Scientific evidence for the **PiCCO-Technology**

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Table of contens

Clinical Indications

Evidence of the clinical benefit for the PiCCO-Technology by indications

Septic shock

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  Improved sepsis bundles in the treatment of septic shock: a prospective clinical study.
  Am J Emerg Med 2015; 33(8): 1045-9.
- Chung FT, Lin HC, Kuo CH, Yu CT, Chou CL, Lee KY, Kuo HP, Lin SM.
  Extravascular lung water correlates multiorgan dysfunction syndrome and mortality in sepsis.
  PLoS One 2010; 5(12): e15265.
- 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)

- Kor DJ, Warner D, Carter R, Meade L, Wilson GA, Li M, Hamersma M, Hubmayr R, Mauermann WJ, Gajic O.
  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): 665-73.
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  Early-phase changes of extravascular lung water index as a prognostic indicator in acute respiratory distress syndrome patients.
  Annals of Intensive Care 2014; 4: 27.
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  Extravascular lung water and pulmonary arterial wedge pressure for fluid management in patients with acute respiratory distress syndrome.
  Multidiscip Respir Med 2014; 9(1): 3.
- Chew MS, Ihrman L, During J, Bergenzaun L, Ersson A, Unden J, Ryden J, Akerman E, Larsson M.
  Extravascular lung water index improves the diagnostic accuracy of lung injury in patients with shock.
  Crit Care 2012; 16(1): R1.

Cardiogenic shock

- Schmid B, Fink K, Olschewski M, Richter S, Schwab T, Brunner M, Busch HJ.
  Accuracy and precision of transcardiopulmonary thermodilution in patients with cardiogenic shock.
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  Evaluation of cardiac function index as measured by transpulmonary thermodilution as an indicator of left ventricular ejection fraction in cardiogenic shock.
  Biomed Res Int 2014; Article ID 598029, http://dx.doi.org/10.1155/2014/598029
- 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.
  Crit Care Med 2009; 37(1): 119-23.

Severe burn injury

- Sanchez-Sanchez M, Garcia-de-Lorenzo A, Herrero E, Lopez T, Galvan B, Asensio MJ, Cachafeiro L, Casado C.
  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: 1263-70.
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Clinical Indications

Evidence of the clinical benefit for the PiCCO-Technology by indications

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.
- Mutoh T, Kazumata K, Terasaka S, Taki Y, Suzuki A, Ishikawa T.
  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.
- Mutoh T, Kazumata K, Terasaka S, Taki Y, Suzuki A, Ishikawa T.
  Early intensive versus minimally invasive approach to postoperative hemodynamic management after subarachnoid hemorrhage.
  Stroke 2014; 45(5): 1280-4.
- 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

- Sun Y, Lu ZH, Zhang XS, Geng XP, Cao LJ, Yin L.
  The effects of fluid resuscitation according to PiCCO on the early stage of severe acute pancreatitis.
  Pancreatology 2015; 15(5): 497-502.
- Trepte C, Bachmann K, Stork JH, Friedheim TJ, Hinsch A, Goepfert MS, Mann O, Izbicki JR, Goetz AE, Reuter DA.
  The impact of early goal-directed fluid management on survival in an experimental model of severe acute pancreatitis.
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  Volume assessment in patients with necrotizing pancreatitis: A comparison of intrathoracic blood volume index (ITBI), central venous pressure, and hematocrit, and their correlation to cardiac index and extravascular lung water index.
  Crit Care Med 2008; 36(8): 2348-54.

Cardiac Surgery

- Goepfert M, Richter HP, Eulenburg CZ, Gruetzmacher J, Rafflenbeul E, Roeher K, Sandersleben AV, Diedrichs S, Reichenspurner H, Goetz AE, Reuter DA.
  Individually optimized hemodynamic therapy reduces complications and length of stay in the intensive care unit: A prospective, randomized controlled trial.
  Anesthesiology 2013; 119(4): 824-36.
- Smetkin AA, Kirov M, Kuzkov VV, Lenkin AI, Eremeev AV, Slastilin VY, Borodin VV, Bjertnaes LJ.
  Single transpulmonary thermodilution and continuous monitoring of central venous oxygen saturation during off-pump coronary surgery.
  Acta Anaesthesiol Scand 2009; 53: 505-14.
- Goepfert M, Reuter D, Akyol D, Lamm P, Kilger E, Goetz A.
  Goal directed fluid management reduces vasopressor and catecholamine use in cardiac surgery patients.
  Intensive Care Medicine 2007; 33: 96-103.

