Clinical Evidence

PiCCO Technology
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Review articles

The PiCCO Technology provides a dynamic, minimally invasive measurement of cardiac output and its determinants (preload, afterload, contractility) as well as the quantification of pulmonary edema for a targeted treatment. It is a clinically proven tool for hemodynamic assessment and management in a broad range of critically ill patients. With its unique combination of intermittent transpulmonary thermodilution and continuous pulse contour analysis, the PiCCO Technology provides a complete picture of the hemodynamic situation. The basic principle of PiCCO has been explained in several review articles:

- Litton E, Morgan M.  
  The PiCCO monitor: a review.  

- Sakka SG, Reuter DA, Perel A.  
  The transpulmonary thermodilution technique.  

- Oren-Grinberg A.  
  The PiCCO Monitor.  

- King D & Price AM.  
  Measuring cardiac output using the PiCCO system.  
Cost effectiveness

Several publications have reported an improved patient outcome when advanced hemodynamic variables are used to set up a goal directed treatment algorithm. In these studies, a reduction in complication rates has been reported and the subsequent treatment costs were reduced. While the incorporation of advanced hemodynamic monitoring is associated with an (initial) investment, the cost-reduction due to the decrease in complications is always higher than the investment.


Validation of PiCCO parameters

Accuracy of PiCCO thermodilution cardiac output compared to the pulmonary artery catheter

The two methods have comparable accuracy, however the PiCCO thermodilution method is less user-dependent and gives more stable measurements.

Accuracy of PiCCO pulse contour cardiac output compared to the pulmonary artery catheter

Several validation studies of the PiCCO pulse contour cardiac output versus pulmonary artery thermodilution have been published, within the early days of introduction of PiCCO in the market.


Accuracy of the lung water measurement (EVLW/ELWI) by PiCCO

Evidence shows that measurement of lung water with PiCCO for quantification of pulmonary edema is accurate and correlates strongly with the ‘gold standard’ gravimetric method.

Recommended clinical application areas

Critically ill patients

**Septic shock**

- Lu NF, Zheng RQ, Lin H, Shao J, Yu JO, Yang G. 
  *Improved sepsis bundles in the treatment of septic shock: a prospective clinical study.*

- Chung FT, Lin HC, Kuo CH, et al. 
  *Extravascular lung water correlates multiorgan dysfunction syndrome and mortality in sepsis.*

- Ritter S, Rudiger A, Maggiorini M. 
  *Transpulmonary thermodilution-derived cardiac function index identifies cardiac dysfunction in acute heart failure and septic patients: an observational study.*
  Crit Care. 2009;13(4):R133

**Acute Respiratory Distress Syndrome (ARDS)**

  *Extravascular lung water and pulmonary vascular permeability index as markers predictive of postoperative acute respiratory distress syndrome: a prospective cohort investigation.*
  Crit Care Med. 2014;43(3):665-673

  *Early-phase changes of extravascular lung water index as a prognostic indicator in acute respiratory distress syndrome patients.*

  *Extravascular lung water and pulmonary arterial wedge pressure for fluid management in patients with acute respiratory distress syndrome.*

- Chew MS, Ihroman L, During J, et al. 
  *Extravascular lung water index improves the diagnostic accuracy of lung injury in patients with shock.*
  Crit Care. 2012;16(1):R1
### Cardiogenic shock

  **Accuracy and precision of transcardiopulmonary thermodilution in patients with cardiogenic shock.**  

- Perny J, Kimmoun A, Perez P, Levy B.  
  **Evaluation of cardiac function index as measured by transpulmonary thermodilution as an indicator of left ventricular ejection fraction in cardiogenic shock.**  

- Friesecke S, Heinrich A, Abel P, Felix SB.  
  **Comparison of pulmonary artery and aortic transpulmonary thermodilution for monitoring of cardiac output in patients with severe heart failure: validation of a novel method.**  

