Les méthodes de pulse contour

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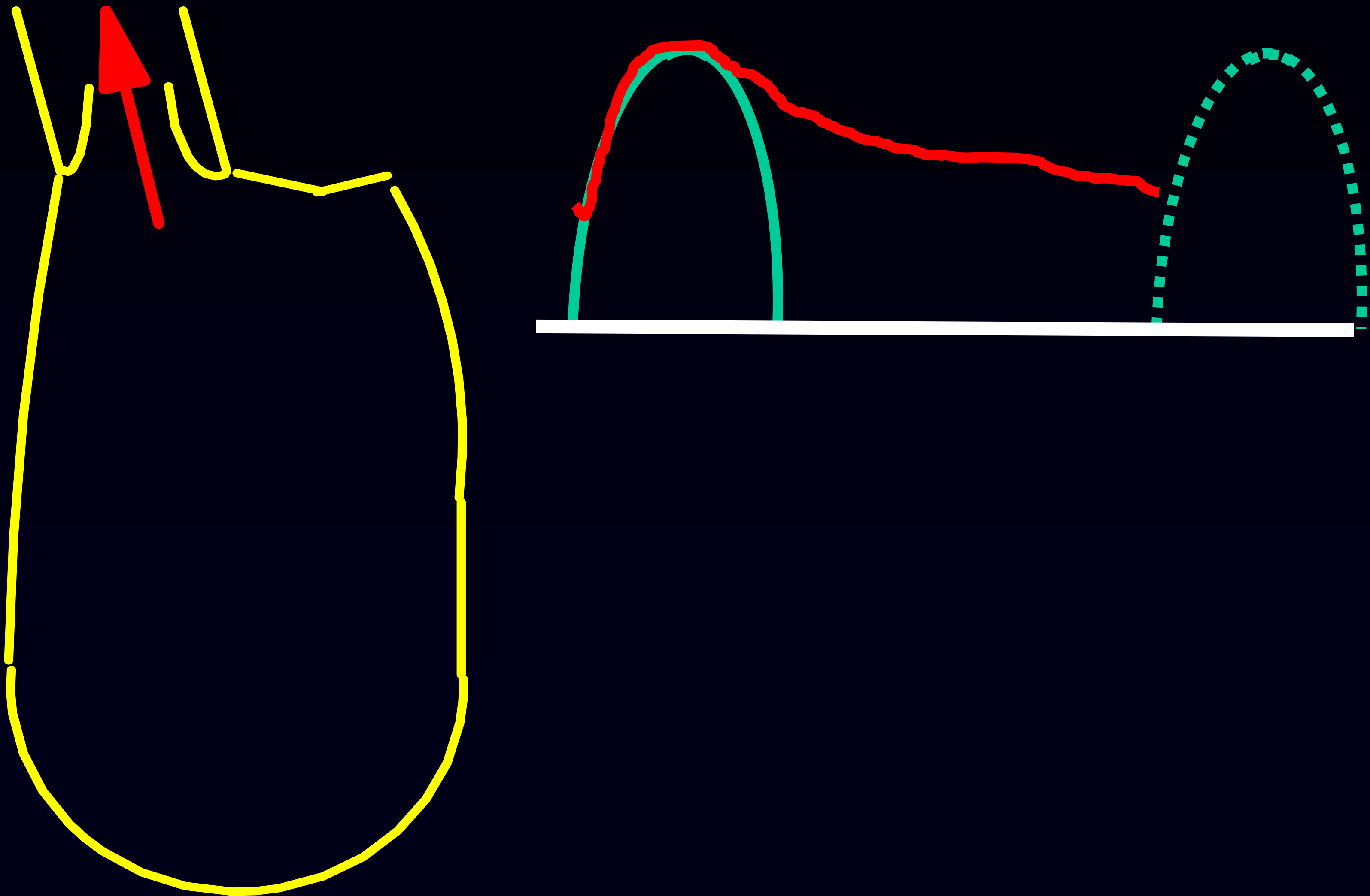
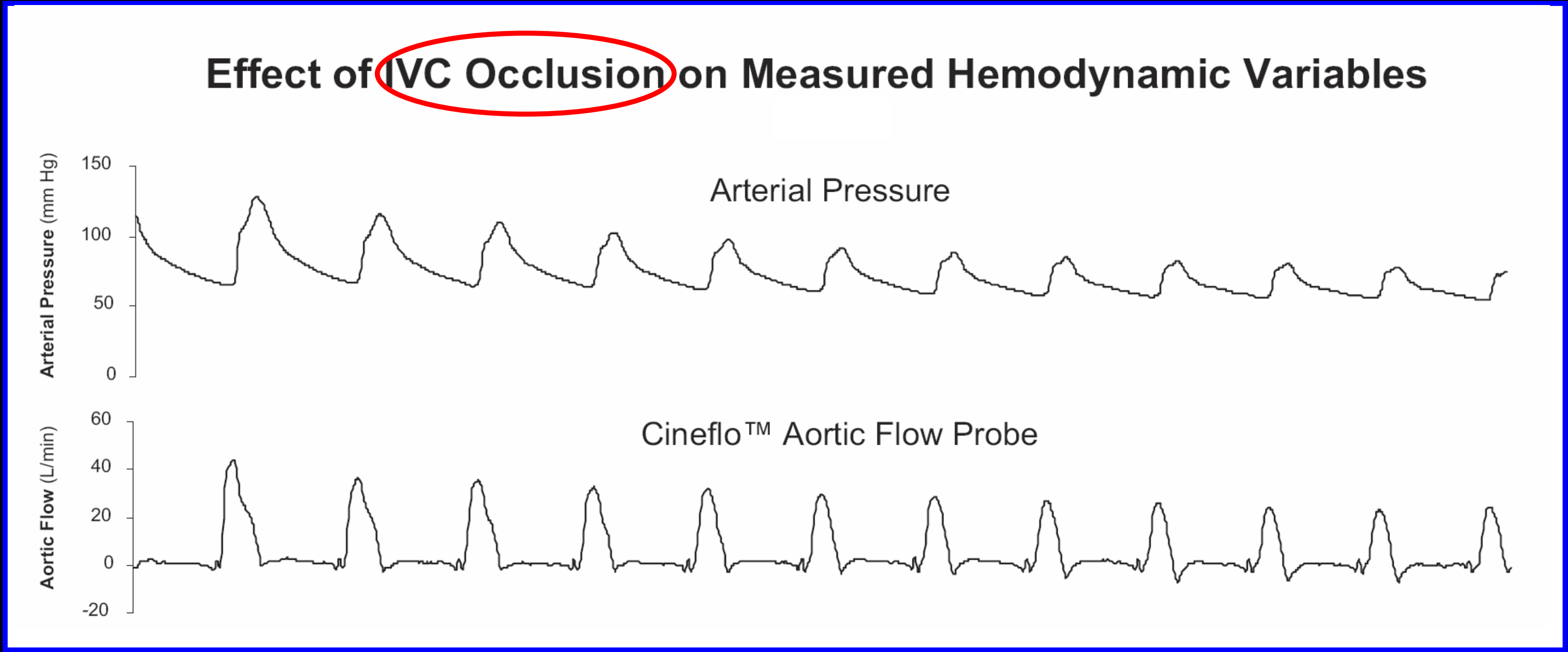
Pulse contour methods:

- **With calibration**
  - **=> Transpulmonary thermodilution (PiCCO)**
  - **=> Lithium dilution (LiDCO)**
- **Without calibration**
  - **=> FloTrac**
  - **=> PRAM**

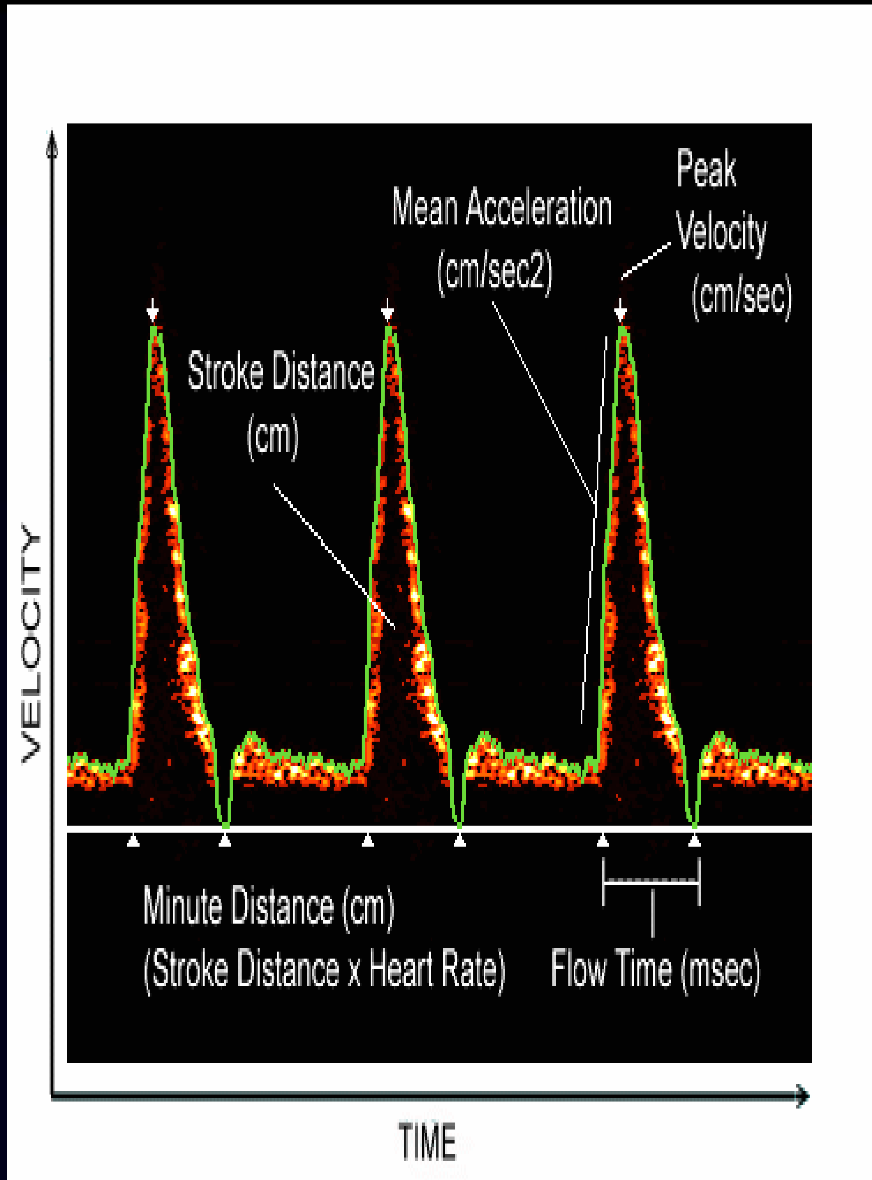
What is the link between stroke volume and arterial pressure ?



Marques et al
Crit Care Med 2008

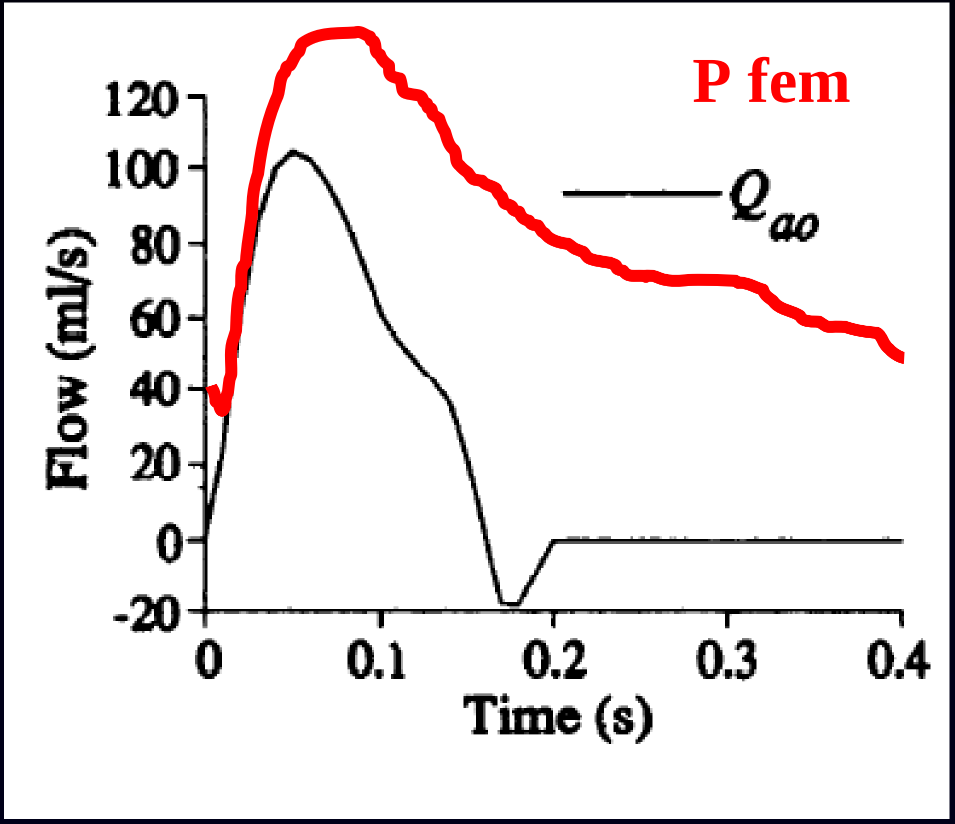


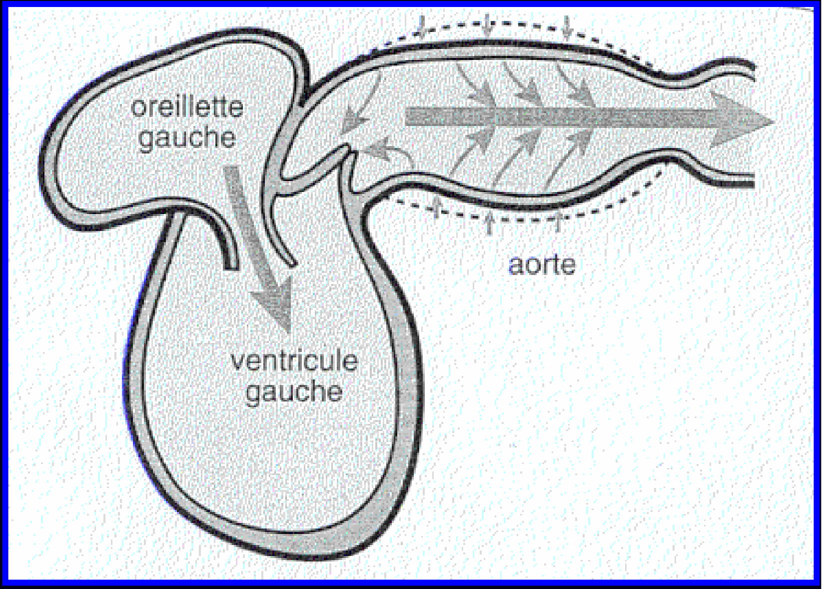
What is the link between stroke volume and arterial pressure ?



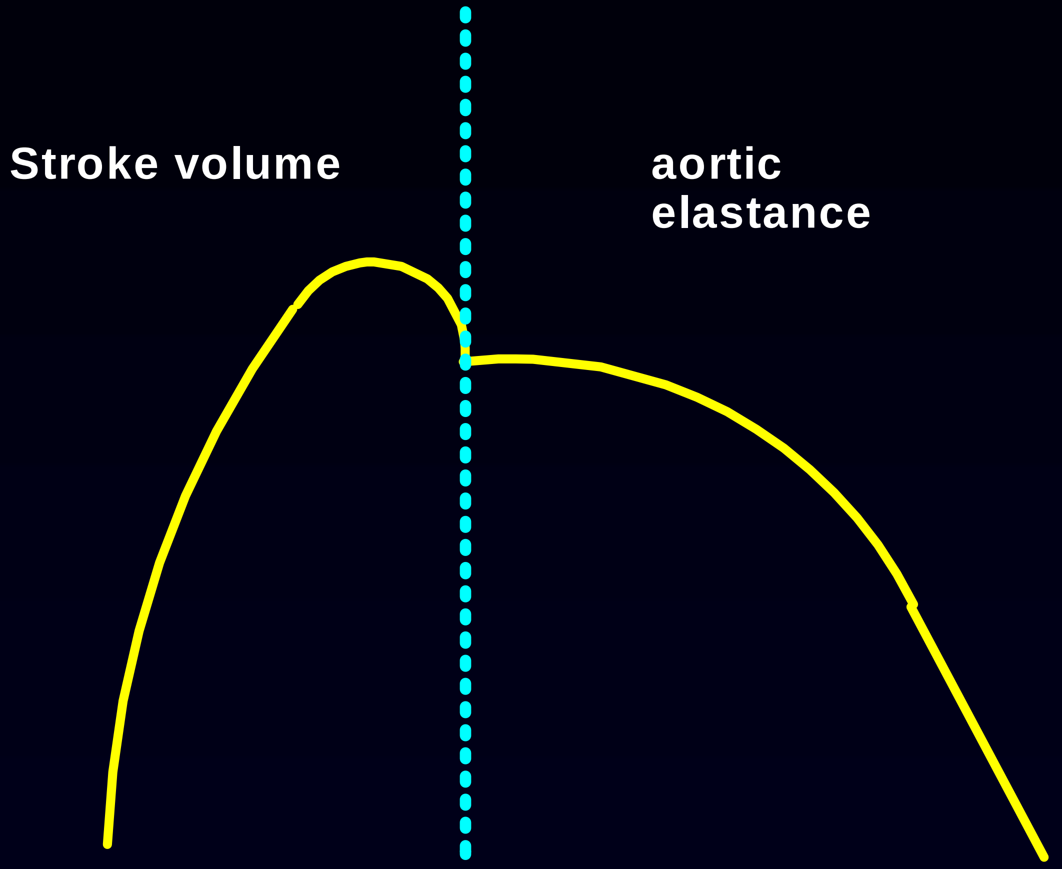
DDB

What is the link between stroke volume and arterial pressure ?