Transplantation

- Garutti I, Sanz J, Olmedilla L, Tranche I, Vilchez A, Fernandez-Quero L, Banares R, Perez-Pena JM.
  Extravascular lung water and pulmonary vascular permeability index measured at the end of surgery are independent predictors of prolonged mechanical ventilation in patients undergoing liver transplantation
  Liver Transplantation. Anesth Analg 2015; 121(3): 736-45.
- Minambres E, Coll E, Duerto J, Suberviola B, Mons R, Cifrian JM, Ballesteros MA.
  Effect of an intensive lung donor-management protocol on lung transplantation outcomes.
  J Heart Lung Transplant 2014; 33(2): 178-84.
- Venkateswaran RV, Dronavalli V, Patchell V, Wilson I, Mascaro J, Thompson R, Coote J, Bonser RS.
  Measurement of extravascular lung water following human brain death; implications for lung donor assessment and transplantation.
  Eur J Cardiothorac Surg 2013; 43(6): 1227-32.
- Venkateswaran R, Patchell V, Wilson I, Mascaro J, Thompson R, Quinn D, Stockley R, Coote J, Bonser R.
  Early donor management increases the retrieval rate of lungs for transplantation.
  Ann Thorac Surg 2008; 85: 278-86.

High risk surgical procedures

- Oshima K, Kunimoto F, Hinohara H, Hayashi Y, Kanemaru Y, Takeyoshi I, Kuwano H.
  Evaluation of respiratory status in patients after thoracic esophagectomy using PiCCO system.
  Ann Thorac Cardiovasc Surg 2008; 14(5): 283-8.
- Sato Y, Motoyama S, Maruyama M, Hayashi K, Nakae H, Tajimi K, Ogawa J.
  Extravascular lung water measured using single transpulmonary thermodilution reflects perioperative pulmonary edema induced by esophagectomy.
  Eur Surg Res 2006; 39(1): 7-13.

Clinical Indications

Evidence of the clinical benefit for the PiCCO-Technology by indications

Pediatric - General intensive care

There are two femoral PiCCO catheters that can be used in paediatrics (PV2013L07, 3F, 7cm and PV2014L08, 4F, 8cm). The decision in which kind of patient (age, weight) this catheter is used 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), where a 3F catheter was used with a body weight less than 10kg and 4F catheters for paediatrics 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 2 months old with a body weight of 3 kg. A review on PiCCO in paediatrics was published by Proulx et al (Pediatr Crit Care Med 2011).

- Proulx F, Lemson J, Choker G, Tibby SM.
  Hemodynamic monitoring by transpulmonary thermodilution and pulse contour analysis in critically ill children.
  Pediatr Crit Care Med 2011; 12(4): 1-8.
- Lemson J, van Die LE, Hemelaar AEA, 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.
  Crital Care 2010; 14: R105.
- Cecchetti C, Lubrano R, Cristaldi S, Stoppa F, Barbieri MA, Elli M, Masciangelo R, Perrotta D, Travasso E, Raggi C, Maano M, Pirozzi N.
  Relationship between global end-diastolic volume and cardiac output in critically ill infants and children.
  Crit Care Med 2008; 36(3): 928-32.
- Cecchetti C, Stoppa F, Vanacore N, Barbieri MA, Raucci U, Pasotti E, Tomasello C, Marano M, Pirozzi N.
  Monitoring of intrathoracic volemia and cardiac output in critically ill children.
  Minerva Anestesiol 2003; 69: 907-18.
- Schiffmann H, Erdlenbruch B, Singer D, Singer S, Herting E, Hoeft A, Buhre W.
  Assessment of cardiac output, intravascular volume status, and extravascular lung water by transpulmonary indicator dilution in critically ill neonates and infants.
  J Cardiothorac Vasc Anesth 2002; 16(5): 592-7.

Clinical Indications

Evidence of the clinical benefit for the PiCCO-Technology by indications

Pediatric - Acute respiratory failure

- Lubrano R, Cecchetti C, Tomasello C, Guido G, Di Nardo M, Masciangelo R, Pasotti E, Barbieri MA, Bellelli E, Pirozzi N. **Prognostic value of extravascular lung water index in critically ill children with acute respiratory failure.** Intensive Care Med. 2011; 37(1): 124-131.

Pediatric - Severe burn injury

- Kraft R, Herndon DN, Branski LK, Finnerty CC, Leonard KR, Jeschke MG. **Optimized fluid management improves outcomes of pediatric burn patients.** J Surg Res 2013; 181(1): 121-8.
- Branski LK, Herndon DN, Byrd JF, Kinsky MP, Lee JO, Fagan SP, Jeschke MG. **Transpulmonary thermodilution for hemodynamic measurements in severely burned children.** Crit Care 2011; 15(2): R118.