### Severe burn injury

- Sanchez-Sanchez M, Garcia-de-Lorenzo A, Herrero E, et al.  
  **A protocol for resuscitation of severe burn patients guided by transpulmonary thermodilution and lactate levels: a 3-year prospective cohort study.**  
  *Crit Care.* 2013;17(4):R176

- Bognar Z, Foldi V, Rezman B, Bogar L, Csontos C.  
  **Extravascular lung water index as a sign of developing sepsis in burns.**  
  *Burns.* 2010;8:1263-1270

- Csontos C, Foldi V, Fischer T, Bogar L.  
  **Arterial thermodilution in burn patients suggests a more rapid fluid administration during early resuscitation.**  

### Neuro surgery (SAH)

- Obata Y, Takeda J, Sato Y, Ishikura H, Matsui T, Isotani E.  
  **A multicenter prospective cohort study of volume management after subarachnoid hemorrhage: circulatory characteristics of pulmonary edema after subarachnoid haemorrhage.**  
  *J Neurosurg.* 2015;1-10

  **Impact of transpulmonary thermodilution-based cardiac contractility and extravascular lung water measurements on clinical outcome of patients with Takotsubo cardiomyopathy after subarachnoid hemorrhage: a retrospective observational study.**  
  *Crit Care.* 2014;18(4):482

  **Early intensive versus minimally invasive approach to postoperative hemodynamic management after subarachnoid hemorrhage.**  
  *Stroke.* 2014;45(5):1280-1284

- Mutoh T, Kazumata K, Ishikawa T, Terasaka S.  
  **Performance of bedside transpulmonary thermodilution monitoring for goal-directed hemodynamic management after subarachnoid hemorrhage.**  
  *Stroke.* 2009;40(7):2368-74
**Pancreatitis**


**Cardiac surgery**


**High risk surgical procedures**


**Transplantation**

Recommended clinical application areas

Pediatrics

**General intensive care**

Two femoral PICCO catheters can be used in pediatrics (PV2013L07, 3F, 7cm and PV2014L08, 4F, 8cm). The decision about which kind of patient (age, weight) these catheters are used for, should be made by the treating physician. Recommendations on the body weight can be derived from publications e.g. Cecchetti et al. (Min Anest 2013), used a 3F catheter in a patient with body weight less than 10kg and 4F catheters in pediatric patients with at least 10kg body weight. In other publications, (e.g. Lemson et al., Crital Care 2010; Szekely et al., Ped Card 2010; Gil Anton et al., An Ped 2009; Egan et al, Intensive Care Med 2005; Cecchetti et al., Min Anest 2003) the youngest patients were aged 2 months with a body weight of 3 kg. A review on PICCO in pediatrics was published by Proulx et al (Pediatr Crit Care Med 2011).


**Normal ranges in pediatric patients**

The normal ranges in pediatric patients are slightly different to those of adult patients. It has been shown that, the younger the patient and the lower their weight, the lower the GEDI and higher the ELWI.

# Acute respiratory failure

  Prognostic value of extravascular lung water index in critically ill children with acute respiratory failure.  

# Severe burn injury

  Optimized fluid management improves outcomes of pediatric burn patients.  

  Transpulmonary thermodilution for hemodynamic measurements in severely burned children.  

# Head trauma

  Neurogenic pulmonary edema and variations of emodynamic volumetric parameters, in children following head trauma.  
  Minerva Anestesiol. 2013;70(10):1140-1146

# Liver transplantation

  Pulse contour cardiac output system use in pediatric orthotopic liver transplantation: preliminary report of nine patients.  
  Transplant Proc. 2005;37(7):3168-3170

# Cardiac surgery

  Cardiac index monitoring by femoral arterial thermodilution after cardiac surgery in children.  
  J Crit Care. 2014;29(6):1132.e1-1132.e4

- Keller G, Desebbe O, Henaine R, Lehot JJ.  
  Transpulmonary thermodilution in a pediatric patient with an intracardiac left-to-right shunt.  