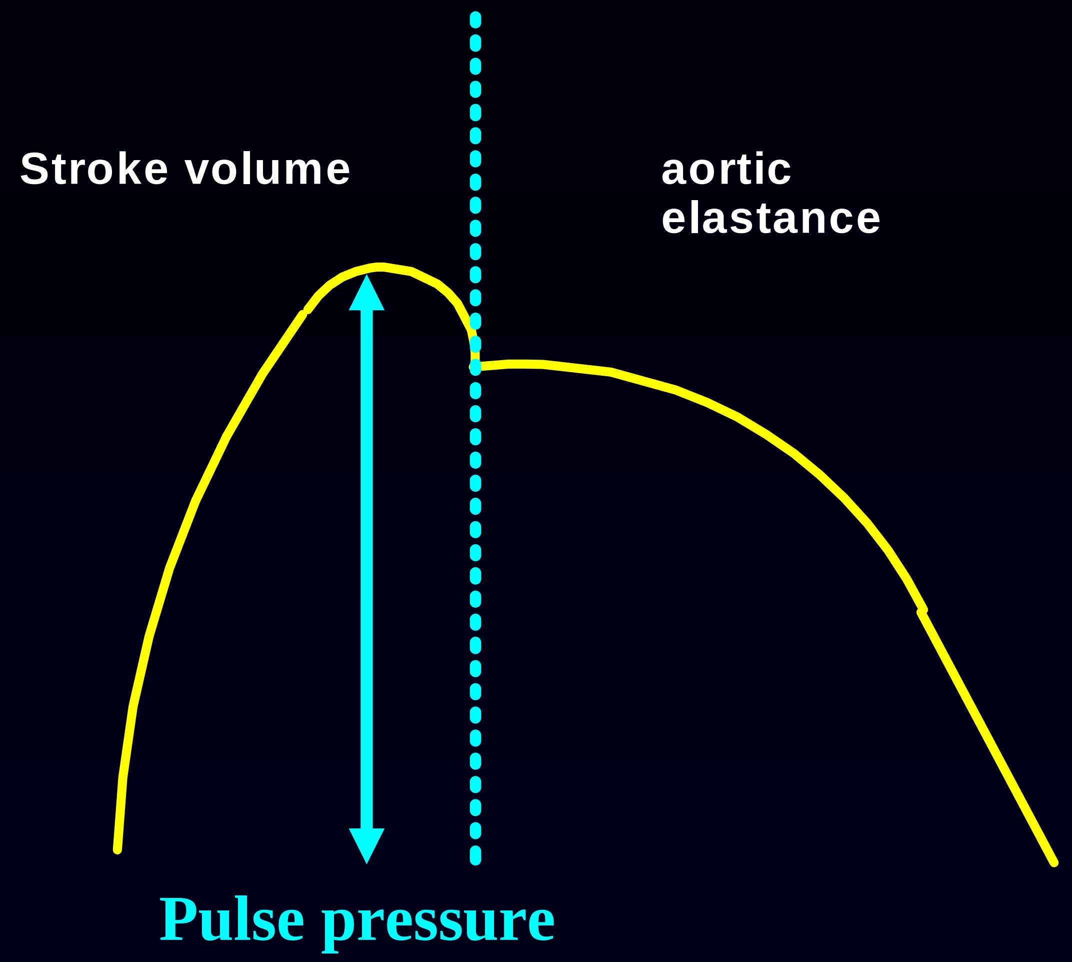


Factors influencing the arterial pressure curve



Pulse pressure ?

Factors influencing the arterial pressure curve

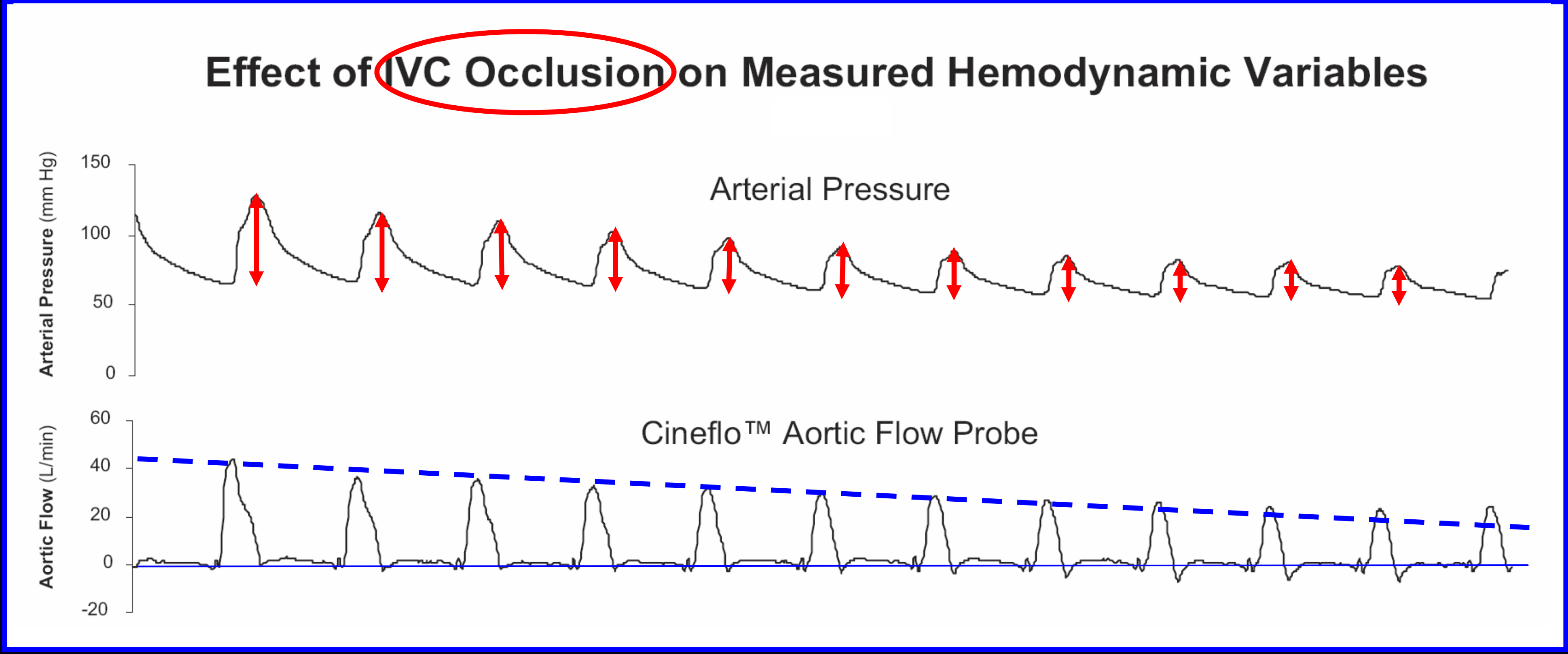


DDB USI

Ability of pulse power, esophageal Doppler and arterial pulse pressure to estimate rapid changes in stroke volume in humans

José Marquez, MD; Kenneth McCurry, MD; Donald A. Severyn, MS; Michael R. Pinsky, MD

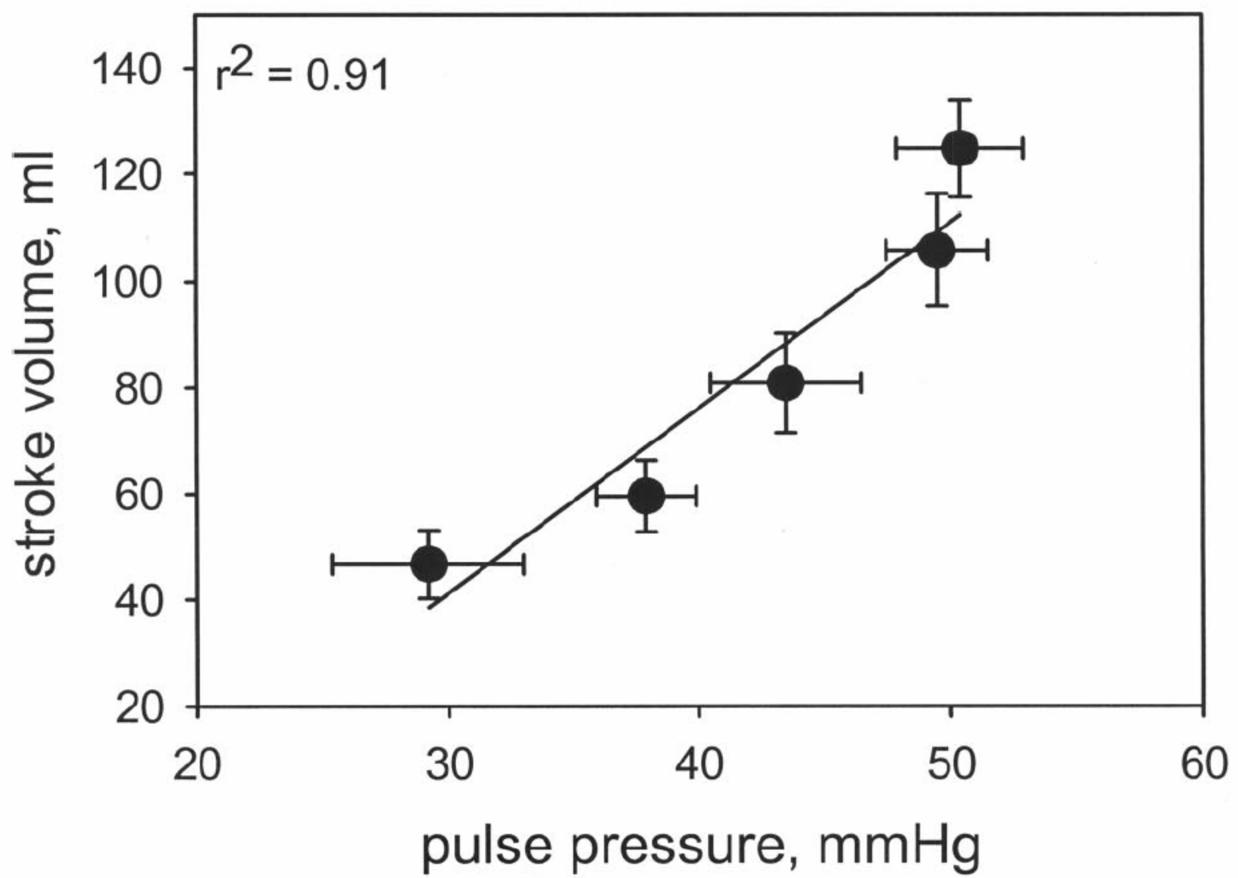
Marques et al
Crit Care Med 2008



Arterial Pulse Pressure and Its Association With Reduced Stroke Volume During Progressive Central Hypovolemia

