Train the Trainer Folder

Advanced Hemodynamic Monitoring

PiCCO-Technology®

Theory and Practice

PULSION
Medical Systems
PULSION Medical Inc.

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Background hemodynamics

Background hemodynamics

Complete hemodynamic picture with PiCCO

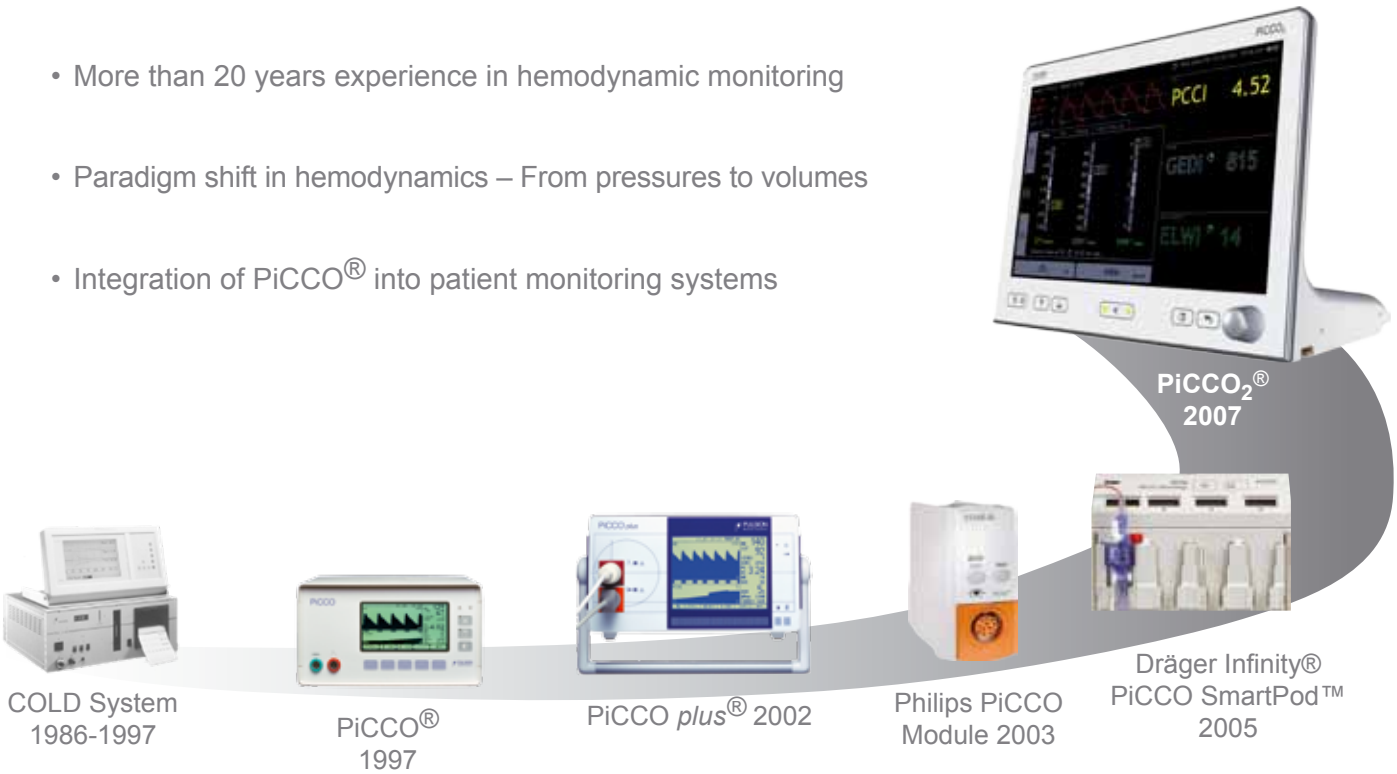
(no pulmonary artery catheter required)

- Continuous cardiac output
- Volumetric preload
- Afterload, contractility
- Volume responsiveness
- Pulmonary edema / Lung water

PiCCO$_2$®

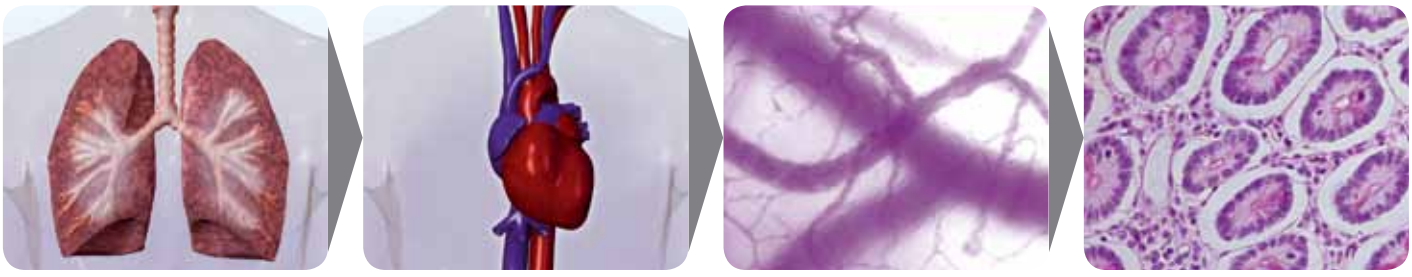
PULSION History

- Leading specialist in less invasive hemodynamic monitoring in ICU
- More than 20 years experience in hemodynamic monitoring
- Paradigm shift in hemodynamics – From pressures to volumes
- Integration of PiCCO® into patient monitoring systems



Background hemodynamics

Optimization of tissue oxygenation - Is measurement of CO enough?



O_2 uptake | O_2 transport | O_2 extraction | O_2 utilization

Oxygen Delivery | Oxygen Consumption

Mixed / Central Venous Oxygenation
SvO_2 / $ScvO_2$*

* 510k for $ScvO_2$ monitoring submitted

Cardiac Output
CO

Arterial Oxygen Content

Stroke Volume
SV

Heart Rate
HR

Oxygenation
SaO_2

Hemoglobin
Hb

Preload
– GEDV
– SVV

Afterload
SVR

Contractility
CFI

Pulmonary edema
EVLW

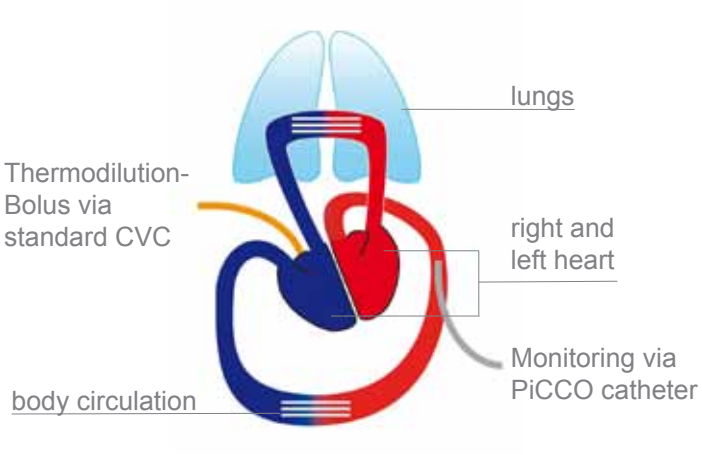
Volume

Vasopressors

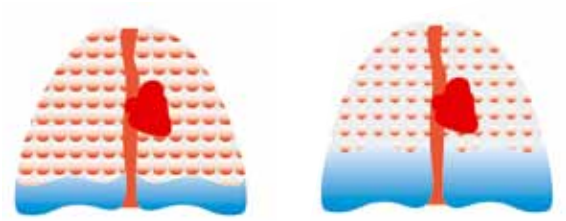
Inotropes

Red Blood Cells

PiCCO$_2$® - See more than others



- Continuous cardiac output
- Volumetric preload
- Afterload
- Contractility
- Volume responsiveness
- Bedside pulmonary edema assessment (Lung water)



General fields of Application

Intensive Care

- Septic Shock
- Cardiogenic Shock
- Burns
- Trauma / Hypovolemic Shock
- ARDS

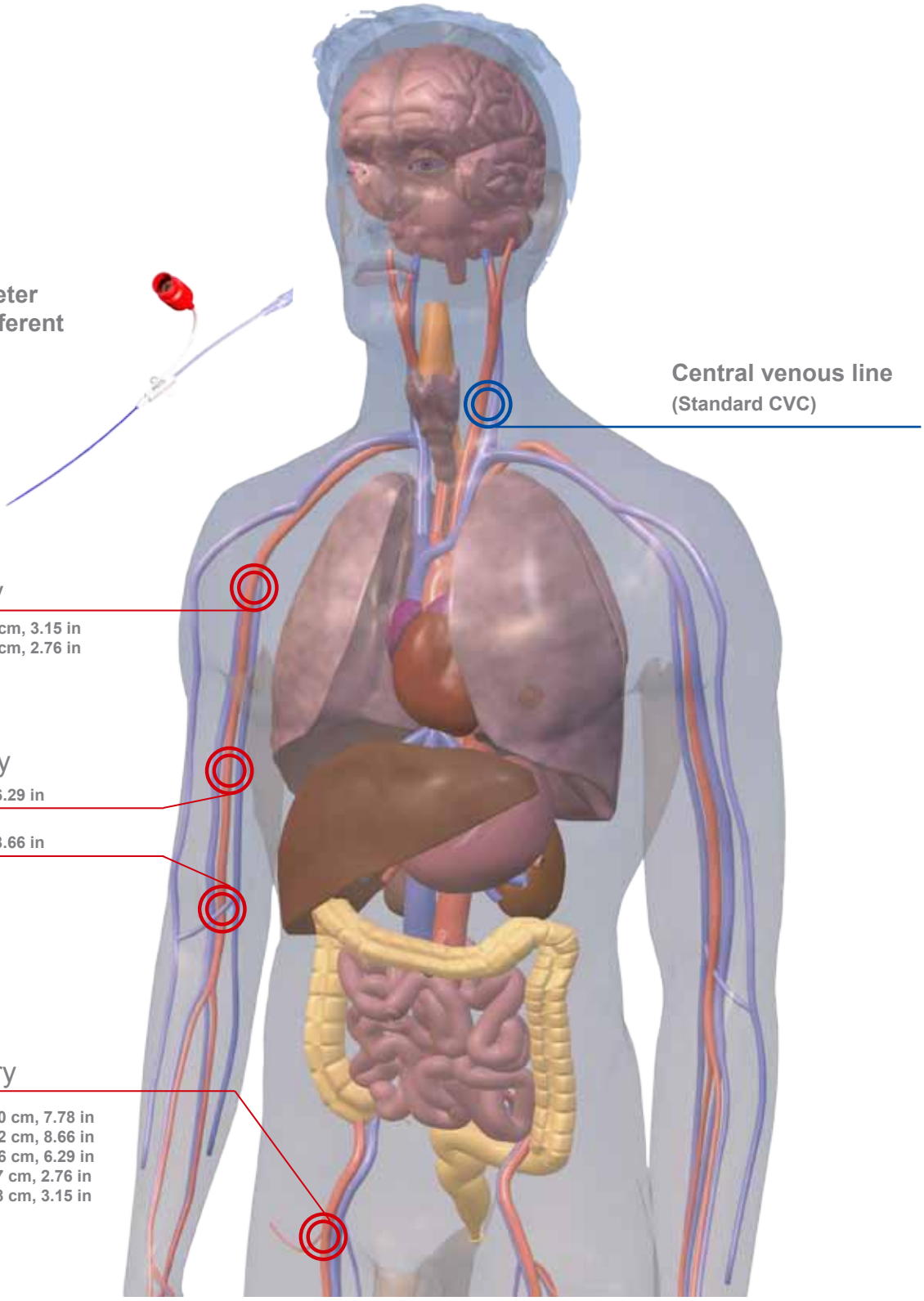
Peri-operative

- Cardiac Surgery
- Major Surgery
- Neuro Surgery

► for pediatrics and adults

Background hemodynamics

Complete hemodynamics - via CVC and arterial line



Arterial line (PiCCO® Catheter available in different sizes)

Central venous line
(Standard CVC)

Axillary artery

Adults: 4F 8 cm, 3.15 in
Small adults: 3F 7 cm, 2.76 in

Brachial artery

Adults: 4F 16 cm, 6.29 in

Adults: 4F 22 cm, 8.66 in

Femoral artery

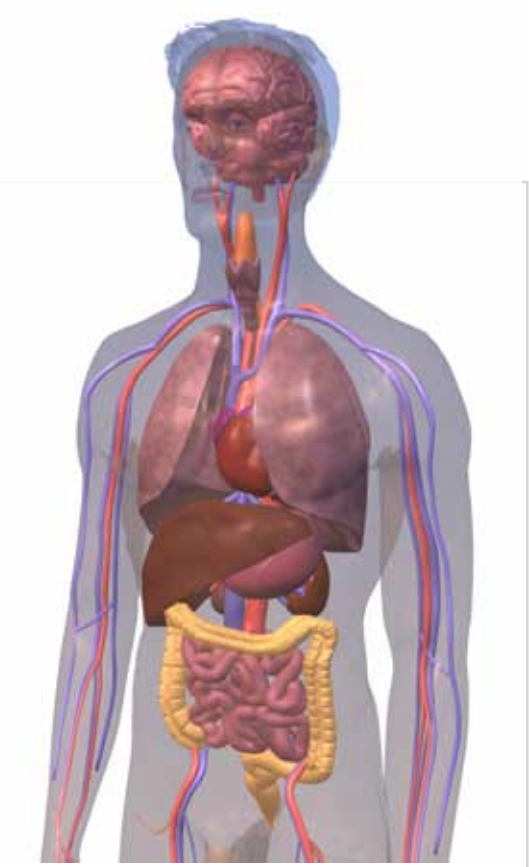
Adults: 5F 20 cm, 7.78 in
Adults: 4F 22 cm, 8.66 in
Small adults: 4F 16 cm, 6.29 in
Children: 3F 7 cm, 2.76 in
Children: 4F 8 cm, 3.15 in

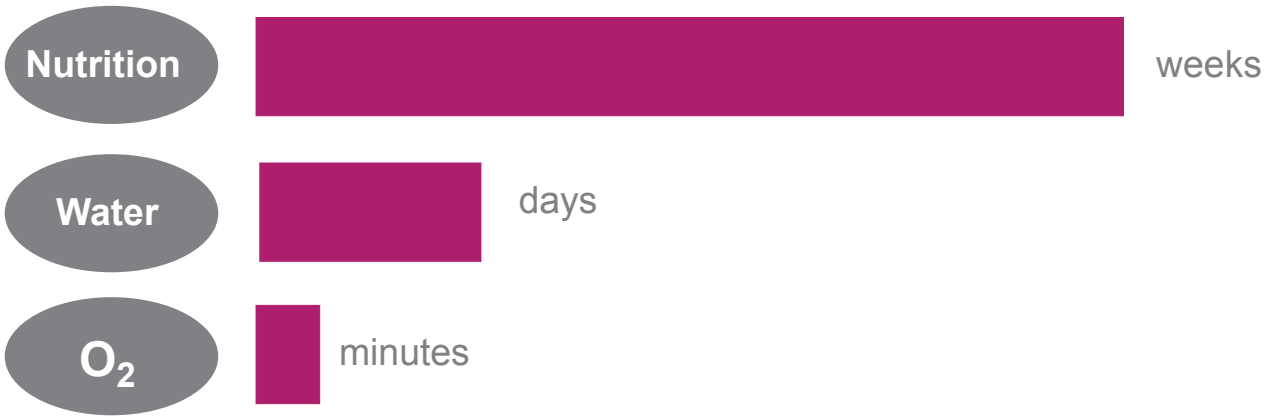
Background hemodynamics

Physiology

Every organism needs energy to function properly

This requires uptake and distribution of nutrition, fluid and oxygen throughout the body



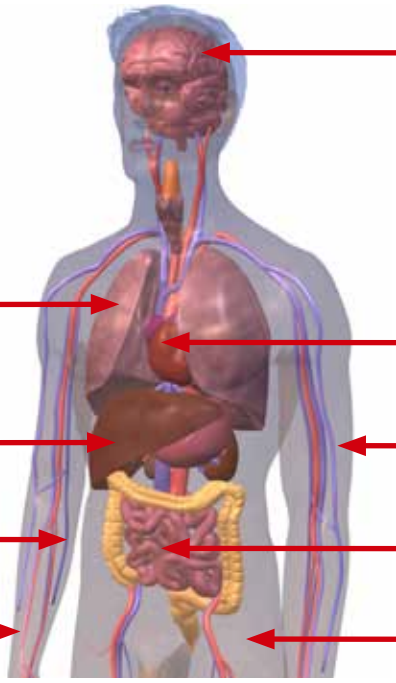


Man can survive for weeks without nutrition, for days without water <u>but</u> for only minutes without oxygen

This means oxygen uptake and distribution is of utmost priority!

Anatomy - the circulation

Nutrition and oxygen are distributed to the organs / tissues via the blood



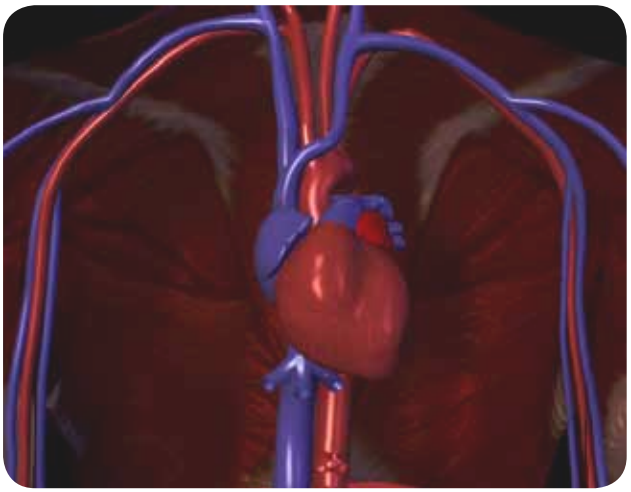
Background hemodynamics

What does 'hemodynamics' mean?

„Hemodynamics“ is the word used to describe the transport function of the cardiovascular system:

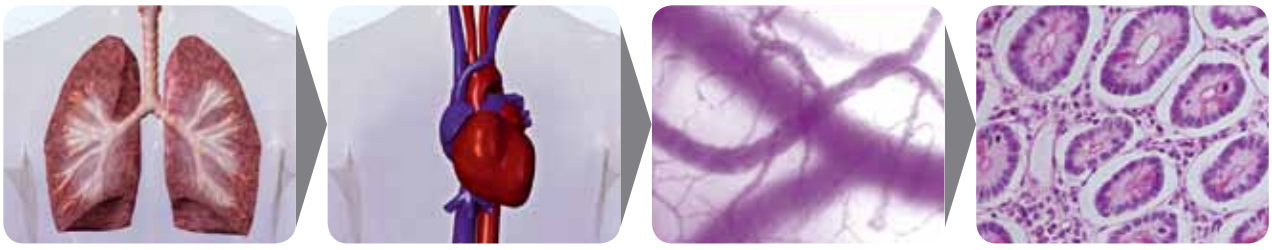
Hemo - blood

dynamics - motion by force



Oxygen transport

The basic aim of the cardiovascular system is cellular oxygen supply



O_2 uptake lungs

O_2 transport blood flow

O_2 extraction organs / tissues

O_2 utilization cells

Insufficient oxygen supply can lead to irreparable damage of vital organs

Physiology and pathophysiology

In healthy individuals, increased oxygen demand is automatically covered by the adaptive mechanisms of the cardiovascular and pulmonary system, e.g. with increased heart rate and breath rate.

In the critically ill patient these normal physiological mechanisms are often impaired, necessitating hemodynamic monitoring and therapies aimed at restoring adequate oxygen supply.

Intensive Care Unit

Intensive care is required for patients with severely impaired vital functions (including circulation and respiration), or for patients at increased risk of developing such impairments.

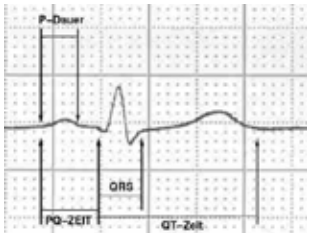
Background hemodynamics

Typical reasons for admission to ICU

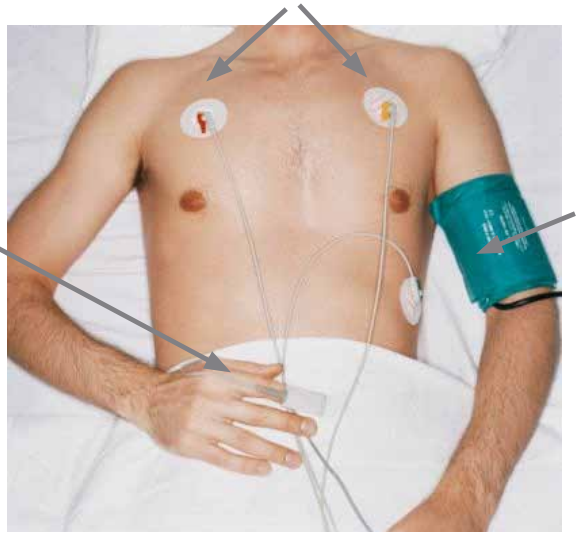
- Severe sepsis
- Septic shock
- Respiratory failure
- Myocardial infarction
- Severe trauma
- Intracerebral bleeds
- Severe liver disease
- Burns
- Transplantation surgery
- Cardiac surgery
- Other high risk surgical procedures

Basic monitoring – non invasive

Electrocardiogram (ECG)



Pulse oximetry (SpO_2)



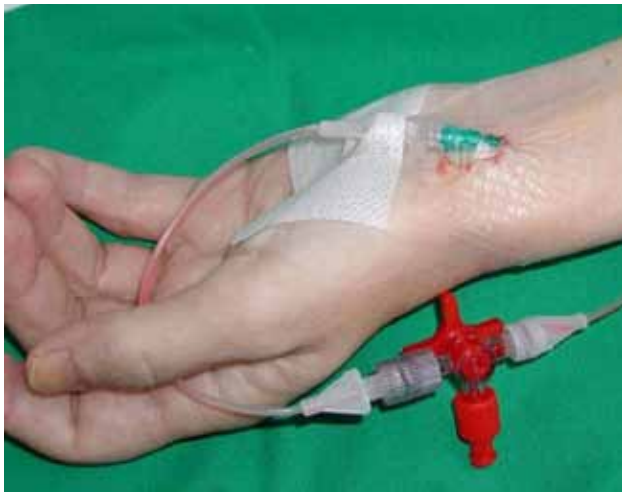
Non invasive blood pressure (NIBP)

These products are examples to illustrate and are not distributed by PULSION Inc.

Basic monitoring – invasive

Central venous catheter

Arterial catheter

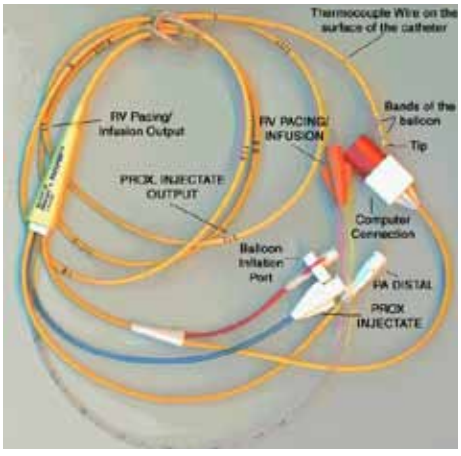


Precise monitoring of certain variables requires often access to the circulatory system.

Advanced hemodynamic monitoring

Echocardiography Transthoracic (TTE) or Transesophageal (TEE)

Pulmonary artery catheter (PAC)

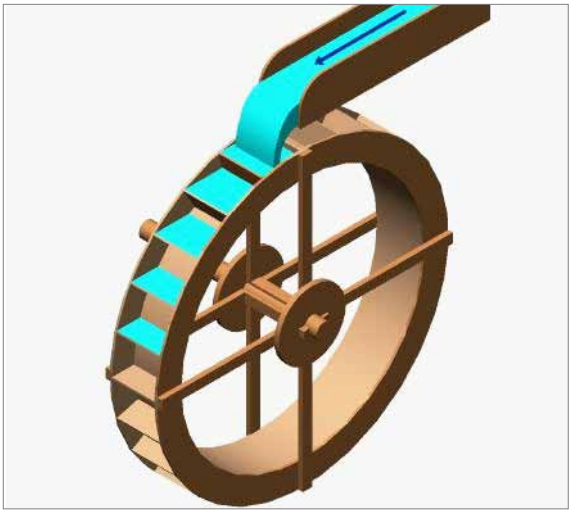


PiCCO-Technology

The Echo technology is a diagnostic tool for visualizing the heart`s morphology. The PA catheter (Swan Ganz) monitors the pulmonary circulation and the PiCCO-Technology monitors the body circulation.

Background hemodynamics

Advanced hemodynamic monitoring – Cardiac output

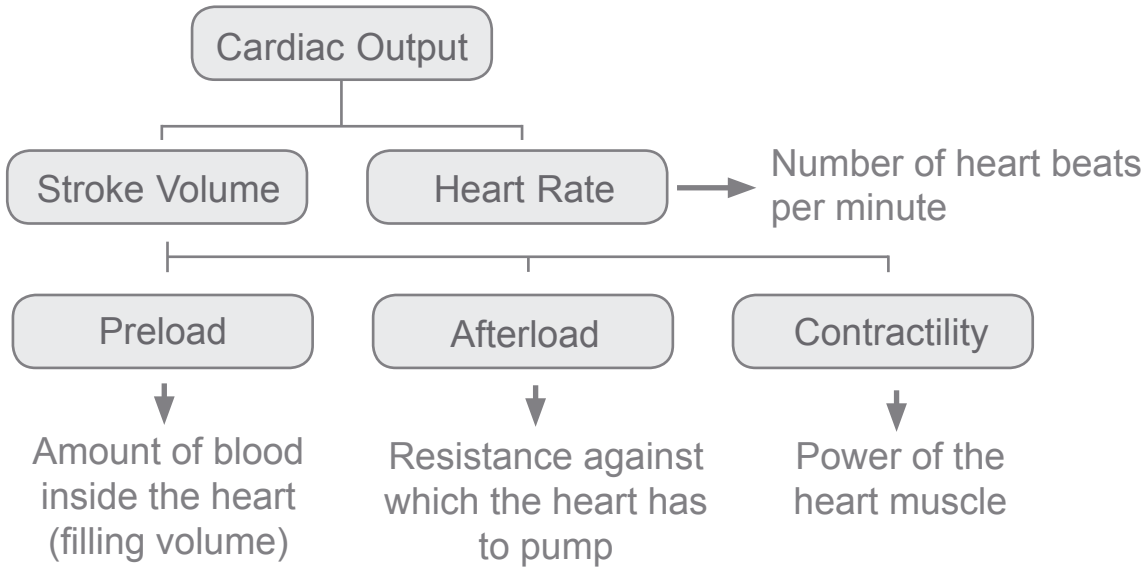


Cardiac Output - CO

Amount of blood that is transported by the heart in one minute

Advanced hemodynamic monitoring – Cardiac output determinants

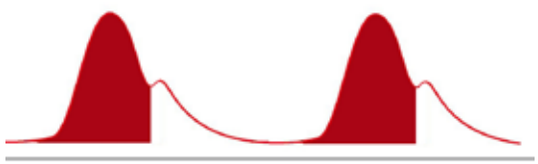
What does Cardiac Output depend on?