Pediatric - Head trauma

- Cecchetti C, Elli M, Stoppa F, Di Nardo M, Pasotti E, Gentile I, Paoli S, Pirozzi N, Lubrano R. **Neurogenic pulmonary edema and variations of emodynamic volumetric parameters, in children following head trauma.** Minerva Anestesiol 2013; 70(10): 1140-6.

Pediatric - Cardiac surgery

- Gil Anton J, Lopez-Bayon J, Lopez-Fernandez Y, Morteruel E, Perez-Estevez E, Lopez-Herce J.
  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.
  J Clin Monit Comput 2011; 25(2): 105-8.
- Szekely A, Breuer T, Sapi E, Szekely E, Szatmari A, Toth M, Hauser B, Gal J.
  Transpulmonary thermodilution in neonates undergoing arterial switch surgery.
  Pediatr Cardiol 2011; 32(2): 125-30.
- Fakler U, Pauli Ch, Balling G, Lorenz HP, Eicken A, Hennig M, Hess J.
  Cardiac index monitoring by pulse contour analysis and thermodilution after pediatric cardiac surgery.
  J Thorac Cardiovasc Surg 2007; 133(1): 224–8.
- 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): 1277-80.
- Egan J, Festa M, Cole A, Nunn GR, Gillis J, Winlaw DS,
  Clinical assessment of cardiac performance in infants and children following cardiac surgery.
  Intensive Care Med 2005; 31(4): 568-73.
- Mahajan A, Shabanie A, Turner J, Sopher MJ, Marijic J.
  Pulse contour analysis for cardiac output monitoring in cardiac surgery for congenital heart disease.
  Anesth Analg 2003; 97(5): 1283-8.

Pediatric - Liver transplantation

- Torgay A, Pirat A, Akpek E, Zeyneloglu P, Arslan G, Haberal M.
  Pulse contour cardiac output system use in pediatric orthotopic liver transplantation: preliminary report of nine patients.
  Transplant Proc 2005; 37(7): 3168-70.

Pediatric - Normal range areas in paediatric patients

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

- Nusmeier A, Cecchetti C, Blohm M, Lehman R, van der Hoeven J, Lemson J.
  Near-normal values of extravascular lung water in children.
  Pediatr Crit Care Med 2015; 16(2): e28-33.
- Lemson J, Merkus P, van der Hoeven JG.
  Extravascular lung water index and global end-diastolic volume index should be corrected in children.
  J Crit Care 2011; 26(4): 443 e7-432 e12.

Cost Effectiveness

Several publications confirmed improved patient outcome when advanced haemodynamic variables have been used to set up a goal directed treatment algorithm. In the studies mainly a reduction of complication rates have been reported and consequently the treatment costs have been reduced. Even when the installation of advanced haemodynamic monitoring is associated with an investment, the cost reduction by avoiding complications is much higher than the investment.

- Sadique Z, Harrison DA, Grieve R, Rowan KM, Pearse RM.
  Cost-effectiveness of a cardiac output-guided haemodynamic therapy algorithm in high-risk patients undergoingmajor gastrointestinal surgery.
  Perioper Med 2015; 4: 13
- Michard F, Mountford WK, Krukas MR, Ernst FR, Fogel SL.
  Potential return on investment for implementation of perioperative goal-directed fluid therapy in major surgery: a nationwide database study.
  Perioper Med 2015; 4: 11
- Manecke GR, Asemota A, Michard F.
  Tackling the economic burden of postsurgical complications: would perioperative goal-directed fluid therapy help?
  Crit Care 2014; 18(5): 566
- Ebm CC, Sutton L, Rhodes A, Cecconi M.
  Cost-Effectiveness in goal-directed therapy: are the dollars spent worth the value?
  J Cardiothorac Vasc Anesth 2014; 28(6): 1660-6.

Validation of the PiCCO parameters

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

In terms of accuracy the two methods are comparable. However, the PiCCO thermodilution measurement is less user dependent and gives more stable measurements. When compared to the gold standard (Fick method) the PiCCO thermodilution cardiac output shows an excellent correlation.