Victor A. Convertino, PhD, William H. Cooke, PhD, and John B. Holcomb, M

J Trauma. 2006;61:629–634



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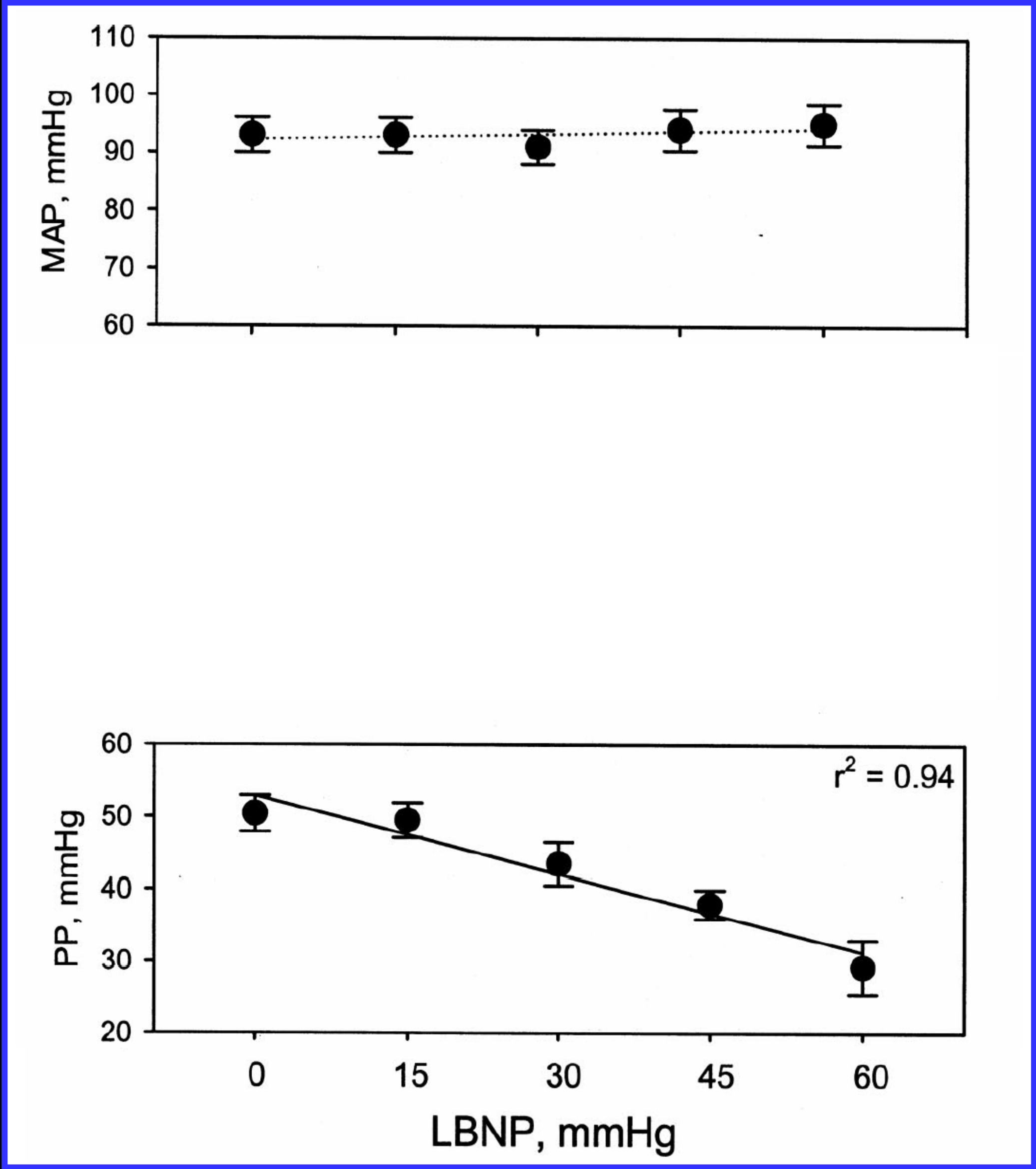
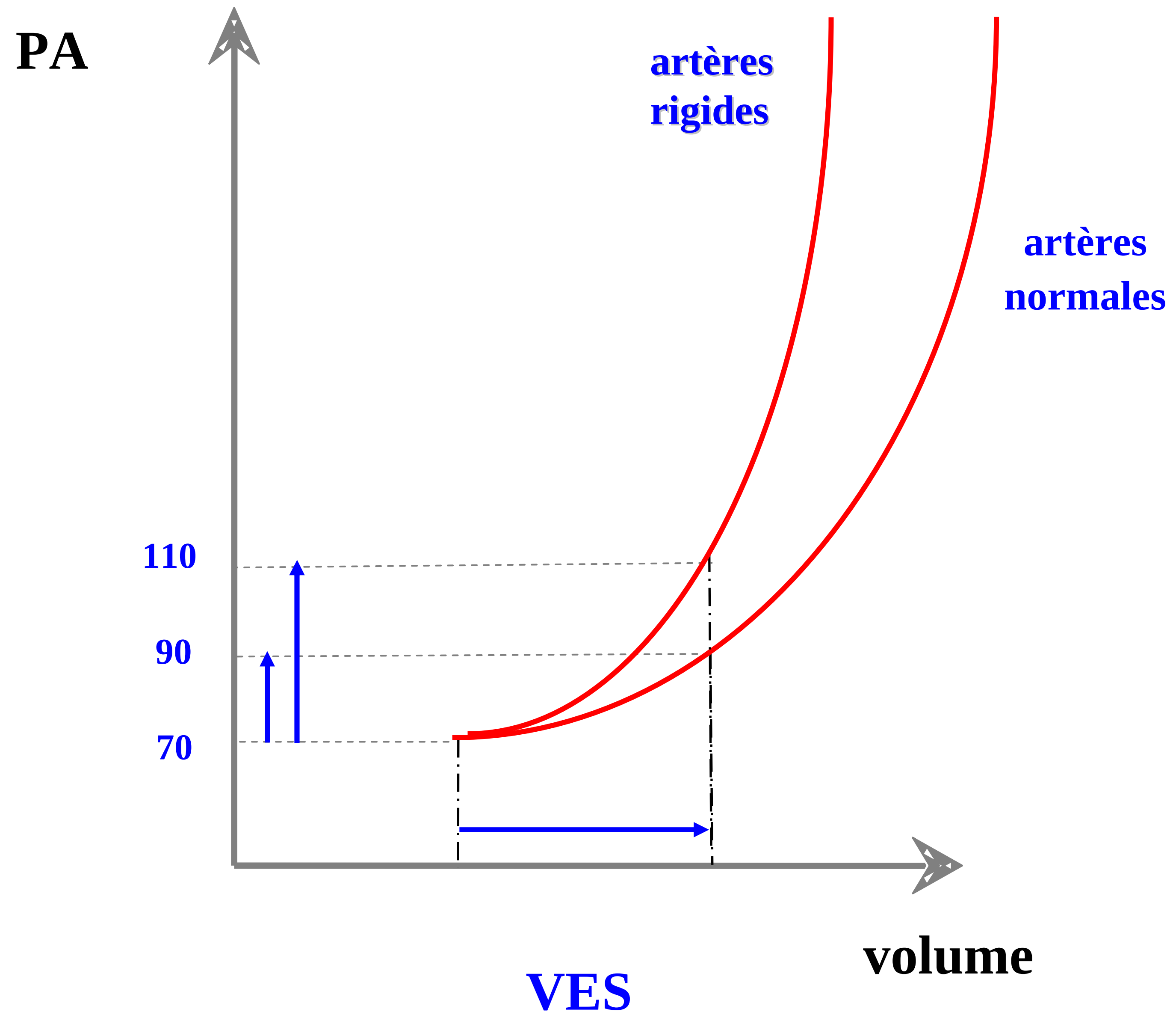
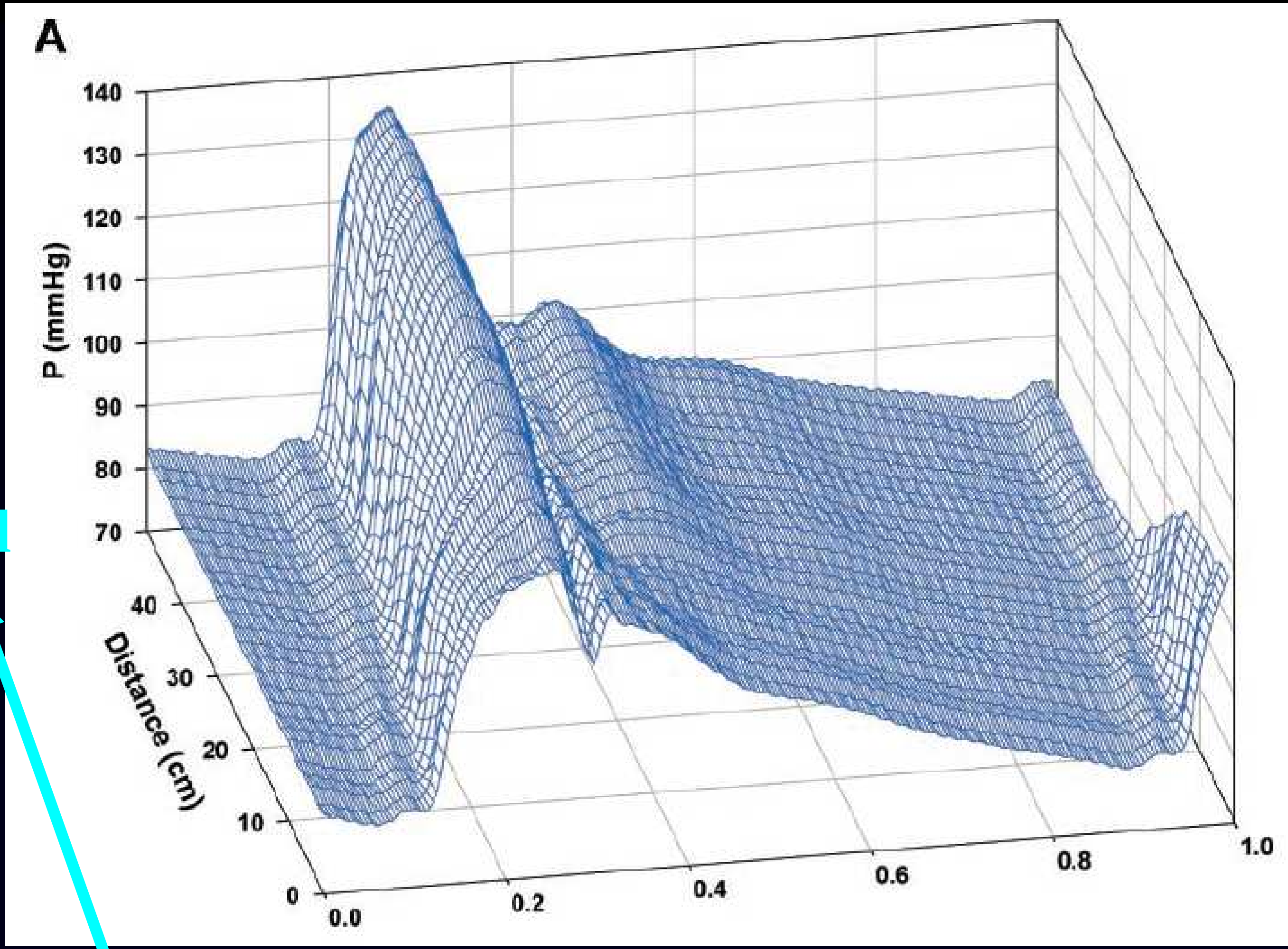




PA
artères
rigides
artères
normales
110
90
70
volume
VES

Distortion of the signal by reflected waves

Wang J et al
AJP 284:1358;2003

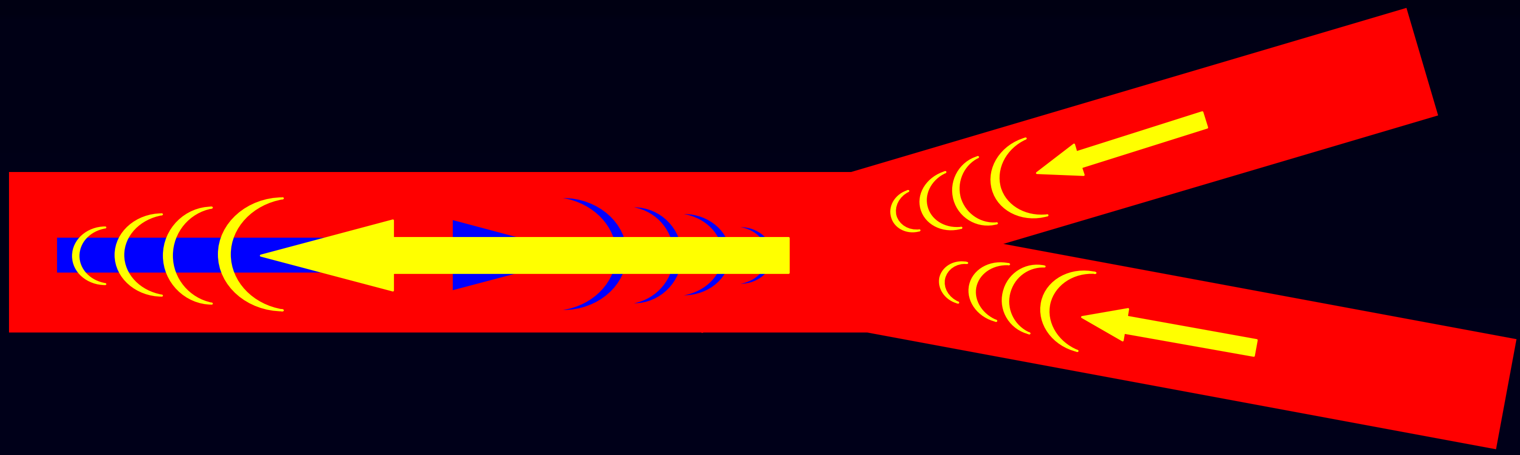


Femoral artery

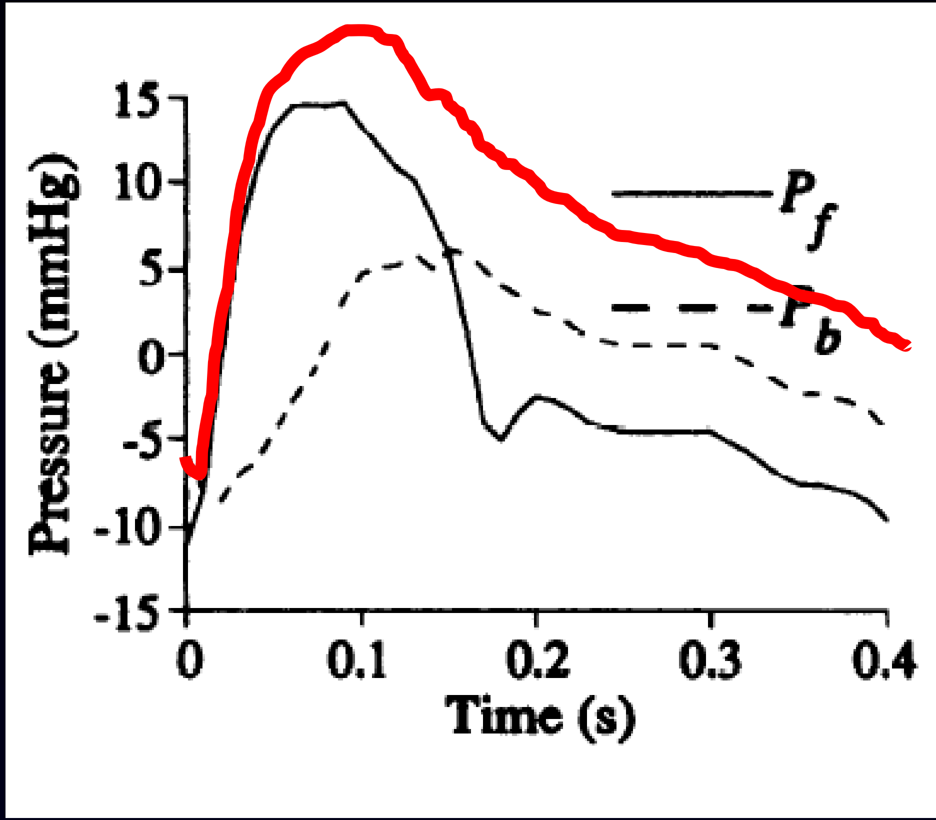
Aortic root

Les ondes de réflexion

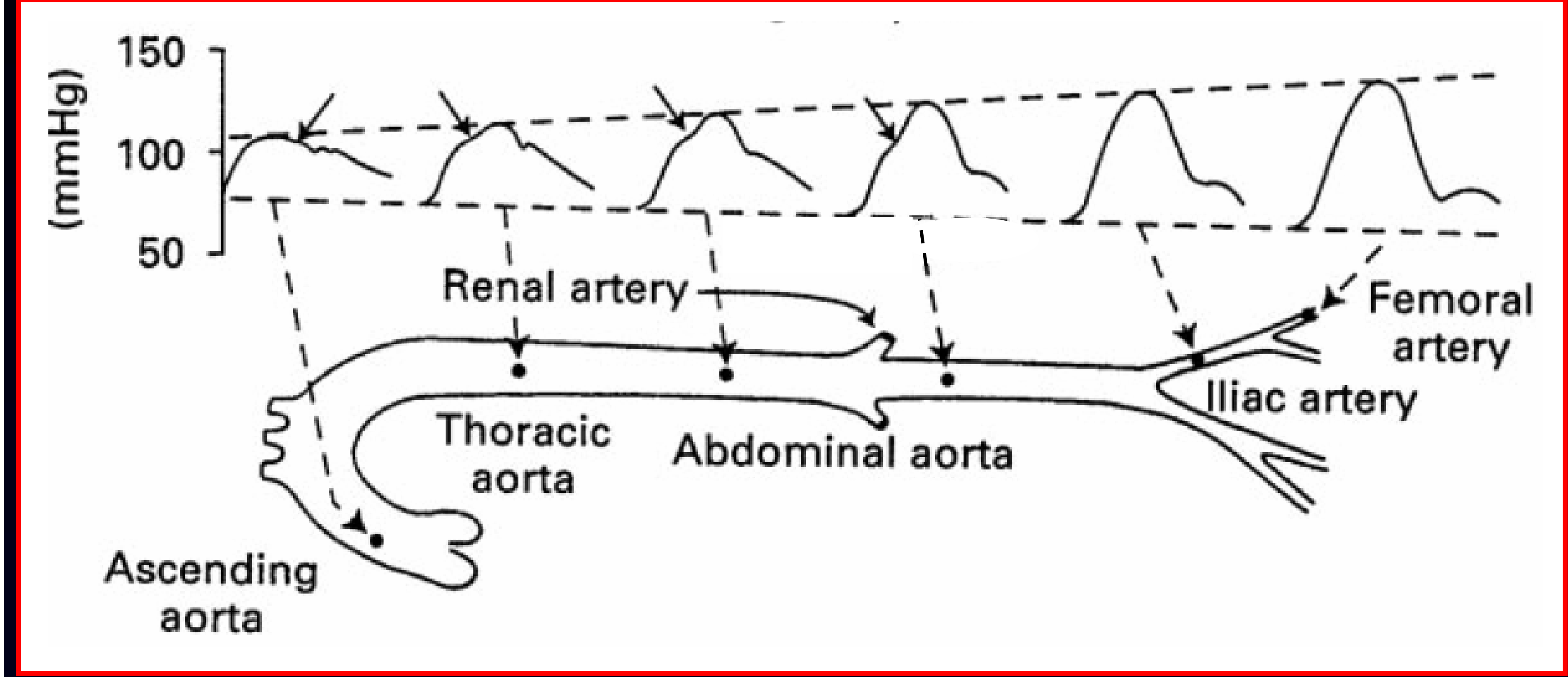
L'onde de pression artérielle se réfléchit chaque fois qu'elle rencontre des zones de changement d'impédance (points de bifurcation)

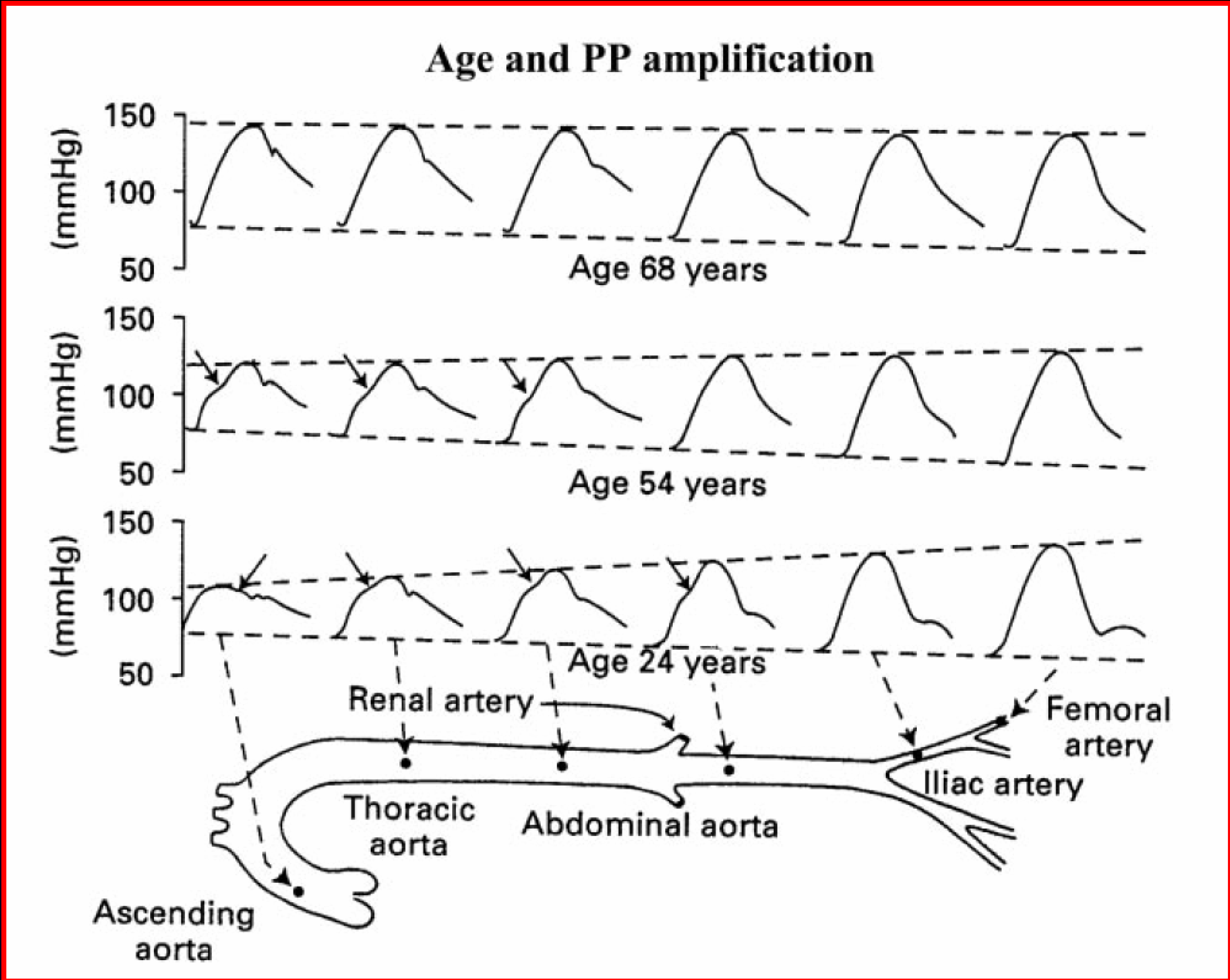


Les ondes de réflexion



Phénomène d'amplification de l'onde de pouls




Age and PP amplification
150
100
50
(mmHg)
Age 68 years
Age 54 years
Age 24 years
Renal artery
Femoral artery
Iliac artery
Thoracic aorta
Abdominal aorta
Ascending aorta

Pulse contour !