Summary

- The main aim of hemodynamic monitoring is to ensure optimal tissue oxygenation
- Measurement of cardiac output (CO) alone is not enough
- The $PiCCO_2$® provides all the determining components of CO (preload, afterload, contractility and heart rate) as well as the unique ability to assess pulmonary edema at the bedside (extravascular lung water)
- $PiCCO_2$® works via a standard central venous catheter and a special arterial catheter and its use is warranted in all cases where the patients volume status is unclear and / or where accurate monitoring is required

PiCCO® technology & parameters



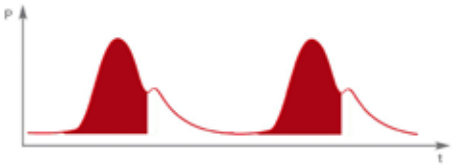
PiCCO® - Two methods combined for precise monitoring

Transpulmonary thermodilution

- Thermodilution cardiac output
- Volumetric preload (GEDV - Global End-Diastolic Volume)
- Contractility (CFI - Cardiac Function Index)
- Lung water (EVLW - Extravascular Lung Water)

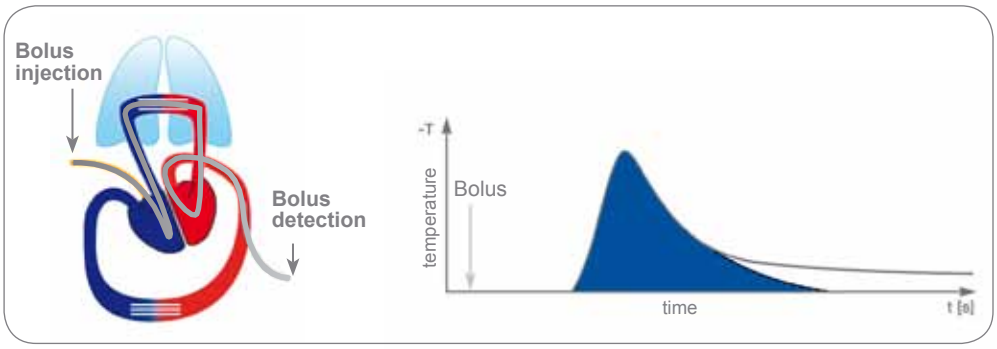
Calibration

Pulse contour analysis



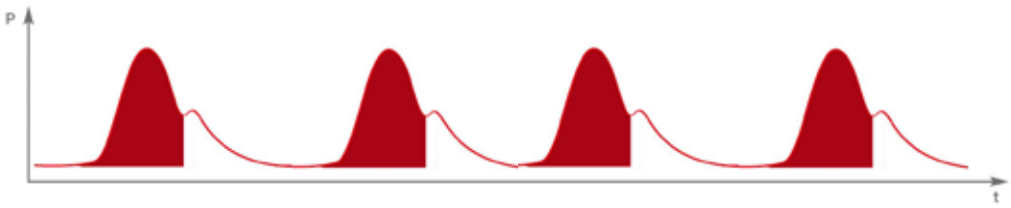
- Continuous cardiac output
- Afterload (SVR - Systemic Vascular Resistance)
- Stroke Volume (SV - Stroke Volume)
- Volume responsiveness (SVV - Stroke Volume Variation, PPV- Pulse Pressure Variation)

Transpulmonary Thermodilution



- The cold indicator passes through the right heart, lungs and left heart
- The indicator is detected in a central artery
- Precise cardiac output measurement based on Stewart-Hamilton algorithm
- Breathing cycle independent
- Passage through the heart and lungs allows determination of preload volumes and lung water

Pulse contour analysis



- Stroke volume is reflected by the area under the systolic part of the pressure curve (red area) of one heart beat
- Cardiac output is calculated beat-by-beat: stroke volume x heart rate

The parameters are identified as either continuous or discontinuous next to the illustration of the $PiCCO_2$ device.

Thermodilution Cardiac Output (CO)

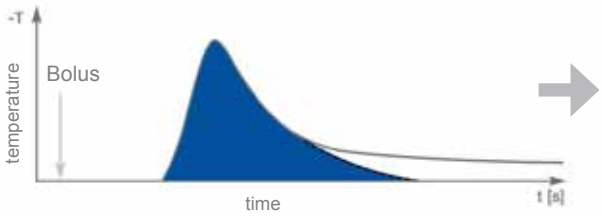
Cardiac Output - Volume of blood pumped by the heart in one minute
Important determinant for oxygen transport

CO – Cardiac Output
CI – Cardiac Index

- Highly precise measurement using the thermodilution technique
- Using the same calculation as the PA catheter

Determination of Thermodilution Cardiac Output

- Cardiac output is calculated by analysis of the thermodilution curve using a modified Stewart-Hamilton algorithm
- After central venous injection of the cold indicator, the thermistor at the tip of the arterial catheter measures the temperature change downstream



Cardiac output calculation:
Area under the thermodilution curve

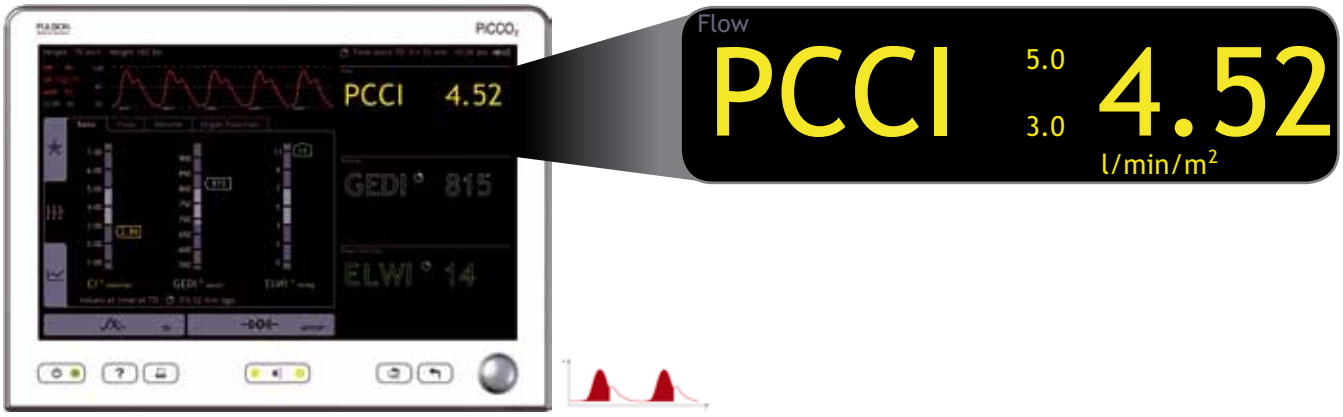
$$CO_{TDa} = \frac{(T_b - T_i) \times V_i \times K}{\int \Delta T_b \times dt}$$

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

Principle of measurement

Calibrated Continuous Cardiac Output (PCCO)

Cardiac Output - Cardiac Output (CO) is regarded as one of the most important hemodynamic variables for the assessment of cardiac function and guidance of therapy in critically ill patients.
Sakka et al. BJA , 2007

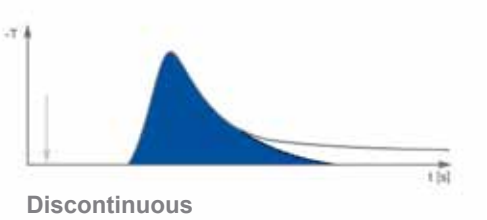


PCCO – Pulse Contour Cardiac Output
PCCI – Pulse Contour Cardiac Index

- Product of stroke volume and heart rate
- Determined beat-by-beat
- Maximum accuracy and safety by recalibration possibility

PiCCO® Continuous Cardiac Output

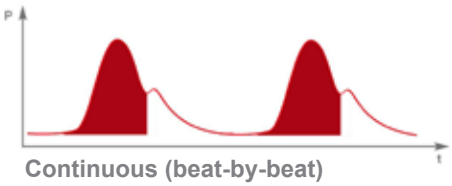
Transpulmonary thermodilution



Discontinuous

Calibration

Pulse contour analysis



Continuous (beat-by-beat)

Cardiac output is the product of stroke volume and heart rate

CO = SV x HR

Parameters

Preload volume instead of filling pressures

Preload - Volume of blood in the heart available to be pumped
'Volumetric preload parameters are superior to filling pressures' *Michard, Chest 2003*

GEDV – Global End-Diastolic Volume
GEDI – Global End-Diastolic Volume Index

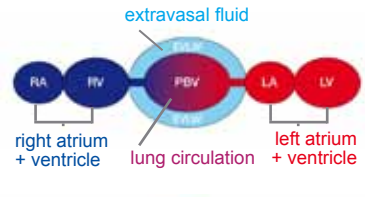
- Filling volume of all four heart chambers
- Adequate preload is an important prerequisite for adequate cardiac output (Frank-Starling curve)
- GEDI is indexed to “predicted body surface area” *

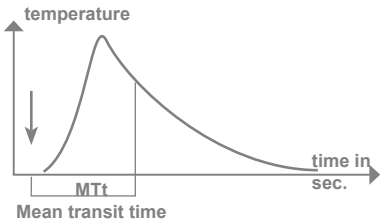
* Indexing particular parameters to the predicted body weight (EVLW) or predicted body surface area (GEDV) rather than the actual body weight or body surface area is more accurate particularly in overweight patients.

Determination of preload

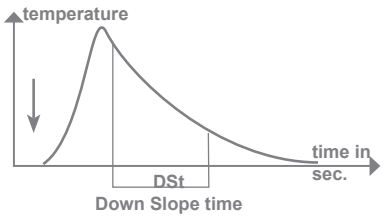
Advanced analysis of the thermodilution curve for transit time and downslope time (MTt, DSt) enables volume determination (Bubble model: each bubble represents a certain blood or fluid volume the bolus is passing (e.g. PBV - Pulmonary blood volume)

Intra-Thoracic Thermal Volume
ITTV = CO x MTt





– **Pulmonary Thermal Volume**
PTV = CO x DSt



= **Global End-Diastolic Volume (GEDV)**

PTV = Pulmonary Thermal Volume; Thermal distribution volume in the biggest mixing chamber, i.e. the lungs (includes blood and water); ITTV = Intra-Thoracic Thermal Volume; The total volume in which the indicator can be distributed (chambers between point of injection and detection); CO = Cardiac output;
MTt = Mean transit time of the cold indicator from the site of injection to the site of detection, DSt = Exponential downslope time of the arterial thermodilution curve

Volume responsiveness

Volume Responsiveness - predicts whether volume resuscitation (preload increase) will result in an increase in cardiac output

SVV – Stroke Volume Variation

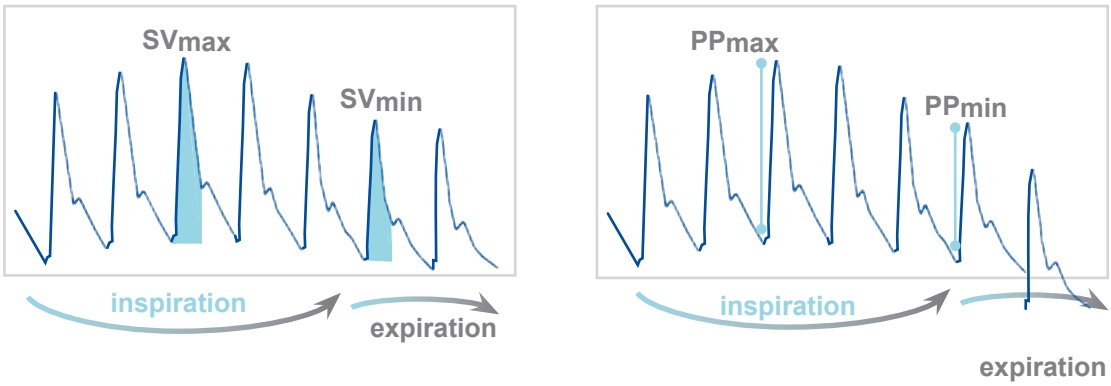
- Variation in stroke volume over the breathing cycle for a specific time frame

PPV – Pulse Pressure Variation

- Variation in pulse pressure over the breathing cycle for a specific time frame

Only applicable in fully mechanically ventilated patients with sinus rhythm!

Determination of volume responsiveness



Mechanical Ventilation

→ **Intrathoracic pressure fluctuations**

→ **Changes in intrathoracic blood volume**

→ **Preload changes**

→ **Fluctuations in stroke volume and pulse pressure**

Lung Water - Lung edema assessment at the bedside

EVLW – Extravascular Lung Water reflects pulmonary edema *Katzenelson, CCM 2004*

EVLW – Extravascular Lung Water
ELWI – Extravascular Lung Water Index

- Extravascular lung water (EVLW) represents the extravascular fluid of the lung tissue
- Includes intra-cellular, interstitial and intra-alveolar water (not pleural effusion)
- ELWI is indexed to “Predicted Body Weight”

*Predicted body weight is determined from the body height, gender and age

* Indexing particular parameters to the predicted body weight (EVLW) or predicted body surface area (GEDV) rather than the actual body weight or body surface area is more accurate particularly in overweight patients.

Determination of lung water

- EVLW is the difference between intra-thoracic thermal volume (ITTV) and intra-thoracic blood volume (ITBV) - see below
- ITBV is the blood volume in the heart plus the pulmonary blood volume
- It has been found that ITBV is consistently 25% higher than GEDV

Bubble model: Each bubble represents a certain blood or fluid volume (e.g. PBV - Pulmonary blood volume)

Intra-Thoracic Thermal Volume (ITTV)

– Intra-Thoracic Blood-Volume (ITBV)
ITBV = GEDV x 1.25

= Extravascular Lung Water (EVLW)

Lung water measurement vs. Chest X-ray

Pulmonary edema

- Pulmonary edema is not easily detected by chest X-ray
- EVLW is a direct quantification of pulmonary edema
- EVLW is much more sensitive than Chest X-ray

ELWI 21 ml/kg BW

Lung water severely increased

ELWI 11 ml/kg BW

Lung water moderately increased

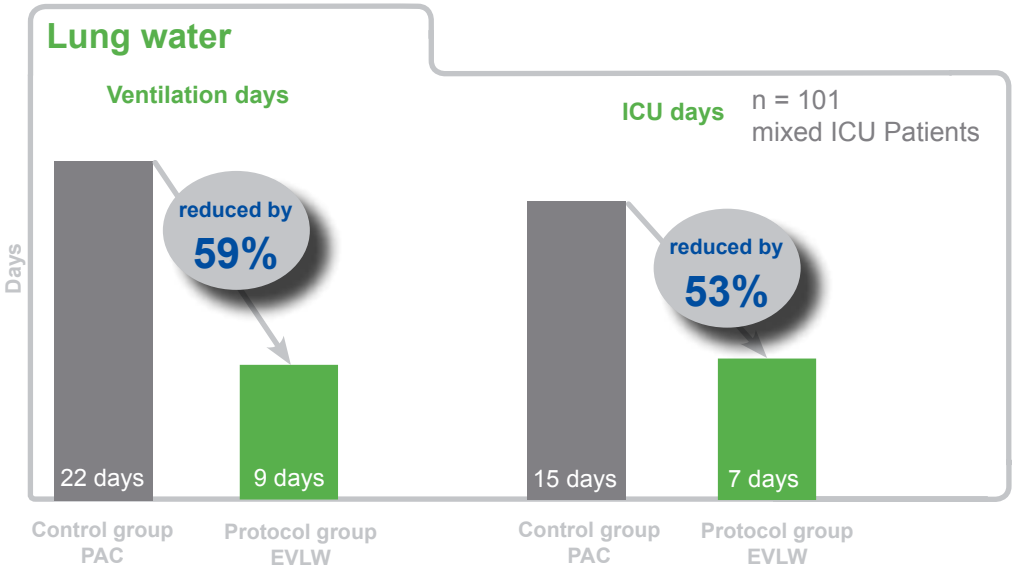
ELWI 5 ml/kg BW

Lung water normal

Source: Unpublished Data; Azriel Perel, MD, Department of Anaesthesiology and Intensive Care, Sheba Medical Center, Tel Aviv University, Tel Hashomer, Israel

Improved outcome based on fluid management

In this study the fluid management was based on wedge pressure monitoring in one and on lung water in the other group out of 101 critically ill patients.



Source: **Improved outcome based on fluid management in critically ill patients requiring pulmonary artery catheterization**
Mitchell JP, Schuller D, Calandrino FS, Schuster DP, Am Rev Respir Dis 1992; 145(5): 990-8

Afterload

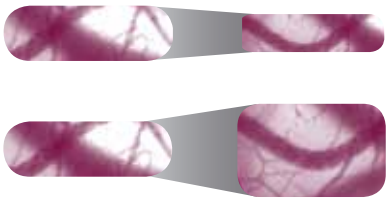
Systemic vascular resistance is an important determinant of afterload

SVR - Systemic Vascular Resistance
SVRI - Systemic Vascular Resistance Index

- SVR is the resistance the blood encounters as it flows through the vascular system
- SVRI is indexed to body surface area

Determination of systemic vascular resistance

$$\text{Flow (CO)} = \frac{\text{Pressure}}{\text{Resistance}}$$



Vasoconstriction: Flow (CO) ↓

Vasodilation: Flow (CO) ↑

if pressure is constant

BSA = Body Surface Area

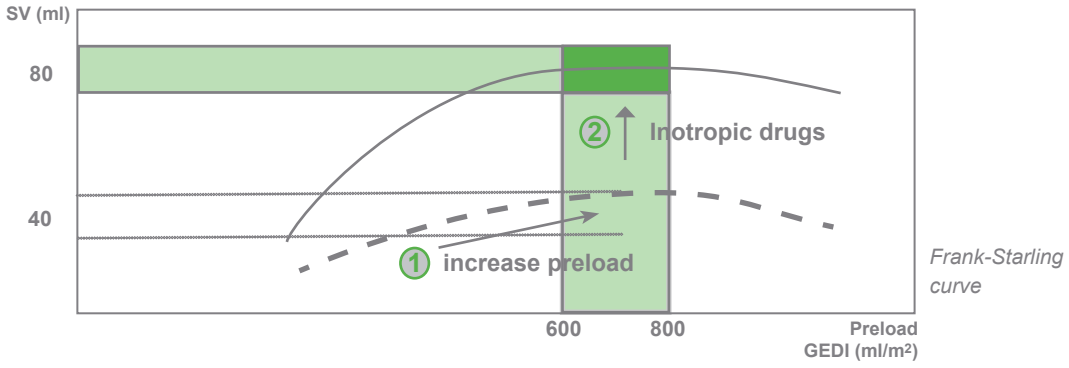
Contractility

Contractility describes the performance of the cardiac muscle

CFI - Cardiac Function Index

- Parameter of the global cardiac contractility
- The cardiac function index is the ratio of flow and preload

Frank-Starling curve



The Frank-Starling curve reflects the interaction between preload and stroke volume. Increasing preload increases the stroke volume up to a maximum.

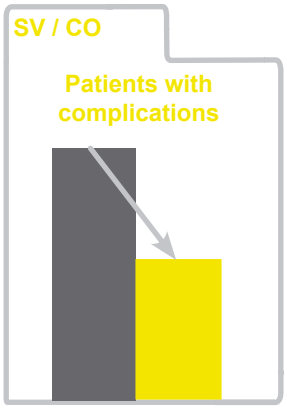
1. Increase preload volume up to its optimum
2. Increased contractility shifts the curve upwards (see graph)

Cost advantage

Reduction of patient complications and hospital / ICU stay decreases costs.

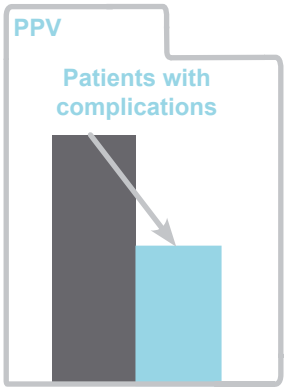
Stroke Volume (SV) / Cardiac Output (CO) - Hospital length of stay reduced

Investigator	*Target-parameter*	*Length of stay - Control group*	*Length of stay - Protocol group*	*Patient Type*
Pearse [13]	CO	14 days	11 days	high risk surgery
Gan [9]	CO, SV	7 days	5 days	major surgery
Wilson [10]	CI, DO_2	22 days	13 days	major surgery
Shoemaker [11]	CI, DO_2	25 days	19 days	high risk surgery
McKendry [4]	CI, DO_2	9 days	7 days	high risk surgery
Sinclair [6]	CO, SV	20 days	12 days	hip fracture repair



Stroke Volume (SV) / Cardiac Output (CO) - Patient complications reduced

Investigator	*Target-parameter*	*Control group*	*Protocol group*	*Patient Type*
Shoemaker [11]	CI, DO_2	1.34 complications per patient	0.76 complications per patient	high risk surgery
Shoemaker [11]	CI, DO_2	33 % mortality	4 % mortality	high risk surgery
McKendry [4]	SVI	31% complications	19% complications	cardiac surgery
Wakeling [7]	SV	59% complications	37.5% complications	colorectal surgery

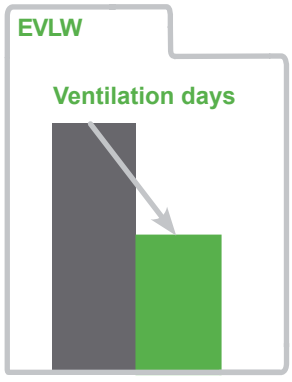


GEDV / PPV / ITBV - Patient complications reduced

Investigator	*Target-parameter*	*Control group*	*Protocol group*	*Patient Type*
Csontos [8]	ITBV	MODS 5.0	MODS 3.0	burn patients
Lopes [3]	PPV	3.9 complications per patient	1.4 complications per patient	high risk surgery
Smetkin[12]	ITBV	5 patients with complications	1 patient with complications	cardiac surgery

GEDV / PPV / ITBV - ICU Hospital stay reduced

Goepfert [2]	GEDV	33 h ICU stay	25 h	cardiac surgery
Smetkin[12]	ITBV	15 days hospital stay	12 days	cardiac surgery



Lung Water (EVLW) - Ventilation / ICU days reduced

Investigator	*Target-parameter*	*Control group*	*Protocol group*	*Patient Type*
Mitchell [5]	EVLW	22 ventilation days	9 ventilation days	mixed ICU patients
Mitchell [5]	EVLW	15 ICU days	7 ICU days	mixed ICU patients

Literature

1) Pearse, R, Dawson, D, Fawcett, J, Rhodes, A, Grounds, R. M, Bennett, E. D.
Early goal-directed therapy after major surgery reduces complications and duration of hospital stay. A randomised, controlled trial
Crit Care 2005; 9(6): R687-93

2) Goepfert MS, Reuter DA, Akyol D, Lamm P, Kilger E, Goetz AE.
Goal-directed fluid management reduces vasopressor and catecholamine use in cardiac surgery patients
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3) Lopes MR, Oliveira MA, Pereira VO, Lemos IP, Auler JO Jr, Michard F.
Goal-directed fluid management based on pulse pressure variation monitoring during high-risk surgery: a pilot randomized controlled trial
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4) McKendry M, McGloin H, Saberi D, Caudwell L, Brady AR, Singer M.
Randomised controlled trial assessing the impact of a nurse delivered, flow monitored protocol for optimisation of circulatory status after cardiac surgery.
British Medical Journal 2004; 329(7460): 258

5) Mitchell JP, Schuller D, Calandrino FS, Schuster DP
Improved outcome based on fluid management in critically ill patients requiring pulmonary artery catheterization
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6) Sinclair S, James S, Singer M.
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7) Wakeling HG, McFall MR, Jenkins CS, Woods WG, Miles WF, Barclay GR, Fleming SC.
Intraoperative oesophageal Doppler guided fluid management shortens postoperative hospital stay after major bowel surgery
Br J Anaesth 2005: 95(5): 634-42

8) Csontos C, Foldi V, Fischer T, Bogar L.
Arterial thermodilution in burn patients suggests a more rapid fluid administration during early resuscitation
Acta Anaesthesiol Scand 2008; 52:742-9

9) Gan TJ, Soppitt A, Maroof M, el-Moalem H, Robertson KM, Moretti E, Dwane P, Glass PS.
Goal-directed intraoperative fluid administration reduces length of hospital stay after major surgery.
Anaesth 2002: 79(4): 820-6

10) Wilson J, Woods I, Fawcett J, Whall R, Dibb W, Morris C, McManus, E.
Reducing the risk of major elective surgery: randomised controlled trial of preoperative optimisation of oxygen delivery
BMJ 1999: 7191(318): 1099-103

11) Shoemaker WC, Appel PL, Kram HB, Waxman K, Lee TS.
Prospective trial of supranormal values of survivors as therapeutic goals in high-risk surgical patients
Chest 1988 94; 6: 1176-86

12) 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 Apr;53(4):505-14. Epub 2009 Jan 15.

Reductions of patient complications and hospital / ICU stay decrease costs.