- 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.
  Crit Care Med 2009; 37(1): 119-23.
- Felbinger TW, Reuter DA, Eltzschig HK, Bayerlein J, Goetz AE.
  Cardiac index measurements during rapid preload changes: a comparison of pulmonary artery thermodilution with arterial pulse contour analysis.
  J Clin Anesth 2005; 17(4): 241-8.
- Marx G, Schuerholz T, Sumpelmann R, Simon T, Leuwer M.
  Comparison of cardiac output measurements by arterial trans-cardiopulmonary and pulmonary arterial thermodilution with direct Fick in septic shock.
  Eur J Anaesthesiol 2005; 22(2): 129-34.
- Bein B, Worthmann F, Tonner PH, Paris A, Steinfath M, Hedderich J, Scholz J.
  Comparison of esophageal Doppler, pulse contour analysis, and real-time pulmonary artery thermodilution for the continuous measurement of cardiac output.
  J Cardiothorac Vasc Anesth 2004; 18(2): 185-9.
- Della Rocca G, Costa MG, Coccia C, Pompei L, Pietropaoli P.
  Preload and haemodynamic assessment during liver transplantation: a comparison between the pulmonary artery catheter and transpulmonary indicator dilution techniques.
  Eur J Anaesthesiol 2002; 19(12): 868-75.

Validation of the PiCCO parameters

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, mainly in the early days after market introduction of the PiCCO technology.

- Felbinger TW, Reuter DA, Eltzschig HK, Bayerlein J, Goetz AE.
  Cardiac index measurements during rapid preload changes: a comparison of pulmonary artery thermodilution with arterial pulse contour analysis.
  J Clin Anesth 2005; 17(4): 241-8.
- Della Rocca G, Costa, MG Coccia C, Pompei L, Di Marco P.
  Cardiac output monitoring: aortic transpulmonary thermodilution and pulse contour analysis agree with standard thermodilution methods in patients undergoing lung transplantation.
  Can J Anaesth 2003; 50(7):707-11.
- Mielck F, Buhre W, Hanekop G, Tirilomis T, Hilgers R, Sonntag H.
  Comparison of continuous cardiac output measurements in patients after cardiac surgery.
  J Cardiothorac Vasc Anesth 2003; 17(2): 211-6
- Felbinger TW, Reuter DA, Eltzschig HK, Moerstedt K, Goedje O, Goetz AE.
  Comparison of pulmonary arterial thermodilution and arterial pulse contour analysis: Evaluation of a new algorithm.
  J Clin Anesth 2002; 14: 296-301.
- Zollner C, Haller M, Weiss M, Morstedt K, Lamm P, Kilger E, Goetz AE.
  Beat-to-beat measurement of cardiac output by intravascular pulse contour analysis. A prospective criterion standard study in patients after cardiac surgery.
  J Cardiothorac Vasc Anesth 2000; 14(2): 125-9.

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

Evidence shows that measuring lung water with the PiCCO for quantification of pulmonary oedema is accurate and correlated strongly with the ‘gold standard’ gravimetric method.

- Venkateswaran RV, Dronavalli V, Patchell V, Wilson I, Mascaro J, Thompson R, Coote J, Bonser RS.
  Measurement of extravascular lung water following human brain death; implications for lung donor assessment and transplantation.
  Eur J Cardiothorac Surg 2013; 43(6): 1227-32.
- Tagami T, Kushimoto S, Yamamoto Y, Atsumi T, Tosa R, Matsuda K, Oyama R, Kawaguchi T, Masuno T, Hirama H, Yokota H.
  Validation of extravascular lung water measurement by single transpulmonary thermodilution: human autopsy study.
  Crit Care 2010; 14(5): R162.
- Kuzkov VV, Suborov EV, Kirov MY, Kuklin VN, Sobhkhez M, Johnsen S, Waerhaug K, Bjertnaes LJ.
  Extravascular lung water after pneumonectomy and one-lung ventilation in sheep.
  Crit Care Med 2007; 35(6): 1550-9.
- Kirov MY, Kuzkov VV, Kuklin VN, Waerhaug K, Bjertnaes LJ.
  Extravascular lung water assessed by transpulmonary single thermodilution and postmortem gravimetry in sheep.
  Crit Care 2004; 8(6): R451
- Katzenelson R, Perel A, Berkenstadt H, Preisman S, Kogan S, Sternik L, Segal E.
  Accuracy of transpulmonary thermodilution versus gravimetric measurement of extravascular lung water.
  Crit Care Med 2004; 32(7): 1550-4.

Clinical & Medical Questions

Influence on PiCCO measurements by special clinical situations or therapies

Aortic aneurysm

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

- Antonini M, Meloncelli S, Dantimi C, Tosti S, Ciotti L, Gasparetto A.
  [The PiCCO system with brachial-axillary artery access in hemodynamic monitoring during surgery of abdominal aortic aneurysm].
  Minerva Anestesiol 2001; 67(6): 447-56.