Also takes into account waveform alteration due to reflection waves

Ejection volume derived from arterial pressure

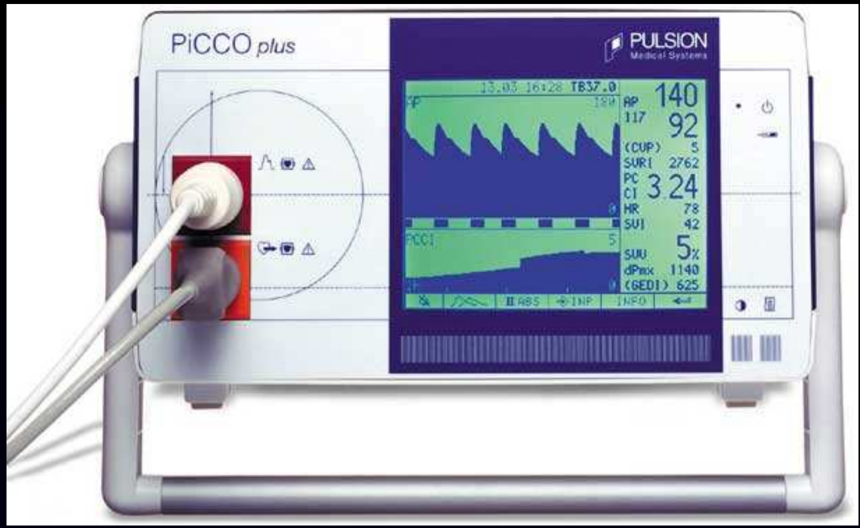
- PiCCO
- LiDCO
- APCO

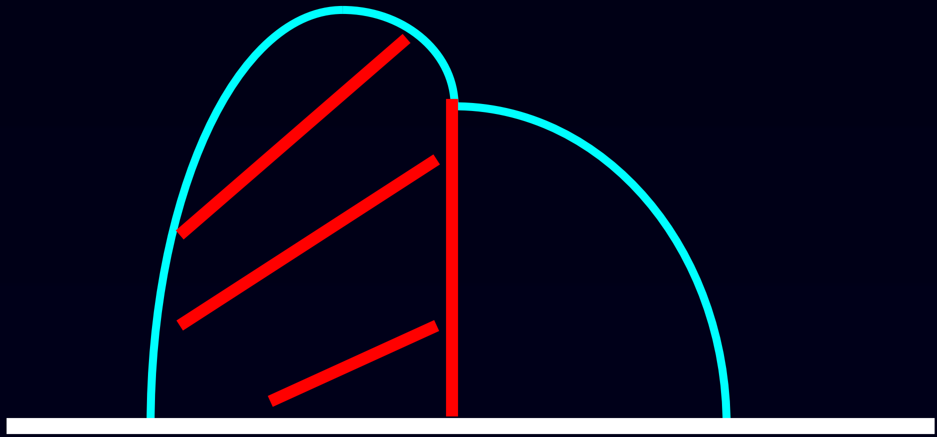
Pulse contour is proportional to ejection volume, aortic elastance and vascular tone

=> calibration is mandatory for any change in vascular tone

DDB

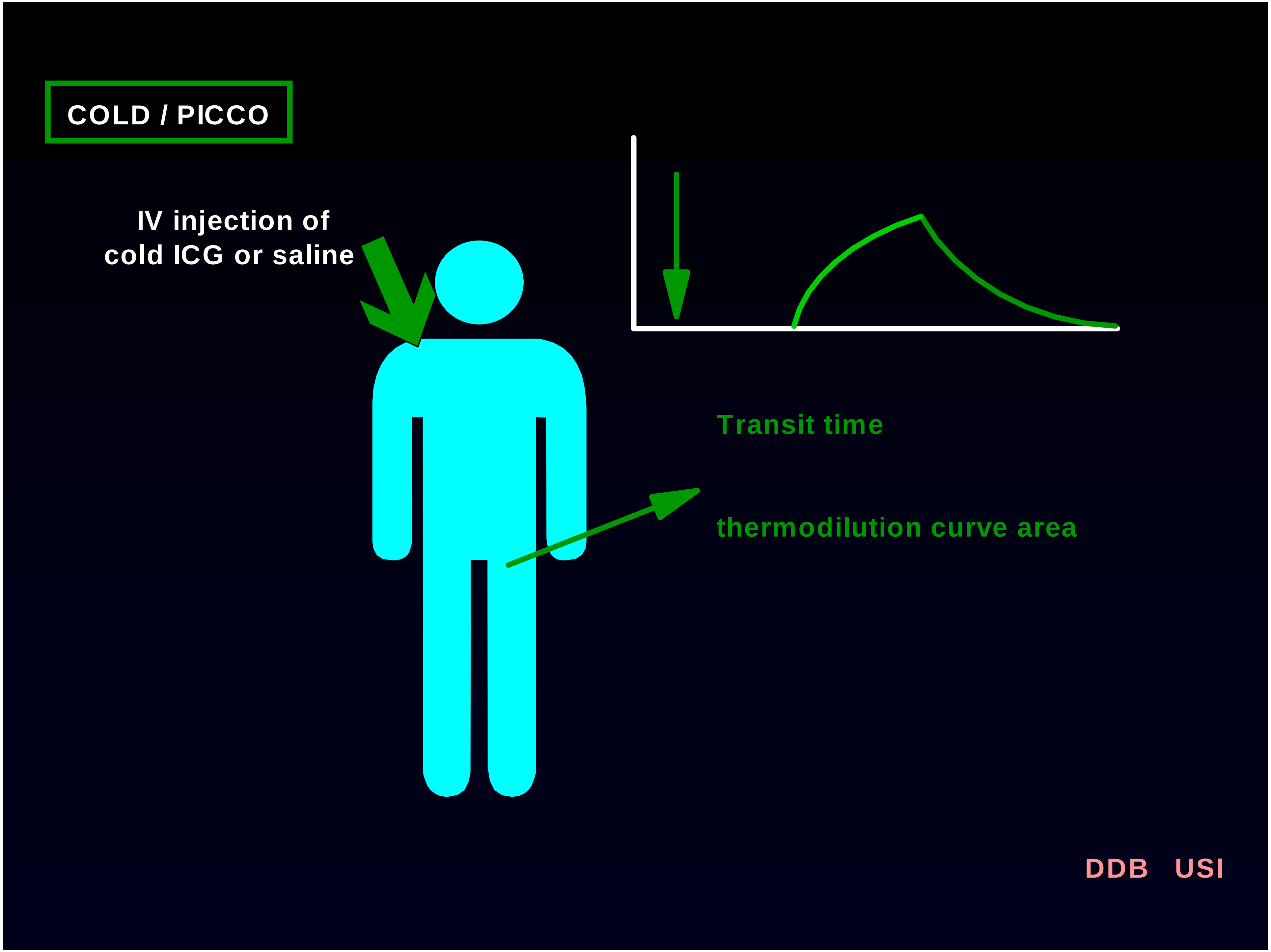
PiCCO

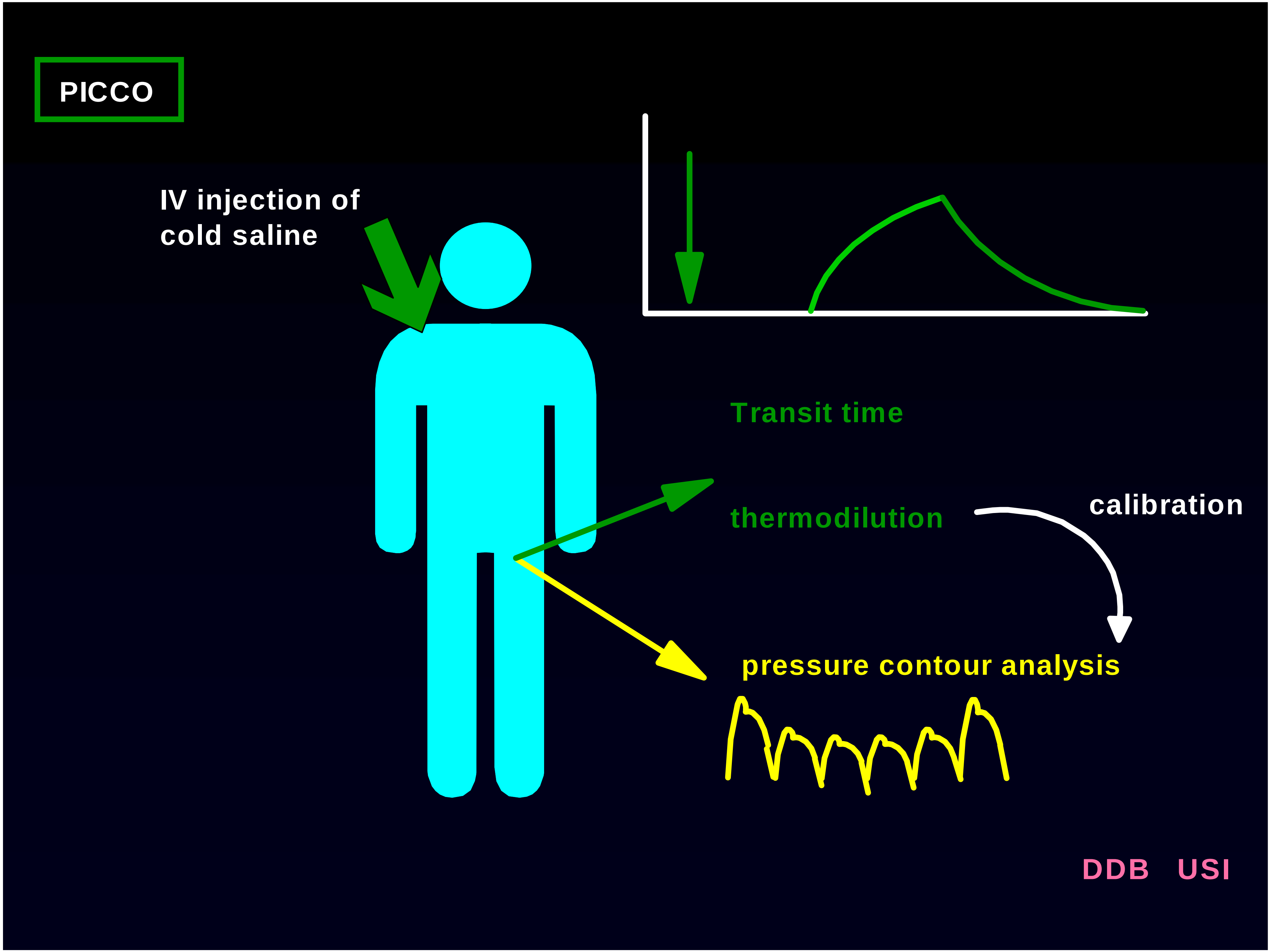




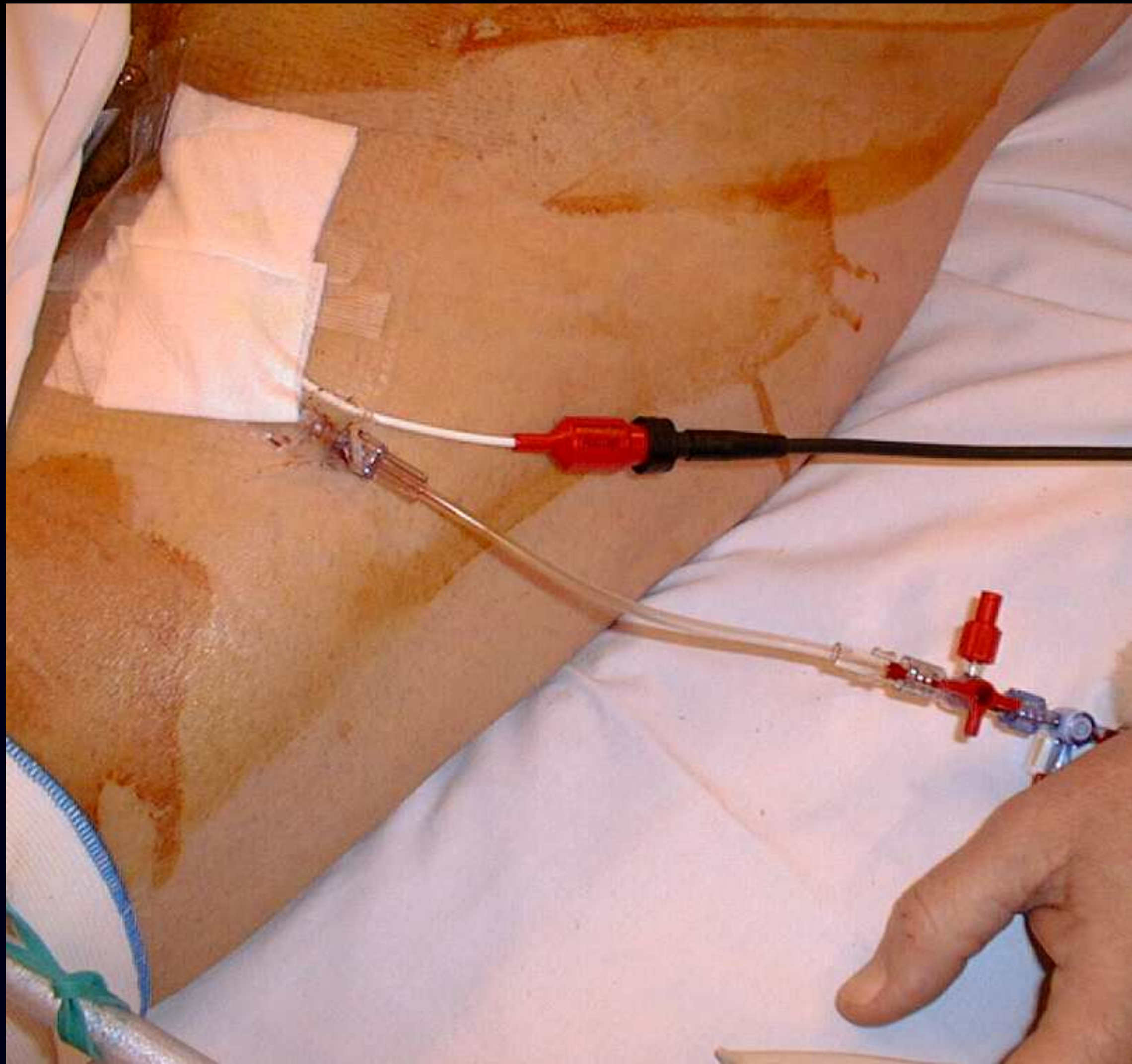
=> Importance of recognition of aortic dicrotic wave