Basis of success - fast decisions

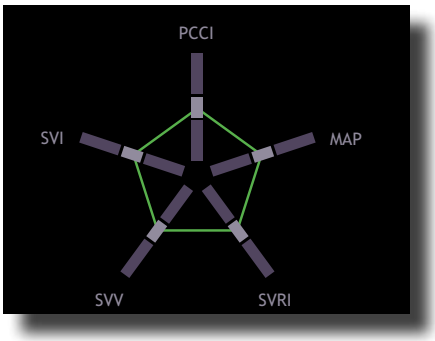
Overview

Details

Trends

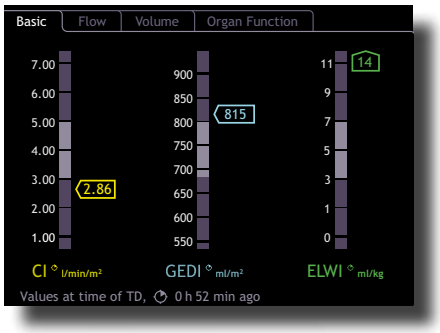
PiCCO$_2$® - Visualization of hemodynamic parameters

Overview



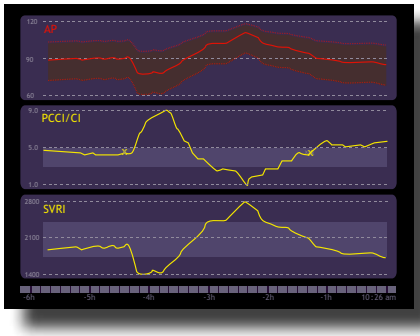
'SpiderVision' screen
Dynamic status indicator

Details



'Profiles' screen
Detailed insight at parameter level

Trends



'Trends' screen
Clinical trends and therapy results

Operation via touch screen or navigation dial

PiCCO$_2$® - The new hemodynamic monitor

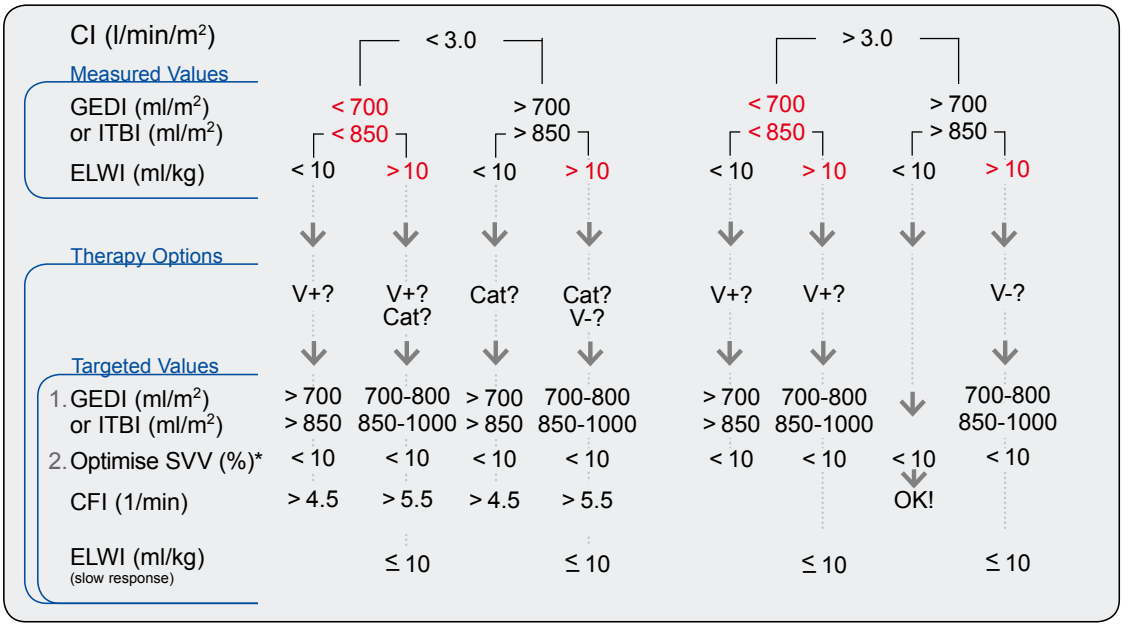
- Brilliant 13.3” color wide screen display
- Touch-screen, navigation dial
- Slim ergonomic design
- Small footprint
- Compatible to standard mounting systems
- Integrated backup battery

Hemodynamic Measurement Guide - Normal Values

Parameter	Abbreviation	Range	Unit
Cardiac Index	CI	3.0 – 5.0	l/min/m²
Stroke Volume Index	SVI	40 – 60	ml/m²
Global End-Diastolic Volume Index	GEDI	680 – 800	ml/m²
Intrathoracic Blood Volume Index	ITBI	850 – 1000	ml/m²
Stroke Volume Variation	SVV	< 10	%
Pulse Pressure Variation	PPV	< 10	%
Systemic Vascular Resistance Index	SVRI	1970 - 2390	dyn*s*cm^{-5} *m²
Cardiac Function Index	CFI	4.5 – 6.5	1/min
Mean Arterial Pressure	MAP	70 – 90	mmHg
Extravascular Lung Water Index	ELWI	< 10	ml/kg

WARNING: PULSION Medical Systems is a medical device manufacturer and does not practice medicine. PULSION does not recommend these normal values for a specific patient. The treating physician is responsible for determining and utilizing the appropriate diagnostic and therapeutic measures for each individual patient.

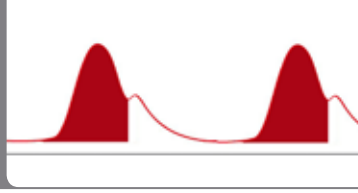
This decision model is not obligatory. It cannot replace the individual therapeutic decisions of the treating physician.



See instructions for use and package insert for full prescribing information. Technical specifications are subject to change without further notice.

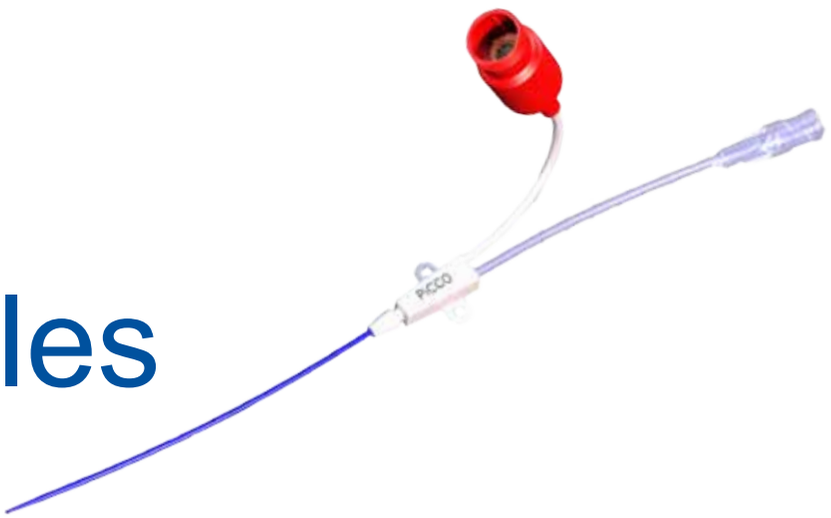
V+ = volume loading V- = volume reduction Cat = catecholamine / cardiovascular agents
*SVV is only applicable in fully ventilated patients without cardiac arrhythmia

Parameters - Summary

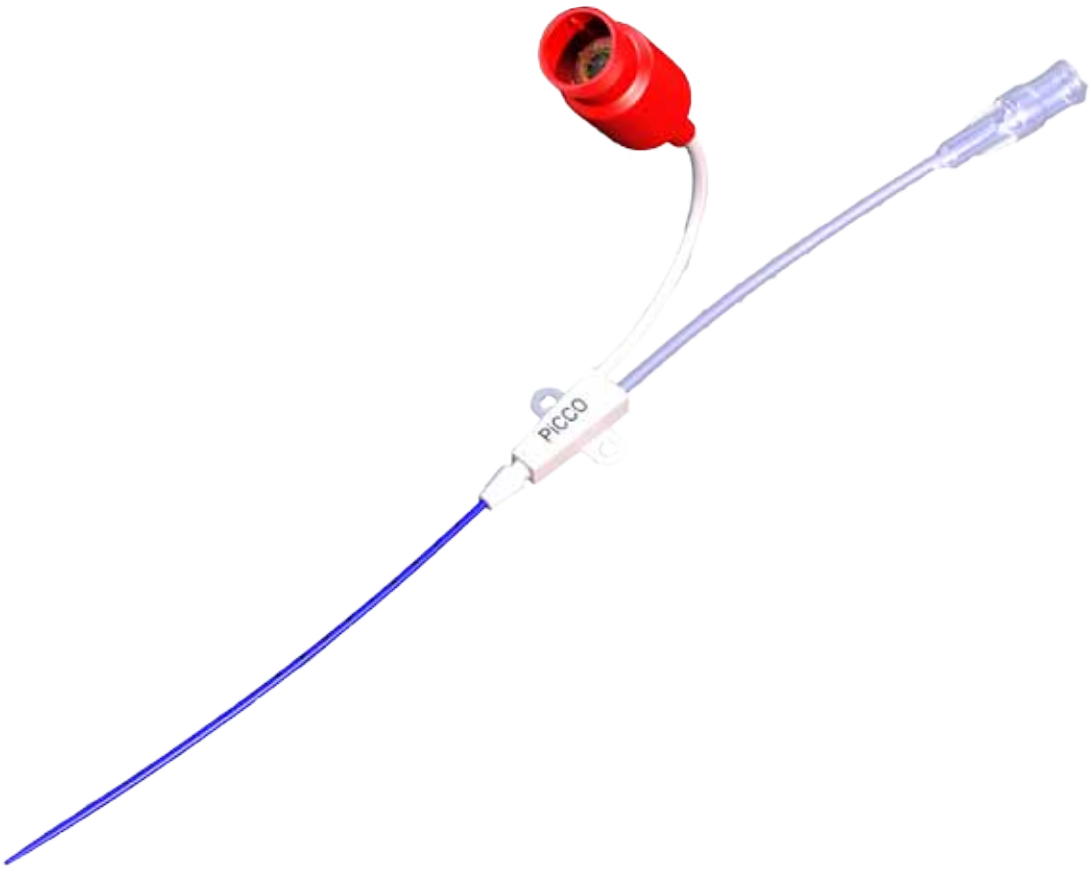


- The PiCCO® Technology utilizes two methods for precise parameter determination: Transpulmonary thermodilution and pulse contour analysis
- The thermodilution method calibrates the pulse contour parameters for increased accuracy and precision
- The PiCCO® parameters (flow, preload, lung water, afterload, contractility and volume responsiveness) are essential for complete hemodynamic assessment of the patient
- Utilization of the various parameters provided by the $PiCCO_2$ have been shown to improve patient outcome
- Innovative visualization of the parameters by $PiCCO_2$ enables quick and accurate patient assessment and management

Setup & disposables



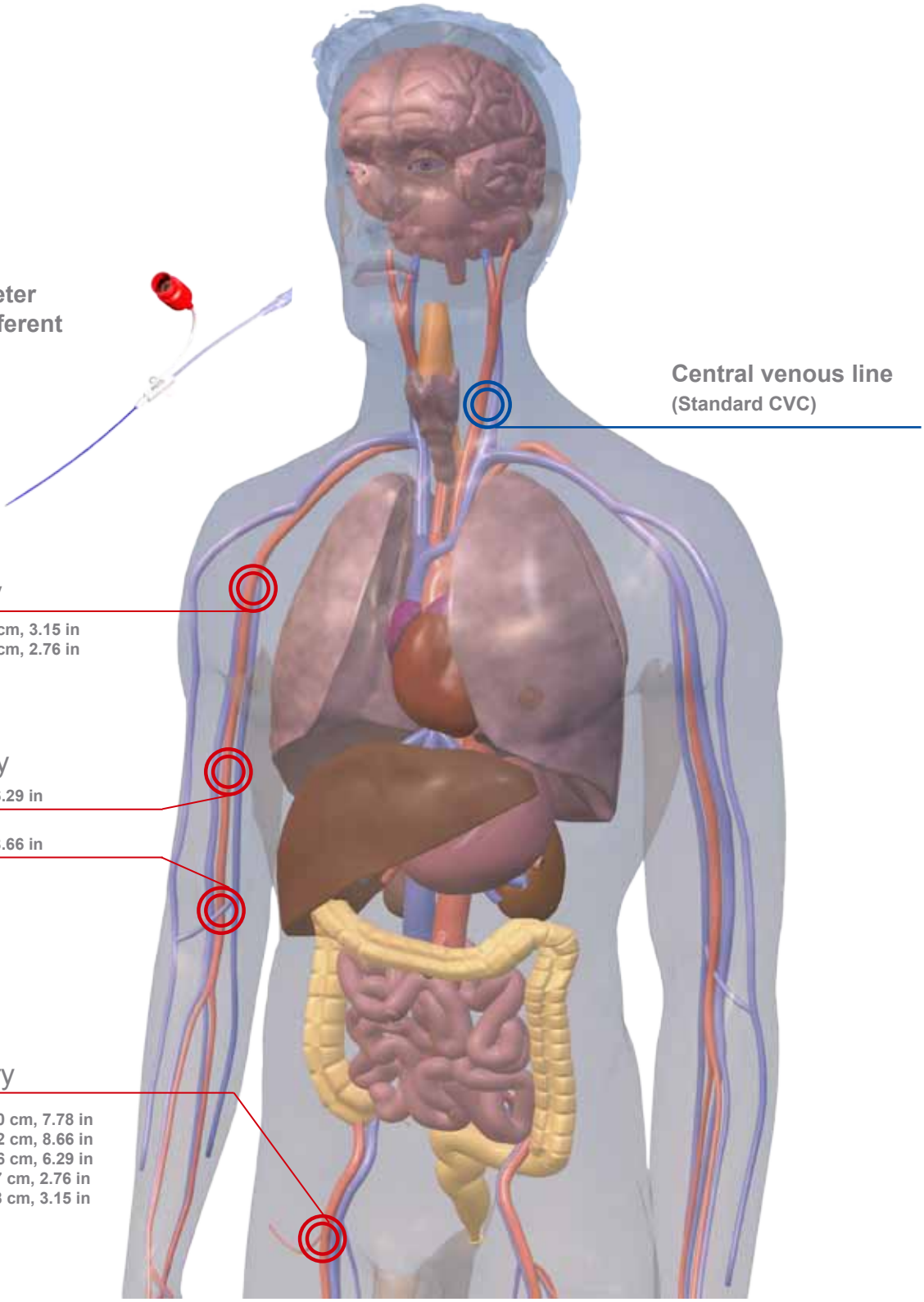
Catheters



- Designed for hemodynamic monitoring with the PiCCO®-Technology
- Equipped with a temperature sensor at the catheter tip for transpulmonary thermodilution
- Pressure extension line for arterial pressure monitoring

For use with PiCCO$_2$®, PiCCO *plus*®, Philips PiCCO-Technology Module and Dräger Infinity® PiCCO SmartPod™.

Catheters - Choice & application



Arterial line
(PiCCO® Catheter available in different sizes)

Central venous line
(Standard CVC)

Axillary artery

Adults: 4F 8 cm, 3.15 in
Small adults: 3F 7 cm, 2.76 in

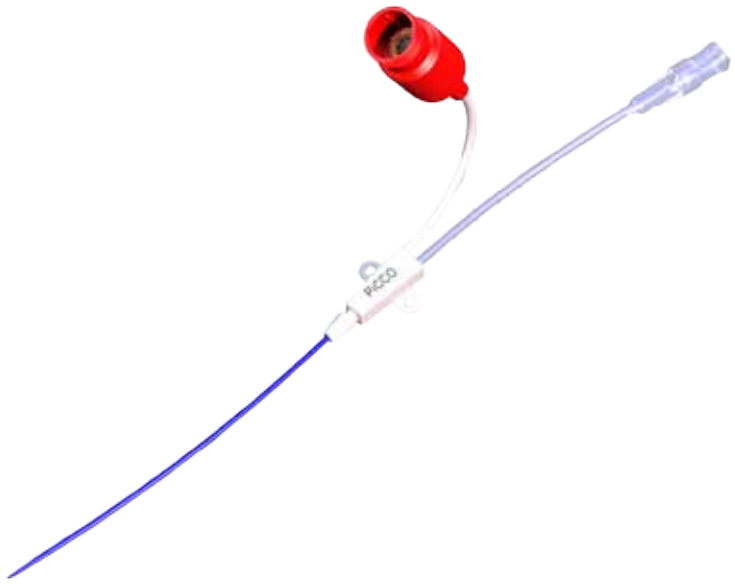
Brachial artery

Adults: 4F 16 cm, 6.29 in

Adults: 4F 22 cm, 8.66 in

Femoral artery

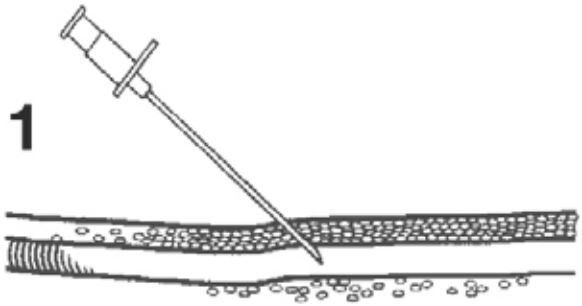
Adults: 5F 20 cm, 7.78 in
Adults: 4F 22 cm, 8.66 in
Small adults: 4F 16 cm, 6.29 in
Children: 3F 7 cm, 2.76 in
Children: 4F 8 cm, 3.15 in



Catheter choice and application

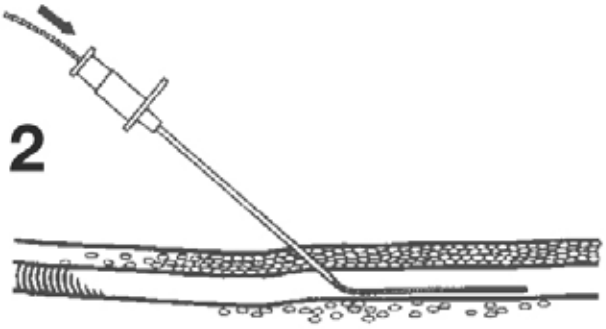
Article number	PV2015L20N	PV2014L22N	PV2014L16N	PV2014L08N	PV2013L07N
Application	Femoral artery in adults Standard catheter	Cubital brachial artery in adults Femoral artery in adults	Femoral artery in small adults Proximal brachial artery in adults	Axillary artery in adults Femoral artery in children	Femoral artery in children and infants Axillary artery in small adults
Outer diameter	5F (~16G) 0.07 in (1.7 mm)	4F (~18G) 0.05 in (1.4 mm)	4F (~18G) 0.05 in (1.4 mm)	4F (~18G) 0.05 in (1.4 mm)	3F (~20G) 0.04 in (1 mm)
Usable length	7.78 in (20 cm)	8.66 in (22 cm)	6.29 in (16 cm)	3.15 in (8 cm)	2.76 in (7 cm)
Inner diameter pressure lumen	0.028 in (0.71 mm)	0.028 in (0.71 mm)	0.024 in (0.61 mm)	0.024 in (0.61 mm)	0.020 in (0.50 mm)
Characteristics and length of the guide wire	Ø 0.021 in /0.53 mm length: 23.62 in (600 mm) both ends soft: - radius of J: 0.118 in (3 mm) - straight	Ø 0.021 in /0.53 mm length: 27.59 in (700 mm) both ends soft and straight	Ø 0.021 in /0.53 mm length: 23.62 in (600 mm) both ends soft: - radius of J: 0.118 in (3 mm) - straight	Ø 0.021 in /0.53 mm length: 17.72 in (450 mm) both ends soft: - radius of J: 0.118 in (3 mm) - straight	Ø 0.017 in /0.43 mm length: 15.75 in (400 mm) both ends soft and straight
Vessel dilator	Ø 5F (0.067 in) length: 6.693 in (17 cm)	Ø 4F (0.051 in) length: 5.118 in (13 cm)	Ø 4F (0.051 in) length: 5.118 in (13 cm)	Ø 4F (0.051 in) length: 5.118 in (13 cm)	-
Article number single packed guide wire	PVSG21-60SJN	PVSG21-70SSN	PVSG21-60SJN	PVSG21-45SJN	PVSG17-40SSN

Catheter insertion – The Seldinger technique



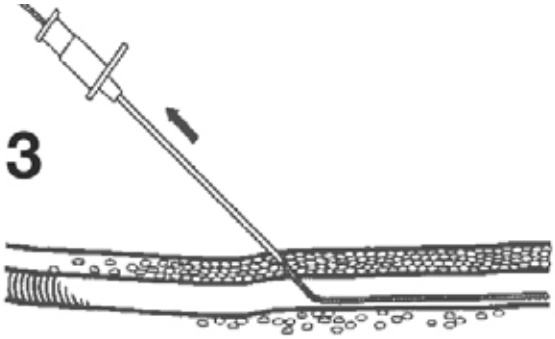
Insert cannula (18G or 20G) into artery at a flat angle (30-45°)

Tips:
- in cases of multiple cannulation efforts, renew cannula
- flush cannula to prevent obstruction



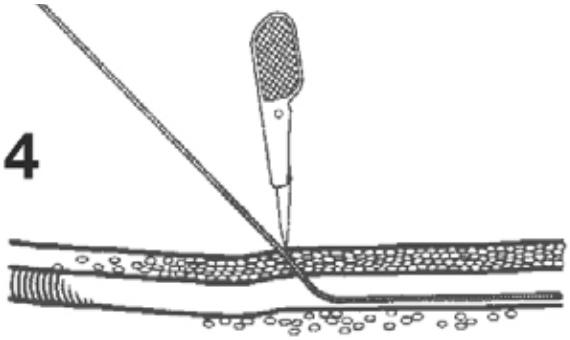
Partially insert guide wire into artery via the cannula

Tips:
- always try end with „J“ first
- advancement of wire must be effortless
- do not unclasp cannula while advancing wire
- never withdraw wire through cannula



Withdraw cannula

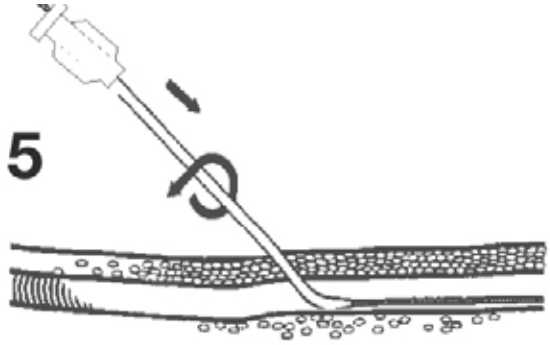
Tip:
- do not let go of wire



Perform small skin incision (not mandatory)

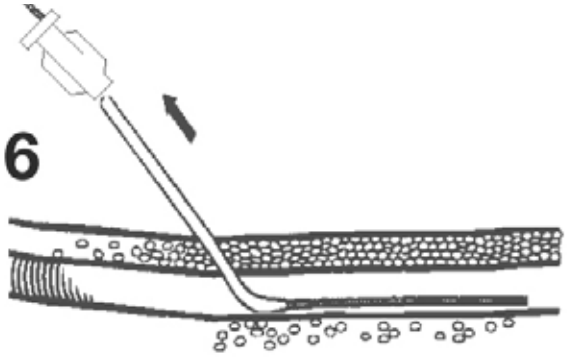
Tips:
- only in cases of particularly thick/strong skin
- Perform only a small incision to avoid cutting through the vessel wall (reduces risk of bleeding)

Catheter insertion – The Seldinger technique



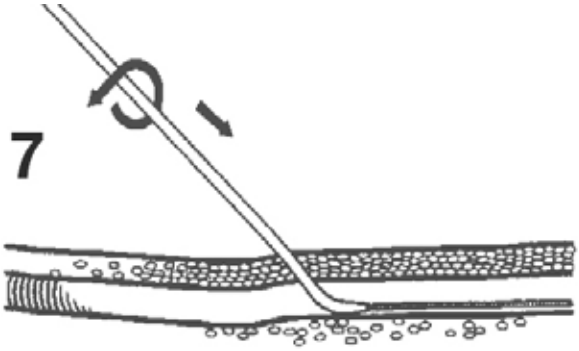
Insert dilator into vessel

Tips:
- end of wire must stick out of the end of the dilator
- grip dilator close to skin surface
- never use excessive force
- if dilator doesn't penetrate skin easily, try rotating movement
- avoid kinking of wire



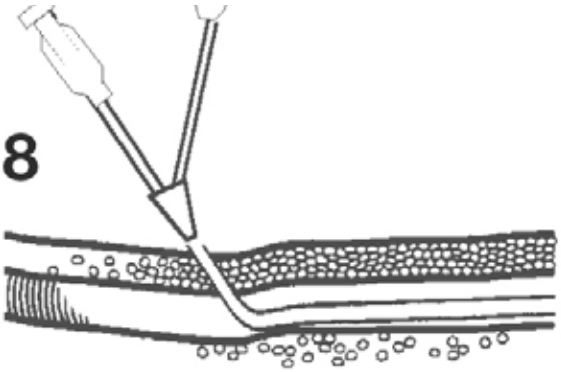
Remove dilator, leaving guide wire in place

Tips:
- do not let go of wire



Insert catheter into vessel

Tips:
- end of wire must stick out of the end of catheter
- grip catheter close to the skin surface
- never use force
- if catheter doesn't penetrate skin easily, try rotating movement
- avoid kinking of wire

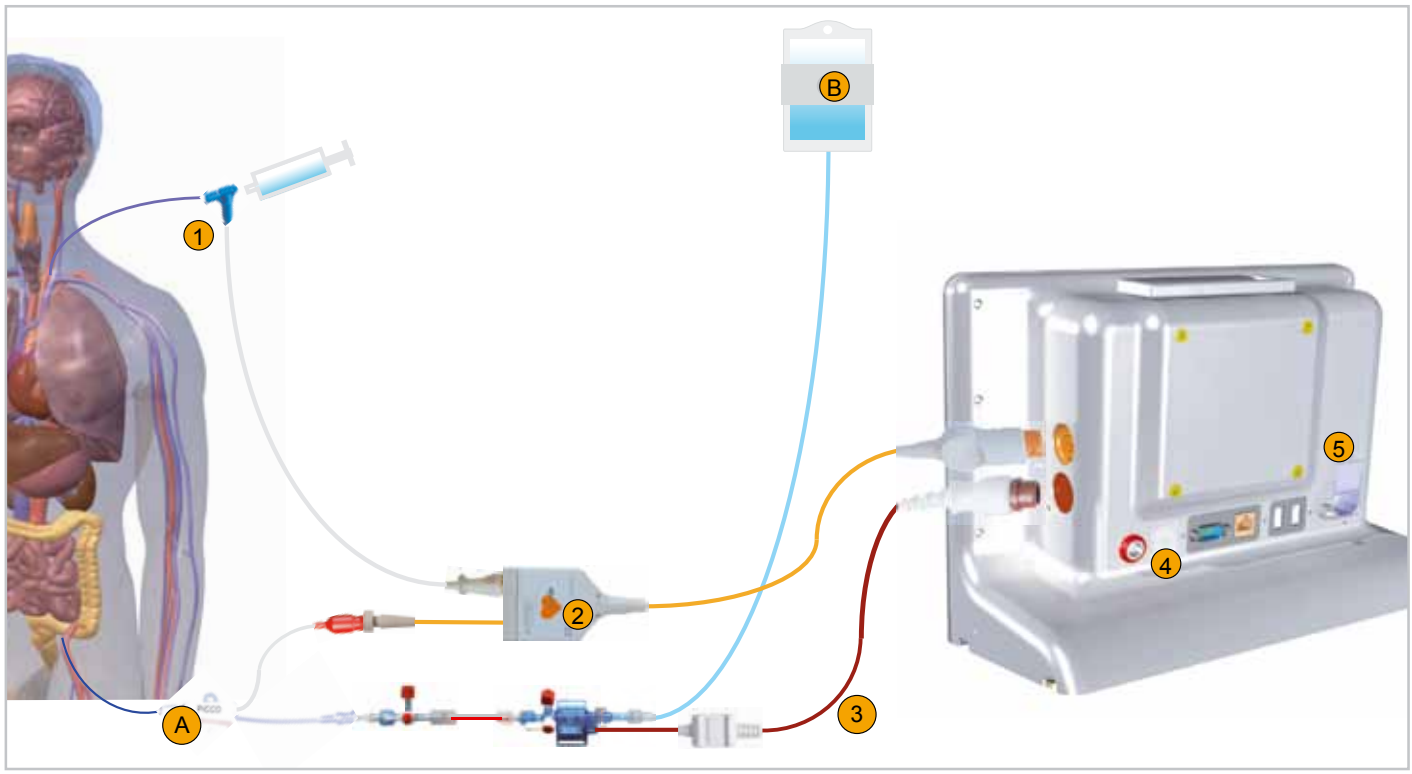


Remove guide wire

Tips:
- do not let go of catheter

Setup PiCCO$_2$®

Standard setup:



1 Injectate sensor cable

2 Arterial connection cable

3 Pressure connection cable

4 Pressure output adapter

5 Power socket

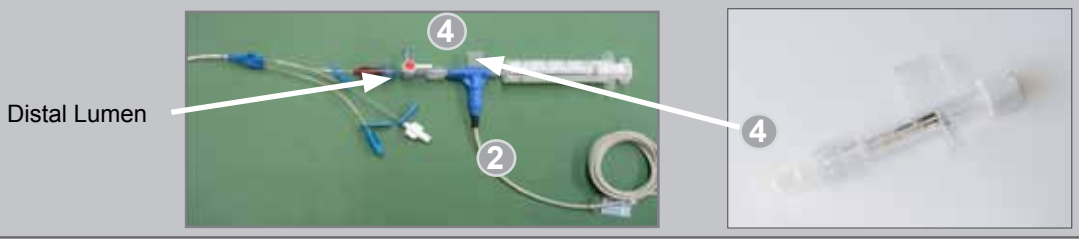
A PiCCO® Catheter

B Flush bag

Setup PiCCO$_2$®

A. Connect the thermistor cable (1) to the orange socket on the right side of the PiCCO$_2$® device. Connect the injectate cable (2) to the brown socket of the thermistor cable (3).

