachial, femoral or radial artery. Femoral artery is the preferred site.

Equipment

- Central line and three way tap
- Sterile drapes, gown, gloves, mask, needles, local anaesthetic, chlorhexidine solution, biopatch and occlusive dressing
- Pressure bag and transducer
- 500ml bag 0.9% sodium chloride
- PiCCO arterial catheter
- Phillips CCO module and white cable



Pulse Contour Cardiac Output (PiCCO) Learning Package

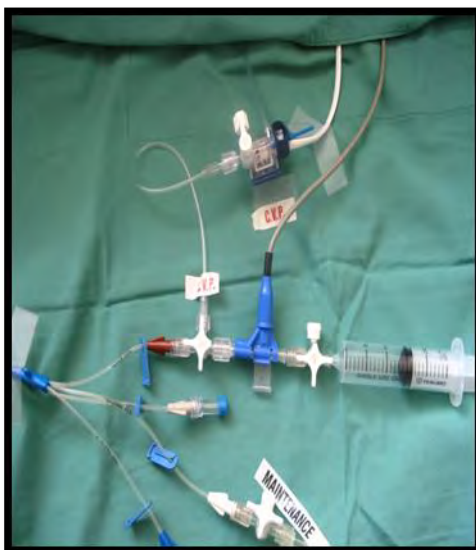


Central venous line (CV)

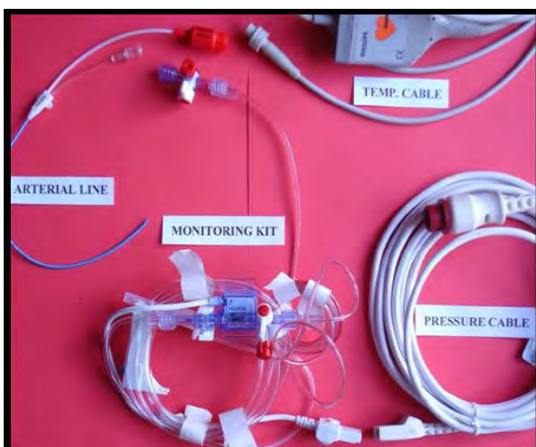
PULSIOCATH thermodilution catheter
with lumen for arterial pressure measurement

Axillary: 4F (1,4mm)	8cm
Brachial: 4F (1,4mm)	22cm
Femoral: 3-5F (0,9-1,7mm)	7-20cm
Radial: 4F (1,4mm)	50cm

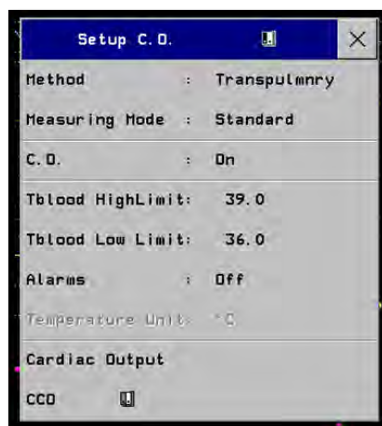
Adapted Pulsion Medical 2008



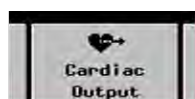
- Phillips blue end thermistor cable
- CVC preferred sites: Internal Jugular or subclavian
- CVP line with transducer set
- 50ml syringe for 2-3 bolus' of 15-20mls
- Cold saline <8°C
- Two 3 way taps



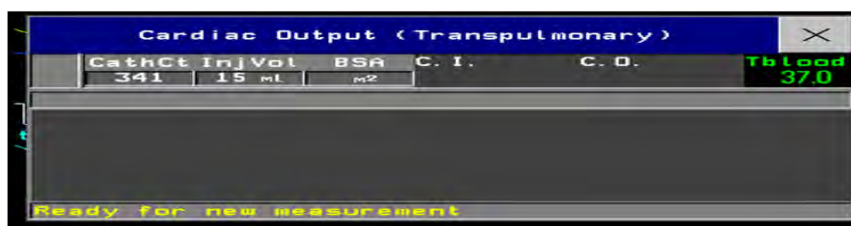
- Philips red pressure module or red port on MMS
- Philips Orange CCO module
- Philips Orange end CCO cable
- PiCCO arterial line
- White Phillips pressure cable
- PiCCO transducer monitoring kit including in-line sensor
- Pressure bag & 500ml 0.9% Sodium Chloride