Valvulopathies, cardiac valve insufficiencies

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

- Staier K, Wilhelm M, Wiesenack C, Thoma M, Keyl C.
  Pulmonary artery vs. transpulmonary thermodilution for the assessment of cardiac output in mitral regurgitation: a prospective method comparison study.
  Eur J Anaesthesiol 2012; 29(9): 431-7.

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. Recalibration of the pulse contour (with thermodilution) substantially improves reliability in severe aortic stenosis.

- Petzoldt M, Riedel C, Braeunig J, Braeunig J, Haas S, Goepfert MS, Treede H, Baldus S, Goetz AE, Reuter DA.
  Stroke volume determination using transcardiopulmonary thermodilution and arterial pulse contour analysis in severe aortic valve disease.
  Intensive Care Med 2013; 39: 601–611.

Hypothermia

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

- Demirgan S, Erkalp K, Sevdi MS, Aydogmus MT, Kutbay N, Firincioglu A, Ozalp A, Alagol A.
  Cardiac condition during cooling and rewarming periods of therapeutic hypothermia after cardiopulmonary resuscitation.
  BMC Anesthesiol 2014; 14: 78.
- Tagami T, Kushimoto S, Tosa R, Omura M, Hagiwara J, Hirama H, Yokota H
  The precision of PiCCO® measurements in hypothermic post-cardiac arrest patients.
  Anaesthesia 2012; 67(3): 236-243.

Vasoconstrictor and/or inotrope therapy

All parameters are correctly calculated. Where there are significant changes in the catecholamine requirements or volume therapy, recalibration of the pulse contour analysis is recommended.

- Gruenewald M, Meybohm P, Renner J, Broch O, Caliebe A, Weiler N, Steinfath M, Scholz J, Bein B.
  Effect of norepinephrine dosage and calibration frequency on accuracy of pulse contour-derived cardiac output.
  Crit Care 2011; 15(1): R22.
- Hamzaoui O, Monnet X, Richard C, Osman D, Chemla D, Teboul JL.
  Effects of changes in vascular tone on the agreement between pulse contour and transpulmonary thermodilution cardiac output measurements within an up to 6-hour calibration-free period.
  Crit Care Med 2008; 36(2): 434-40.

Clinical & Medical Questions

Influence on PiCCO measurements by special clinical situations or therapies

Intra-aortic Balloon Pump (IABP)

The thermodilution measurement with the PiCCO is not influenced by the IABP, but the Pulse Contour Analysis is unable to provide valid continuous cardiac output.

- Schmid B, Fink K, Olschewski M, Richter , Schwab T, Brunner M, Busch HJ.
  Accuracy and precision of transcardiopulmonary thermodilution in patients with cardiogenic shock.
  J Clin Monit Comput. 2015; DOI 10.1007/s10877-015-9782-8
- Janda M, Scheeren TWL, Bajorat J, Westphal B, Vagts DA, Pohl B, Popescu C, Hofmockel R.
  The impact of intra-aortic balloon pumping on cardiac output determination by pulmonary arterial and transpulmonary thermodilution in pigs.
  J of Cardiovasc and Vasc Anesth 2006; 20 (3): 320-4.

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

When a patient is on ECMO there is no way for the thermodilution injectate to get from the point of injection to the point of detection as the ECMO machine lies in its path. It is not known if the pulse contour analysis is accurate or not.

Ventricular assist device (VAD)

With a VAD 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): 73-5.

Continuous renal replacement therapy (CRRT), haemofiltration, dialysis

PiCCO works when patients are on CRRT, with the following recommendations from the literature: thermodilution measurements should be avoided directly after the CRRT is switched on or off due to potential unstable blood temperatures and the CRRT catheter outflow and inflow should not lie in the PiCCO indicator passage track.

- Pathil A, Stremmel W, Schwenger V, Eisenbach C.
  The influence of haemodialysis on haemodynamic measurements using transpulmonary thermodilution in patients with septic shock: an observational study.
  Eur J Anaesthesiol 2013; 30(1): 16-20.
- Dufour N, Delville M, Teboul JL, Camous L, Favier du Noyer A, Richard C, Monnet X.
  Transpulmonary thermodilution measurements are not affected by continuous veno-venous hemofiltration at high blood pump flow.
  Intensive Care Med 2012; 38(7): 1162-8.