- Szekely A, Breuer T, Sapi E, et al.  
  Transpulmonary thermodilution in neonates undergoing arterial switch surgery.  
  Pediatr Cardiol. 2011;32(2):125-130

- Fakler U, Pauli Ch, Balling G, et al.  
  Cardiac index monitoring by pulse contour analysis and thermodilution after pediatric cardiac surgery.  
  J Thorac Cardiovasc Surg. 2007;133(1):224-228

- Cherqaoui I, Raux O, Dehour L, Rochette A, Dadure C, Capdevila X.  
  Transpulmonary thermodilution hemodynamic monitoring for pheochromocytoma surgery in a child with complex congenital heart disease.  
  Paediatr Anaesth. 2006;16(12):1277-1280

- Egan J, Festa M, Cole A, Nunn GR, Gillis J, Winlaw DS.  
  Clinical assessment of cardiac performance in infants and children following cardiac surgery.  

  Pulse contour analysis for cardiac output monitoring in cardiac surgery for congenital heart disease.  
Clinical situations

Aortic aneurysm

In patients with a known aortic aneurysm, if a femoral arterial catheter is used, the GEDI will be overestimated due to the volume of the aneurysm itself. In these cases, a brachial or axillary PICCO catheter is recommended.


Valvulopathies, cardiac valve insufficiencies

Valve insufficiency, especially aortic valve insufficiency, may cause regurgitation of the thermodilution injectate and prolong the transit time of the indicator; or interfere with the thermodilution curve. However, when a sufficient thermodilution curve is detected, the calculation of the cardiac output is considered correct. In mitral valve insufficiency, the accuracy of the PiCCO cardiac output measurement has been confirmed.


Aortic stenosis

In aortic stenosis, arterial thermodilution accurately reflects cardiac output. The arterial pressure curve may have reduced systolic and elevated diastolic pressures. However, the area under the arterial curve still reflects stroke volume. In severe aortic stenosis, recalibration of the pulse contour (with thermodilution) substantially improves reliability.


Kinetic therapy (e.g. prone positioning)

Research shows that the EVLW can be used to demonstrate the positive effect of laying the patient in a prone position. It has also been shown that the calibrated PiCCO is more accurate than non-calibrated systems.

Effect of pleural effusion on ELWI

Pleural fluid does not affect the EVLWI measurement. The capillary surface of the lung parenchyma that is in contact with the pleural fluid is very small in comparison to the pulmonary capillary network. Temperature loss to pleural fluid is also negligible.

Effect of pulmonary embolism on ELWI

In pulmonary embolism, due to an obstruction in the pulmonary vasculature, EVLW is underestimated. Despite this, in this case the cardiac output and the global end-diastolic volume (GEDV) are still measured correctly.


Therapies

Hypothermia

There is no influence on the thermodilution measurements as long as the patient's temperature is stable. Cooled injectate should be used.


Vasoconstrictor and/or inotrope therapy

All parameters are correctly calculated. In case of significant changes in catecholamines or volume therapy, recalibration of the pulse contour analysis is recommended.


Intra-aortic Balloon Pump (IABP)

The thermodilution measurement with PiCCO is not influenced by the IABP, but the pulse contour analysis is usually unable to provide valid continuous cardiac output and related parameters.


Extracorporeal membrane oxygenation (ECMO), extracorporeal lung assist (ECLA)

Clinical experience shows that PiCCO thermodilution does not give reliable results during ECMO. The reason for this is the relatively high flow rates and the positioning of the ECMO catheters. Therefore, it is recommended that PiCCO thermodilution measurements are performed before or after ECMO treatment. When running ECMO, the PiCCO pulse contour analysis is considered correct as long as no significant changes in the vascular compliance are present and required that the initial calibration from thermodilution was correct.

- Wiesenack C, Prasser C, Liebold A, Schmid FX. Assessment of left ventricular cardiac output by arterial thermodilution technique via a left atrial catheter in a patient on a right ventricular assist device. Perfusion. 2004;19(1):73-75

Ventricular assist device (VAD)

With a right ventricular assist device the PICCO thermodilution measurement has been shown to work.