Pulse Contour Cardiac Output (PiCCO) Learning Package

- Ensure that arterial pressure port for PiCCO is labelled ABP not ART
- Zero and level ABP & CVP to phlebostatic axis
- Press Change Screen - PiCCO Screen
- Access Admit/Discharge Window
- Admit the patient
- Enter the patient's Height and Weight
- Enter patients Gender Press Confirm
- Press Cardiac Output Module hard key or Main Setup and select Measurement and CO Method: choose Transpulmonary
- This will be automatically detected C.O to ON
- Adjust temp alarms as required
- Select Alarms ON or as per policy
- Press CCO
- Choose where alarms are to be detected from either CCO or CCI
- Adjust alarm limits
- CCO from ABP
- CCO to ON



➤ Select cardiac output

PERFORMING THERMODILUTIONS

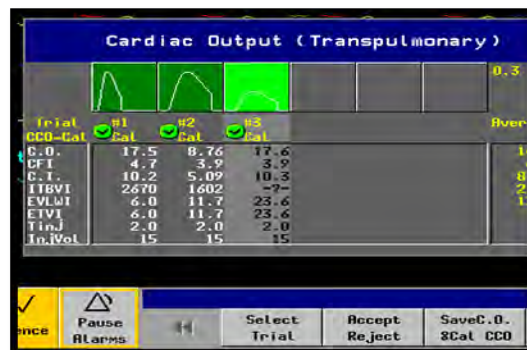
- Press CathCt & change number as required- CathCt is detected automatically or found on red hub or catheter package
- Press Inj Vol and change volume to 15 or 20mls
 - Dependant on patients body wt
 - If pt has increase in the amount of EVTV more than 10ml/kg the injection volume should be increased
 - Most patients require standard of 15-20mls but if more than 100kgs should use an IDEAL body weight to obtain an accurate EVLW

Pulse Contour Cardiac Output (PiCCO) Learning Package

- Initially Perform 3 thermodilution measurements
- Must be cold 0.9% sodium chloride
 - A probe attached to the central venous catheter measures the initial temperature of the saline, and the resulting change is measured in the proprietary arterial line
 - There must be a difference in temperature of at least 0.125 for the thermodilution measurement to be recognized
- Wait for Ready for new measurement
- Press Start C.O for each injection



- Wait for screen to say: Stable baseline Inject Now
- Perform 2-3 thermodilution measurements. These measurements should only be selected if they are within $\pm 15\%$, if not, keep going until you get triplicate measurements in that range. Ideally you want $\pm 10\%$ but this might take a few more measurements. The more precise calibration, the better the guidance provided by the monitor.
- Select curves to be deleted (using the criteria above to decide which ones to keep and which to delete). The ones to be deleted will turn red. Measurement curves to be kept and used for calculations will be green.



- Press Save CO & CCO
- This will determine CCO continuously
- Press Hemo Calc
- Ensure CVP is correct. There should be no other infusions running through the lumen at the time of obtaining the CVP measurement. Ensure the transducer is positioned at the phlebostatic axis and has been re-zeroed prior to obtaining reading.
- Press Perform Calc
- Print results

Calculations now available

Hemodynamic		Respiratory	
CO	14.60 l/min	Height	165 cm
HR	60 bpm	Weight	65.0 kg
SBPs	120 mmHg	BSA	1.72 m ²
SBPd	70 mmHg	SV	243.3 ml
SBPm	91 mmHg	SVR	449 DS/cm ⁵
SVI	9 mmHg	LCM	18.1 kg/m
EVLWI	898 ml	LVSWI	301.1 g/m ²
TBV	4299 ml	EVLWI	13.8 ml/kg
EDV	3440 ml	ITBVI	2499 ml/m ²
		GEDVI	2000 ml/m ²