B. Connect the blue end of the injectate cable (2) to the injectate sensor housing (4) which should be preferably on the distal lumen of the central venous catheter.



C. Connect the end of the thermistor cable (4 pin end) to the red thermistor connector of the already placed catheter.

D. Connect the pressure connection cable (5) to the red socket on the right side of the PiCCO$_2$® device. Connect the white end of the pressure connection cable (6) to the monitoring cable (7) in the pressure transducer kit (8).

E. Prime the monitoring kit and attach to a flush bag. Attach the pre-primed arterial pressure line and three-way stopcock to the PiCCO® catheter (9).

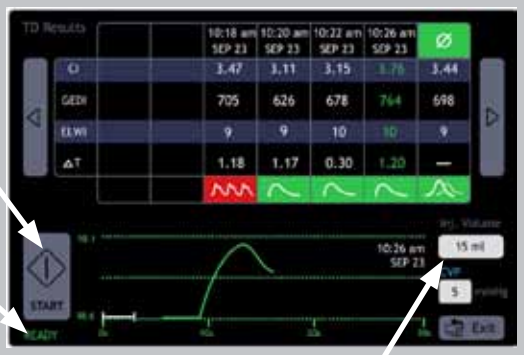
F. Switch on the device. The device will ask whether it is a new patient or not. Select ‘YES’ accordingly, confirm, then enter patient specific data, including height, weight, category (adult/ped), gender by touching the screen over the area you want to change. Press ‘EXIT’ (10) to move to the Zero Adjustment Screen.

G. Perform Zero Adjustment on the PiCCO$_2$® first (after opening transducer to the atmosphere) and then the bedside monitor. Enter the patient CVP here (11). Press ‘EXIT’ to go to the thermodilution screen.

H. Perform 3 initial thermodilution measurements to calibrate the device and obtain the parameters. Press exit once finished to go to the main monitoring screen.

Press ‘START‘ when you and the machine are ready to inject

Wait for ‘READY‘ to appear before pressing start

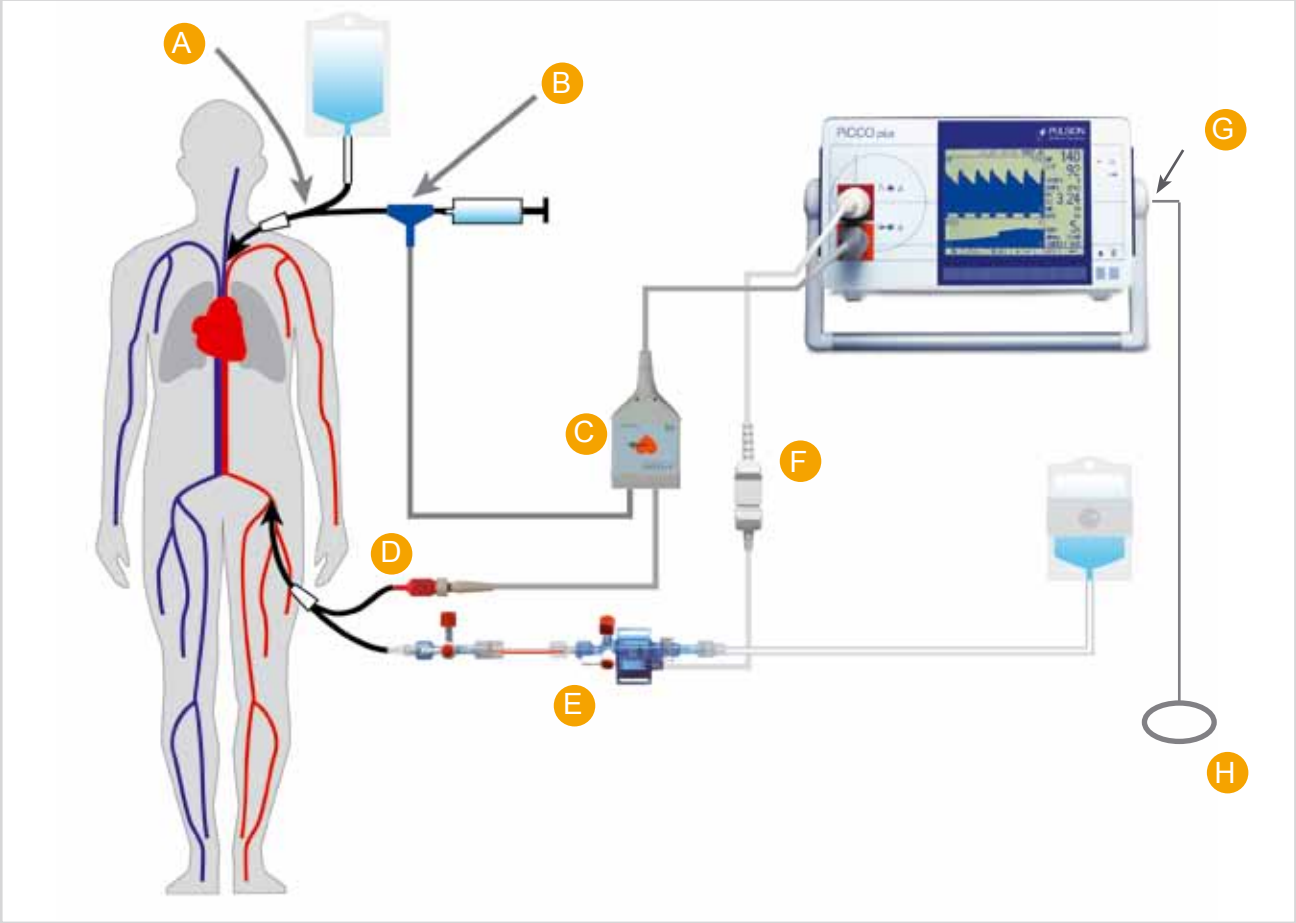


Amount to be injected

	ELWI < 10	ELWI > 10
kg BW	iced	iced
< 3	2 ml	2 ml
< 10	2 ml	3 ml
< 25	3 ml	5 ml
< 50	5 ml	10 ml
< 100	10 ml	15 ml
≥ 100	15 ml	20 ml

I. To navigate around the screen either touch the area you wish to change or use the navigation dial.

Setup PiCCO *plus*®



A Central venous catheter

B Injectate-temperature sensor housing PV4046 (included in PV8115)

C Injectate-temperature sensor cable PC80109

D PiCCO® Catheter (e.g. PV2015L20N)

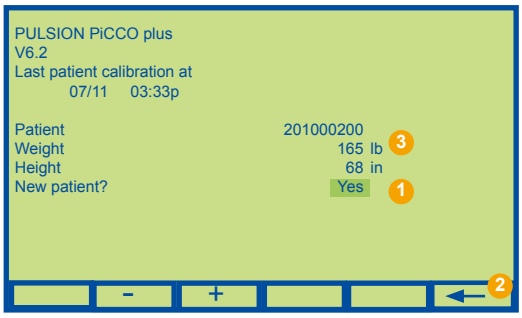
E PULSION® disposable pressure transducer
PiCCO® Monitoring Kit PV8115

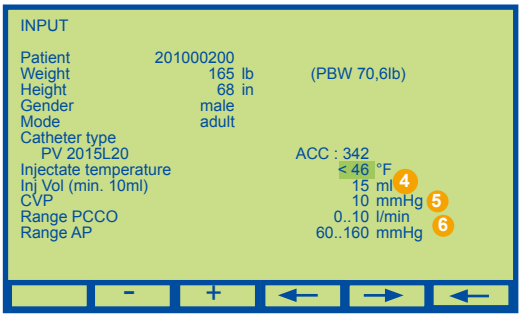
F Pressure cable PMK-206

G AUX Adapter cable PC81200 (to connect on rear panel)

H Connection cable to bedside monitor PMK-XXX

Patient Admission





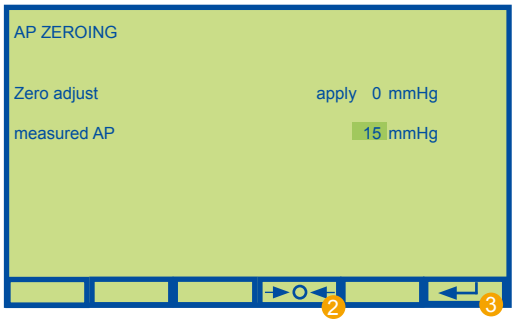
<75°F = room tempered injectate; <46°F = iced injectate

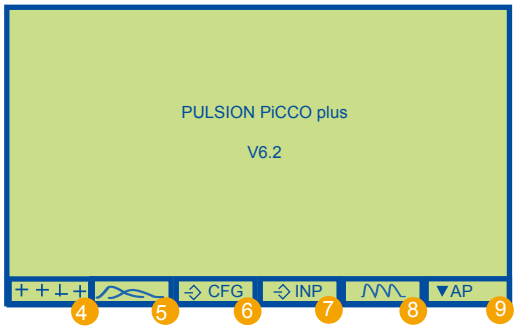
1. Choose <Yes> for a new patient, old data will be deleted, modify with [-] and [+]
2. Confirm with [↵]
3. Enter patient ID number, weight, height and gender of the patient. If ID number is changed, previously stored data will be deleted for safety reasons.

   Arterial catheter will be detected automatically.
4. The minimal required injectate volume is recommended in ( ). 15ml iced NaCl 0.9% as the default setting for adult patients.
5. Enter CVP.
6. Upper/lower limit of the display range of PCCO.

   Upper/lower limit of the display range of the arterial blood pressure.

Zeroing





1. Open transducer to the atmospheric pressure.
2. Press zero button.

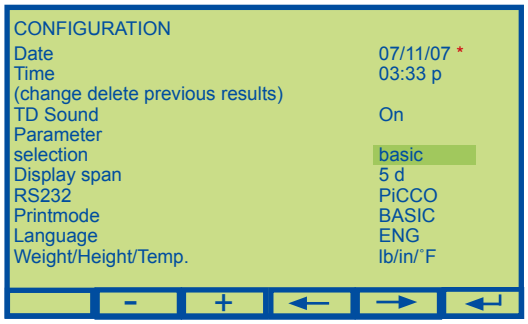
   Perform zeroing first on PiCCO *plus*® then on bedside monitor.
3. Confirm with [↵]

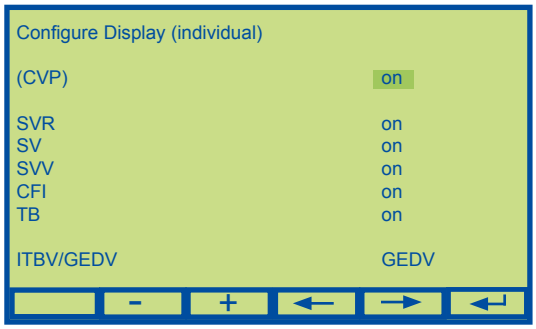
   Difference from pressure transducer to patient's heart level can be corrected.

   Default setting <0>.
4. Profile screen
5. Thermodilution screen
6. Configuration screen
7. Input screen
8. Pulse-contour screen
9. Pressure-zeroing screen

Setup PiCCO *plus*®

Configuration





* Caution: Modifying date and/or time will automatically delete patient related data.

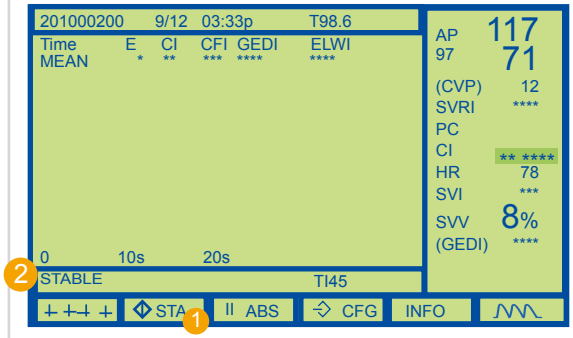
Press CFG to go to the Configuration-screen (see previous page)
To select most important PiCCO® parameters choose <basic> and ↵

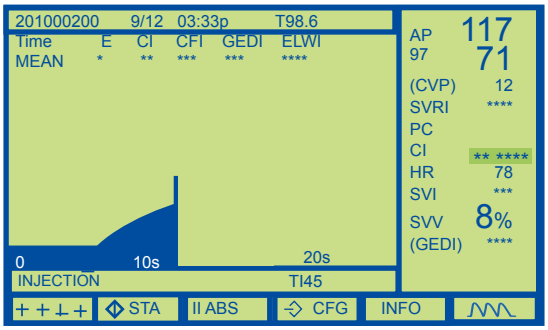
Basic setup: Can not be changed and displays most common parameters as default.

Individual: User can configure own parameter selection.

For customized parameter selection switch from <basic> to <individual> with + and -

Thermodilution

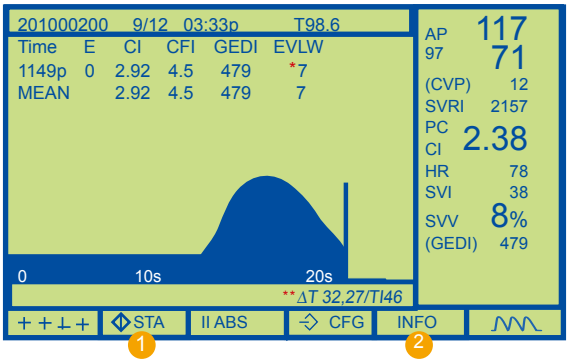




Press ∿ for Thermodilution screen.

1. Press STA to perform a measurement.
2. Wait until STABLE appears.
   Perform a rapid and smooth injection.

Thermodilution II



1 Press STA for further measurements.

Initially perform 3 thermodilution measurements.

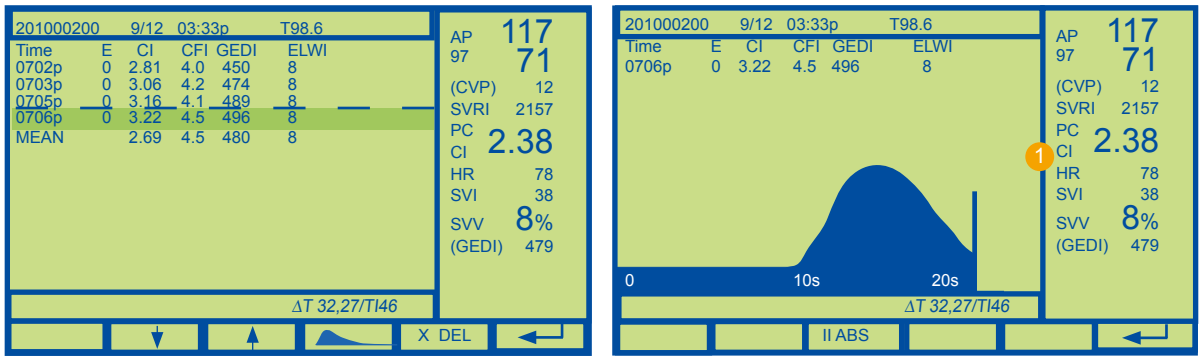
*In cases where EVLW >10ml/kg it is recommended to use iced injectate for further measurements.

**If ΔT <0,15°C (32,27°F), it may be necessary to increase the injectate amount and/or use iced injectate. In this case, select iced injectate <46°F in the input screen.

2 Press INFO to change to info screen.

Deviating measurements (“?” at value) should be deleted.

Calibrate

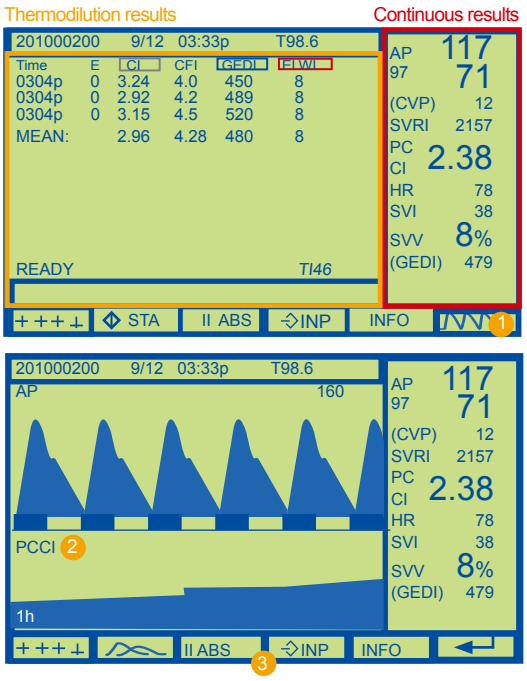


Deviating measurements ("?") should be selected with ▲ and ▼, confirm by pressing X DEL once. Selected thermodilution curve is displayed.
To delete this measurement press X DEL again.
It is only possible to delete the current measurements under the dashed line.

1 The mean results of the thermodilution measurements of the last 10 minutes automatically calibrate the continuous cardiac output.

Setup PiCCO *plus*®

Results



CI = Cardiac Index
GEDI or ITBI = Global End-Diastolic Volume Index or Intrathoracic Blood Volume Index
EVLW = Extravascular Lung Water
PCCI = Pulse Contour Cardiac Index

1. Press [~] to display arterial pressure curve.
2. The display range of PCCI can be changed in the Configuration-Screen.
3. NB: Values can be displayed either as index values (CCI) or absolute values (CCO) by pressing [II ABS].

Setup - Summary

- Set up of the PiCCO-Technologies including the PiCCO$_2$®, PiCCO *plus*®, Philips PiCCO Module and Draeger Smart Pod involves an initial calibration of the cardiac output measurement by 3 thermodilution measurements.

- Entering accurate patient data including height and weight ensures the volumetric parameters are specifically indexed to that patients individual properties.

- Thermodilution measurements automatically recalibrate the continuous parameters thereby ensuring accurate dynamic patient data.

- Zeroing adjustment of the pressure transducer on the PiCCO® first then the patient's bedside monitor ensures accurate measurements.

Disposables - Summary

- The PiCCO® catheter is available in a range of sizes for different patient applications.
- The Seldinger technique is used for inserting the catheter, independent of site of insertion.
- Choice of insertion site is dependent on the patients specific clinical situation.
- Use of the femoral artery for the catheter insertion site has been shown to provide accurate information even in profoundly shocked patients, with no increased risk of blood stream infections (see literature - 'Catheters' page 6-17).

Tips & tricks

Tips & tricks

Error	Cause	Remedy
Arterial pressure measurement		
Pressure curve absent	• Pressure line not correctly attached	• Check pressure line, stop-cock, cable and plug
	• Pressure line blocked	• Flush pressure line
	• Cable or device defect	• Connect pressure transducer directly to the bedside monitor for testing
Abnormal pressure curve	• Catheter malpositioned	• Check or change catheter position
	• Blocked catheter lumen	• Flush catheter
	• Arrhythmia, extra systole	• Regulate therapeutically
	• Tachycardia (> 240 bpm)	• Regulate therapeutically
Flat pressure curve	• Inappropriate scale settings	• Set scale of pressure curve
	• Failed connection of pressure system	• Check and ensure pressure system connected correctly
	• Flush has insufficient pressure	• Increase the flush pressure to 250-300 mmHg
	• None or wrong zero adjustment	• Carry out / repeat zero adjustment
	• Damped pressure transducer transmission from: - Airbubbles	 - Disconnect from patient and remove air bubble
	- Modifications of pressure line	- Remove any additional lines and or stop cocks
	- Malposition of stop cocks	- Adjust stop cocks correctly
	- Kinked catheter or pressure line	- Remove kinks, possibly change patient position
	• Hypotonia	• Regulate therapeutically
Indicator injection		
Injection was not detected	• CVC malpositioned	• Correct position
	• 3-way-stopcock incorrectly adjusted	• Adjust 3-way-stopcock
	• Temperature sensor housing pin clotted	• Change temperature sensor housing
	• Temperature sensor housing / sensor not connected correctly	• Check connection („click-sound“)
	• Defective temperature sensor	• Check or change sensor
Thermodilution results		
Results implausible	Amount injected does not match amount to be injected displayed by device	Inject correct volume
Pulse contour results		
Calibration PCCO not possible	Arterial pressure curve absent or faulty	Check / optimize arterial pressure measurement
Large variation in values	Arrhythmia, extra systoles	Regulate therapeutically

Tips & tricks

Error	Cause	Remedy
Thermodilution curve		
Unstable temperature baseline measurement	• Rapid cooling or warming of patient	• Wait for stabilisation phase
	• Massive volume loading	• Stop volume supply if possible
	• Arterial connection cable broken or not correctly connected	• Check cable connection, replace if necessary
	• Faulty thermistor on PiCCO catheter	• Check temperature change when flushing catheter, replace catheter if no temperature change seen
	• Thermistor lying against vessel wall	• Change catheter or patient position
Thermodilution curve is not displayed	• Incorrect injection at central venous catheter	• Perform central venous injection correctly
	• Faulty thermistor on PiCCO catheter	• Check temperature change when flushing catheter, replace catheter if no temperature change seen
	• Broken or failed cable-connection of arterial connection cable	• Check cable connection, change if necessary
Thermodilution curve display is too late (Time out limit)	• Injection too slow	• Inject faster (< 7s)
	• Very low cardiac output or very high lung water	• Use colder and/or more injectate
Thermodilution curve very flat	• Inappropriate scale settings	• Adjust scaling
	• Injectate too warm	• Use colder injectate
	• Very low cardiac output or very high lung water	• Use colder and/or more injectate
Thermodilution curve displays more than one peak	• Injection not smooth	• Ensure smooth injection
	• Existing intracardiac shunts	• Perform shunt diagnosis

PiCCO$_2$ Guidelines

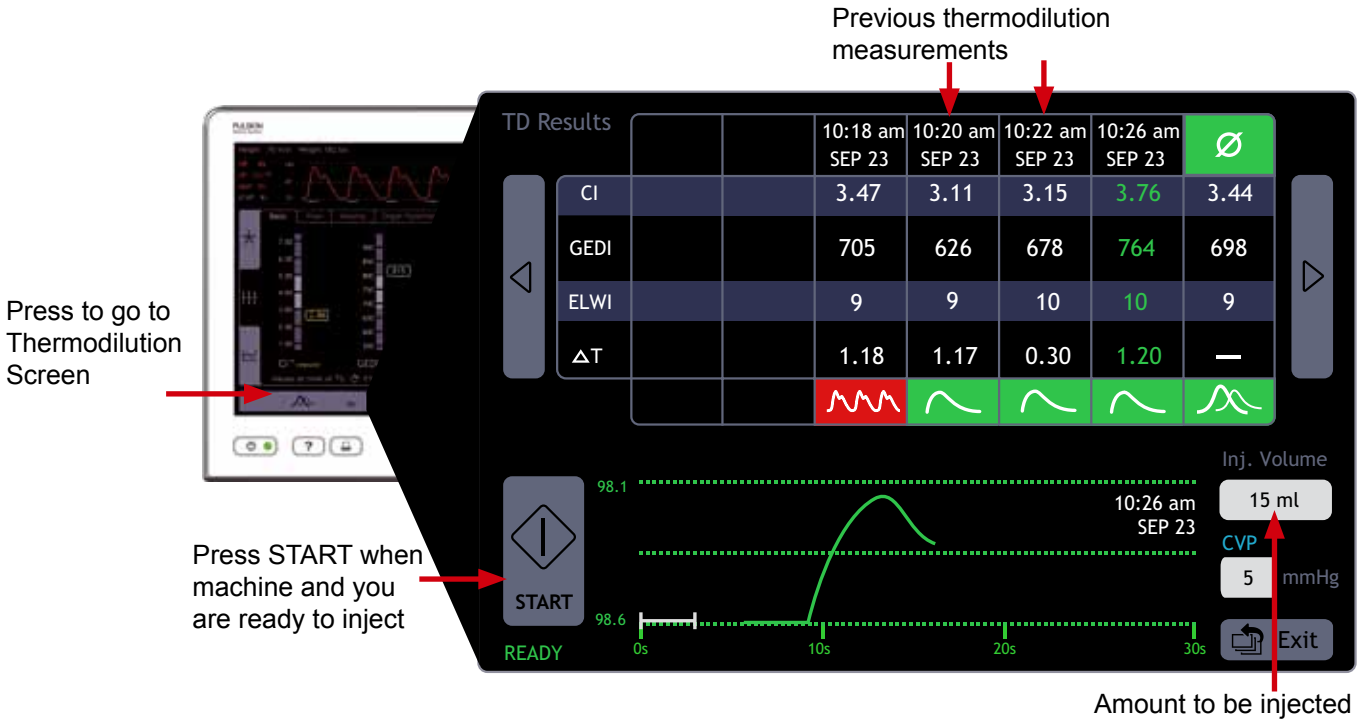
1. **Have you got a good arterial pressure waveform trace?**

Press on the waveform to change the amplitude of the waveform. If the trace is absent or dampened, check position of patient and/or catheter, check for presence of air bubbles in blood pressure tubing, remove any additional pressure lines, check for kinks in tubing. Check that the transducer is open to catheter and pressure bag inflated. Check all cables are correctly attached (see operator manual for further details). Flush with saline using flush device.

2. **Have you got an arterial pressure appropriate for this patient?**
The arterial pressure numbers are located on the top left hand side of the display page (see above). If a false low or high measurement is suspected, check level of transducer (it should be placed in line with the phlebostatic axis). Check the machine was 'zeroed' correctly (see operator manual for further details).

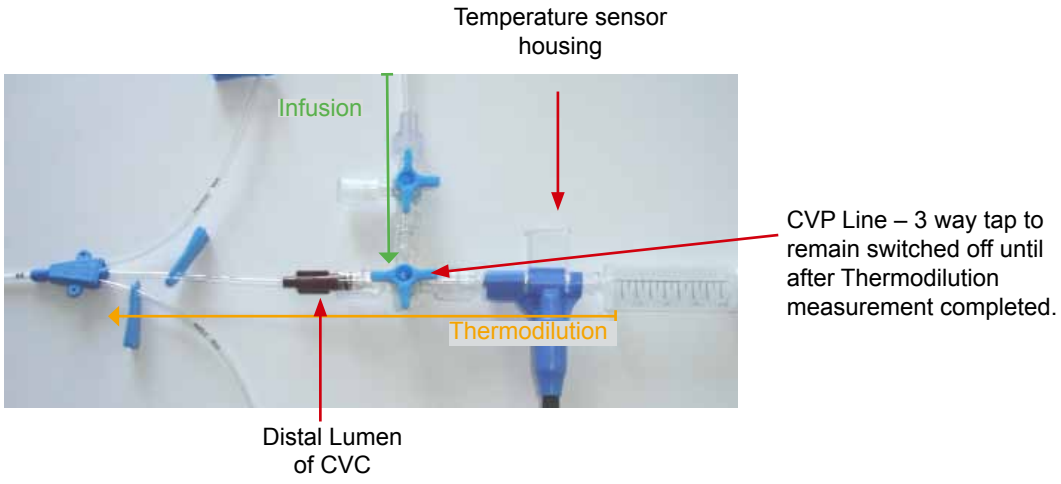
3. **Have you got an adequate / appropriate Cardiac Output / Index for the patient's clinical situation?**
If CO/CI appears inappropriate (too low or too high), check in the <Patient> screen that the patients correct weight and height have been entered. To enter this screen press the patient information bar at the top of the screen.
NB the thermodilution measurement may not work in patients who have extremely low CO/ CI, for e.g. <1.2 l/min.