DDB

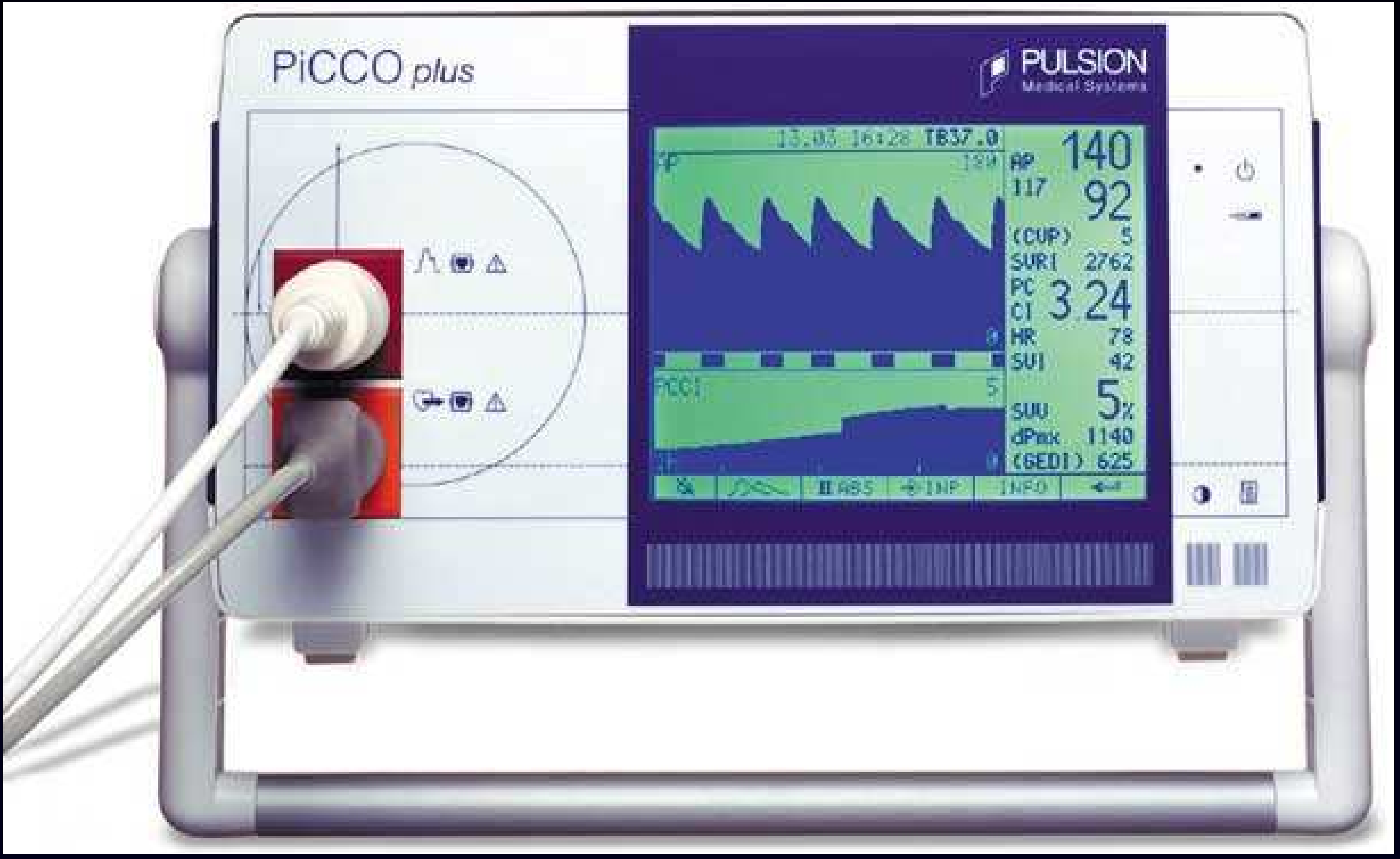

COLD / PICCO
IV injection of
cold ICG or saline
Transit time
thermodilution curve area
DDB USI


PICCO
IV injection of
cold saline
Transit time
thermodilution
calibration
pressure contour analysis
DDB USI

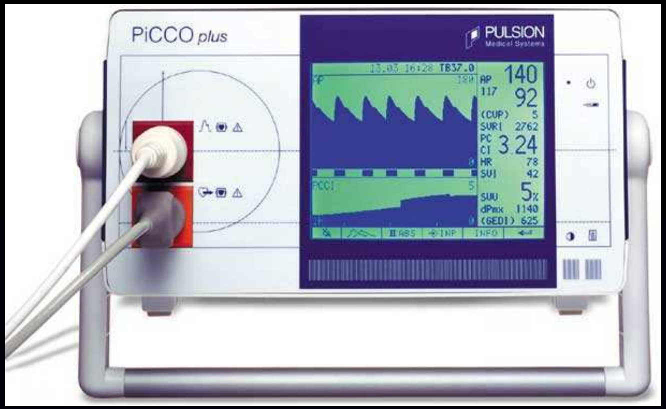
PiCCO



PiCCO


PiCCO plus
PULSION
Medical Systems
AP 140
117 92
(CVP) 5
SVRI 2762
PC CI 3.24
HR 78
SVI 42
SVV 5%
dPmx 1140
(GEDI) 625
INFO

PiCCO



Advantages of PiCCO:

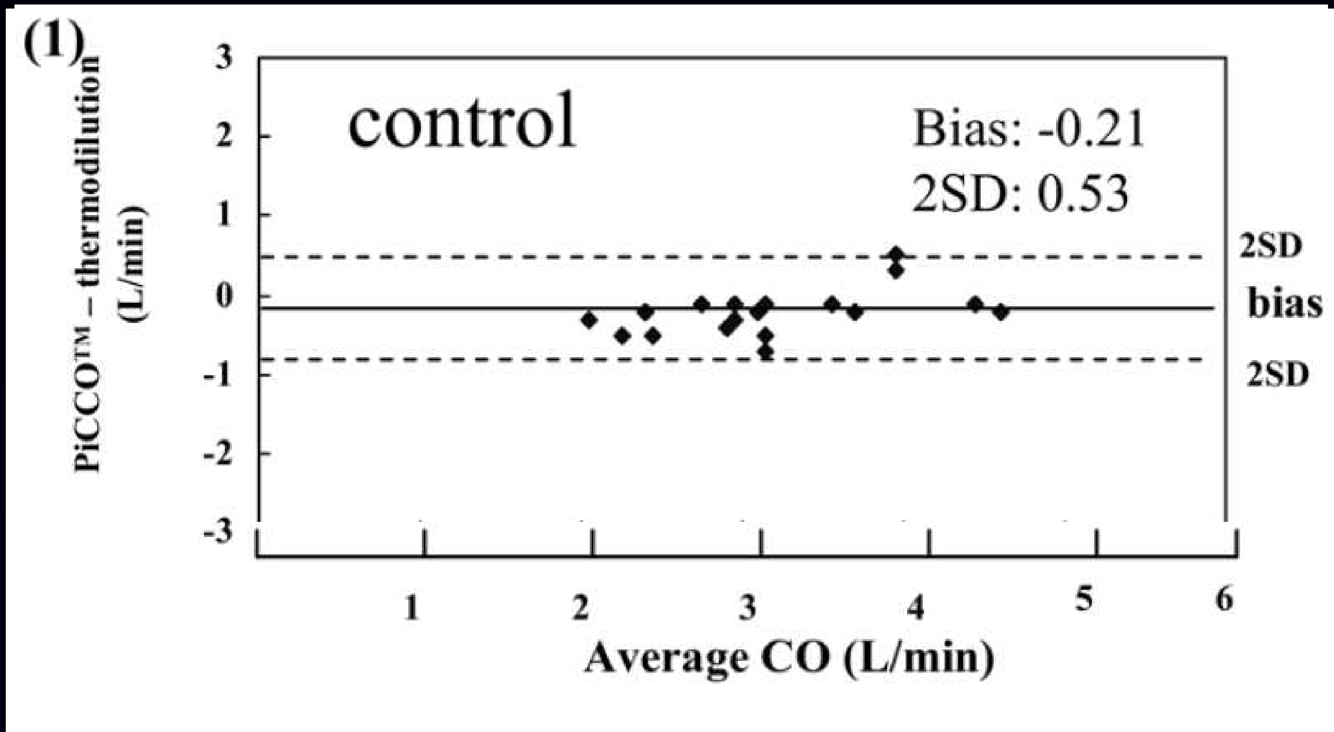
- Accurate measurements of CO (and DO2)
- Additional data (GEDV, EVLW)
- Measurements of SVV

Disadvantages of PiCCO:

- Combines the errors of calibration and pulse contour
- Good signal required
- Mathematical coupling of CO and derived measurements (GEDV)
- Specific arterial catheter required

Yamashita K et al
J Cardioth Vasc Anesth
22:688;2008

PiCCO vs PAC



20 pts OPCAB

Button et al
BJA 99:329;2007

	PCO-ICO (litre min^{-1})	CCO-ICO (litre min^{-1})
Intraoperative		
T1	0.5 (1.5)	0.2 (1.7)
T2	0.4 (1.7)	0.2 (2.0)
T3	0.3 (3.0)	0.4 (2.5)
Postoperative		
T4	0.2 (3.8)	0.3 (3.7)
T5	0.2 (2.5)	0.4 (2.2)
T6	0.1 (3.1)	0.5 (2.2)

PiCCO vs PAC
N=31

Mean CO ~4.5 – 5.5 L/min

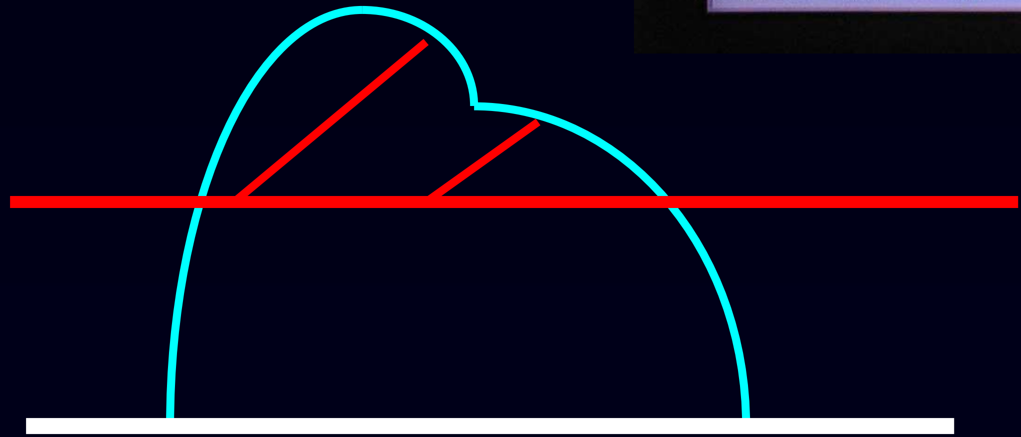
Impact of changes in SVR (>15%)

Hamzaoui et al
CCM 36:434;2008

Intervals of Time (Elapsed from the Previous Calibration)	n	r^2	p	Bias ± SD, L/min/m^2	Percentage Error
Within the first half hour	60	.79	<.001	0.04 ± 0.47	27
Between 30 mins and 1 hr	72	.74	<.001	0.07 ± 0.46	26
Between 1 and 2 hrs	66	.72	<.001	0.09 ± 0.58	32
Between 2 and 3 hrs	59	.65	<.001	0.16 ± 0.66	37
Between 3 and 4 hrs	45	.65	<.001	0.03 ± 0.63	35
Between 4 and 5 hrs	47	.62	<.001	0.14 ± 0.63	35
Between 5 and 6 hrs	51	.62	<.001	0.13 ± 0.66	36

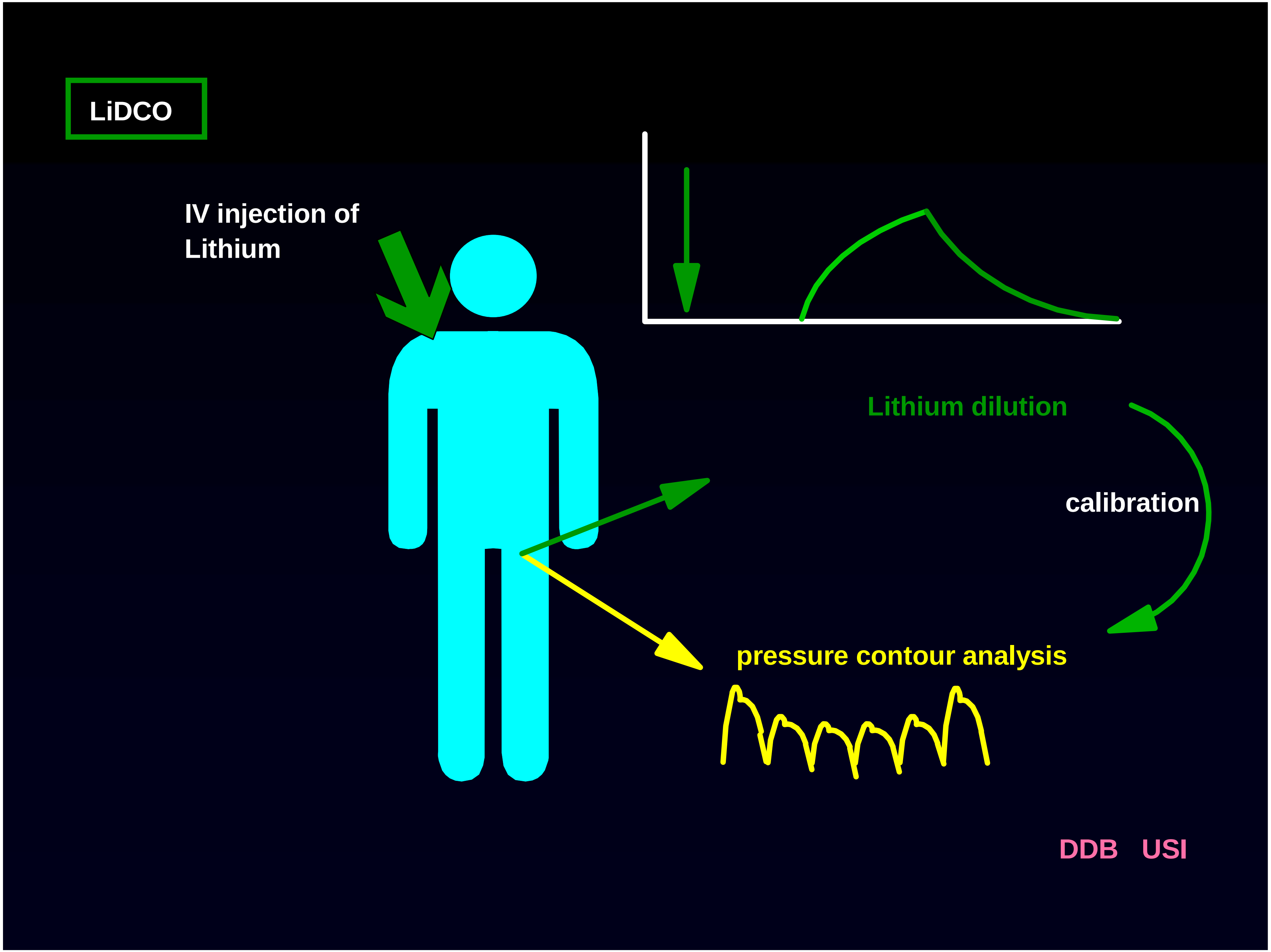
PiCCO
N=59

LiDCO



=> Recognition of aortic dicrotic wave less important

DDB

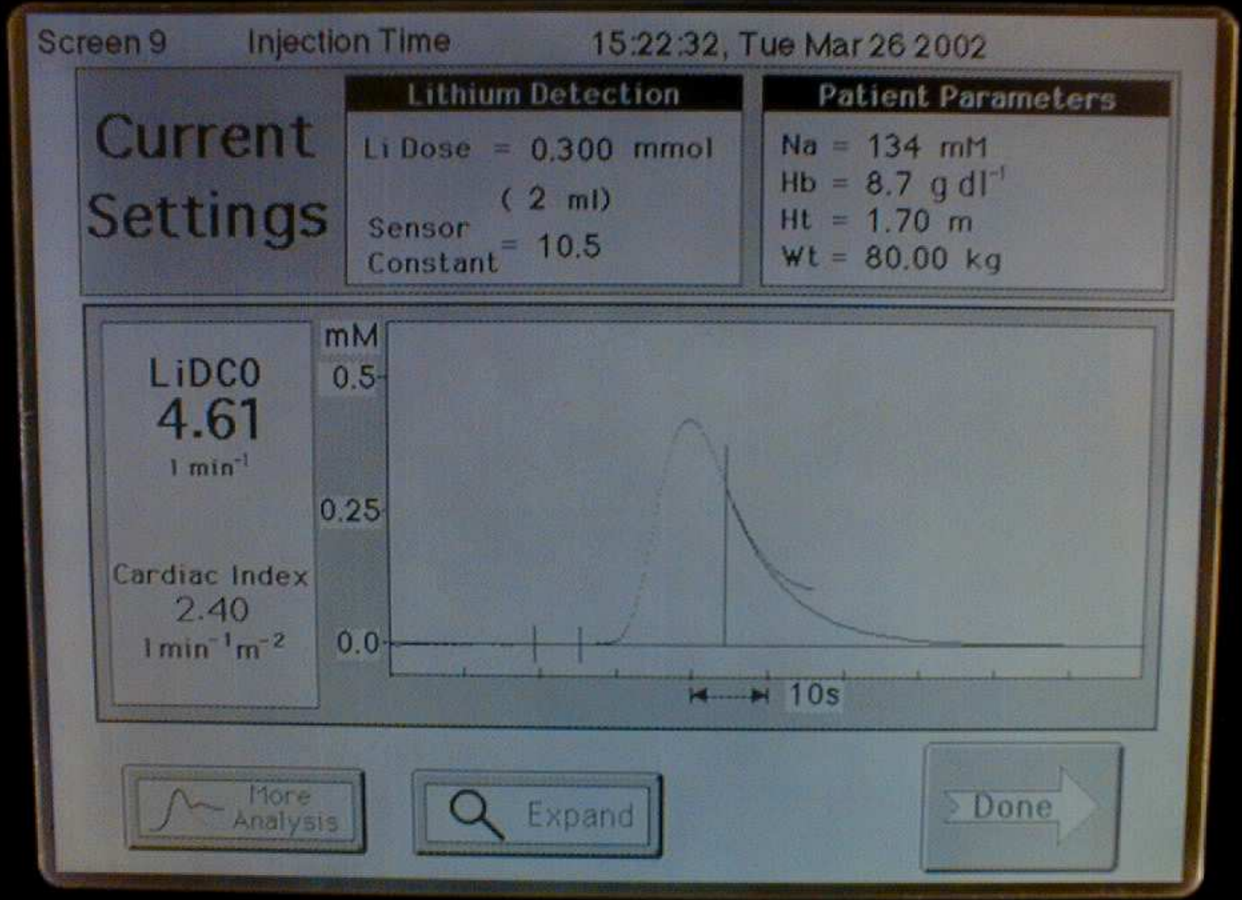


LiDCO
IV injection of Lithium
Lithium dilution
calibration
pressure contour analysis
DDB USI