MAINTAINING ACCURACY OF CALCULATIONS

The continuous cardiac monitoring relies on the accuracy of the arterial waveform therefore the Arterial trace needs to be:

- calibrated, levelled to the phlebostatic axis, re-zeroed and checked each shift
- continually monitored
- checked for kinks

The CVP reading is also needed for calculations so it should be:

- Calibrated, re-zeroed and checked each shift
- Ensure correct reading is entered before calculating

The accuracy of the CCO also relies on thermodilution:

- The cardiac output needs to be recalibrated via the thermodilution technique at least every 8 hours
- Recalibrate if giving volume or changing inotropes
- Large changes in the patients' heart rate, blood pressure or systemic vascular resistance. Recalibration is needed to account for the sudden change in haemodynamic status

TROUBLESHOOTING

Physiological conditions that may affect Thermodilutions

Intracardiac shunts

- Right to left shunts would result in premature delivery of the cold injectate, before appropriate mixing in the true ITTV, and hence an overestimate of CO.
- Conversely, left to right shunts would result in re-mixing of the injectate within the ITTV before reaching the femoral thermistor and hence an underestimate of CO

Severe aortic valve disease

- Aortic stenosis will not affect CO measurement based on thermodilution, although interpretation of a waveform with a flatter systolic gradient can impair continuous contour analysis.
- In significant aortic incompetence, however, there is re-mixing of the cold injectate within the left ventricle with the regurgitant back flow.
- Thus the indicator delay time is prolonged and the CO is underestimated.

Lung perfusion (Q) deficit

- Pulmonary macroemboli causing significant perfusion deficits will result in gross underestimation of intrathoracic volumes.
- This is because the cold injectate will not perfuse and thermally disperse in the non-perfused areas.

Intra-aortic balloon counterpulsation (IABC)

- The diastolic augmentation of arterial pressure by the balloon pump alters the waveform of the arterial pulsation
- Therefore accurate calculation of continuous cardiac output cannot be guaranteed
- The initial calculation of CO during the thermodilution calibration is also affected during IABC

Equipment troubleshooting**Catheter**

- Red temperature plug on arterial catheter- 4 prongs bent
- Monitoring kit not zeroed
- Arterial catheter in wrong place(femoral catheter in Radial artery; Arterial catheter in venous circulation)
- Faulty catheter

Injectate sensor (blue)

- Is in the monitoring kit – do not throw away
- Pin bent when inserting into BLUE housing
- Faulty or gone off after few days. If possible don't run other fluids/drugs through it

Thermodilution

- Use iced saline injectate only. Need difference $>12^{\circ}\text{C}$ between injectate & blood temperature to get best readings
- Beware of pressure on plunger prior to injection. This can set off monitor early & give false readings
- Ensure volume of cold saline injected is same volume entered on monitor
- If over resistance when injecting check CVC not kinked

Poor arterial waveform

- Flush, zero and level to phlebostatic axis
- Do not alter monitoring kits; e.g. do not take out 150cm of red lined transducer tubing

No CCO trace/numbers

- Ensure PiCCO / CCO module is in place
- Arterial trace needs to be named ABP not ART
- CVP is correct
- Poor arterial waveform

Haemofiltration

- Readings accurate as long as the haemodialysis catheter is not placed in the cardiopulmonary circulation & the whole bolus goes into the cardiopulmonary circulation
- If CVC and vascath in internal jugular and subclavian veins the CRRT will need to be paused while doing the thermodilutions
- Warming of blood temp may lead to baseline drift or instability

LEARNING ACTIVITIES

1. Explain how the PiCCO system works. How is it used for to guide with patient management?
2. Explain preload, afterload , cardiac output, stroke volume and contractility
3. Explain how Thermodilution and pulse contour analysis works on PiCCO
4. What are ELWVI, ITBV, GEDI, GEF and SVR?
5. What equipment is needed to set up PiCCO?
6. What should the arterial pressure port be labelled?
7. Discuss the determinants for accuracy of the calculations?
8. What are the recommended volumes of saline for thermodilution?
9. Can PiCCO be used for a patient on CRRT?
10. How often should the PiCCO be calibrated?

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