- Wiesenack C, Prasser C, Liebold A, Schmid FX. Assessment of left ventricular cardiac output by arterial thermodilution technique via a left atrial catheter in a patient on a right ventricular assist device. Perfusion. 2004;19(1):73-75

Continuous renal replacement therapy (CRRT), hemofiltration, dialysis

- PiCCO thermodilution measurements should not be taken directly after the CRRT is switched on or off
- A stable blood temperature baseline needs to be achieved before performing PiCCO measurements
- The CRRT catheter out- and inflow should not lie in the PiCCO indicator passage track
**Effect of lung resection on ELWI**

Lung resection procedures (lobectomy, bilobectomy, pneumectomy) theoretically reduce the pulmonary blood volume (PBV) and may lead to an underestimation of the extravascular lung water (EVLW). To evaluate this theoretical assumption, a double indicator dilution technique is required to determine PBV before and after lung resection. Clinical studies using this approach show that:

- The amount of extracted lung tissue and pulmonary blood volume do not correlate
- Clear correction factors for PBV calculation cannot be determined
- An initial effect on PBV is widely physiologically compensated, two days post-operatively at the latest

Thus, it is not recommended to correct the measured values for PBV and EVLW with fixed calculation factors. Clinical evidence is not available for this action. Such corrections may lead to unexpected and unpredictable errors in the calculation of EVLW in patients after lung resection.


**Magnetic resonance imaging (MRI)**

The effect of MRI on the PICCO catheter has been investigated in model experiments and has also been published as correspondence in congress newsletters. These investigations do not report any negative effects on the functionality of the PICCO Catheter during MRI. However, there are currently no systematic tests for all available MRI systems under various measurement conditions. Therefore PULSION cannot confirm the compatibility of the PICCO catheter with MRI systems and must recommend the removal of the PICCO catheter before MRI. It is the treating physician's full responsibility for the decision to leave the PICCO Catheter in the patient during the MRI.

- Greco F, Vendrell JF, Deras P, Boullan A, Perrigault PF. [The Pulsiocath catheter and magnetic resonance imaging.]
  Ann Fr Anesth Reanim 2011;30(9):697

**Passive leg raising (PLR)**

The PiCCO has been used in several investigations to show if a patient is volume responsive using passive leg raising.

Clinical significance of PiCCO parameters

**Global end-diastolic volume index (GEDI) as an indicator of cardiac preload**

Strictly defined, cardiac preload is the myocardial fibre stretch at the end of ventricular diastole. A parameter that accurately reflects preload in clinical practice is not yet available. However, studies have demonstrated that GEDI (or ITBI) is a reproducible and sensitive parameter and a good approximation of preload.


**Fluid responsivenes by stroke volume variation (SVV) and pulse pressure variation (PPV)**

The following requirements have to be fulfilled:

- Fully controlled mechanical ventilation with a tidal volume ≥ 8 ml/kg PBW (predicted body weight)
- Sinus rhythm
- Pressure curves free of artifacts
Validity and clinical relevance of the PiCCO Technology contractility parameters

The PiCCO Technology offers several contractility related parameters like the intermittent cardiac function index (CFI) and global ejection fraction (GEF) as well as the continuous left ventricular contractility (dPmx). The cardiac power index (CPO/CPI) can be considered a contractility parameter, even though it is usually classified as an organ function (cardiac) parameter.


Cardiac function index (CFI)


Left ventricular contractility (dPmx)


Cardiac power (CPO/CPI)

The cardiac power output/index (CPO/CPI) has been investigated in the past in patients with heart failure. It has been found that cardiac power is a direct indicator of the overall cardiac function and is the strongest independent predictor of in-hospital mortality in patients with cardiogenic shock. CPI is established as one of the target parameters in the German-Austrian S3 Guideline on diagnosis, monitoring and treatment of cardiogenic shock patients (Werdan et al., Dtsch Arztebl Int 2012).