- Heise D, Faulstich M, Morer O, Brauer , Quintel M.
  Influence of continuous renal replacement therapy on cardiac output measurement using thermodilution techniques.
  Minerva Anestesiol 2012; 78(3): 315-21.
- Sakka S, Hanusch T, Thuemer , Wegscheider K.
  The influence of venovenous renal replacement therapy on measurements by the transpulmonary thermodilution technique.
  Anesth Analg 2007; 105(4): 1079–82.

Kinetic therapy (e.g. prone positioning)

Research shows that the EVLW can be used to show the positive effect of proning the patient. It has also been shown that the calibrated PiCCO is more accurate than non-calibrated systems.

- Grensemann J, Bruecken U, Treszl A, Wappler F, Sakka SG.
  The influence of prone positioning on the accuracy of calibrated and uncalibrated pulse contour-derived cardiac index measurements.
  Anesth Analg 2013; 116(4): 820-6.
- Brucken U, Grensemann J, Wappler F, Sakka SG.
  Influence of prone positioning on the measurement of transpulmonary thermodilution-derived variables in critically ill patients.
  Acta Anaesthesiol Scand 2011; 55(9): 1061-7.
- Michelet P, Roch A, Gainnier M, Sainty JM, Auffray JP, Papazian L.
  Influence of support on intra-abdominal pressure, hepatic kinetics of indocyanine green and extravascular lung water during prone positioning in patients with ARDS: a randomized crossover study.
  Crit Care 2005; 9(3): R251.

Effect of lung resection on ELWI

Lung resection procedures (lobectomy, bilobectomy, pneumectomy) theoretically reduce the Pulmonary Blood Volume (PBV) and may lead to inaccurate calculation (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 latest two days post-operatively

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

- Naidu BV, Dronavalli VB, Rajesh PB.
  Measuring lung water following major lung resection.
  Interact CardioVasc Thorac Surg 2009; 8: 503-506.
- Schroder C, Kuhn K, Macchiarini P.
  Radical lymphadenectomy does not effect intrathoracic fluid volume changes after lung surgery.
  Internet J Thorac Cardiovasc Surg 2005; 7(2).

Clinical & Medical Questions

Influence on PiCCO measurements by special clinical situations or therapies

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 the pleural fluid is negligible.

- Deeren D, Dits H, Daelemans R, Malbrain ML.
  Effect of pleural fluid on the measurement of extravascular lung water by single transpulmonary thermodilution.
  Clinical Intensive Care 2004; 15: 119-22.

Effect of Pulmonary Embolism on ELWI

With pulmonary embolisms, because there is an obstruction in the pulmonary vasculature, EVLW is underestimated.

- Schreiber T, Huter L, Schwarzkopf K, Schubert H, Preussler N, Bloos F, Gaser E, Karzai W.
  Lung perfusion affects preload assessment and lung water calculation with the transpulmonary double indicator method.
  Intensive Care Med 2001; 27(11): 1814-8.

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 and as letters. These investigations don't show 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 the 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 if the decision is made to leave the PiCCO-Catheter in the patient during the MRI.

- Greco F, Vendrell JF, Deras P, Boularan A, Perrigault PF.
  [The Pulsiocath catheter and magnetic resonance imaging.]
  Ann Fr Anesth Reanim 2011; 30(9): 697.
- Kampen J, Liess C, Casadio C, Tonner PH, Reuter M, Scholz J.
  Safety of the Pulsiocath for haemodynamic monitoring during magnetic resonance imaging.
  Anaesthesia 2004; 59(8): 828-9.
- Kampen J, Liess K, Casadio C, Tonner PH, Scholz J.
  [Thermal lesions caused by a PiCCO catheter left in place in the MRT? – Fibre optical measurements of temperature in a No-flow-model.]
  Intensivmedizin und Notfallmedizin 2002; 39: 113

Passive leg raising (PLR)

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

- Guerin L, Teboul JL, Persichini R, Dres M, Richard C, Monnet X.
  Effects of passive leg raising and volume expansion on mean systemic pressure and venous return in shock in humans.
  Crit Care 2015; 19: 411.
- Jabot J, Teboul JL, Richard C, Monnet X.
  Passive leg raising for predicting fluid responsiveness: importance of the postural change.
  Intensive Care Med 2009; 35(1): 85-90.

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.