4. **Were you in the Thermodilution screen when you performed the injection?**
Press the grey Thermodilution screen button on the bottom left of the display. Press start and wait until the message "INJECT" appears on the screen. Inject as quickly and smoothly as possible.



Thermodilution measurement

5. **Did you inject the correct amount and correct temperature of injectate?**
   Check the thermodilution screen. The amount of injectate can be changed depending o patients weight.
   In general 15cc is the appropriate amount for an adult patient. It is recommended that the temperature of injectate be ≤ 46,4°F in all instances. Change injectate volume in configuration 'Measurement Screen' if necessary.
6. **Did you inject as quickly (under 7 secs) and steadily as possible?**
   The device will ignore or reject injections under 0.5 sec or over 10 seconds. If necessary inject again, injecting as quickly and as smoothly as possible. Make sure you do not touch the end of the plunger UNTIL you are ready to inject.
7. **Was the bolus cold enough?**
   The temperature of the injectate (Tinj) is displayed on the Thermodilution screen in the summary data above each completed thermodilution curve. There must be a difference in temperature of at least 0.15 °C (32,27°F) for the thermodilution measurement to be recognized (shown as ΔT).To display this information go into the 'Measurement Screen' and ensure 'Display Vinj & Tinj ' says <Yes>.
8. **Did the device display 'Injection' whilst you were injecting?**
   The device will detect if you have performed a correct thermodilution measurement (the word "injection" appears below the start button). If this did not happen, check the device was ready (see section above), check amount and temperature of injectate (see section above) and try again.
9. **Is there only one three way tap between the patient and the injectate temperature sensor housing?**
   The point of injection must be a close as possible to the injectate temperature sensor housing which must be as close as possible to the patient. Remove any additional 3 way taps.



10. **When you injected did the injectate pass through the injectate temperature sensor housing?**
    Check the position of the three way tap is only open to the patient not other infusions (see above). If this is not the case, correct and re-inject.
11. **Were all other infusions switched off during the injection?**
    To ensure the injectate remains in a bolus and as cold as possible other infusions that are running through the same lumen should be temporarily suspended during the thermodilution injection. Do not turn the 3 way tap back until the thermodilution curve has been completed. This includes the pressure line for the CVP.
12. **Is the injectate temperature sensor cable connected correctly?**
    Ensure the cable is connected to both the sensor at the CVC port and the arterial PiCCO catheter.

Special clinical situations

General

Hypothermia

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

Fluctuating blood temperature

- Temperature fluctuations from baseline are compensated by the device. Thermodilution measurement is not recommended in the event where a stable baseline is not possible.

Basic requirements for the assessment of the volume responsiveness parameters (SVV, PPV)

- Controlled mechanical ventilation with no spontaneous breaths
- Sinus rhythm without arrhythmias or artefacts

Contraindications and complications

No absolute contraindications

- Usual precautions should be considered when accessing larger blood vessels. For example presence of coagulation problems, grafts etc. Other sites such as the axillary artery can be used.

No increased complication rate

- Usual risks associated with arterial puncture: puncture injury, infection (extremely rare), impaired blood flow, hematoma.
- The maximum recommended placement period for the PiCCO catheter is 10 days.

No specific application restrictions

- As it is possible to use normal saline for the thermodilution measurements, there are no restrictions on the number of measurements possible, including in pregnancy and with children

Specific Therapies

Vasoconstrictors / Inotropes / Volume Therapy

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

Intra-aortic Balloon Pump (IABP)

- The thermodilution parameters (CO, GEDI, EVLW) are measured correctly.
- Pulse contour analysis is not always accurate.

Renal Replacement Therapy (continuous hemofiltration / dialysis)

- All the parameters are measured correctly provided the dialysis out- and inflow catheters are not in the path of the indicator

Heart

Valvular Insufficiency

- Regurgitation of the thermodilution injectate can 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. The extended mean transit time of the injectate can result in an over-estimation in the GEDI / ITBI.

Aortic Stenosis

- All parameters are correctly measured

Intra-cardiac Shunts

- Due to the marked alteration in the thermodilution curve, no valid values are able to be calculated. In less severe shunts, measurements may be possible. In left-to-right shunts, the CO is determined correctly.

Aortic aneurysms

- GEDI / ITBI is increased due to the volume of the aortic aneurysm, this can be avoided by placement of the PiCCO catheter in the axillary artery.

Cardiac Arrhythmia

- The thermodilution parameters are measured correctly.
- The pulse contour analysis is correct in mild to moderate rhythm disturbances (normal rate atrial flutter / fibrillation, bigeminal –, trigeminal or incidental extra systoles)
- In severe cardiac rhythm disturbances (tachyarhythmias, supraventricular tachycardia), pulse contour analysis may be inaccurate. It is recommended to recalibrate with 3-5 thermodilution measurements.

Lung

Partial Lung Resection

- Correct calculation of the cardiac output and GEDI. The degree of potential under-estimation of the ELWI is dependent on the amount of lung resected. The trend of the ELWI remains accurate.

Pulmonary perfusion disturbances (e.g. pulmonary embolism)

- The ELWI is underestimated when there are significant perfusion disturbances.

Pleural effusion

- There is no influence on the ELWI measurement because the contact area between the indicator and pleural fluid is minimal.

PiCCO$_2$® Demo mode

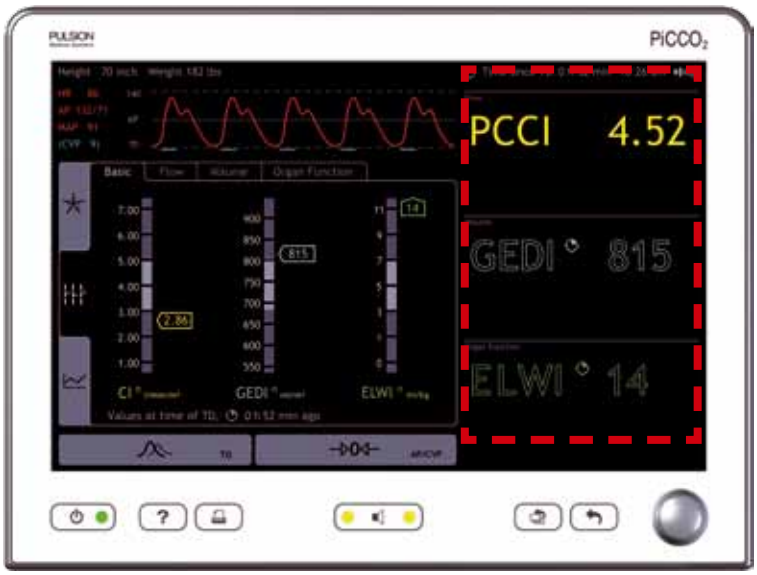
For training and demonstration purposes, a fully functional demo mode is available from version 8.1.0.3 onwards.

- All procedures are able to be demonstrated in demo mode, including Admission, Zeroing, Thermodilution Measurement and Calibration of the Pulse Contour Analysis, and Basic Monitoring.
- The demo mode is marked with "DEMO DEMO DEMO" at the top of the screen
- Under no circumstances should the PiCCO$_2$® Monitor be connected to the patient whilst it is in Demo Mode

Switch to Demo Mode

1. Remove all cables from the patient and the device

2. Press the parameter field on the right hand side of the screen

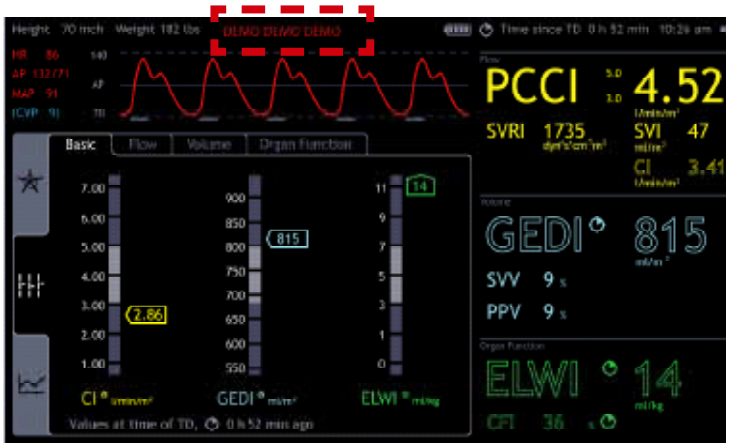


3. Press the 'SERVICE'-button in the 'Monitor' configuration tab

4. Enter the password 'EDUCATION' and confirm with return

5. Choose 'PiCCO' mode

6. The $PiCCO_2$ now switches to the 'DEMO' Mode



7. To switch the 'DEMO' off, simply switch the device off and then on again.

8. Please ensure after switching the device off and on again that the DEMO mode warning is no longer present at the top of the display.

Tips & tricks - summary

- Injecting as smoothly and quickly as possible (under 7 seconds) is essential for correct thermodilution measurement. As normal saline is used there are no restrictions on the number of possible measurements.

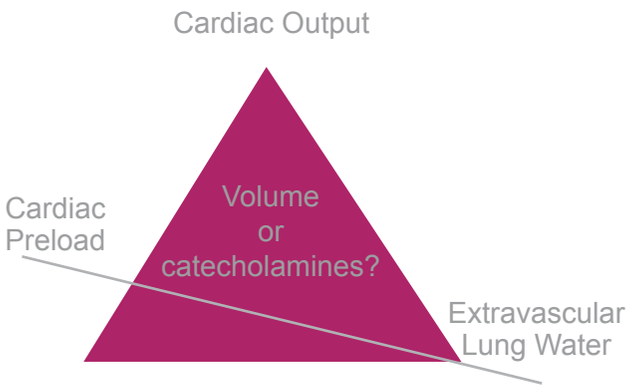
- Patients with very low cardiac output, or very high extravascular lung water may require more and / or colder injectate.

- All other infusions must remain turned off during the duration of the thermo-dilution measurement.

- The usual precautions when accessing larger blood vessels should be considered when inserting the PiCCO catheter.

- All PiCCO$_2$® monitors can be put into demo mode for training purposes.

Case studies



Hemodynamic monitoring: More or Less?

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Optimal management of critically ill patients demands accurate and continuous monitoring of their hemodynamic status. Such monitoring can be done by clinical assessment and by using a variety of available advanced monitoring techniques. It seems, however, that in recent years many clinicians have become wary of these techniques, and have either minimized or altogether stopped using any advanced methods of hemodynamic monitoring when managing critically ill patients.

An illustrative case of what I perceive to be insufficient monitoring has been presented in one of the Internet critical care discussion groups. The presentation described a 72 year old man with a significant cardiac history, who became septic (worsening acidosis, oliguria and hypotension) following major surgery that included the removal of a large renal tumor and a necrotic gallbladder. The patient had a positive fluid balance of 20 l over 24h, received „a bit of noradrenaline“ and eventually had a sudden cardiac arrest. In answer to a comment that the patient may have been under-monitored, the response was: *“He was actually on noradrenaline to achieve a target blood pressure of 70 mmHg…we actually monitored metabolic function of the liver (lactate), skin perfusion (clinical assessment), urine output - all good measures of organ function and perfusion rather than simply arbitrary pressures, volumes or flows….So what cardiac output is the right one for this patient? What level of preload is right? What level of lung water is right?...I would be happy to use more monitors if somebody could show me they made a difference… The biggest problem with ALL the fancy numbers…is that…in the individual patient… you have NO idea what the „best“ number is supposed to be“.*

One of the main reasons for this ‚back to basics‘ movement is the repeatedly reported failure of the PAC to improve patient outcome. These reports have led not only to repeated pleas to discontinue the use of the PAC and to a significant decrease in its clinical use, but also to a general feeling of mistrust towards any of the new alternative monitoring techniques which have emerged in the meantime. We have to remind ourselves, however, that earlier studies have repeatedly shown that the PAC is superior to clinical evaluation in the hemodynamic assessment of critically ill patients, and that as many as half of the significant hemodynamic abnormalities cannot be adequately assessed based on clinical experience and physical examination alone. These studies have also shown that physicians were generally confident of their clinical estimates of hemodynamic variables, but there was no relation between confidence and accuracy. Moreover, experienced physicians were no more accurate than less experienced ones, although they were significantly more confident. Hence the critical care community seemed to have learned at that time that clinical examination and vital signs alone are unreliable in the evaluation of the hemodynamic status and that more advanced monitoring tools may give us new important information that is relevant to patient care.

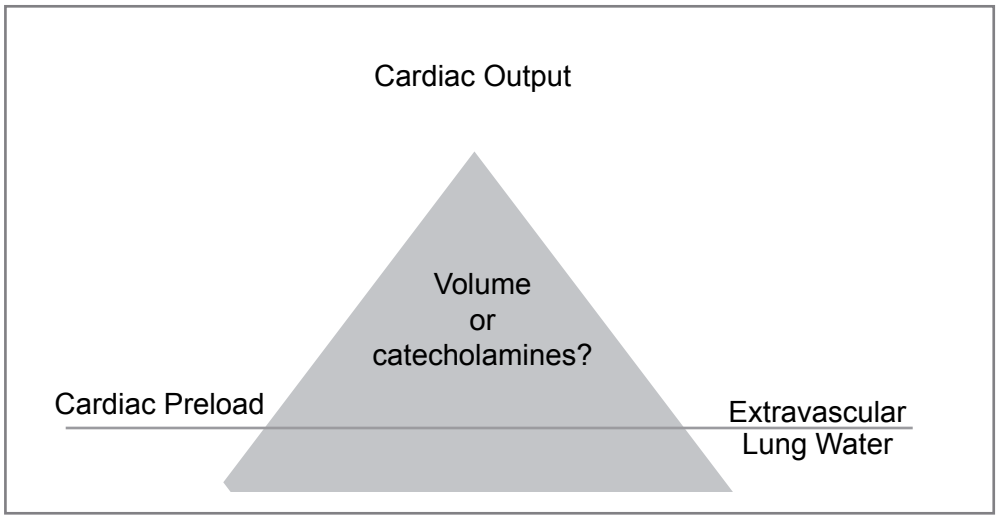
The major value of the PAC lies in its ability to measure the cardiac output (CO). Although the conflicting results of the various studies that were aimed at optimizing oxygen delivery made it unclear what target CO values we should aim for, it is still imperative to identify those instances in which a very low or a very high CO is undetectable by clinical examination alone. However, although identifying a low CO is of great importance, it still does not necessarily point to the right therapeutic decision, e.g., fluids, inotropes, vasopressors. The next step in the hemodynamic assessment is the evaluation of the volume status, which, when the PAC is being used, is based on the measurement of the filling pressures (CVP, PAOP). This indeed is the major flaw of the PAC since filling pressures have been repeatedly shown to be unreliable in assessing the volume of the heart chambers and in predicting the response of the patient to fluid loading.

It is therefore unclear why so many clinicians still rely on filling pressures to guide fluid therapy. What is even more disturbing is the fact that pre-determined levels of filling pressures are being used as end-points of resuscitation, as is the case in both the 2004 Update of the

Practice Parameters for Hemodynamic Support of Sepsis in Adult Patients and in the Surviving Sepsis Campaign Guidelines for Management of Severe Sepsis and Septic Shock. The current literature clearly shows that volumetric parameters of preload (e.g., the LV end-diastolic area measured by echo or the global end-diastolic volume – GEDV – measured by the PiCCO, reflect better the status of preload than the filling pressures. In addition, in patients who are on fully controlled mechanical ventilation, functional hemodynamic parameters (i.e., SPV, SVV, PPV, RSVT) are far superior to both filling pressures and volumetric parameters in the prediction of fluid responsiveness. Hence the information provided by the PAC is not reliable enough to identify latent hypovolemia, neither can it reliably prevent fluid overload or alert the care-giver to the development of pulmonary edema. This is especially true in the presence of increased pulmonary microvascular permeability, where aggressive optimization of the cardiovascular status may have grave pulmonary consequences. It is in these situations that a direct measurement of extravascular lung water is of utmost importance.

These shortcomings of the PAC may explain the claim that the use of the PAC is frequently associated with an aggressive style of treatment which, in turn, leads to adverse outcomes. In particular the PAC was shown in a number of studies to be associated with a high positive fluid balance. Obviously the non-uniformity of patient management in response to hemodynamic data obtained from PAC both within and between institutions may have caused great impact on outcome. This confusion has led to the performance of a few large randomized trials which were aimed at elucidating the effect of the PAC on patient outcome. To date none of these studies have shown that the PAC has any beneficial effect on outcome.

The conclusion of all this is that even with improved training in the insertion, interpretation, and implementation of the PAC and the data it generates, the PAC has inherent limitations as an advanced hemodynamic monitoring tool. This is why, as an alternative to expensive clinical trials on the PAC, it was proposed that our limited financial resources for clinical investigation be invested in the development of innovative techniques that may replace the PAC. These techniques are already out there, each trying to prove its superiority over the others. This of course is a very natural and very necessary process. Nevertheless, what is needed more is the realization that advanced hemodynamic monitoring should be further explored rather than completely abandoned. Admittedly, it is difficult to use published data as a basis from which to draw meaningful conclusions about the effects of any monitoring technique on outcome. However, these techniques provide us with a road map which, although incomplete by nature, may be more helpful than having no map at all, provided that one is aware of its pitfalls and limitations. The same logic is being employed whenever any physiological parameter is being measured. The ultimate study that will tell us, once and for all, how to best monitor hemodynamic status at any circumstance, at any time, is not out yet, and may never be. In the meantime we can either do nothing, or further explore the available technologies as well as our understanding of the pathophysiological processes that occur in the critically ill.



Volume or catecholamines? The „Hemodynamic triangle“ gives the answer

Acute lung injury post trauma

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Director of Medical and Coronary Intensive Care Units,
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Atlanta, Georgia, USA

Situation:

- 34 year old male passenger in motor vehicle accident with pelvic and femur fractures
- Hemorrhagic shock upon arrival in the emergency department, requiring fluid and blood product resuscitation
- Taken to theatre for pelvic stabilization
- Post-operative day 2 developed worsening hypoxemia consistent with Acute Lung Injury (ALI): chest X-ray showed bilateral pulmonary infiltrates and poor oxygenation ratio of 211 (PaO_2/FiO_2 ratio)

- A PiCCO was inserted showing the following parameters:
  - Mean Arterial Pressure (MAP) 87 mmHg
  - Global End-diastolic Volume Index GEDI 800 ml/m^2 (normal: 680 – 800 ml/m^2)
  - Cardiac Index CI 4.8 l/min/m^2
  - Stroke Volume Variation SVV 21 % (normal: ≤ 10 %)
  - Extravascular Lung Water Index ELWI 19 ml/kg (normal: 3 – 7 ml/kg)
  - Central Venous Pressure CVP 13 mm Hg

Therapeutic Problems:

Traumatically injured patient with pulmonary edema, high ELWI and GEDI after resuscitation. Acute Lung Injury (ALI) requiring conservative fluid management and active diuresis, as tolerated.

Further Therapeutic Interventions:

- Patient managed with pressure-limited low tidal volume ventilation to protect lungs against further injury
- Monitoring of GEDI and CI against the ELWI and PaO_2/FiO_2 permitting successful fluid management with active diuresis
- After 96 hours of ventilator support, nutrition and diuretic-based therapy, PaO_2/FiO_2 ratio increased to 345 on FiO_2 0.40 indicating resolution of ALI

Further Progress:

- Patient underwent operative fixation of femoral neck fracture
- He began spontaneous breathing trials on post-operative day 1

Comments:

Clinical management after acute fluid resuscitation and development of ALI can be successfully guided by the PiCCO parameters.

Simultaneous monitoring of GEDI and ELWI allows fluid restriction (reduction of pulmonary edema) whilst avoiding organ hypoperfusion (maintenance of preload).

Clinical Measurement of Extravascular Lung Water: Its time has come

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Introduction

Increased extravascular lung water is an important cause of acute respiratory failure in the critically ill. The amount of extravascular lung water (ELWI) in the lung results as a balance of factors that cause pulmonary edema formation and those that cause edema clearance from the distal airways and interstitum. Inflammatory and coagulation processes in acute lung injury (ALI) increase the microvascular permeability while causing a decrease in alveolar fluid clearance, resulting in a net accumulation of protein rich pulmonary edema fluid in the interstitium and distal airways [1]. In patients with acute exacerbations of chronic left heart failure or with acute myocardial infarction, hydrostatic pulmonary edema frequently develops leading to hypoxemia and decreases in lung compliance and ultimately to respiratory failure. Resolution of edema from the alveolar space predicts outcome and is essential for survival in ALI [2] In fact there is a growing body of evidence to suggest that a strategy to limit or reduce the amount of extra-vascular lung water (ELWI) from all causes improves outcome [3-8].

Measuring ELWI – The How and the Why

Pulmonary edema can be detected on physical examine by the presence of rales and confirmed roughly through chest radiography. But clinical examination, chest radiography and blood gases, either alone or together, have proven to be relatively poor indicators of the amount of lung edema or in changes in edema with treatment, of various etiologies [9]. The direct measurement of ELWI has been shown to be more sensitive than any non-invasive indirect method [10].

The ability to directly measure ELWI at the bedside has been available for over 25 years now. Lewis and colleagues developed the first bedside method in 1982 using the thermal-green dye method [11]. Subsequent advances by PULSION Medical Systems perfected the single thermal indicator technique employed today – representing a significant advance in reliability and ease of use.

The PiCCO® catheter system uses a single thermal indicator technique to determine ELWI, CO, and volumetric parameters. CO is calculated using the modified Stewart–Hamilton equation for thermodilution, with accuracy comparable with that of pulmonary artery thermodilution. Cold water injectate is introduced into a central vein and detected in the distal aorta. The volume of distribution of the thermal indicator represents the intrathoracic thermal volume (ITTV), where ITTV (ml) = CO × mean transit time (MTt) of the thermal indicator. The pulmonary thermal volume (PTV) is given by PTV (ml) = CO × down slope time (DSt), where DSt is the exponential decay time of the thermodilution curve. Global end-diastolic volume (GEDV) is given by ITTV – PTV (ml). This permits calculation of intrathoracic blood volume (ITBV) from the linear relationship with GEDV: ITBV = 1.25 × GEDV – 28.4 (ml). ELWI is the difference between the thermal indicator distribution in the chest (ITTV) and the blood volume of the chest (ITBV): ELWI = ITTV – ITBV (ml).

Concern has been expressed that the thermal dilution method would lose accuracy in patients with high dead-space fractions and areas of lung with poor perfusion. This is an especially important consideration in patients with ALI where deadspace fractions can be as high as 60-70%. But the accuracy of this method has been validated by comparison with the ”gold standard” postmortem gravimetric technique, and with the double dilution (thermo-dye) technique in animals and humans in a variety of disease states [12-14]. Moreover it has been shown to have a sensitivity that allows detection of clinically relevant changes in ELWI in animal models of severe ALI and congestive heart failure [15]. Furthermore ELWI measured in this way has been shown in several studies to reliably predict disease severity and outcome in sepsis and sepsis associated with ALI. In fact it has been shown to be the best pulmonary specific predictor for mortality we have available – even in patients with high dead space fractions.

Eisenberg et al and Mitchell et al, in two separate studies, first demonstrated that when fluid and hemodynamic management is guided by measured ELWI as opposed to central pressures and usual care, out-

come is significantly improved. ELWI fell to a greater extent in patients with ALI and in patients with heart failure and the duration of time spent on the ventilator and in the ICU was less in both studies [3,8]. Eisenberg showed that mortality was improved in patients with higher initial ELWI and ALI ($p<0.05$). Mitchell's study was not powered to examine mortality but there was a strong albeit statically non-significant trend to improved mortality. And there is new evidence from the ARDSnet group at the recent conclusion of a large multi centered fluid and catheter treatment trial (FACTT), showing that an aggressive approach to diuresis and fluid management in patients with established ALI/ARDS not in shock improves outcome. Such a strategy has been shown to increase the number of ventilator-free days in patients with lung injury with no increase in the rates of shock or renal failure [17]. Referring back to the striking results of Eisenberg's and Mitchell's studies would not even more benefit have been possible in FACTT had ELWI been measured and targeted directly? This is an even more relevant question today since from work since the early 1980's we now know we can significantly manipulate measured ELWI with diuresis, diuresis and albumin, and in ALI - continuous intravenous infusion of β-agonists (albuterol) [6,16].

Conclusions:

Taken as a whole these studies provide strong evidence to support the direct measurement of ELWI in patients in whom a clinical suspicion of pulmonary edema exists, or in those felt to be at risk to develop it and that treatment strategy be specifically designed around attempting to lower elevated ELWI to normal goals. Twenty years have now passed since Eisenberg and Mitchell first tried to show us the way in managing patients with pulmonary edema – directing therapy to measured lung water. The time for more widespread adaptation of fluid and hemodynamic treatment strategies designed around measured ELWI is now. Lets not let another twenty years pass.

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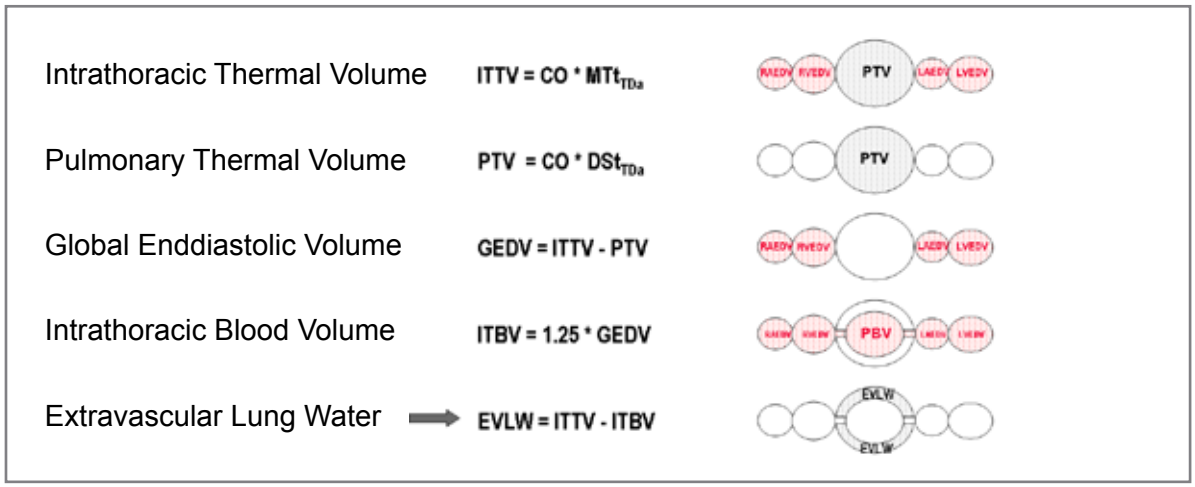

Determination of voulmes with the PiCCO-Technology

Measurement of extravascular lung water at the bedside: Why and how?

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Why do we measure Extravascular Lung Water?