- Mendoza DD, Cooper HA, Panza JA. Cardiac power output predicts mortality across a broad spectrum of patients with acute cardiac disease. Am Heart J. 2007;153(3):366-370
Weaning from the ventilator

• Dres M, Teboul JL, Anguel N, Guerin L, Richard C, Monnet X.
  Passive leg raising performed before a spontaneous breathing trial predicts weaning-induced cardiac dysfunction.
  Intensive Care Med. 2015;41:487-494

• Redondo Calvo FJ, Bejarano Ramirez N, Una Orejon R, Villazala Garcia R, Yuste Pena AS, Belda FJ.
  Elevated extravascular lung water index (ELWI) as a predictor of failure of continuous positive airway pressure via helmet (Helmet-CPAP) in patients with acute respiratory failure after major surgery.
  Arch Bronconeumol. 2015;51(11):558-563

• Dres M, Teboul JL, Monnet X.
  Weaning the cardiac patient from mechanical ventilation.

Accuracy of chest x-ray for measuring pulmonary oedema

Research confirms that presently, it is not possible to quantify the extent of pulmonary edema with a chest x-ray. The interpretation of a chest x-ray is complex since it is a density measurement and influenced by all compartments in the chest, like bones, muscles, vessels, blood, air, skin layers, tissue edema, pleural effusion and, amongst the others, also by the extravascular lung water.

• Brown LM, Calfee CS, Howard JP, Craig TR, Matthay MA, McAuley DF.

• Saugel B, Ringmaier S, Holzapfel K, et al.
  Physical examination, central venous pressure, and chest radiography for the prediction of transpulmonary thermodilution-derived hemodynamic parameters in critically ill patients: a prospective trial.

• Lemson J, van Die LE, Hemelaar AE, van der Hoeven JG.
  Extravascular lung water index measurement in critically ill children does not correlate with a chest x-ray score of pulmonary edema.
  Crit Care. 2010;14(3):R105
CLINICAL INDICATIONS

Quantification of pulmonary edema by the measurement of extravascular lung water index (ELWI)

The PiCCO Technology offers direct and accurate bedside quantification of pulmonary edema by the measurement of extravascular lung water index (ELWI). This enables a sensitive and early detection of the development of pulmonary edema and thus an early therapeutic intervention before pulmonary edema can cause alveolar damage and other complications. It is also an early predictor of acute respiratory distress syndrome (ARDS) and enables an improved classification of origin and severity.


- Schuster DP. Identifying patients with ARDS: time for a different approach. Intensive Care Med. 1997;23(12):1197-203
Outcome improvement in ARDS patients

ARDS patient management based on the PiCCO Technology parameter of ELWI resulted in shorter ventilation time, better oxygenation index and improved survival.


Pulmonary vascular permeability index (PVPI) for differential diagnosis of pulmonary edema origin

In case of diagnosed pulmonary edema (high ELWI), the parameter of pulmonary vascular permeability index (PVPI) enables a differential diagnosis of its origin. Based on clinical studies, a PVPI value of less than 3 most likely indicates cardiogenic pulmonary edema (left heart failure, fluid overload) whereas a PVPI value 3 or above indicates pulmonary edema most likely due to permeability damage (sepsis, ARDS).


Outcome studies

Hemodynamic monitoring itself is not able to improve outcome. However, when the hemodynamic variables are used in a clearly defined treatment algorithm to manage individualized goal-directed therapy, there is a high potential for an improvement in outcome. Several studies have already confirmed improved outcome when PiCCO parameters are used to apply therapy for hemodynamic optimization in critically ill patients.

  ICU management based on PiCCO parameters reduces duration of mechanical ventilation and ICU length of stay in patients with severe thoracic trauma and acute respiratory distress syndrome.
  Ann Intensive Care. 2016;6:113

  Early Intensive Versus Minimally Invasive Approach to Postoperative Hemodynamic Management After Subarachnoid Hemorrhage.
  Stroke. 2014;45(5):1280-1284

  Extravascular lung water and pulmonary arterial wedge pressure for fluid management in patients with acute respiratory distress syndrome.