- Umgelter A, Wagner K, Reindl W, Nurtsch N, Huber W, Schmid RM.
  Hemodynamic effects of plasma-expansion with hyperoncotic albumin in cirrhotic patients with renal failure.
  A prospective interventional study. BMC Gastroenterol 2008; 8(1): 39.
- Sander M, Spies CD, Berger K, Grubitzsch H, Foer A, Kramer M, Carl M, von Heymann C.
  Prediction of volume response under open-chest conditions during coronary artery bypass surgery.
  Crit Care 2007; 11(6): R121.
- Michard F, Alaya S, Zarka V, Bahloul M, Richard C, Teboul JL.
  Global end-diastolic volume as an indicator of cardiac preload in patients with septic shock.
  Chest 2003; 124(5): 1900-8.
- Della Rocca G, Costa GM, Coccia C, Pompei L, Di Marco P, Pietropaoli P.
  Preload index: pulmonary artery occlusion pressure versus intrathoracic blood volume monitoring during lung transplantation.
  Anesth Analg 2002; 95(4): 835-43.

Contractility parameters Cardiac Function Index (CFI) and Global Ejection Fraction (GEF)

These parameters have been compared to the left ventricular ejection fraction from Echocardiography, for e.g. and have been found to closely correlate.

- Meybohm P, Gruenewald M, Renner J, Maracke M, Rossee S, Hocker J, Hagelsteins S, Zacharowski K, Bein B.
  Assessment of left ventricular systolic function during acute myocardial ischemia: A comparison of transpulmonary thermodilution and transesophageal echocardiography.
  Minerva Anestesiol 2011; 77(2): 132-41.
- Trepte CJ, Eichhorn V, Haas SA, Richter HP, Goepfert MS, Kubitz JC, Goetz AE, Reuter DA.
  Thermodilution-derived indices for assessment of left and right ventricular cardiac function in normal and impaired cardiac function.
  Crit Care Med 2011; 39(9): 2106-12.
- Jabot J, Monnet X, Lamia B, Chemla D, Christian R, Teboul JL.
  Cardiac function index provided by transpulmonary thermodilution behaves as an indicator of left ventricular systolic function.
  Crit Care Med 2009; 37(11): 2913-8.

Fluid responsiveness by Stroke Volume Variation (SVV) and Pulse Pressure Variation (PPV)

To fulfil the criteria for SVV and PVV to be accurate, the patient must be on positive pressure ventilation with a tidal volume > 8ml/kg (no spontaneous breathing or assisted breaths) and in sinus rhythm with no artifacts. This is the case for every monitor that provides these parameters.

- Hofer CK, Muller SM, Furrer L, Klaghofer R, Genoni M, Zollinger A.
  Stroke volume and pulse pressure variation for prediction of fluid responsiveness in patients undergoing off-pump coronary artery bypass grafting.
  Chest 2005; 128(2): 848-54.
- Reuter DA, Kirchner A, Felbinger TW, Weis FC, Kilger E, Lamm P, Goetz AE.
  Usefulness of left ventricular stroke volume variation to assess fluid responsiveness in patients with reduced cardiac function.
  Crit Care Med 2003; 31(5): 1399-40.

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: 487-94.
- 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): 558–63.
- Dres M, Teboul JL, Monnet X.
  Weaning the cardiac patient from mechanical ventilation.
  Curr Opin Crit Care 2014; (5): 493-8.

Accuracy of chest x-ray for measuring pulmonary oedema

Research confirms that even today, it is not possible to quantify the extent of pulmonary oedema with a chest x-ray. The reason is the complexity to interpret a chest x-ray, a density measurement which is influenced by all compartments in the chest, like bones, muscles, vessels, blood, air, skin layers, tissue oedema, pleural effusion and, amongst the others, also by the extravascular lung water.

- Brown LM, Calfee CS, Howard JP, Craig TR, Matthay MA, McAuley DF.
  Comparison of thermodilution measured extravascular lung water with chest radiographic assessment of pulmonary oedema in patients with acute lung injury.
  Ann Intensive Care 2013; 3(1): 25.
- Saugel B, Ringmaier S, Holzapfel K, Schuster T, Phillip V, Schmid RM, Huber W.
  Physical examination, central venous pressure, and chest radiography for the prediction of transpulmonary thermodilution-derived hemodynamic parameters in critically ill patients: A prospective trial.
  J Crit Care 2011; 26(4): 402-10.
- 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.


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PHILIPS

Technique and Technology Questions

Risk of the PiCCO femoral catheter compared to other arterial catheters

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

- Belda FJ, Aguilar G, Teboul JL, Pestana D, Redondo FJ, Malbrain M, Luis JC, Ramasco F, Umgelter A, Wendon J, Kirov M, Fernandez-Mondejar E.
  Complications related to less-invasive haemodynamic monitoring.
  Br J Anaesth 2011; 106: 482-6
- 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. From a hygienic point of view this is not recommended for clinical practice. Based on a publication by the Commission for Hospital Hygiene and Infection Prevention of the Robert-Koch Institute, Germany (Bundesgesundheitsbl – Gesundheitsforsch – Gesundheitsschutz 2002) 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 this disposable articles, e.g. bleeding, haematoma, 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 a downstream temperature required for the thermodilution measurement.