LiDCO

LiDCO

LiDCO



Screen 9
Injection Time
15:22:32, Tue Mar 26 2002
Current Settings
Lithium Detection
Li Dose = 0.300 mmol
(2 ml)
Sensor Constant = 10.5
Patient Parameters
Na = 134 mM
Hb = 8.7 g dl-1
Ht = 1.70 m
Wt = 80.00 kg
LiDCO
4.61
l min-1
Cardiac Index
2.40
l min-1 m-2
mM
0.5
0.25
0.0
10s
More Analysis
Expand
Done

LiDCO


16:53
BP Data OK
Data Stable
BP OK
CO OK
Event
Blood Pressure Waveform
Systolic 214
Mean 75
Diastolic 48
PP var 5.2%
CO
4.6
CI
2.4
SVR
[RAP = 14]
1050
SVRI
2050
MAP
76
mm Hg
SV
48
ml
HR
95
16:53:19

LiDCO

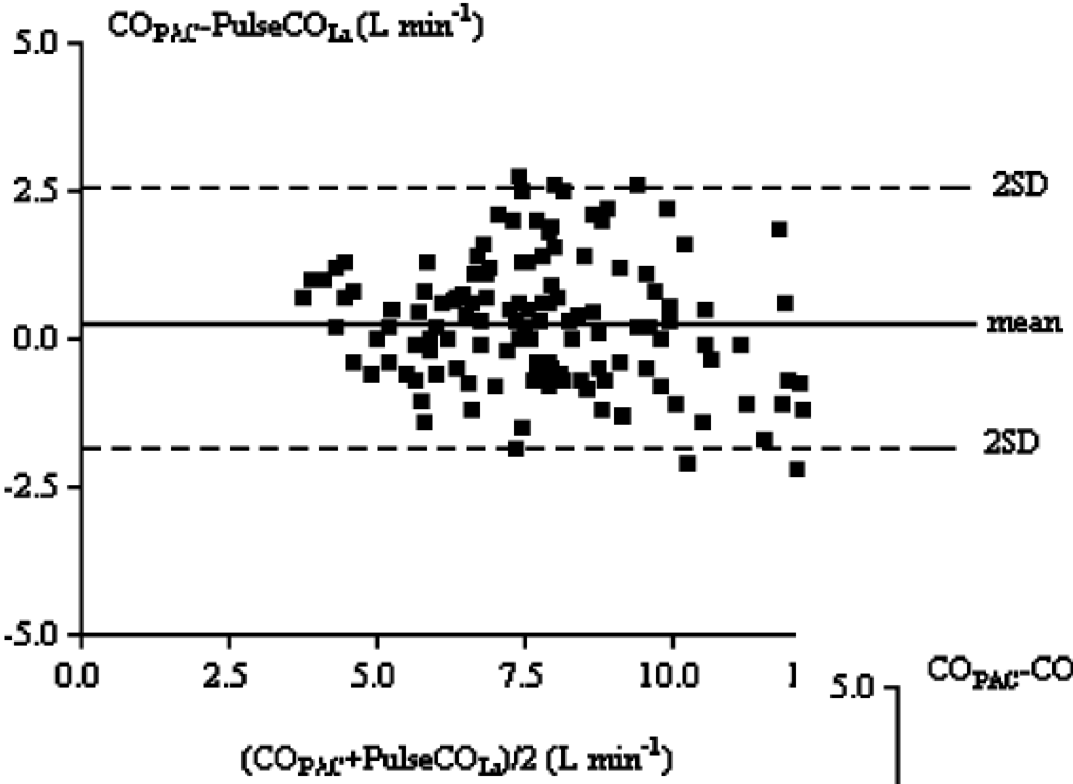
Advantages of LiDCO:

- Accurate measurements of CO (and DO2)
- Calibration with Li more reliable than thermodilution
- Robust algorithm
- Measurements of SVV

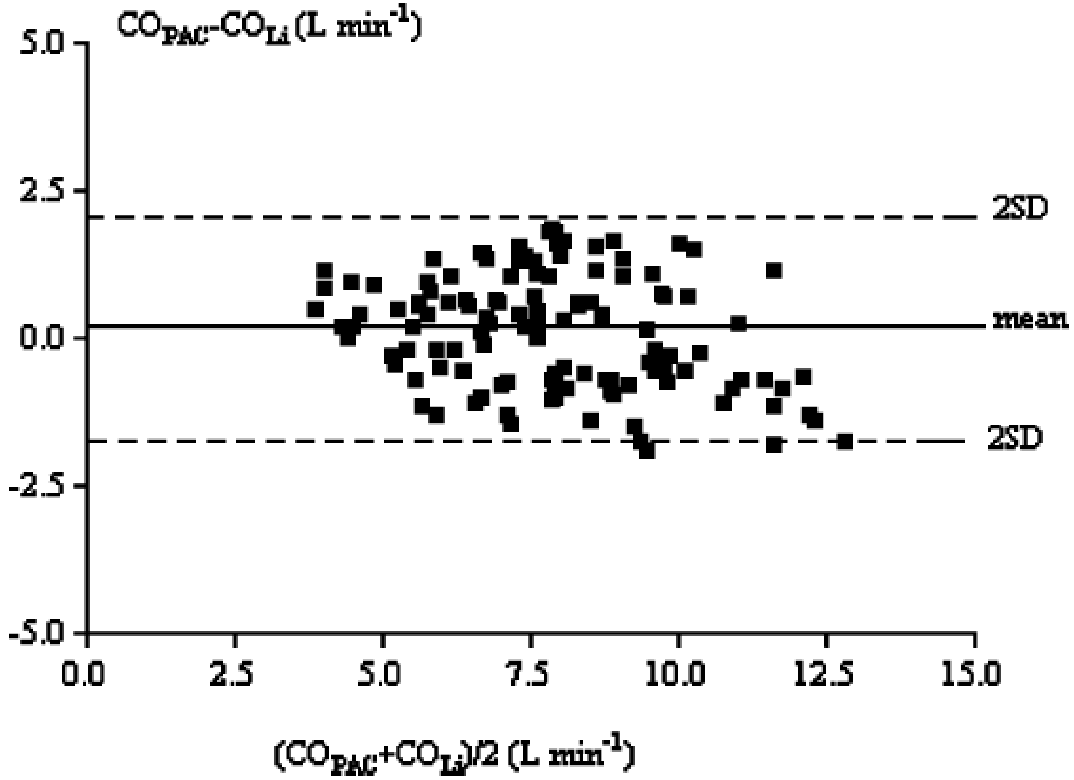
Disadvantages of LiDCO:

- Li can not always be used (=> calibration with other techniques?)
- Costs
- No other information than CO

DDB



Cecconi et al
ICM 34:257;2008



LiDCO vs PAC
Liver Tx N=23

Cecconi et al
ICM 34:257;2008

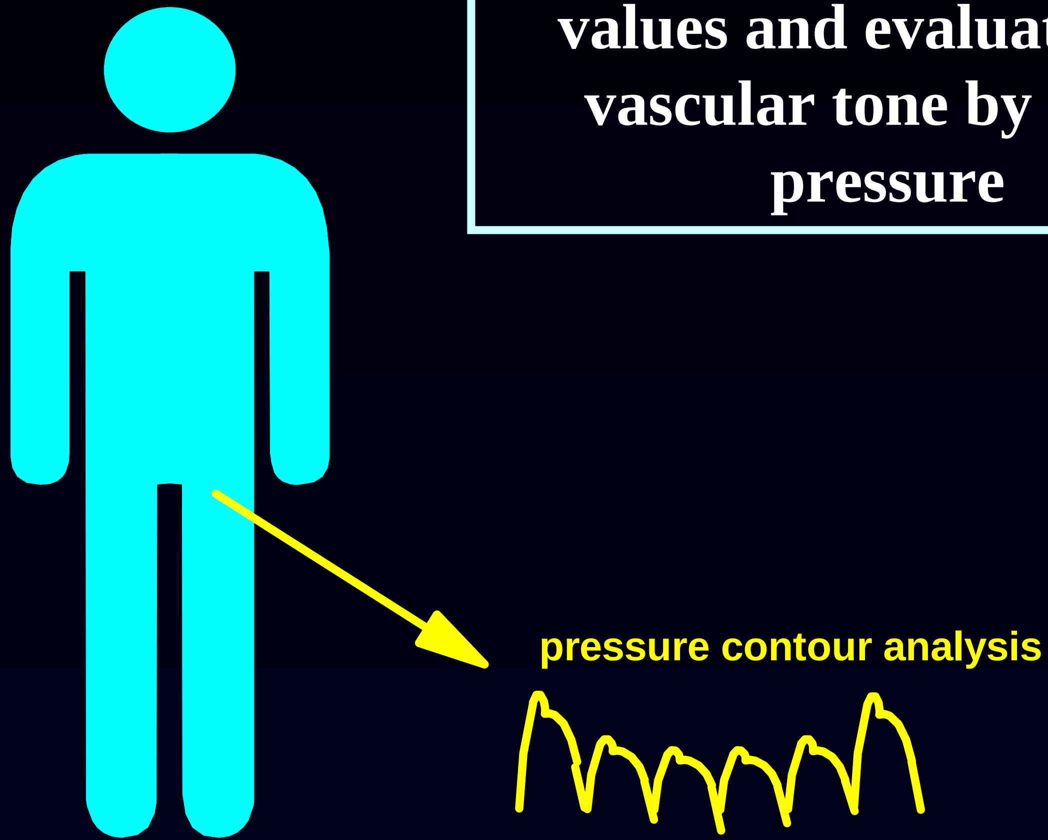
Level of CO	Observation	Bias ($l\ min^{-1}$)	95% Limit of agreement	PE (%)
$< 8\ l\ min^{-1}$				
CO_{PAC}–CO_{Li}	78	0.08±1.61	–1.53 to 1.69	15.7
CO_{PAC}–$PulseCO_{Li}$	78	0.10±1.54	–1.44 to 1.64	15.1
CO_{Li}–$PulseCO_{Li}$	78	–0.06±1.19	–1.25 to 1.13	10.5
CO_{PAC}–CCO	78	0.52±2.37	–2.89 to 1.84	18.7
$> 8\ l\ min^{-1}$				
CO_{PAC}–CO_{Li}	73	0.14±2.25	–2.09 to 2.36	15.5
CO_{PAC}–$PulseCO_{Li}$	73	0.49±2.62	–2.13 to 3.11	18.5
CO_{Li}–$PulseCO_{Li}$	73	0.21±1.61	–1.40 to 1.82	9.24
CO_{PAC}–CCO	73	–0.44±2.71	–3.15 to 2.28	14.5

LiDCO vs PAC

Liver Tx   N=23

APCO/Florac (Vigileo)

No calibration but calculation of aortic elastance form biometric values and evaluation of vascular tone by pulse pressure



DDB USI

Human database (AP curves and CO measurements using the reference iCO-PAC technique) in different clinical conditions

Biometric variables (age, gender)

$$CO = \text{pulse rate} \cdot AP_{sd} \cdot \chi$$

Shape variables

FloTrac 1st generation

G1

$$CO = \text{pulse rate} \cdot AP_{sd} \cdot \chi$$

Updated every 10'
(shape variables)

FloTrac 2nd generation

G2

$$CO = \text{pulse rate} \cdot AP_{sd} \cdot \chi$$

Updated every 1'
(shape variables)

FloTrac (APCO)
G1

McGee et al
Crit Care 11:R105;2007

84 patients (69 surgical) from four ICUs. Average age was 68 (24-80) years, and 65% of the patients were male.

Range of cardiac output: 1.7 – 9.2 L/min (mean 6)

Grouped measurements (561 data points) for APCO, ICO and CCO were analyzed for bias, precision and correlation via Bland–Altman analysis.

Flowtrach (APCO)

McGee et al
Crit Care 11:R105;2007

APCO – ICO: Bias 0.2 L/M²
Limits of agreement +/- 2.6 L/min.M²

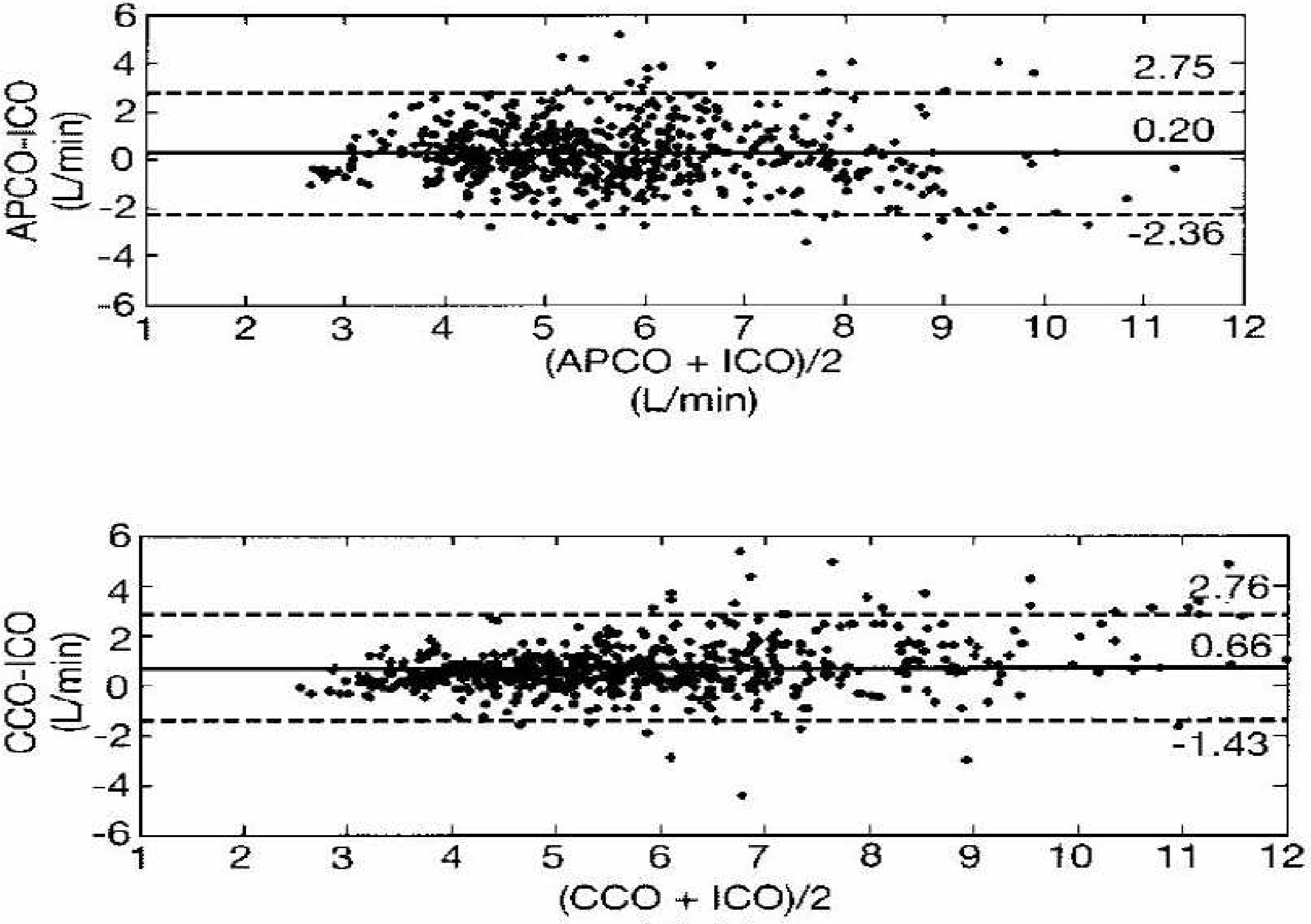
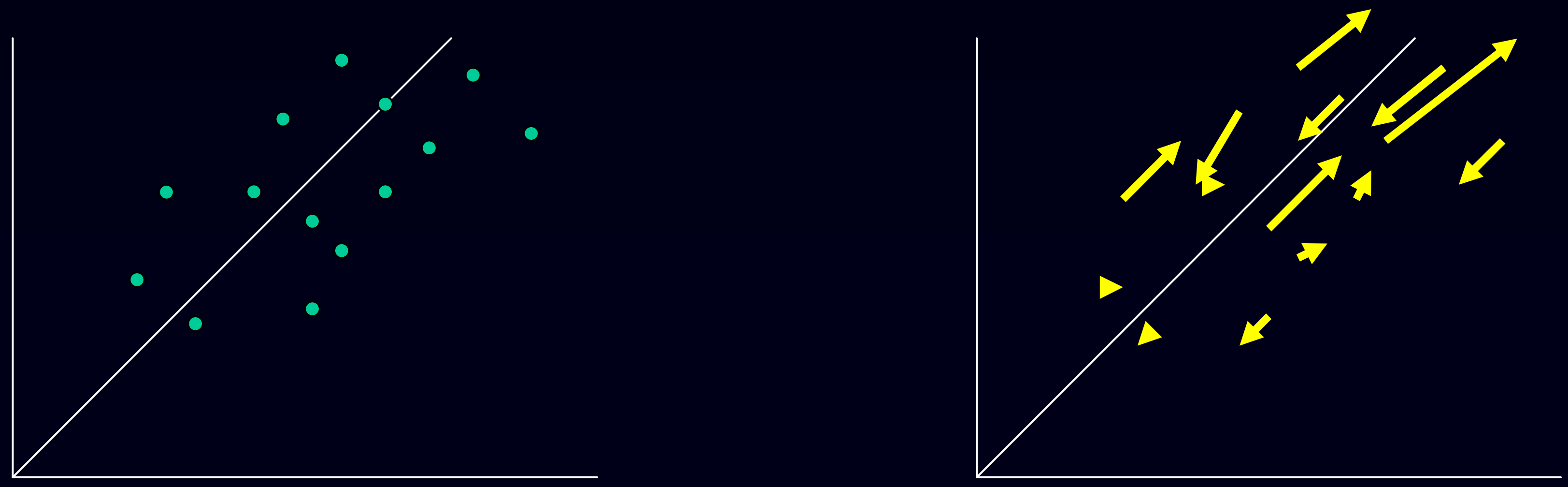