Many critical conditions lead to pulmonary edema. During systemic inflammation and sepsis, acute lung injury (ALI), burns, pancreatitis, multiple trauma with severe blood loss, ischemia-reperfusion injury and other states, the release of inflammatory mediators may enhance pulmonary microvascular pressure and permeability, thus promoting the accumulation of fluid in the lungs. In contrast to hyperpermeability states, during cardiac failure the main mechanism for edema includes increased hydrostatic pressure in the pulmonary circulation. However, both cardiogenic and non-cardiogenic origins of pulmonary edema have one common sign – increased extravascular lung water (ELWI). Moreover, both types of lung edema are accompanied by a high mortality rate that necessitates a search for strategies that will improve our therapy. Consequently, reliable tools for monitoring lung fluid balance are increasingly needed in modern intensive care.

The amount of edema is, however, difficult to estimate at the bedside. Clinical examination, chest radiography, and blood gases have proven to be of limited significance in quantifying pulmonary edema. Therefore, several techniques have been developed to assess ELWI. Among them, single transpulmonary thermodilution today is used most frequently.

How can we determine Extravascular Lung Water?

Originally, the thermo-dye dilution (TDD) was used for measuring lung water. This technique is based on the simultaneous detection of two indicators with different properties: a freely diffusible indicator ("cold") and a dye (indocyanine green), which binds to the plasma albumin. Based on the Stewart-Hamilton principle, "cold" and dye allow the calculation of the intrathoracic thermal volume (ITTV) and the intrathoracic blood volume (ITBV), respectively. The difference between the two distribution volumes is used for estimation of ELWI (ELWI = ITTV – ITBV). The TDD method has been validated in animal models of lung edema and in the clinical setting. However, TDD is relatively time consuming, cumbersome and expensive, thus motivating the search for a reasonable bedside alternative.

Employing the PiCCO technique based on the injection of a single thermo-indicator that can be detected with an indwelling arterial thermodilution catheter, is an appealing idea. ELWI determined by single thermodilution (STD) can be calculated using the specific analysis of the thermodilution curve.

In addition to ELWI, STD combined with pulse contour analysis of cardiac output also gives the possibility of displaying a variety of cardiopulmonary variables, thus expanding the options for hemodynamic monitoring.

Recent experimental and clinical studies have shown that ELWI assessed by STD demonstrates good reproducibility and close agreement with the double indicator technique and postmortem gravimetry. Compared with both TDD and right heart catheterization, STD is simpler to apply, less invasive and more cost-effective, all factors that make it more suitable for use at the bedside. However, the detection of ELWI by the thermodilution method can be impaired by several factors, for example, severe changes in cardiac output and pulmonary blood volume and positive end-expiratory pressure (PEEP). Therefore, determination of ELWI by TDD and STD requires repeated measurements.

What do we measure Extravascular Lung Water for?

Several categories of both pediatric and adults intensive care patients have been shown to benefit from monitoring ELWI, including any patient who has cardiogenic and non-cardiogenic pulmonary edema, massive fluid shifts and severe changes in microvascular permeability. Thus, I consider any critical illness that results in shock and tissue hypoperfusion refractory to fluid resuscitation is a valid subject for ELWI monitoring. In addition, ELWI monitoring may also be of value in patients undergoing major surgical procedures, particularly cardiothoracic surgery and organ transplantation.

In septic shock, invasive cardiovascular monitoring with arterial catheterization and "beat-to-beat"

analysis facilitates the administration of large quantities of fluids, vasopressor/inotropic support, and ventilatory settings. Hence, such monitoring has recently been recommended as one of the guiding parameters for hemodynamic support in sepsis. During sepsis-induced pulmonary edema, accumulation of ELWI occurs before changes in blood gases, chest radiogram and pressure variables such as right atrial pressure (RAP) and pulmonary artery occlusion pressure (PAOP). It is important to emphasize that the latter variables are in fact unspecific diagnostic tools and influenced by a variety of factors. In contrast to RAP and PAOP, ELWI in severe sepsis correlates with markers of lung injury such as the oxygenation ratio, lung compliance, and the number of affected roentgenogram quadrants, as well as with the total lung injury score. During the onset of septic shock, ELWI is increased in three out of four patients. Therefore, in sepsis, ELWI serves as a marker of ALI, provides a valid estimate of the interstitial water content in the lungs and might become an alternative to RAP and PAOP in the management of fluid resuscitation.

In critically ill patients, ELWI has important prognostic value and increase in non-survivors. When evaluated in combination with other cardiopulmonary parameters, ELWI may reduce the duration of mechanical ventilation and shorten the periods of stay in ICU and hospital. Moreover, measurement of ELWI can support the diagnosis and therefore improve the clinical outcome of pulmonary edema, if used cautiously in combination with treatment protocols known to hasten its resolution. In patients with increased ELWI, such protocols include fluid restriction, administration of diuretics and inotropes, ultrafiltration, PEEP, and so on.

Summary:

Many critical states can be accompanied by the accumulation of Lung Water and development of pulmonary edema. Among the various methods for measurement of ELWI at the bedside, single transpulmonary thermodilution is most useful. Recent clinical studies have shown that ELWI correlates with the severity of lung injury and has a prognostic value, especially in sepsis and ALI.

Moreover, monitoring ELWI is an important tool for prevention and the goal-directed treatment of pulmonary edema of both cardiogenic and non-cardiogenic origins. Thus, the success of our therapy often depends on the correct answers to the following questions: (1) How much water is in the lungs, (2) Why is it there, and (3) What can we do to return lung water to the normal limits. I suspect that if we can answer these questions correctly, the measurement of ELWI and the individually therapeutic implications can contribute to improvement of outcome in many critically ill patients.

Case studies

„Failure to thrive“ post abdominal laparotomy for gall stone ileus

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Patient Diagnosis:
Pulmonary aspiration and acute respiratory distress syndrome following an abdominal laparotomy for gallstone ileus.

Medical History:
An 85 year woman was admitted to the ICU following an abdominal laparotomy for the treatment of a gall stone ileus. A limited small bowel resection was performed and the patient was extubated after 48 hours. Over a period of 72 hours, she “failed to thrive” complaining of abdominal pain and distension. Abdominal examination revealed some rebound tenderness and the absence of bowel sounds. TPN was initiated on the 3rd post operative day and she required CPAP for respiratory support. On the 4th day, the intra-abdominal pressure was measured at 18 mmHg (bladder catheter technique using 100 mL 0.9% saline) and the patient had an abdominal CT scan with contrast that suggested the presence of a post-operative ileus. On her return from the CT scanner, the patient vomited and became very short of breath suggesting pulmonary aspiration. She required emergency intubation and gastric contents were aspirated from the airway. She was immediately bronchoscoped and her airway washed out with 250 ml of 0.9% saline. Subsequently, she was difficult to ventilate, requiring pressure controlled ventilation (inspiratory pressure of 20 cmH_2O, PEEP of 15 cmH_2O, inspiratory time 2 seconds, respiratory rate 15 breaths/minute, FiO_2 of 0.8) to achieve a PaO_2 of 58 mmHg. She was also hypotensive despite 7.5 mcg/kg/min of dobutamine (80/45, MAP 55 mmHg) and her CVP was 15 mmHg (central venous saturation 66%). An ECHO cardiogram (poor views) suggested a hyperdynamic left ventricle that was reasonably well filled. A chest X-ray demonstrated bilateral fluffy infiltrates consistent with an acute lung injury secondary to aspiration. Her urine output had fallen to less than 0.5 ml/kg/hr and she had a metabolic acidosis with a blood lactate level of 2.9 mmol/l.

Clinical Course:
At this stage, the attending physician wished to measure this patient’s cardiac output, preload (GEDV) and extravascular lung water so as to optimize cardiovascular performance. He especially wanted to know the lung water in order to understand how aggressive he should be with fluid therapy. Before obtaining any hemodynamic data other than the CVP and central venous saturation ($ScvO_2$), he was inclined to give this lady at least 20 ml/kg of colloid (4% albumin) in an attempt to improve her hemodynamics. He was also concerned to administer a vasopressor (dopamine or nor-adrenaline) to such an elderly patient without some measure of cardiac output. The resident medical officer inserted a PiCCO arterial catheter into the right femoral artery without difficulty. The first set of measurements (mean of three) was as follows: cardiac index 1.8l/min/m^2, GEDI 880 ml/m^2, SVV 7%, ELWI 18 ml/kg (see Table 1). The intensive care specialist interpreted these data as suggesting that although preload was probably adequate, flow was too low. Given the elevated ELWI (normal < 7 ml/kg), he did not think further fluid therapy was appropriate since she was unlikely to be “fluid responsive” (GEDI at the upper limit of normal, SVV < 10% during controlled ventilation [tidal volume 7ml/kg]). Instead, the dose of dobutamine was increased to 15 mcg/kg/min and a low dose noradrenaline infusion (0.15 mcg/kg/min) was added to increase the MAP to greater than 70 mmHg. Three units of blood were administered to maintain a hematocrit of 32% and hydrocortine 50 mg qid was also prescribed.

Subsequently:
The patient was treated by fluid restriction, a 20% albumin infusion (12 ml/hour to maintain serum albumin greater than 30 G/l) and a fursemide infusion (2-15 mg/hour to maintain urine output greater than 150 ml/hour). After 48 hours of therapy, the patient was in negative fluid balance and inotropic and vasopressor support could be reduced over the next five days as oxygenation improved. The patient was successfully extubated on day 8.

Summary:
Advanced hemodynamic monitoring with the PiCCO allowed the attending physicians to manipulate fluid therapy, inotropes/vasopressors and diuresis in such a way as to improve hemodynamics and pulmonary gas exchange. Excessive fluid therapy was avoided and active measures were taken to maintain colloid osmotic pressure and to obtain negative fluid balance.

Table 1: PiCCO Measurements

Measurement	Day 0	Day 1	Day 2	Day 4	Day 5	Day 6
CVP	15	14	12	11	10	8
GEDI	880	680	810	825	830	790
SVV	8	12	N/A	N/A	N/A	N/A
CI	1.8	2.7	3	3.5	3.3	3.1
ELWI	18	18	14	12	10	9
PaO_2:FiO_2	95	125	210	270	295	330
PEEP	15	15	15	12	12	10

CVP Central Venous Pressure; GEDI Global End Diastolic Volume Index; SVV Stroke Volume Variation; CI Cardiac Index; ELWI Extra Vascular Lung Water Index; PaO_2:FiO_2 Partial Pressure Oxygen divided by Fraction of Inspired Oxygen; PEEP Positive End Expiratory Pressure

Incipient pulmonary edema in systemic inflammatory response after multiple trauma

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Medical History

A 28 year old man suffering multiple trauma after an accidental fall from approximately 10 meters.
Injuries included:

- Complex facial fractures
- Open fractures of left humerus and left tibia
- Closed fracture of right femur
- Transverse fracture of sacrum
- Absence of pulse in left arm

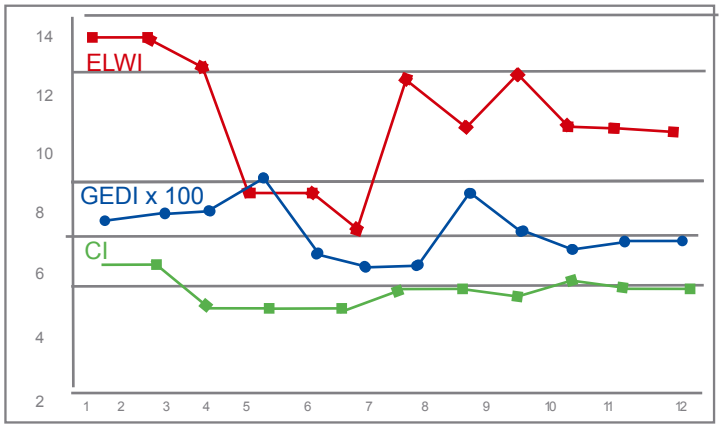
On arriving to our Trauma Centre Emergency Room (35 min after the accident) the patient was alert, conscious and breathing spontaneously O_2. Arterial oxygen saturation was 96% with an oxygen mask. The hemodynamic status was volume dependent and the patient was intubated and connected to a mechanical ventilator. Arterial blood gas analysis on mechanical ventilation with FiO_2 0.4 and zero-PEEP: PaO_2 175, $PaCO_2$ 33, pH 7.29, Base deficit -6.5, lactate 2.3 mmol/l and hemoglobin 9.8 g/dl. After radiological and sonographic explorations to rule out internal injuries the patient was transferred to OR (approximately 30 minutes after admittance) for external fixation of the long bone fractures and vascular repair of left axilla artery.

First 24 hours

The principal problems early after OR were:

1. Extreme hemodynamic instability requiring massive, volume replacement (positive balance of 12 litres in the first 12 hrs) and vasoactive support with noradrenalin in increasing doses (from 0.35 to 2.7 µg/kg/min).
2. Coagulopathy requiring replacement of hemo-derivates: Plasma 1500 ml, Red Blood Cells 2000 ml, platelets 12 units.

After 12 hrs the hemodynamic picture remained unstable with noradrenalin at 1.5 µg/kg/min (BP: 120/70 mmHg, CVP 5-7 mmHg, urine output 1.5 ml/kg/h, heart rate 120 beat/min and a positive fluid balance of 2 liters in the last 12 hrs. The patient became febrile (38.5 ºC) and developed a generalized skin erythema. Blood cultures were taken. Peripheral edema was apparent. Severe Systemic Inflammatory Response was considered as responsible for the hemodynamic situation. Chest radiograph was normal and the patient showed excellent oxygenation on mechanical ventilation with FiO_2 0.4 and 6 cmH_2O of PEEP (PaO_2 166, $PaCO_2$ 27, pH 7.37, Base deficits -4, Lactate 1.6 mmol/L).



Simultaneous monitoring of lung water and preload allows reduction of pulmonary edema while maintaining preload and cardiac output

Fluid therapy for the next days

Based on a relatively low CVP in a patient with high vasopressor support and normal lung function, fluid therapy for the next 24 hours was planned to maintain the fluid infusion as necessary and to maintain the noradrenalin infusion or, if possible to reduce it. A PiCCO catheter was inserted which provided the following data: Cardiac Index (CI): 4.7 l/min/m^2, Global End-Diastolic Volume Index (GEDVI): 630 ml/m^2, Extravascular Lung Water Index (ELWI): 13 ml/kg and Stroke Volume Variation (SVV): 17%. As SVV is only applicable in patients receiving fully controlled mechanical ventilation, so we did not use this parameter. As the GEDV was in the low range of normal this indicated that the patient could tolerate more fluids. However, by contrast, the high ELWI of 13 ml/kg (normal <7 ml/kg) indicated that even with normal lung function, the patient had "incipient pulmonary edema", probably due to the high permeability situation, indicating the need to infact reduce fluid intake. Therefore we reduced fluid intake and added bolus doses of fursemide.

Evolution

Following this plan a moderate but sustained negative fluid balance (300 – 1400 ml/day) was obtained in the following 5 days with close monitoring of continuous cardiac index. ELWI dramatically decreased to 6ml/kg (see figure). On day 8, following a 5 hour operation (maxillofacial surgery and intra medullar femur osteosynthesis), the patient received a positive fluid balance of 2500 ml and the ELWI increased to 12 ml/kg. This reduced slowly over time. The patient was extubated day 11, the PiCCO catheter was removed on day 12 and four days later, the patient was discharged to the normal ward.

Summary

1. Although this patient's oxygenation and chest radiograph were completely normal, the lungs were moderately edematous (ELWI 13 ml/kg, normal <7 ml/kg). This is of no surprise as it is known that both oxygenation and chest radiograph are not sensitive when detecting incipient pulmonary edema.
2. The optimum approach to fluid therapy is based on adequate interpretation of several physiologic parameters. ELWI gives unique and crucial information about lung fluid accumulation that can not be obtained in any other way.
3. Including ELWI monitoring in the fluid therapy decision tree allow us to take the right decisions according to the pathophysiological patient situation.

Case studies

Postoperative volume management after total hip replacement

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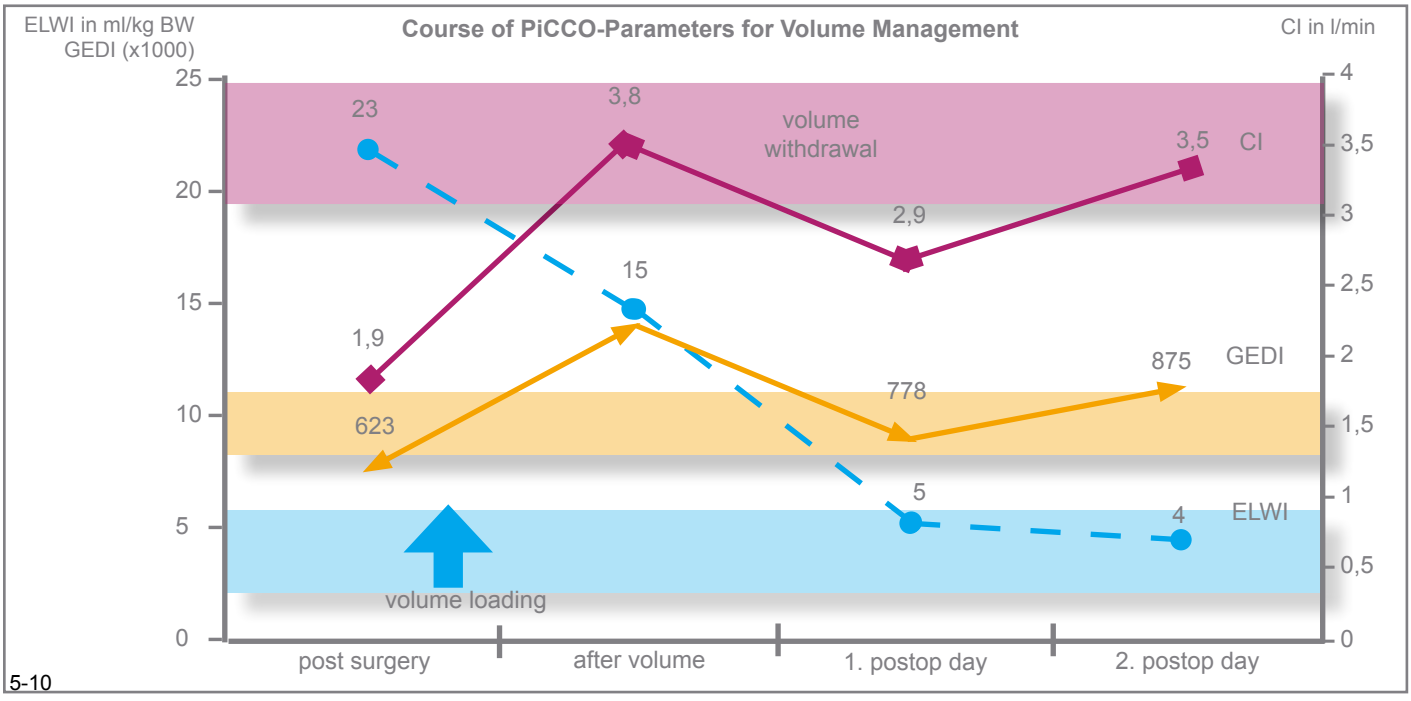
Situation:
- 63 year old patient undergoing total hip replacement
- uneventful course of anaesthesia
- stable hemodynamics intraoperatively; after 4h surgery clinical signs of pulmonary edema with oxygen saturation (SaO_2) dropping below 80%
- recovery room: blood pressure 63/40mmHg, heart rate 137 bpm
- stabilization of blood pressure with dobutamine and epinephrine
- blood gas analysis (ventilation with 100% oxygen): pH 7.23 (norm 7.35-7.45), pCO_2 42mmHg (norm 35-46), pO_2 75mmHg (norm 70-104), Hct. 37% (norm 40-52%)

Possible diagnoses:
- acute myocardial infarction with cardiac decompensation (cardiogenic shock)
- hypovolemia (hypovolemic shock)
- reaction to transfusion (anaphylactic shock)
- reaction to bone cement (anaphylactic shock)
- pulmonary embolism

Hemodynamic stabilization:
- installation of PiCCO-system: CI 1.91, GEDI 623, ELWI 23, SVV 22%
- despite the high lung water, volume loading started because of low GEDI and high SVV
- reduction of catecholamine dosage with volume therapy
- TEE showed a hyperdynamic left ventricle with small enddiastolic volume

Further course:
- further decrease and eventually cessation of catecholamines
- fluid withdrawal after hemodynamic stabilization
- extubation on 2nd postoperative day with normal ELWI
- at the time of extubation there were still radiologic signs of significant pulmonary edema
- extubation was nevertheless successful

Conclusion:
- detection of hypovolemia by means of PiCCO (low preload volume, high volume responsiveness) as the cause of hemodynamic instability.
- recognition and subsequent monitoring of pulmonary fluid accumulation.
- goal-oriented fluid- and catecholamine therapy with PiCCO: initial volume loading, and then volume withdrawal after circulatory stabilization.
- despite persisting radiologic signs of pulmonary edema the low ELWI showed an acceptable pulmonary water content allowing a successful extubation (Lung Water as a weaning parameter).



Admission to ICU for loss of consciousness

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Situation:

- 39 year old woman presented to the emergency department following coma related to benzodiazepine and antidepressant self poisoning
- Previous psychological disorder for which she was treated with antidepressants and benzodiazepines
- Intubated and mechanically ventilated then transferred to ICU
- On admission laboratory results normal with exception of Lactate 1.6 mmol/L, White Blood Cells (WBC) 24.8 10^9/L, Creatinine 120 µmol/L, CK 13400 IU, CRP 382 mg/dL

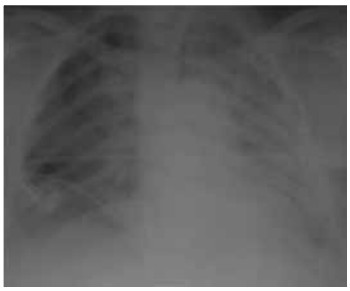
Therapeutic problems:

Aspiration pneumonia and moderate renal failure, with staph aureus found in tracheal secretions. Treated with fluids (saline), antibiotics and continued on mechanical ventilation

Ongoing problems:

Day 3 patient developed ARDS (Acute Respiratory Distress Syndrome) P/F ratio decreased from 280 to 120.

Day 2



Day 3

Patient remained hemodynamically stable from day 3 – 7 with no other organ dysfunction and resolution of renal failure following fluid management.

Further problems:

- Day 7 sudden development of severe acute circulatory shock - blood pressure 42/20 mmHg, tachycardia 130 bpm, oliguria and pyrexia 40 °C
- Grossly abnormal arterial blood gases (pH 6.89, lactate 24 mmol/L), WBC 79.3 10^9/L, Creatinine 169 µmol/L, potassium 6.3 mmol/L, CK 1157 IU, CRP 394 mg/L
- X-ray, abdominal echo, transthoracic echo – all normal
- Patient given 2 liters normal saline and commenced on noradrenaline.
- PiCCO was inserted showing the following;
  - Cardiac Index: 3.85 l/min/m^2
  - Stroke Volume Variation (SVV) 21 % (normal: ≤ 10%)
  - Stroke Volume Index: 31 ml/m^2 (normal: 40-60 ml/m^2)
  - Global End-Diastolic Volume Index (GEDI): 630 ml/m^2 (normal: 680-800 ml/m^2)
  - Extra-Vascular Lung Water Index (ELWI): 29 ml/kg (normal: 3 – 7 ml/kg)
  - Heart Rate: 125 beats/min
  - Arterial pressure: 80 / 35 mmHg

In the light of the very high Lung Water (ELWI) and despite the low preload (GEDI) and high stroke volume variation, the noradrenaline was increased to 8 µg/kg/min by hour 10 to achieve a MAP > 65 mmHg. Continuous veno-venous hemofiltration was started on hour 6. Activated Protein C was started at hour 10. Finally the antibiotics were changed.

Following noradrenaline increase PiCCO parameters were:

- Cardiac Index: 4.42 l/min/m^2, SVV: 13 %,
  Stroke Volume Index: 37 ml/m^2, GEDI 700 ml/m^2 ,
  ELWI 24 ml/kg, HR: 120 beats/min,
  Arterial pressure: 100/50 mmHg

Further Therapeutic Interventions:

From hour 18 the hemodynamic condition improved dramatically resulting in progressive reduction in the dose of noradrenaline, which was stopped at hour 36. At that time, blood lactate level returned to a normal value.

At hour 24, continuous hemofiltration was replaced by intermittent hemodialysis for the following two weeks until recovery of renal function. The patient also experienced an episode of nosocomial pneumonia on day 12.

Further Progress:

Patient was extubated on day 19 and was discharged to the ward on day 26 with normal renal function and normal chest X-ray.

Comments:

Despite the obvious need for fluid therapy (low preload – GEDI 630 and high value of SVV) during the development of acute severe circulatory shock, the patient was treated with noradrenaline to support her blood pressure because the priority was to avoid worsening the pulmonary edema (ELWI 29). In this case the knowledge of the very high ELWI allowed a more complete cardiopulmonary picture which provided the treating physicians with beneficial tools to make the right therapeutic decision.

Why filling pressures alone are not enough - Patient with acute respiratory failure and abdominal compartment syndrome

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Patient History:

A 55 year old man with a previous history of acute myeloid leukemia was admitted to the ICU because of acute respiratory failure. He had gained 7kg in weight the previous week on the ward where he was diagnosed as having a gastro-enteritis related to the chemotherapy (cytosar). His central venous pressure measured on the ward was 32cm H_2O. The tentative diagnosis hence was acute lung edema and a bolus of 40 mg fursemide was administered.

Clinical Course:

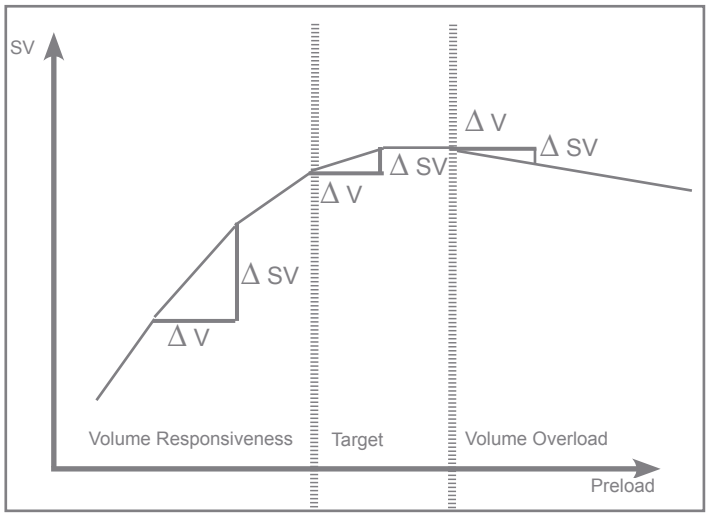
On admission to ICU he was in distress with a respiratory rate of 34 breaths per minute. Further examination of his vital signs showed a core temperature of 34.4°C, a MAP of 59 mmHg and a sinus tachycardia of 140 beats per minute. Because of clinical exhaustion, he was intubated and mechanically ventilated (machine rate 24 x 500ml, inspiration: expiration ratio 1:1 and a PEEP of 15) however oxygenation was poor with a pO_2/FiO_2 ratio of 115.
Breaths sounds were diminished and fine crackles were heard over both lungs. The abdomen was tender, firm and distended with an intra-abdominal pressure of 26 mmHg. Neurological and extremities examination were unremarkable, however, the patient was oliguric. A PiCCO catheter was inserted and confirmed the diagnosis of septic shock with a cardiac index of 5.1 l/min/m^2 (normal range 3.0-5.0) and low SVRI. The CVP was 24 mmHg with a SVV of 15% and a GEDI of 650 ml/m^2, confirming intravascular under-filling and fluid responsiveness, despite the high CVP. Blood cultures grew enterococcus faecalis and clostridium difficile toxins were positive on a recent stool sample. The patient's MAP was initially responsive to fluids together with doses of noradrenaline up to 1 mcg/kg/min and dobutamine up to 15 mcg/kg/min, however he soon became anuric and the cumulative fluid balance was positive for another 12 l. Due to ongoing fluid resuscitation and profound capillary leak his pO_2/FiO_2 ratio further deteriorated to 75. At that time CVP was 29 mmHg, MAP 65 mmHg, SVV 13%, GEDI 780 ml/m^2, IAP 28 mmHg, but ELWI increased from 12 initially to 17 ml/kg.