- Camporota L and Beale T.
  Pitfalls in haemodynamic monitoring based on the arterial pressure waveform.
  Crit Care 2010; 14(2): 124
- Orme RMLE, Pigott DW, Mihm FG.
  Measurement of cardiac output by transpulmonary arterial thermodilution using a long radial artery catheter. A comparison with intermittent pulmonary artery thermodilution.
  Anaesthesia 2004; 59: 590–594

Technique and Technology Questions

How many thermodilution measurements are recommended?

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

- Giraud R, Siegenthaler N, Merlani P, Bendjelid K.
  Reproducibility of transpulmonary thermodilution cardiac output measurements in clinical practice: a systematic review.
  J Clin Monit Comput 2016; DOI 10.1007/s10877-016-9823-y
- Monnet X, Persichini R, Ktari M, Jozwiak M, Richard C, Teboul JL.
  Precision of the transpulmonary thermodilution measurements.
  Crit Care 2011; 15(4): R204.

Importance of an accurate value for the central venous pressure (CVP)

The central venous pressure (CVP) value is only required for the calculation of the afterload parameter, systemic vascular resistance (SVR/SVRI). In the calculation formula [SVR = (MAP-CVP) / CO * 80] the CVP value does not have a significant influence and the default CVP value of 5mmHg enables a sufficiently accurate SVR calculation. Only in case of extremely high or low values the CVP should be adjusted manually. Usually CVP is not measured continuously when PiCCO is applied, but in case of the availability of a continuous CVP measurement this can be connected to the PiCCO and the continuous values are used for the SVR calculation**.**

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 paediatric patients.

- Lemson J, Eijk RJ, van der Hoeven JG.
  The “cross-talk phenomenon” in transpulmonary thermodilution is flow dependent.
  Intensive Care Med 2006; 32(7): 1092.

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 femorally, thermodilution measurement is possible, however, the PiCCO preload value, Global End-diastolic Volume (GEDI) will be slightly higher than the actual volume. From PiCCO2 software version V3.1 onwards the PiCCO asks for confirmation of where both the central venous and arterial catheters are placed to ensure accurate calculation of GEDI.

- Saugel B, Umgelter A, Schuster T, Phillip V, Schmid RM, Huber W.
  Transpulmonary thermodilution using femoral indicator injection: a prospective trial in patients with a femoral and a jugular central venous catheter.
  Crit Care 2010; 14: R95.
- Schmidt S, Westhoff TH, Hofmann C, Hofmann C, Schaefer JH, Zidek W, Compton F, van der Giet M.
  Effect of the venous catheter site on transpulmonary thermodilution measurement variables.
  Crit Care Med 2007; 35: 783–786.

Thermodilution injection via a peripherally inserted central catheter (PICC line)

In order to get an adequate thermodilution curve for accurate parameter calculation, the injectate bolus must be injected in under 7 seconds, and remain cool enough for the PiCCO catheter to detect a difference between the patient's blood and the bolus. Depending on the PICC used, it may be that these conditions cannot be fulfilled.

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 raised lung water, the use of cold injectate is recommended.

- Huber W, Kraski T, Haller B, Mair S, Saugel B, Beitz A, Schmid RM, Malbrain ML.
  Room-temperature vs. iced saline indicator injection for transpulmonary thermodilution.
  J Crit Care 2014; 29(6): 1133e7–1133 e14.

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 haemodynamic instability, the pulse contour will deviate from the thermodilution cardiac output. In such cases frequent recalibration (via thermodilution) is recommended.

- Huber W, Koenig J, Mair S, Schuster T, Saugel B, Eyer F, Phillip V, Schultheiss C, Thies P, Mayr U, Einwachter H, Treiber M, Hoellthaler J Schmid RM.
  Predictors of the accuracy of pulse-contour cardiac index and suggestion of a calibration-index: a prospective evaluation and validation study.
  BMC Anesthesiol 2015; 15: 45
- Hamzaoui O, Monnet X, Richard C, Osman D, Chemla D, Teboul JL.
  Effects of changes in vascular tone on the agreement between pulse contour and transpulmonary thermodilution cardiac output measurements within an up to 6-hour calibration-free period.
  Crit Care Med 2008; 36(2): 434-40

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