Figure 1

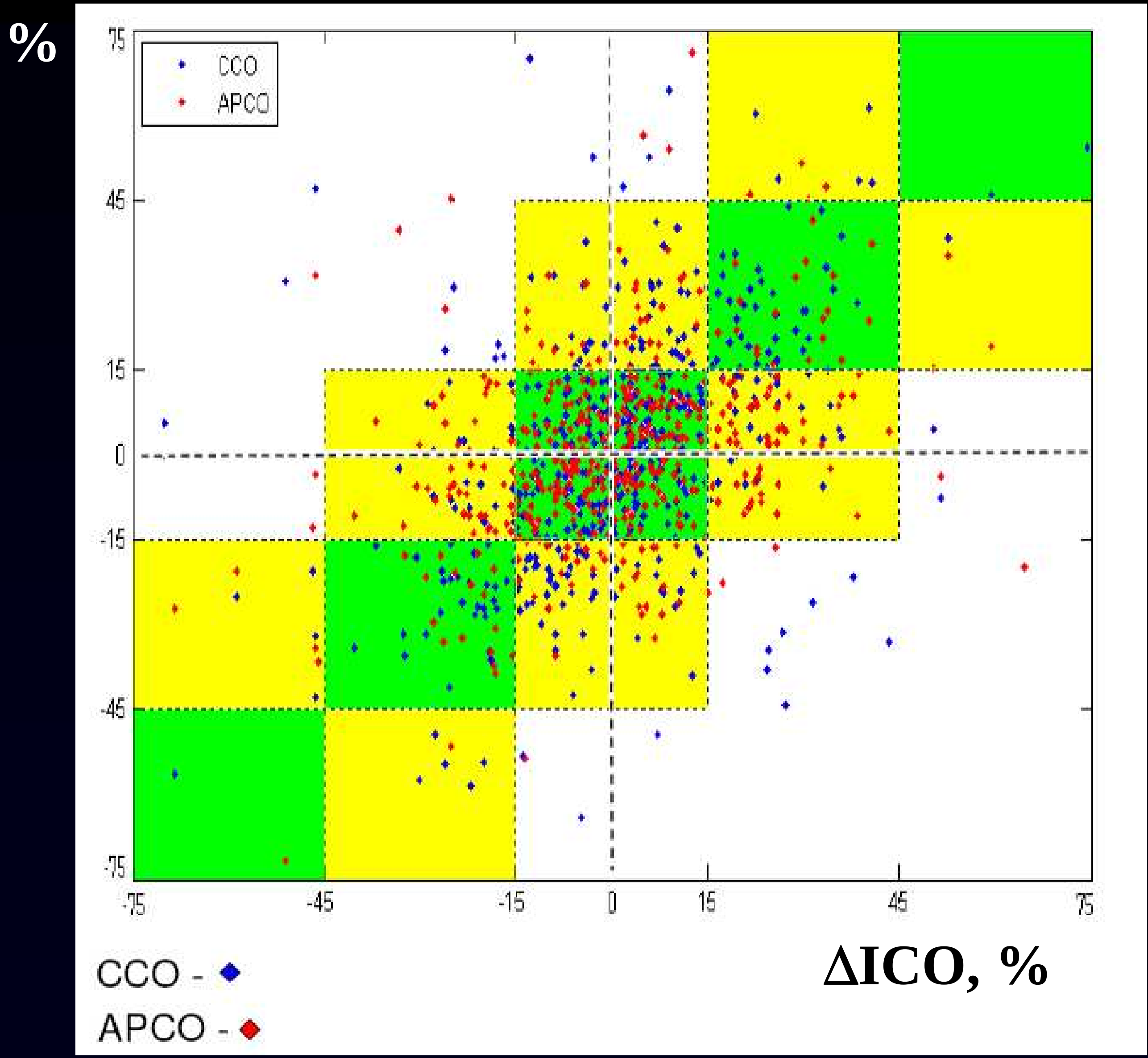
CCO – ICO: Bias 0.7 L/M²
Limits of agreement +/- 2.1 L/min.M²

Precision of a given value of cardiac output is less important than reliability in trends.



Flowtrach (APCO)

McGee et al
Crit Care 11:R105;2007



Button et al
BJA 99:329;2007

	FCO-ICO (litre min^{-1})	PCO-ICO (litre min^{-1})	CCO-ICO (litre min^{-1})
Intraoperative period			
T1	0.6 (1.8)	0.5 (1.5)	0.2 (1.7)
T2	0.4 (1.9)	0.4 (1.7)	0.2 (2.0)
T3	0.1 (2.4)	0.3 (3.0)	0.4 (2.5)
Postoperative period			
T4	0.2 (2.5)	0.2 (3.8)	0.3 (3.7)
T5	0.1 (2.6)	0.2 (2.5)	0.4 (2.2)
T6	0.1 (2.4)	0.1 (3.1)	0.5 (2.2)

FloTrac vs PiCCO vs PAC
N=31

Mean CO ~4.5 – 5.5 L/min

Author	Year	Patients	Software	2SD/mean
deWaal and colleagues	2007	CABG	V 1.01	33%
Mayer and colleagues	2007	Cardiac	V 1.01	46%
Opdam and colleagues	2006	Cardiac	V 1.03	40%
Sander and colleagues	2006	CABG	V 1.03	54%
Manecke and Auger	2007	Cardiac	V 1.03	33%
Prasser and colleagues	2007	Neuro-ICU	V 1.03	49%
McGee and colleagues	2007	Mixed	V 1.03	50%
Breukers and colleagues	2007	Cardiac	V 1.03	36%
Sakka and colleagues	2007	Septic	V 1.07	35%
Lorsomradee and colleagues	2007	Cardiac	V 1.07	29–56%
Button and colleagues	2007	Cardiac	V 1.07	40%
Cannesson and colleagues	2007	CABG	V 1.07	37%
Prasser and colleagues	2007	CABG	V 1.10	26.9%
Mayer and colleagues	2008	CABG	V 1.10	24.6%
Compton and colleagues	2008	Medical-ICU	V 1.07/V 1.10	51.7%

Scheeren et al
BJA 101:279;2008

Marque et al
Crit Care 13:R73;2009

Time response (min)

	Time		
	PAC-CCO	NICOM™	Vigileo™
Negative	7.0 ± 2.6	1.3 ± 0.5*	1.1 ± 0.3*
Positive	9.4 ± 4.9	1.4 ± 0.5*	1.1 ± 0.3*

* $P < 0.05$

FloTrac G2

FloTrac 2nd generation (G2): good results in cardiac surgical patients

However, concerns have been raised in <u>vasoplegic states</u> (septic shock & liver transplantation) where FloTrac G2 may underestimate cardiac output

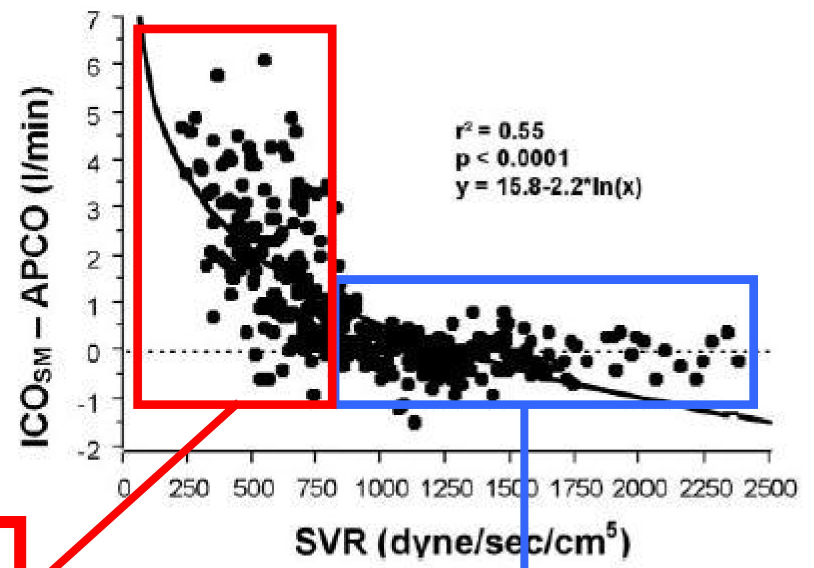
Cardiac Output Measurement in Patients Undergoing Liver Transplantation: Pulmonary Artery Catheter Versus Uncalibrated Arterial Pressure Waveform Analysis

Biais Matthieu, MD
Nouette-Gaulain Karine, MD, PhD
Cottenceau Vincent, MD
Vallet Alain, MD
Cochard Jean François, MD
Revel Philippe, MD
Sztark François, MD, PhD

CONCLUSIONS: Our results suggest that Vigileo/FloTrac CO monitoring data do not agree well with those of automatic thermodilution in patients undergoing liver transplantation, especially in Child-Pugh grade B and C patients with low systemic vascular resistance.

(Anesth Analg 2008;106:1480–6)

ANESTHESIA & ANALGESIA



FloTrac underestimates Swan-Ganz cardiac output in low SVR patients (<800 dynes/sec/cm^5)

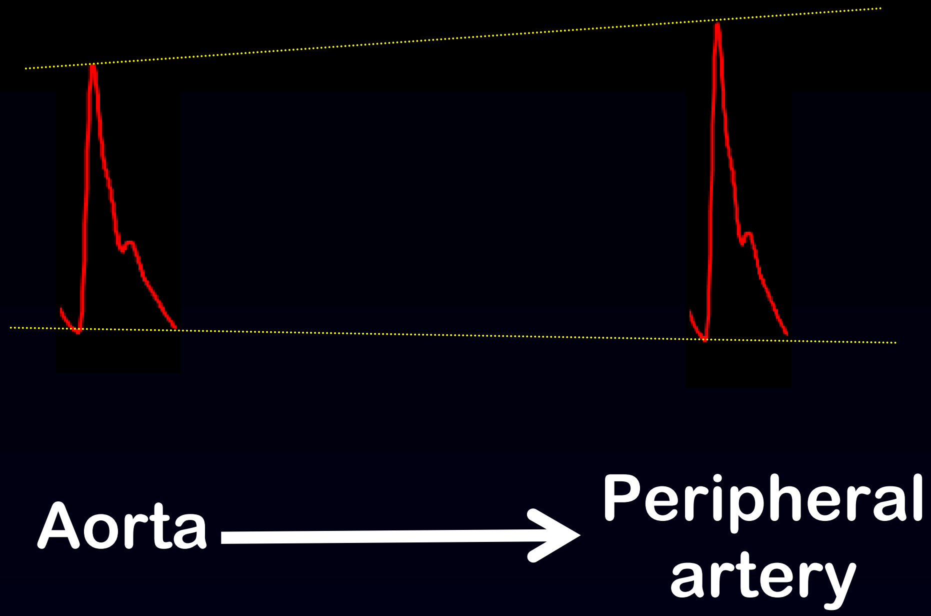
FloTrac shows very good agreement in "normal to high" SVR patients (>800 dynes/sec/cm^5)

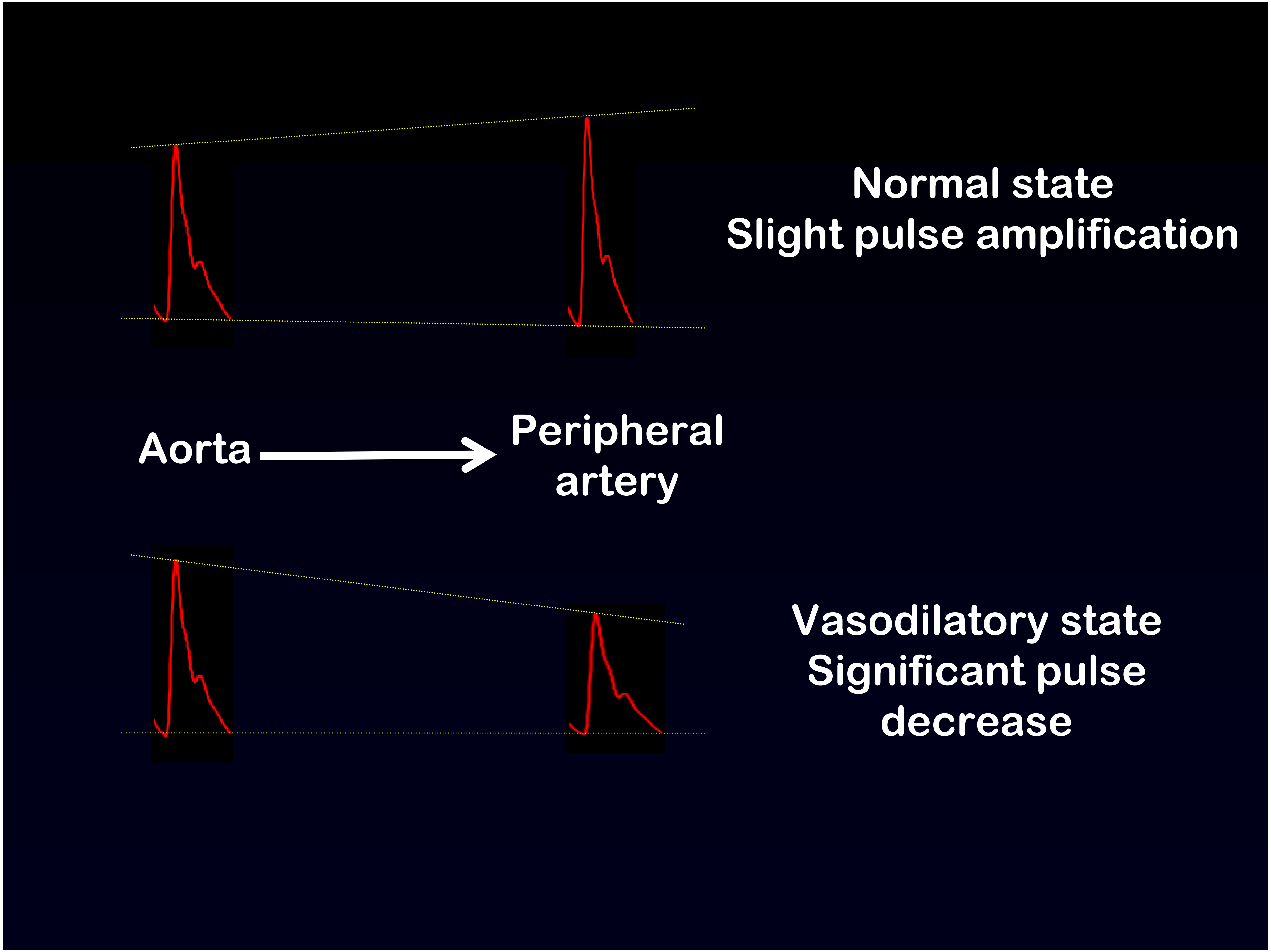
Suspected mechanism?