Subsequently:

The patient was diagnosed having an abdominal compartment syndrome with abdominal sepsis related to the toxic megacolon following diffuse clostridium difficile pseudomembraneus colitis. On abdominal CT the caecum diameter was 18cm with wall thickening up to 3.5cm, the whole colon was infiltrated and dilated. Therefore the option was taken to perform a total colectomy and decompressive laparotomy with temporal abdominal vacuum assisted fascial closure. After decompression despite the good CI and SVV parameters the patient was put on CVVH with aggressive ultra-filtration combined with albumin substitution because of the high ELWI and low pO_2/FiO_2 ratio. Over the following days his condition improved with a decrease in IAP to 16 mmHg and ELWI to 13 ml/kg and a concomitant rise in pO_2/FiO_2 ratio to 175. The CVP remained stable at 18 to 22 mmHg while SVV normalized at 10-13%.

Summary:

- Traditional filling pressures are erroneously increased in incidences of high intra-thoracic pressures (related to IAP or PEEP). In this situation volumes are better preload indicators.
- SVV is NOT an indicator of preload but a marker of fluid responsiveness (in fully ventilated patients).
- Measurement of flow (CI) does not allow you to discriminate between over-or under filling.
- After the initial resuscitation phase an even more important question that needs to be answered is: "when to stop filling?"
- ELWI can guide you to get rid of the excess fluids.



Relation of preload and stroke volume in different fluid loading conditions

Hemodynamic management of a patient with pneumonia

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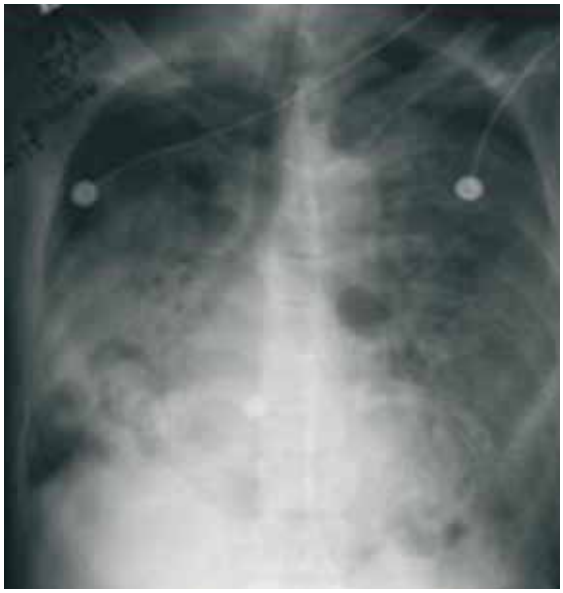
Situation

- 66 year old male patient with pneumonia
- Difficult to oxygenate with PaO_2/FiO_2 ratio 128 on Positive End Expiratory Pressure (PEEP) of 18 cmH_2O
- A PiCCO was inserted showing the following parameters:
  - Mean Arterial Pressure (MAP) 58 mm Hg
  - Global End-diastolic Volume Index GEDI 560 ml/m^2 (normal: 680 – 800 ml/m^2)
  - Cardiac Index CI 3.8 $l/min/m^2$
  - Stroke Volume Variation SVV 21 % (normal: ≤ 10 %)
  - Extravascular Lung Water Index ELWI 16 ml/kg (normal: 3 – 7 ml/kg)
  - Central Venous Pressure CVP 12 mm Hg



Therapeutic Problems:

Patient with severe sepsis due to pneumonia, low MAP with elevated SVV, inappropriate CI (sepsis!), Acute Lung Injury (ALI) with increased ELWI.

Further Therapeutic Interventions:

- Patient managed with pressure-limited low tidal volume ventilation to protect lungs against further injury
- Fluid resuscitated to target GEDI, increased CI, lower SVV
- Patient remained hypotensive (MAP< 60, SVV 14%, ELWI 19), so vasopressors (norepinephrine) started for blood pressure support
- $ScvO_2$ measured at 58% → early goal-directed therapy used to normalize $ScvO_2$ at > 70% (normal: 70% - 80%)
- PaO_2/FiO_2 decreased further to 110

Further Progress:

- Septic shock eventually resolved with antibiotics
- Invasiveness of mechanical ventilation decreased, PaO_2/FiO_2 increased and ELWI decreased to 7 ml/kg

Summary

- Patient required mechanical ventilation for 16 days
- After extubation, patient transferred to rehabilitation facility before going home

Comments

- PiCCO parameters GEDI and SVV – in contrast to the CVP of 12 mmHg - indicated and guided fluid resuscitation to improve hemodynamics.
- $ScvO_2$ tracked the effectiveness of the therapy by showing an increase to the normal range.

Case studies

Hemodynamic stabilization of a burn patient

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Situation:

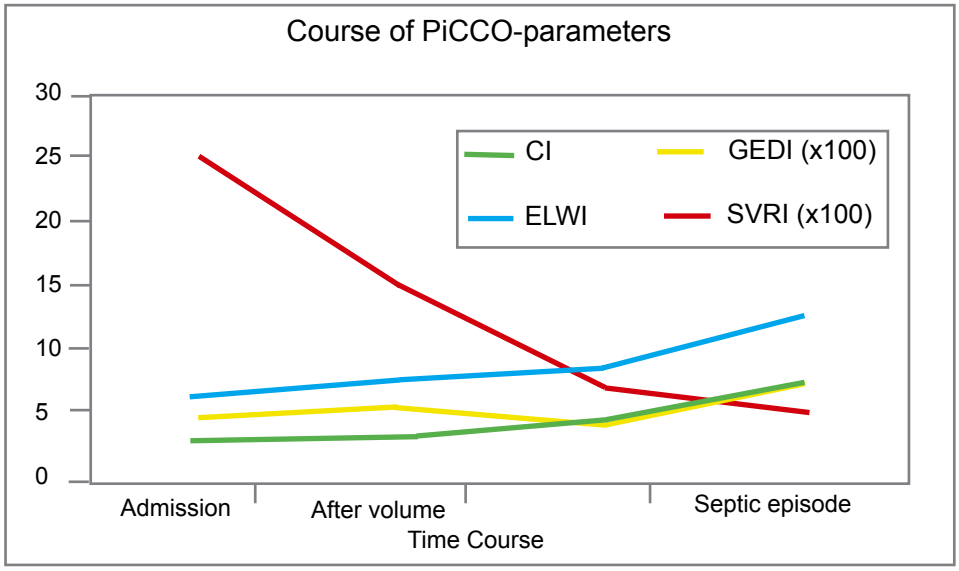
- 36 year old patient with 20% burns of face and upper body (3% 3rd degree, 17% 2nd degree)
- Patient was admitted intubated, hypothermic but hemodynamically stable to Burns ICU
- Gas exchange adequate with FiO_2 65, PEEP 10 cmH_2O
- Bronchoscopy showed inhalation trauma
- Laboratory parameters consistent with rhabdomyolysis
- Need for comprehensive monitoring due to complexity of case

Hemodynamic Stabilization:

- PiCCO monitoring installed; low CI 3.0, very low GEDI 520, and high-normal ELWI 7 and SVRI 2500 indicating patient was hypovolemic with a capillary leak syndrome, typical in burns patients
- Guided by further thermodilution measurements, patient was given in total 18 liters of crystalloids over first 24 hours, allowing sufficient diuresis with decrease in rhabdomyolysis parameters
- Despite the high need for fluid, pulmonary function improved and the patient was able to breathe spontaneously (FiO_2 .4. CI 3.8, GEDI 600, ELWI 8, SVRI 1500)
- Capillary leak syndrome continued causing ongoing need for volume (CI 5.0, GEDI 480, ELWI 9, SVRI 750)
- Under continued fluid therapy there was a slight decrease in gas exchange and increase in lung water, but normalization of the GEDI was possible with careful fluid loading
- Once preload was normalized, a reduction in volume administration was possible
- On day 5 patient became hemodynamically unstable (CI 7.9, GEDI 760, ELWI 13, SVRI 560, with pulmonary deterioration requiring FiO_2 1.0 with IRV (inverse ratio ventilation)
- General picture of a fulminant SIRS / sepsis reaction, noradrenaline commenced. Diagnosed with sepsis (streptococcal cultures found in tracheal secretions and enterococcus in wound swabs)
- Further requirement for fluid boluses, catecholamines and antibiotics resulted in a slow recovery
- After 9 days a negative fluid balance was possible, with cessation of catecholamines from day 12. Throughout this PiCCO parameters (CI, GEDI, ELWI and SVRI) remained within the normal range
- Following completion of a course of operative wound management, patient discharged to rehabilitation

Summary

- Volume status is difficult to predict in burn patients due to large fluid shifts
- In this case the hypovolemic episodes were reliably detected by the PiCCO
- ELWI is a helpful parameter in the evaluation of pulmonary permeability in burns, showing good correlation with the pulmonary function
- Because of the rapid initiation of appropriate volume-management, renal failure (rhabdomyolysis) was avoided



Resuscitation post Lung Embolism

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Situation

- 58 year old patient with history of vertebral disc operation
- On 1 day postop patient had a cardiac arrest during mobilization
- Successfully resuscitated, suspected to have fulminant pulmonary embolism, admitted to the Intensive Care Unit
- Echocardiography confirmed right heart dysfunction
- Started on thrombolysis therapy, hemodynamic stabilization with high dose catecholamines
- Development of anuric renal failure

Hemodynamic Stabilization

Installation of the PiCCO-Technology in order to accurately assess the cardiac pump function and to differentiate between need for volume and need for catecholamine treatment:
First results CI 5.87, GEDI 698, ELWI 5.

- Also had CeVOX-Technology* installed for the continuous measurement of the central venous oxygen saturation ($ScvO_2$) 63 % (normal range 70% - 80%)
- Rapidly began to display early characteristics of a developing SIRS with significant capillary leak (CI 4.78, GEDI 578, ELWI 5).
- Stabilization of Mean Arterial Pressure >80 mmHg possible with adrenaline and noradrenaline, and $ScvO_2$ reached >70%
- Reduction of adrenaline possible on day 3.
- With PiCCO monitoring stabilization of GEDI and ELWI to within normal range (CI 7.2, GEDI 696, ELWI 5).
- On day 3 development of a significant pulmonary dysfunction with clear requirement for high PEEP (18 mbar) and FiO_2 (0.8)
- Because ELWI remained at 5, a CT-scan of the thorax was done showing marked ventilation disturbances in the dorsal basal regions
- Simultaneously, a cranial CT-scan showed multiple central bleeding spots in the brain tissue and generalized brain edema, probably resulting from the thrombolysis therapy
- Patient died on day 4 from cardiac failure

Summary:

- Help in distinguishing between need for volume or catecholamine therapies possible by monitoring with the PiCCO and CeVOX-Technologies*
- The ELWI parameter allowed the exclusion of pulmonary edema as the reason for the pulmonary deterioration (confirmed by diagnosis of atelectasis in the thoracic CT)

Case studies

Acute pancreatitis and myocardial insufficiency

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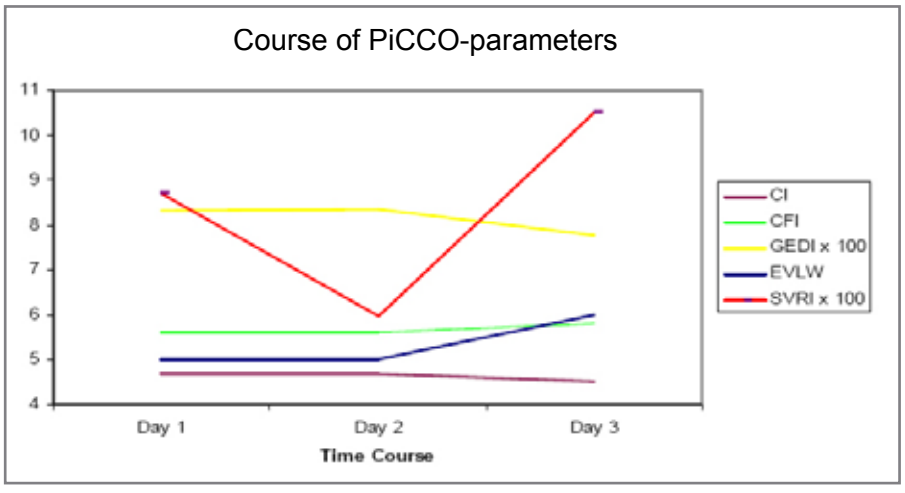
Situation:
- 82 year old patient with one day history of acute pancreatitis, CT showed extensive exudate around the head of the pancreas
- Biliary source suspected, so patient admitted for ERCP
- Previous medical history: compensated cardiac insufficiency & renal insufficiency due to right nephrectomy, diabetes mellitus II, arterial hypertension, general atherosclerosis
- On day 1 of admission clinically under resuscitated as shown by breath dependent variations on the arterial pressure curve, CVP 12 mmHg however

Therapeutic Problems:
- Apparent need for further volume management in patient with pancreatitis and atherosclerosis
- Previous history of cardiac and renal insufficiency requiring extreme caution with any volume loading

Hemodynamic Stabilization:
- Installation of the PiCCO-System, CI 4.67, GEDI 833, ELWI 5 , SVRI 870, CVP 12, SVV 28.7%
- Patient given 5 liters fluid
- PiCCO thermodilution measurement 7 hours later: CI 4.67, GEDI 834, ELWI 5, SVRI 598, CVP 12, SVV 33.8%
- Noradrenalin commenced and digitoxine was given for frequent tachy-arrhythmias
- PiCCO thermodilution measurement 16 hours later: CI 4.53, GEDI 778, ELWI 6, SVRI 1051, CVP 14, SVV 16.6%
- Following this, and because of cardiac decompensation with respiratory failure patient started on high dose diuretics and NIV-BIPAP (non-invasive ventilation)

Further Course:
- With the negative fluid balance and NIV the patient condition began to stabilize
- Resolution of the acute pancreatitis (aetiology presumed ischemic because of absence of gallstones in ERCP)
- Discharge to original hospital on day 9

Summary:
- Despite the volume therapy there was no increase in GEDI or ELWI, thereby pancreatitis responsible for large losses into the third space
- Noradrenalin was probably responsible for the decompensation in the cardio-respiratory function because of the increase in afterload
- Unfortunately no measurements are available once the patient began to recover
- SVV was not valid in this example as the patient was not receiving controlled ventilation and was having intermittent arrhythmias.



Multiple trauma

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Situation:

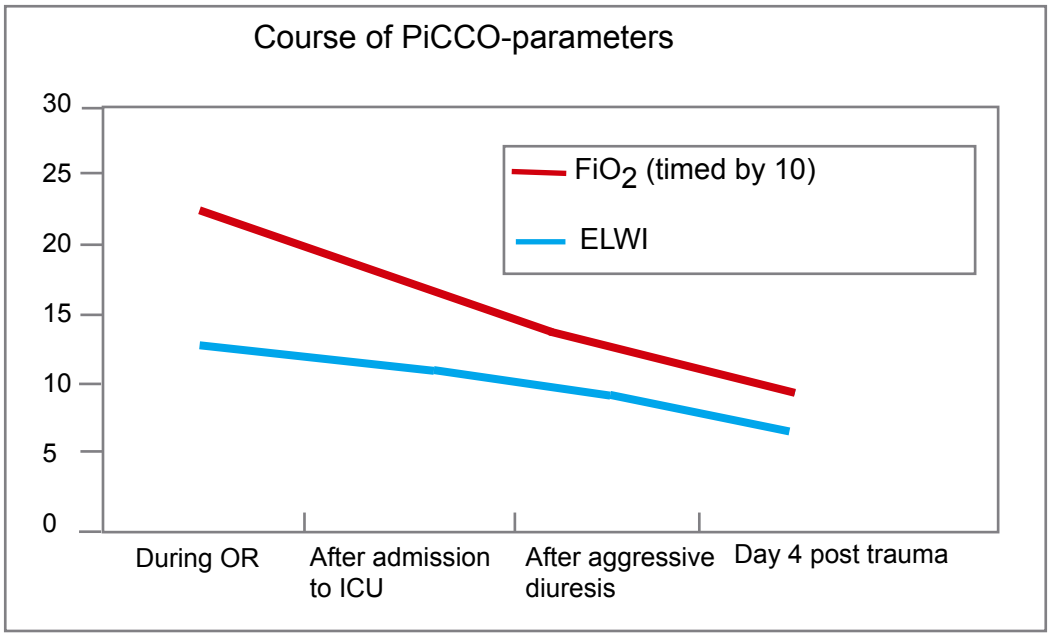
- 20 year old patient with multiple trauma including ruptured spleen, open fracture of lower leg, open fracture of lower jaw, craniocerebral injury (grade 2) as well as severe bilateral lung contusions and pneumothoraces and pneumomediastinum
- Patient had already undergone emergency laparotomy with development of severe oxygenation problems requiring invasive ventilation with FiO_2 of 1.0
- Massive blood transfusion required for hemodynamic stabilization
- On admission to the ICU, very gradual improvement seen in the pulmonary situation (FiO_2 7) with airway pressure release ventilation (APRV) and patient positioning

Hemodynamic Stabilization

- After installation of the PiCCO system, CI was high normal, GEDI normal with 720 after massive transfusion and ELWI elevated at 15
- As a result of the high ELWI with poor pulmonary function, aggressive diuresis started with fursemide, guided by the GEDI. After only a few hours ELWI decreased to 11, with a corresponding decrease in FiO_2 to 4
- Further negative fluid balance possible with close attention paid to GEDI
- On day 4 post trauma ELWI had decreased to 8, with a corresponding improvement in the pulmonary function (FiO_2 3), and increasing rate of spontaneous breathing
- Stable hemodynamically (CI 4.5) with low dose dobutamine therapy
- Patient condition continued to slowly improve with intensive care treatment, and still in ICU at time of writing

Summary:

- There was a direct correlation between pulmonary function, ELWI and need for mechanical ventilation
- By simultaneous monitoring of ELWI and GEDI, an effective reduction of pulmonary edema was possible while maintaining adequate preload and hemodynamic stability.



Case studies

Respiratory failure post aspiration

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Situation

- 59 year old patient with previous history of liver cirrhosis Child A from Hepatitis C
- Portal hypertension with long standing esophageal varices
- Need for emergency laparotomy because of small bowel ileus (cause: perforated appendicitis)
- During anesthetic induction massive vomiting with aspiration
- Consequently difficult to ventilate intraoperatively
- On first day post op patient transferred to larger hospital for further management
- On admission to ICU marked respiratory insufficiency with PaO_2 85 mmHg on FiO_2 8, hypotension, with SBP 100 mmHg with dopamine and dobutamine infusions, CVP 12 mmHg, diuresis 0.5 ml/kg/h
- Radiological findings: basal delineation increase and central congestion
- Ventilation adjusted to inverse ratio BiPAP 24/14 mmHg
- Laboratory parameters showed a worsening liver function along with a ascitic picture, and high CVP of 20 cm_H2O

Therapeutic Problems:

- Hemodynamic assessment indicating volume depletion
- X-ray showing pulmonary congestion, hence maybe volume restriction would be more appropriate?
- Deterioration of the liver function as the result of cardiac congestion or of volume depletion?

Further Therapeutic Interventions:

- Installation of the PiCCO system, CI 5.2, low SVR, therefore suggestive of a SIRS / sepsis reaction, GEDI 520, ELWI 8
- Given 5 liters fluid over 36 hours, later GEDI 680
- Low dose noradrenaline started
- With gradual volume loading no significant increase in ELWI
- Patient treated in different positions including prone, bronchoscopy for suction of secretions, antibiotic therapy

Further Progress:

- Improvement in pulmonary status over the following days
- Stabilization of the hemodynamic status with further volume administration, gradual cessation of noradrenaline infusion
- Normalization of the liver and renal function
- Extubation on day 10 post op

Summary

- Through the parameters provided by the PiCCO rapid detection of the volume depletion despite high CVP and radiology showing congestion
- Control of the volume loading by close monitoring of GEDI and simultaneously avoidance of any relevant increase in ELWI
- Through rapid hemodynamic stabilization prevention of any further deterioration in the liver and renal function.

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Literature

Literature

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Questionnaire & competencies

Questionnaire

PiCCO® questionnaire

1. What is the rationale for using the PiCCO® Technology?

2. What does PiCCO® stand for?

3. Can you name the most important specific parameters that using PiCCO® will give?

4. Describe these parameters in terms of what they mean to patient care?

5. What does SVV represent and therefore what patients is it limited to?

6. What arterial sites can be used when placing the PiCCO® catheter?

7. What 2 principles does the PiCCO® use to obtain its values?

_____

_____

8. What fluid do you use when calibrating the system?

_____

_____

9. How much cold bolus should be given, and what influences this volume?

_____

_____

10. How many boluses should be used to calibrate and how often is it necessary to calibrate the PiCCO®?

_____

_____

11. What temperature should the thermodilution bolus be?

_____

Questionnaire - Answers

1. What is the rationale for using the PiCCO® Technology?
   Hemodynamic monitoring of the patient

2. What does PiCCO® stand for?
   Pulse Contour Cardiac Output (i to facilitate the pronunciation)

3. Can you name the six most important specific parameters that using PiCCO® will give?

   - *Cardiac Output (CO)*
   - *Volumetric Preload (GEDV)*
   - *Lung water (EVLW)*
   - *Afterload (SVRI)*
   - *Contractility (CFI)*
   - *Volume responsiveness (SVV/PPV)*

4. Describe these parameters in terms of what they mean to patient care?

   - *CO - flow created by the heart*
   - *Volumetric preload – because it is a volume you can use it to guide fluid management*
   - *Afterload – for use of vasoactive drugs*
   - *Contractility – heart function, for use of inotropic drugs*
   - *Lung water – indicates presence of pulmonary edema, therefore you can use to titrate filling. Can indicate early sepsis i.e. leaky capillaries*

5. What does SVV represent and therefore what patients is it limited to?
   Stroke Volume Variation – shows if the patient is volume responsive or not, means if fluid administration will result in an increase of CO. Limited to patients with no arrhythmias and those who are fully ventilated.

6. What sites can be used when placing the PiCCO® arterial catheter?
   Femoral
   Brachial
   Axillary

7. What 2 principles does the PiCCO® use to obtain its values?
   Transpulmonary Thermodilution and Arterial Pulse Contour Analysis

8. What fluid do you use when calibrating the system?
   Saline usually
   Can use dextrose also if Na high

9. How much cold bolus should be given, and what influences this volume?
   The weight of the patient influences the amount of the bolus which should be given.
   The monitor displays the recommended amount in the thermodilution screen

10. How many boluses should be used to calibrate and how often is it necessary to calibrate the PiCCO®?
    3; should be calibrated every 8 hours or if there is a major change in hemodynamics or in the patients clinical condition (e.g. volume loading, change of ventilation mode, application of vasoactive and/or inotropic drugs)

11. What temperature should the thermodilution bolus be?
    At most room temperature. To ensure optimal thermodilution signals a temperature of 8 °C (64.4°F) maximum is recommended

Assessment of competencies
PULSION PiCCO-Technology monitoring – Clinical Education

This competency will assess the following areas:

- Knowledge of the PiCCO® system and set-up
- Management of the PiCCO® monitoring system in situ

Note: Profound knowledge of arterial and CVC line management is required prior to attempting this competency.

Part A	Assessment Criteria	Competent
1	Discuss the rationale for PiCCO® monitoring	
2	Discuss appropriate sites for PiCCO® A-Line insertion	
3	List the equipment required	
4	Discuss complications associated with PiCCO® monitoring.	
5	Specify essential nursing observations and actions involved in caring for a patient with a PiCCO® monitor.	
6	Discuss the parameters monitored, normal ranges and treatment protocols	
7	Discuss the calibration process, recommended fluids and temperatures for thermodilution.	
8	Discuss unit policy regarding frequency of line replacement, change of flush systems and decontamination process.	

Part B	Assessment Criteria	Competent
1	Prepares flushing device and transducer as for A-line competency	
2	Demonstrates ability to comply with unit infection control and disposal of sharps policies	
3	Demonstrates process, ensuring all connections are color coded and secure	
4	Demonstrates accessing input menu, completes data input	
5	Follows unit and manufacturer's guidelines for calibration	
6	States how often the system should be calibrated / zeroed.	
7	Demonstrates familiarity with specified chart	
8	Demonstrates safe removal of components and follows decontamination procedures	

I confirm that _____ has achieved the required competence for PiCCO® monitoring.

Signature of assessor:
Name: Position: Date:

I acknowledge my responsibility to meet the standards within the Code of Professional Conduct: standards for Conduct, Performance and ethics (NMC 2004)

Signature of Participant:

Name: Position: Date

Assessment of competencies
PULSION PiCCO-Technology monitoring – Clinical Education
Assessor's Notes

Part A	Assessment Criteria
1	Discuss the rationale for PiCCO® monitoring • In depth assessment of cardiovascular function • Volumetric/hemodynamic management
2	Appropriate sites for PiCCO® A-line • Axillary • Brachial • Femoral
3	List the equipment required for PiCCO®monitoring • Sterile dressing pack, local anaesthetic, needles, syringes, cleansing agent, suture, bio-occlusive dressing (all as per unit policy) • Existing CVC, 3-way tap • Pressure cuff • Saline 0.9% (500-1000 ml bag) • PULSION® disposable pressure transducer pack (includes injectate temperature sensor housing device) • Appropriate arterial thermodilution catheter set (see guide for details) • PULSION® PiCCO® monitor with injectate temperature sensor cable, thermistor cable, transducer cable for pressure signal, and slave cable to bedside monitor.
4	Discuss complications associated with PiCCO® monitoring • As per Art Line & Central Venous Pressure competencies • Inaccurate calibration, leading to potential misinterpretation of results
5	Specify essential nursing observations and actions to care for a patient with PiCCO® monitoring • As per Art Line and Central Venous Pressure competencies • Ensure accurate input of essential data • Ensure accurate calibration of system
6	Discuss basics of monitored parameters- refer to guide • Cardiac Output (index) • Cardiac Preload - Global End Diastolic Volume (index) • Afterload - Systemic Vascular Resistance (index) • Cardiac Contractility - Cardiac Function Index • Pulmonary Edema - Extravascular Lung Water (index) Discuss Decision tree – guidelines for management
7	Discuss calibration process • Calibrate the PiCCO® system once per shift. • Maximum interval between calibrations – 8 hours and/or when massive changes of hemodynamics • Type of fluid used for injectate – 0.9% saline, 5% Glucose • Recommended temperature of fluid <8°C (64.4°F) cold bolus (saline in fridge then on ice)
8	Discuss frequency of line replacement • Manufacturer's recommendation – 10 days • Unit Policy for line replacement, flushing device renewal

See instructions for use and package insert for full prescribing information. Technical specifications are subject to change without further notice.