- Goepfert M, Richter HP, Eulenburg CZ, et al.
  Individually Optimized Hemodynamic Therapy Reduces Complications and Length of Stay in the Intensive Care Unit: A Prospective, Randomized Controlled Trial.
  Anesthesiology. 2013;119(4):824-836

  Optimized fluid management improves outcomes of pediatric burn patients.

- Csontos C, Foldi V, Fischer T, Bogar L.
  Arterial thermodilution in burn patients suggests a more rapid fluid administration during early resuscitation.
Technique & technology questions

Risk profile of PiCCO femoral catheter versus other arterial catheters

Evidence shows there is no additional risk when using any of the PiCCO arterial catheters when compared to standard arterial lines.

- Scheer BV, Perel A, Pfeiffer UJ. Clinical review: Complications and risk factors of peripheral arterial catheters used for haemodynamic monitoring in anaesthesia and intensive care medicine. Critical Care. 2002;6(3):198-204

Recommended application duration of the PiCCO catheter and monitoring kit

Related to the registration (CE approval) PULSION disposables can stay in place for a maximum of 28 days. However, this is not recommended in clinical practice for hygiene purposes. Based on a publication by the Commission for Hospital Hygiene and Infection Prevention at the Robert-Koch Institute, Germany (Empfehlung der Kommission für Krankenhaushygiene und Infektionsprävention (KRINKO) beim Robert Koch-Institut. Prävention von Infektionen, die von Gefäßkathetern ausgehen, https://www.rki.de/DE/Content/Infekt/Krankenhaushygiene/Kommission/Downloads/Gefaesskath_Inf_Teil2.pdf?__blob=publicationFile) the following recommendations are given:

- Exchange interval for PiCCO catheters: every 10 days (exception: long radial artery catheter PV2014L50: max. 3 days)
- Exchange interval for PiCCO monitoring kits: every 4 days

The exchange interval can be shorter in case of detection of complications associated with the application of these disposable articles, e.g. bleeding, hematoma, signs of infection, perfusion impairment, misplacement of the catheter; or if local regulations or standard operating procedures overrule this recommendation.

PiCCO measurements from a standard short radial artery catheter is not possible

In critically ill patients the arterial pressure waveform at the radial site is affected by vascular tone (vasoconstriction and dilation) and compliance, making arterial blood pressure measurements inaccurate. Also, due to the distance involved, it is not possible to record the downstream temperature required for the thermodilution measurement.

How many thermodilution measurements are recommended?

It is recommended that three consecutive measurements, with less than 15% (+/-) variation compared to the mean value are performed within a 10 minute time frame.


Considerations in case of thermodilution injection into the femoral vein and the PiCCO catheter placed in the femoral artery

If both the central venous catheter and PiCCO arterial catheters are placed on the same side (e.g. right femoral groin), the injectate may be detected immediately through the vessel wall (cross talk phenomena) resulting in measurement errors. This is more common in pediatric patients.


Cross talk can be avoided if the PiCCO arterial catheter is either placed in the opposite femoral artery or in the brachial / axillary artery. If placed femoral, thermodilution measurement is possible. PiCCO preload value and global end-diastolic volume (GEDI) will be slightly higher than the actual volume. The PiCCO software version V3.1 (and later versions) a confirmation of where both the central venous and arterial catheters are placed is asked, to ensure accurate calculation of GEDI.


Thermodilution injection with a room temperature instead of a cold injectate

Evidence shows that the use of room temperature injectate may not be as accurate. Therefore, particularly in patients with elevated lung water, the use of cold injectate is recommended.


Frequency of thermodilution injections to recalibrate continuous cardiac output

In general, the PiCCO should be calibrated every 8 hours by thermodilution. However, individual patient needs vary greatly. In case of hemodynamic instability, the pulse contour will deviate from the thermodilution cardiac output. In such cases, frequent recalibration (via thermodilution) is recommended.


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