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Frequently asked questions and answers:

General

1) What are the indications and contraindications for PiCCO-Technology?

Indications:

Patients in whom cardiovascular and circulatory volume status monitoring are necessary. This includes patients in surgical, medical, cardiac and burn speciality units, as well as other speciality units where cardiovascular monitoring is desired, and patients undergoing major surgical interventions where cardiovascular monitoring is necessary. In short, every patient who requires a central venous and arterial catheter for monitoring.

Contraindications:

Patients in whom there are arterial access restrictions, for example due to femoral artery grafting or severe burns in areas where the arterial catheter would normally have been placed. Note: The Axillary or Brachial artery can be used as an alternative site. Additionally a long radial artery catheter can be placed for short term use.

The PiCCO-Technology may give incorrect thermodilution measurements in patients with intracardiac shunts, aortic aneurysm, aortic stenosis, mitral or tricuspid insufficiency, pneumonectomy, macro lung embolism and extracorporeal circulation (if blood is either extracted from or infused back into the cardiopulmonary circulation). Please see more detailed answers below.

2) What external factors could influence the measured parameters in a false direction and what kind of pathological situations and illnesses may result in incorrectly measured parameters?

Air bubbles in the arterial pressure monitoring kit will dampen the curve and possibly influence the pulse contour cardiac output. Clotting of the catheter due to improper flushing might also influence pulse contour analysis.

An inadequate amount of indicator (i.e. not enough, or injectate too warm) will influence the thermodilution and volume calculations. The status line will alert you if the thermodilution is incorrect.

Clinical situations that may result in an incorrect measurement include severe arrhythmias (causing incorrect pulse contour cardiac output), raised EVLW (requiring more indicator), aortic aneurysm (causing the ITBV and GEDV to be overestimated when using the femoral arterial line), severe valve insufficiency (the CO will be correct, but volumes will be overestimated), rapidly changing body temperature (as malignant hyperthermia or rewarming influences the blood temperature baseline) and intracardiac shunts (causing recirculation of indicator). In pediatric patients you may also encounter patent ductus botalli (recirculation of indicator).

3) How long can a PiCCO thermodilution catheter and other disposables be left in a patient?

In general the arterial line can be left for up to 10 days unless there are signs of infection around the catheter insertion site. Each hospital usually has its own local protocols for indwelling catheters and the frequency they should be changed or removed. It is very rare for a patient to get a systemic infection from the arterial catheter. Systemic infections are more commonly associated with central venous catheters.

Depending on the individual hospital's policy, the monitoring kit and inline injectate sensor housing should be changed approximately every 3-5 days.

The long radial artery catheter (PV2014L50) is only intended for short term use, due to the intravascular length of up to 50cm.

4) Are there special recommendations for the use of the PiCCO in open-heart surgery?

On pump:

The initial calibration of the PiCCO should be done by thermodilution measurements after induction of anesthesia, before opening of the chest. During pulse contour calibration with thermodilution measurements the patient should be hemodynamically stable and have no significant change in body temperature. A recalibration can be done immediately before going to cardiopulmonary bypass (CPB), but this is not a necessity. During extracorporeal circulation the PiCCO cannot give any valid results due to lack of arterial waveform. Thermodilution measurements are not useful during extracorporeal circulation. As soon as the heart is pumping again the PiCCO will show the cardiac output from pulse contour analysis. Immediate recalibration of pulse contour is usually not necessary, but volume status (GEDI) will be of interest immediately after bypass and after closing of the chest.

Off pump:

Initial calibration is done after induction of anesthesia. During the whole procedure, continuous cardiac output can be followed on a beat to beat basis. Recalibration during the procedure is not necessary. During the procedure, the index of left ventricular contractility (dPmax) gives additional contractility information and can serve as an early warning for ischemic events.

It has also been shown that SVV serves as an indicator of cardiac volume responsiveness, even under open chest conditions.

5) Is it possible to use the PiCCO with a patient on 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 output. However, the PiCCO-Technology can be used to measure CO, preload volume GEDV and ITBV as well as EVLW with every thermodilution measurement.

6) What does the abbreviation "PiCCO" stand for?

"PiCCO" is neither a small Italian beer nor a coffee maker.

"PiCCO" means **P**ulse **C**ontour **C**ardiac **O**utput. The "i" is only included to have an easy sounding and pronounceable word.

Transpulmonary indicator dilution

1) Is it possible to use the PiCCO in patients with variations in blood temperature or with hypothermia?

The PiCCO compensates for baseline temperature drifts. If the baseline drift is higher than 0.05°C per minute, the display shows the message UNSTABLE and a thermodilution measurement is not recommended. Hypothermia does not affect the PiCCO, if the PiCCO detects a stable baseline. However, please note, room temperature injectate may not be used in these circumstances.

2) Is it possible to use the PiCCO in patients treated with continuous hemofiltration?

In patients with hemodialysis/hemofiltration PiCCO readings will be accurate as long as the hemodialysis catheter is not placed in the cardio-pulmonary circulation and the whole bolus goes into the cardiopulmonary circulation.
However, warming / cooling devices for maintaining the blood temperature may lead to baseline drift or baseline instability.

3) Is it possible to inject the cold bolus through a venous catheter placed in the right atrium? Are the results obtained by this thermodilution exactly the same than those obtained by the bolus injection into the vena cava?

The catheter used for indicator injection should be placed centrally, either directly before the right heart or in the right atrium to obtain correct volume measurements. For calibration of the pulse contour analysis, injection of indicator into a peripheral vein is possible as long as the arterial catheter shows a good quality thermal response curve. Please note however, the volume determinations will be incorrect.

4) What is the effect of injecting the temperature indicator for the PiCCO into the femoral vein instead of the superior vena cava / right atrium? Does this make a clinically significant difference to the GEDV, ITBV and EVLW?

Double hump indicator curves and the resulting measurement errors could occur because of a disturbed temperature signal from "cross talk" between the venous and arterial blood stream. In other words cold injectate can pass to the arterial thermistor without going through the cardiopulmonary system but directly from vein to artery.
Even when using long femoral venous catheters, there is a small effect from “cross talk” caused by thermal migration of the wall of the long catheter into the vessel.
“Cross talk” can be avoided if the PiCCO catheter is either placed in the opposite femoral artery or in the brachial / axillary artery.
If cross talk is avoided, thermodilution measurement is possible, but the PiCCO readings for ITBV and GEDV will be about 75 ml (as absolute values) higher than the volumes really are. This is caused by the volume from the point of injection to the point of detection being higher, because the catheter for indicator injection is not placed directly before or in the right atrium. The value for EVLW will be correct, as both ITTV and ITBV are about 75ml higher than their real value and EVLW results from the formula EVLW = ITTV - ITBV.

5) Can temperature artefacts appear during baseline analysis?

Sometimes temperature artefacts will be visible if the thermistor in the arterial thermodilution catheter is in contact with the vessel wall. The artefacts are more prominent if the artery is narrow. In general blood temperature does not change so quickly as to cause spikes on the baseline. Withdrawing the catheter by approximately 1cm, or placing the catheter in an extremity will help in most cases.

6) What are the recommended volumes of injectate required for arterial thermodilution measurement?

The injection volume is dependent on the patients body weight. If the patient has an increased amount of extravascular thermal volume (i.e. EVLW* or ETVI is more than 10 ml/kg body weight), the injection volume must be increased.

kg BW	ETVI < 10 ml/kg iced	ETVI > 10 ml/kg iced	ETVI < 10 ml/kg RT
< 3	2	2	3
< 10	2	3	3
< 25	3	5	5
< 50	5	10	10
< 100	10	15	15
>= 100	15	20	20

Iced = temperature of solution <8°C, RT = temperature of solution < 24°C

In clinical practice, most people use a standard volume of 15ml of cold saline solution. This setting works in most patients and avoids confusion and mistakes. However, injectate volume has to be adapted for patients with very low or very high body weight.

7) How many times is the injection of injectate recommended to perform thermodilution measurements in a new patient?

We recommend three measurements with less than 20% (+/-) variation compared to the mean value performed within a 5 minute time frame. Technically once is usually enough. However, if the patient has elevated EVLW the first measurement may not be accurate and more or cold injectate may be required (e.g. if you are using room temperature injectate initially, EVLWI reading is > 10ml /kg).

8) What kind of injectate can be used with the PiCCO-Technology?

Theoretically any fluid can be used, however, we recommend using **only** saline solution. Use of glucose for example, may cause the small piston inside the injectate temperature sensor to agglutinate with the housing thus impeding movement during injection. Also, it is imperative that lipids are not run through the sensor housing.

9) Can the PiCCO detect an abnormally shaped thermodilution curve?

Yes, PiCCO-Technology monitors and analyzes the shape of the thermodilution curve for plausibility. On the display screen a status line will give an error code or error message if there is an abnormal curve detected. Remember that the thermodilution curve is displayed on the screen and can be examined by the user.

Pulse Contour Analysis

1) If all continuous values are dependent on just "one" calibration of the pulse contour algorithm, what happens if the calibration is not done correctly?
There are certain criteria that need to be met during calibration. Both the thermodilution curve and the arterial waveform must be considered technically acceptable before the PiCCO is calibrated. To exclude any possible errors, 3 thermodilution measurements are recommend.

2) Does the PiCCO give accurate values even when the patient is on vasoconstrictors ?
The PiCCO gives correct results as long as the vascular resistance remains relatively stable. If there is a change of more than 20% in systemic vascular resistance, a recalibration is recommended. Additionally, we recommend re-calibration by thermodilution every 8 hours. In the clinical situation where vascular volume monitoring is performed, more frequent calibrations will usually be required due to the thermodilution measurements done to obtain GEDV, ITBV and EVLW.

3) What are the time intervals or under what circumstances is it recommended that new thermodilution measurements are done so that results from the pulse contour analysis are updated and more accurate according to the patient status?
In general the PiCCO should be calibrated every 8 hours by thermodilution; however individual patient needs vary greatly. For example, if your patient is in shock you may have to determine their GEDV hourly. Once the patient is stabilized you may be able to decrease the frequency of measurement to once every 2 hours and then, if the patient remains stable decrease to every 4-6 hours. Another guide may be to perform a thermodilution measurement if the continuous cardiac output has trended consistently in the same direction for 15 minutes or if there are large and/or sudden changes in the patients clinical status.
Another helpful indicator in patients on mechanical ventilation is the Stroke Volume Variation (SVV). If the SVV increases to over 10%, without any change to the patients ventilatory support, a thermodilution measurement is necessary to determine the volume status of the patient.

4) What about pulse contour in case of cardiac arrhythmias?
In cases of severe cardiac arrhythmia (i.e. ventricular fibrillation, supraventricular tachycardia) the pulse contour cardiac output will not be accurate. However, in cases of mild to moderate arrhythmia (atrial flutter/fibrillation, bi-gemini, tri-gemini or occasional extra beats) the pulse contour will reflect the current cardiac output. It is recommended to calibrate the pulse contour more frequently if the arrhythmia changes, and use 3-5 bolus injections every time to ensure more accurate measurement.

5) The pulse contour cardiac output shows a vast difference when compared to the cardiac output determined by arterial thermodilution. What are the possible reasons?
a) Significant hemodynamic instability.
b) Errors in detection of the arterial wave form and therefore errors in the wave form analysis.
c) Extreme arrhythmia or frequent extra systoles.

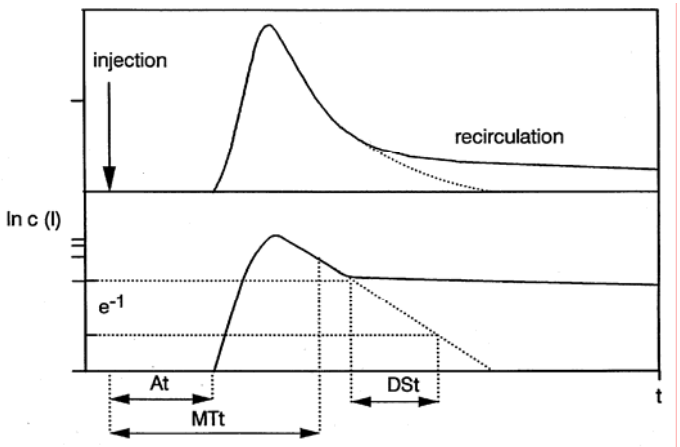
Technical Questions

1) Does PiCCO measure or calculate volumes?
The PiCCO calculates volumes based on the shape of the thermodilution curve using measurement of mean transit time (MTt) and down slope time (DSt) multiplied with cardiac output.

Time [min] x **Flow** [l / min] = **Volume** [l]

2) How is mean transit time (MTt) detected and what does it represent?
The concentration of the indicator is distributed over time because of the volume of the system, i.e. there is a given time for each indicator particle to travel between the point of injection and point of detection. This time is called the transit time and each particle has its own transit time. The MTt is the mean value of all these transit times.
The MTt multiplied with the CO gives the whole thermal volume (intrathoracic thermal volume, ITTV) the indicator has to go through.

3) How is the exponential down-slope time (DSt) detected?
The down-slope time is detected by plotting the thermodilution curve with the temperature change (indicator concentration) on a logarithmic scale (ln) and time change on a linear scale (lin). When you plot the thermodilution curve as a linear-ln graph, the indicator decay approximates a linear function. Two points, the starting point located at 85% of the maximum temperature response and an end point defined as 45% of the maximum temperature response (see figure), are identified. The time difference is determined and labeled the down-slope time (DSt). DSt multiplied with CO leads to the pulmonary thermal volume (PTV) which is the largest volume in the series of "mixing chambers" of the cardiopulmonary system. PTV consists of pulmonary blood volume (PBV) and Extravascular Lung Water (EVLW).



4) How does PiCCO calculate the BSA to get the indexed values?
Different BSA calculation formulas are used in the PiCCO plus with software V6.0.

BSA for patients with BW< 15kg
Haycock **$BSA = (W^{0.5378} \times H^{0.3964}) \times 0.024265$**
BSA for patients with BW>= 15kg
DuBois: **$BSA = (W^{0.425} \times H^{0.725}) \times 0.007184$**

5) We want to standardize pressure-monitoring kits, why do we have to use PULSION kits?
The PULSION kits have been tested for frequency response and are matched to the algorithms used in the PiCCO to give maximum reliability. The most important factor to maintain reliability is the connection tubing used with the PULSION transducer. This tubing is very inflexible and of a certain length and inner diameter. If you use any other transducers or connection tubing, or if you modify the connection tubing (e.g. with a needle less blood sampling port) the pulse contour cardiac output may not be correct. To ensure correct pressure transfer, a square wave test has to be performed (please refer to the IFU of PULSION pressure transducers). The PiCCO-Technology is only validated with original, unmodified PULSION pressure transducer systems.

Medical and Physiological Questions

1) **Does the respiratory cycle influence the value of measured parameters?**
No, the respiratory cycle does not influence PiCCO measurements because the thermodilution curve is approx. 20 seconds long. Therefore at least 3 respiratory cycles could fit under the curve. This means that compared to the pulmonary artery catheter, the PiCCO thermodilution cardiac output has a much lower coefficient of variation.

2) **Which cardiac output is more accurate, the one measured by PiCCO or the one measured by right heart catheter?**
This is a difficult question to answer as both methods use the Stewart-Hamilton algorithm and thermodilution. In terms of accuracy the two methods are comparable. However, the PiCCO method has a much lower coefficient of variation. In other words, the PiCCO method is less user dependent and gives more stable measurements. When compared to the gold standard (Fick method) the PiCCO shows an excellent correlation (r^2 = 0.9 or better with bias of approximately 130 ml/min). PiCCO pulse contour cardiac output shows a high correlation and low bias to the arterial thermodilution cardiac output.

3) **We observe a slight overestimation of PiCCO Cardiac Output (COa) compared to the pulmonary artery catheter (COpa) of 5 to 10%: What is the reason for this?**
There are several **theories** to explain this:
1. **Early recirculation** and overlap of the original downslope:
Early recirculation has not been demonstrated thus far, however, since the PiCCO extrapolates the downslope from such an early point, (between 85% and 45% of the peak of the arterial thermodilution curve) it is very unlikely that the indicator could pass the whole system during this time and overlap with the original curve.
2. **Indicator loss**:
Theoretically, indicator could be lost into the pulmonary gas volume.
If thermal loss through the lungs is calculated based on the different heat capacity between gas and liquid, theoretically there is a possible loss of about one promille. This would not be enough to significantly influence the measurement results.
3. **Slowing of heart rate during injection of cold indicator:**
The most likely reason for this would be cooling of the sinus node. This affects COpa, which is normally completed within 3-6s post injection, much more than transpulmonary thermodilution curves. Transpulmonary thermodilution takes much longer, depending on the magnitude of CO, ITBV / GEDV and EVLW. Slowing of the heart rate is not detected with a normal bedside monitor, because the average time is too long (usually 12s)
4. **Blood flow through the Vasa Privatae**. This blood comes from the aorta to perfuse the lung tissue and returns to the left ventricle. This means that aortic blood flow might be slightly higher than pulmonary artery blood flow. Although not examined thus far, blood flow through the Vasa Privatae should, theoretically, be significantly lower than the above mentioned 5 to 10%

4) **Is the cardiac output measurement correct in the case of aortic stenosis?**
In aortic stenosis arterial thermodilution accurately reflects the cardiac output. The arterial pressure waveform is basically normal with possibly reduced systolic and elevated diastolic pressures. The area under the arterial waveform still reflects the stroke volume.

5) Is the cardiac output measurement correct in the case of aortic, mitral or tricuspid valve insufficiency?

In the case of valve insufficiency the valve does not close correctly. Therefore, the thermodilution curve is affected by indicator regurgitation, resulting in a prolonged indicator decay time. In the case of severe aortic insufficiency the curve may ´time out`. However, if a thermodilution curve is obtained, it will accurately reflect the cardiac output as the systemic blood flow is measured.

In the case of mild aortic insufficiency, if the thermodilution cardiac output is compared to Doppler flow measurements, the Doppler measurements will show a higher cardiac output because the Doppler only measures instantaneous forward flow, not the regurgitated blood. Thus a higher cardiac output is calculated based on forward flow. The PiCCO gives a correct CO based on the measurement of systemic blood flow.

6) Will the volumetric measurement be affected by severe valve insufficiency?

The thermodilution curve will be affected by indicator regurgitation. This results in a prolonged indicator decay time. Severe regurgitation may lead to an overestimation of GEDV and ITBV.

7) Is it possible to calculate the volume demand of a patient directly from the values of the transpulmonary thermodilution measurement?

The Global End-Diastolic Volume (GEDV) is approximately 1/4 of total blood volume. If the patient has a body surface area of 1.8 m^2 and a GEDVI of 500 ml/m^2, the normal value for GEDVI is 680 - 800 ml/m^2, therefore you can calculate the amount of fluid necessary to restore normal GEDVI.

Volume needed = (680 - $GEDVI_{measured}$)* body surface area * 4

In our example: Volume needed = (680 - 500)* 1.8 * 4 = 1296

The patient needs a fluid bolus of approximately 1300ml increase in order for their vascular volume to return to the normal GEDVI if using colloid solutions. However if crystalloid solutions are used, 4 times this volume is necessary to reach this required volume. Of course a combination of crystalloid and colloid solutions may be used, remembering that whatever portion of GEDVI replaced with crystalloid solution will have to be multiplied by 4.

8) Cardiac preload volume is not the equal to global end diastolic volume (GEDV). Why is GEDV a good indicator of cardiac preload? How is it possible to estimate cardiac preload from the GEDV?

This raises the question: “What is preload? “ Strictly defined, cardiac preload is the myocardial fiber 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;

1. ITBV and thus GEDV is a reproducible and sensitive parameter for close approximation of preload.
2. Neither the so-called filling pressures (central venous pressure, pulmonary artery occlusion pressure), nor right ventricular end-diastolic volume reflect cardiac preload.

9) Why is GEDV bigger than one would expect from the physiology?

GEDV is the total volume of the heart divided by the time it takes the indicator to traverse the cardiopulmonary circulation. Thus, it is not a measurement of the volume of the heart during a single cardiac cycle. An indicator injected into a compartment will be diluted into the largest available volume of that compartment. When this reasoning is applied to the heart, there are 4 compartments that have to be considered: end-diastolic volume of the right atrium, right ventricle, left atrium, and left ventricle.
The indicator dilution curves from each compartment is additive both individually and in time. Thus, GEDV is the sum of the end-diastolic volumes, the largest available volume, of the 4 compartments of the heart over the time necessary for the indicator to traverse the cardio-pulmonary system. The GEDV is thus a sum of these cardiac cycles as opposed to a discrete value from one cardiac cycle. In addition there is a small amount of volume added by the aorta. Additionally, the volume passing through the atria during diastolic filling of the ventricles may be greater than the physical geometry of the atria. This phenomenon is due to the fact that there are no inflow valves in the atria and thus once the atrial-ventricular valve is open the pressure gradient between inflow pressure and current ventricular pressure dictates the amount of volume passing through the atria. As a result, the end-diastolic volume of the atria may appear larger than predicted by the atrial geometry.

Practically the most important point here is that all of the above is represented in the normal PiCCO values for GEDV. So, GEDV measured by the PiCCO is larger than the GEDV given by for example by an echo. However, the GEDV normal values of the PiCCO are higher than those measured with an echo.

10) What is the level of error in the case of an aortic aneurysm?

It is very hard to predict the amount of error in ITBV or GEDV as a result of an aortic aneurysm. In the case of an abdominal aortic aneurysm when using an axillary arterial line, there will be no error. Theoretically GEDV and ITBV will be raised by the volume of the aortic aneurism, as the indicator will also have to pass through here (from CV injection to arterial detection).

11) Does pleural fluid influence the measurement of extravascular lung water (EVLW)?

Pleural fluid is not measured in the EVLW for two reasons,
1. 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. Thus, the temperature loss to the pleural fluid is negligible.
2. The distance for diffusion is very large requiring a long time for equilibrium.
Temperature only can distribute to the extravascular space that has direct contact with the passing indicator. As a result, only intra-interstitial, intra-alveolar and intracellular water is measured as EVLW. In contrast, a pleural effusion will have no direct contact and is thus not included.

12) Is EVLW displayed correctly in a patient following pneumonectomy or when parts of the lungs are not perfused?

Generally, EVLW is only measured in the parts of the lungs that are perfused.
In the case of a pneumonectomy, there will be discrepancies in the Intrathoracic Blood Volume (ITBV) and Extravascular Lung Water (EVLW), but the values for Cardiac Output as well as GEDV are correct.

To estimate the error in EVLW measurement post pneumonectomy we have to go in the formulas:

Generally:

ITTV = CO x Mtt	ITTV = Intrathoracic Thermal Volume, "needle to needle volume"
PBV = CO x Dst	PBV = Pulmonary Blood Volume, biggest "mixing chamber"
GEDV = ITTV – PBV	
ITBV = GEDV x 1.25	empiric determination for normal lungs
EVLW = ITTV – ITBV	

Post pneumonectomy:

ITTV	post pneumonectomy will decrease, but measured correctly
PBV	post pneumonectomy will decrease, but measured correctly
GEDV = ITTV – PBV	will be calculated correctly
ITBV = GEDV x 1.25	factor 1.25 is valid for 2 lungs, post pneumonectomy this factor is assumed to be smaller

➔	ITBV	will be overestimated post pneumonectomy
➔	EVLW = ITTV – ITBV	overestimated ITBV subtracted from correct ITTV
➔	EVLW	will be underestimated post pneumonectomy

The extent to which EVLW could be underestimated is dependent on the amount of removed lung tissue.
High EVLW will be underestimated less than low EVLW. However, the trend of EVLW is still a valuable tool to guide the fluid therapy.

13) In obese patients I do not trust EVLW measurements: How is the measurement influenced under these circumstances?

The PiCCO displays absolute values and indexed parameters. Extravascular lung water is indexed to body weight of the patient (ml / kg).
In obese patients, extravascular lung water index (EVLWI) is underestimated because it is related to the body weight.
Example: Absolute EVLW: 1400ml

200kg person:	EVLWI = 7ml/kg	upper range of normal value
70kg person:	EVLWI = 20ml/kg	severe pulmonary edema

However, EVLW is a valuable parameter to detect pulmonary edema and guide fluid therapy if this relationship is considered. In case of severe obesity, you might consider using the ideal body weight of the patient.

14) What body weight should I use and type in to the PiCCO in a patient with severe edema, e.g. burn patients with a difference of "dry"- to current weight of e.g. 25kg to get comparable "normal ranges" as indicated in the decision tree card

In particular, burn patients receive large amount of fluids (up to 30l and more) during their initial resuscitation period. The "dry weight" of the patient has to be used to be typed in the PiCCO INPUT screen, since the cardiopulmonary system did not change during this short time the patient developed edema.

15) What are the normal ranges for pediatric patients?

The normal ranges on the decision tree cards (GEDI 680-800ml/m2) are related to adult patients only. These figures are based on a huge patient data base which is not yet available for pediatric patients, moreover not for pediatric patients of different age and weight.
Our experience thus far shows a lower normal range for GEDVI and ITBVI in pediatrics and a higher value of EVLWI. Kozlik-Feldmann et al. 1998 published GEDI 490 +/- 100 ml/m2, ITBI of 700+/- 150ml/m2, and a value of 8,3+/-1,6 ml/kg for the ELWI. 38 patients, 7.5 to 23kg bodyweight. The patients in Schiffman et al. 2002 had a mean GEDI of 440 ml/m2 after volume loading. EVLW was much higher in these patients (n=10, 3.9 to 8.2 kg, mean 5.4kg) with a mean EVLWI of 27 ml/kg after volume loading.
In summary: In pediatric patients, the normal range for the preload volume is lower, whereas the normal range of the EVLW is higher than in adults.
The method itself works reliably, CO is derived accurately and GEDV/ ITBV and EVLW are excellent tools for volume management in pediatric patients.

16) What is the clinical relevance of stroke volume variation (SVV) especially in cardiac surgery?

To interpret SVV, the patient has to be on continuous positive pressure ventilation with no spontaneous breathing efforts. SVV may be within normal limits even during hypovolemia (GEDVI 520-600 ml/m^2) indicating that the heart is not responding to changes in preload. As a result, even during hypovolemia, with regard to the Frank-Starling mechanism the heart is already relatively volume overloaded, corresponding to severe cardiac insufficiency.

17) In the case of an open chest or during low tidal volume ventilation, can we still use SVV?

By using low tidal volumes or even under open chest conditions, SVV is dependent on cardiac filling, thus cardiac preload can be used for volume management. However, the absolute extent of SVV will be lower.

18) What is the clinical value of the index of left ventricular contractility (dPmx)?

dPmx is a direct measurement of contractility. The dPmx is a measure of how fast the pressure rises during systole. If pressure is measured close to the aortic valve, the rise in blood pressure during ventricular systole is proportional to the force of contraction. The PiCCO measures blood pressure either in the femoral or axillary artery, thus, the increase in pressure during systole is somewhat blunted. However, the rise is still indicative of the force of ventricular contraction. dPmx can be used to document the effects of inotropic drugs. Recent experience has shown that dPmx can be used as an early warning for ischemic events during off pump coronary artery bypass grafting (OPCAG).