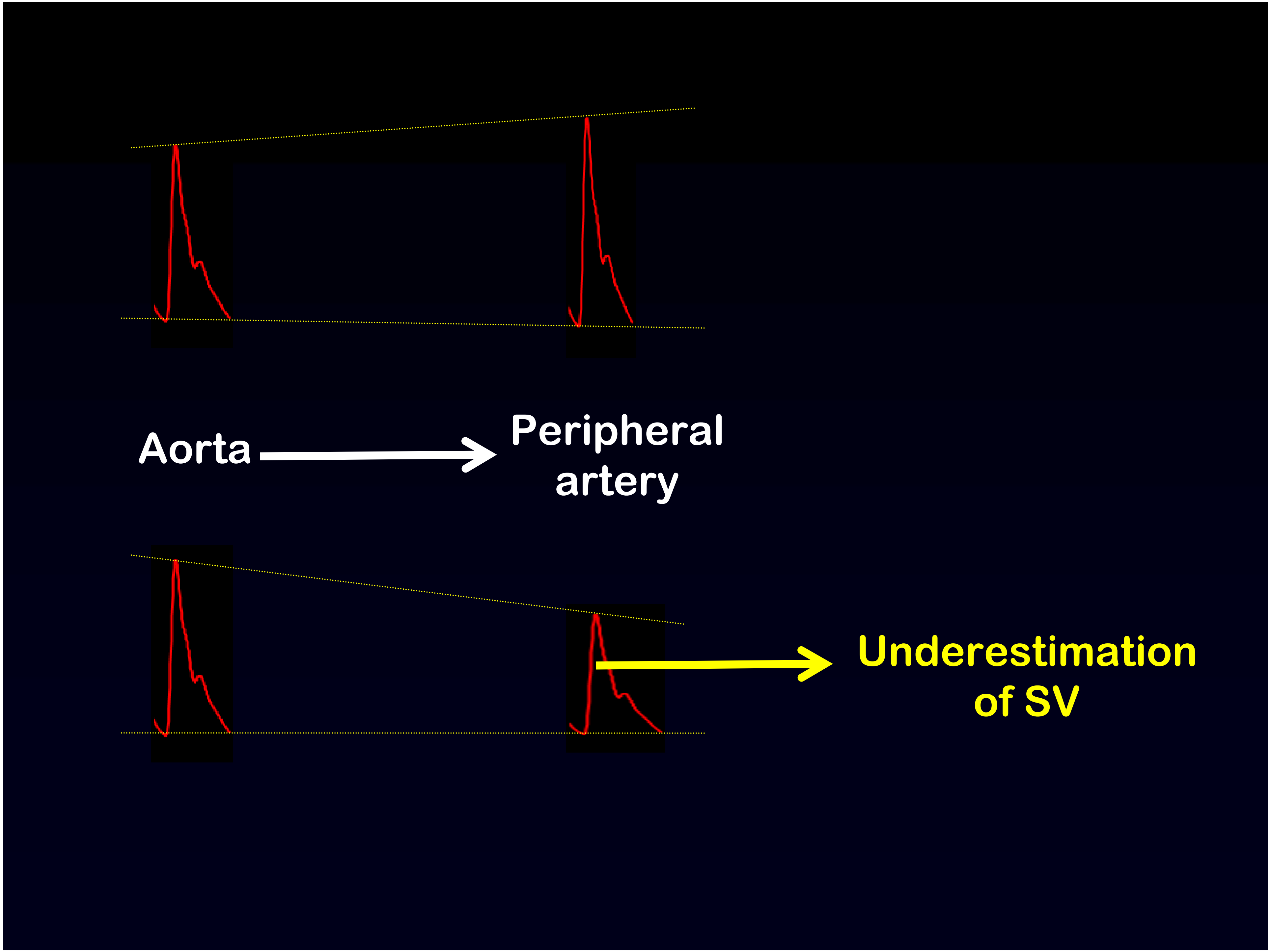
« Peripheral decoupling » ?

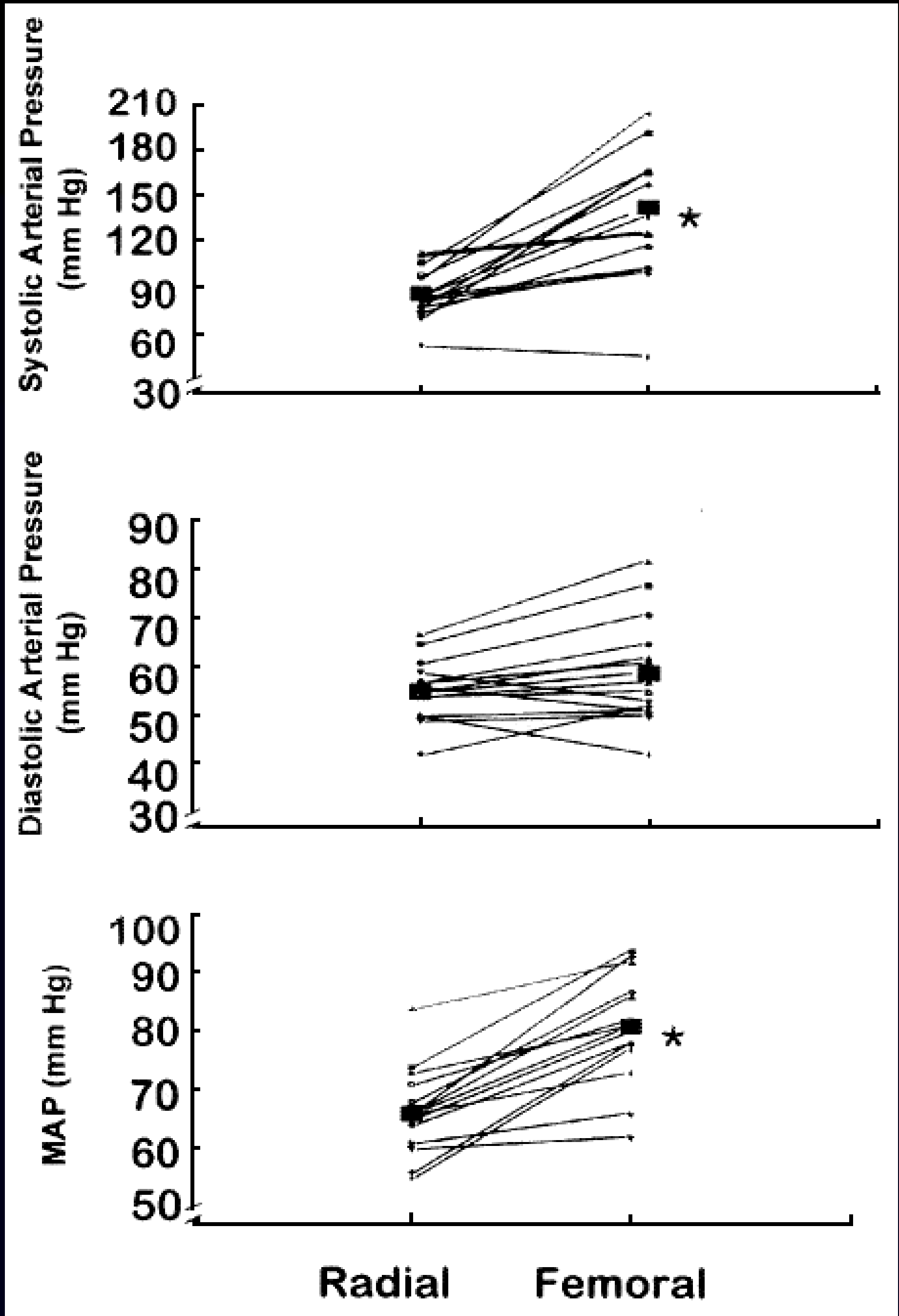
= gradient between central and peripheral arterial pressure

Normal state
Slight pulse amplification

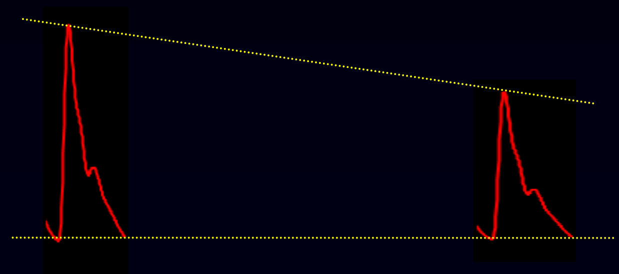



Normal state
Slight pulse amplification
Aorta
Peripheral artery
Vasodilatory state
Significant pulse decrease


Aorta
Peripheral artery
Underestimation of SV



Dorman T et al
CCM 26:1646;1998



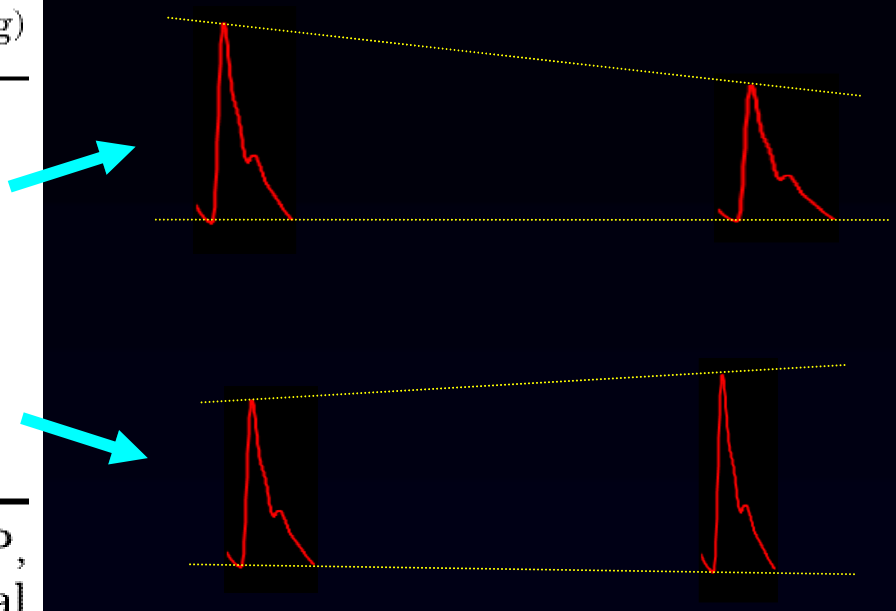
14 pts with septic shock

Dorman T et al
CCM 26:1646;1998

	SBP (mm Hg)	DBP (mm Hg)	MAP (mm Hg)
On Norepinephrine			
Patient 1	–55	0	–15
Patient 2	–80	0	–18
Off Norepinephrine			
Patient 1	22	–19	0
Patient 2	21	–17	0

SBP, systolic blood pressure; DBP, diastolic blood pressure; MAP, mean arterial pressure.

This two-part table shows the radial to femoral pressure gradient from the two patients in whom simultaneous recordings were obtained while the patients received vasopressors, and after they were weaned from vasopressors. The gradients were calculated by subtracting the femoral pressure from the simultaneously recorded radial artery pressure.

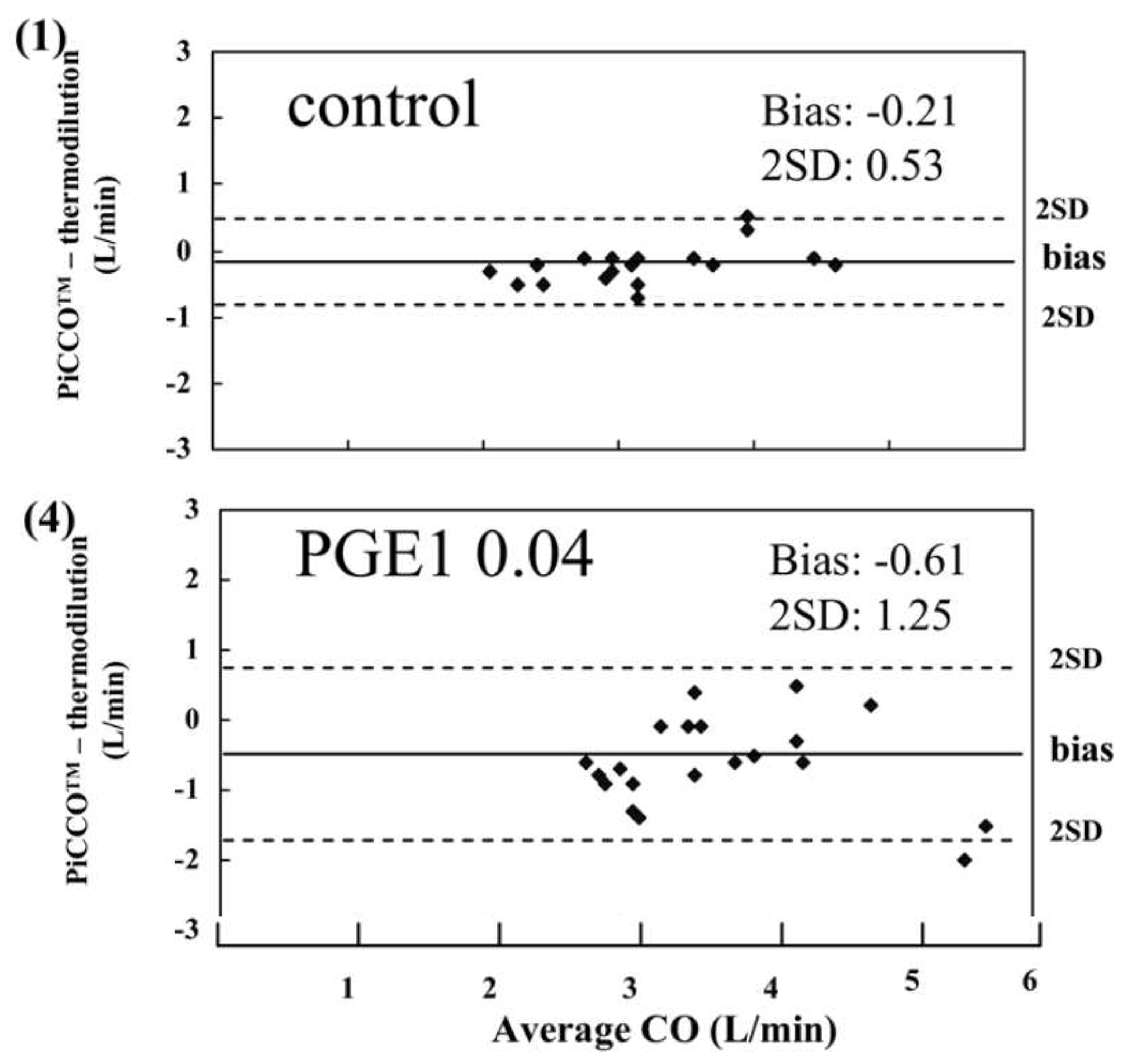


…also with other pulse contour methods

Jellena et al
Anesthesiology 1999

	Precalibration Measurements of Day 1			Postcalibration Measurements		
	Number	Bias (l/min)	95% Limits of Agreement	Number	Bias (l/min)	95% Limits of Agreement
TDCO < 8	18	−0.86 ± 1.51	−3.81 to 2.10	58	−0.05 ± 0.59	−1.21 to 1.10
TDCO ≥ 8	14	−2.45 ± 1.92*	−8.19 to 1.63	79	−0.15 ± 0.87	−1.86 to 1.56
HR < 110	16	−1.88 ± 1.78	−5.4 to 1.6	74	−0.02 ± 0.60	−1.19 to 1.14
HR ≥ 110	16	−1.96 ± 2.82	−7.5 to 3.6	63	−0.21 ± 0.92	−2.01 to 1.59
MAP < 80	15	−2.06 ± 2.82	−7.58 to 3.46	65	−0.05 ± 0.70	−1.42 to 1.32
MAP ≥ 80	17	−1.80 ± 1.85	−5.42 to 1.83	72	−0.16 ± 0.82	−1.77 to 1.42
SVR < 800	15	−2.66 ± 2.79	−8.14 to 2.81	84	−0.17 ± 0.87	−1.87 to 1.53
SVR ≥ 800	17	−1.26 ± 1.61	−4.4 to 1.90	53	0.01 ± 0.54	−1.05 to 1.07
Radial	25	−2.32 ± 2.35	−6.93 to 2.28	108	−0.04 ± 0.74	−1.49 to 1.40
Femoral	7	−0.48 ± 1.59	−3.59 to 2.64	29	−0.18 ± 0.73	−1.58 to 1.33

Yamashita K et al
J Cardioth Vasc Anesth
22:688;2008

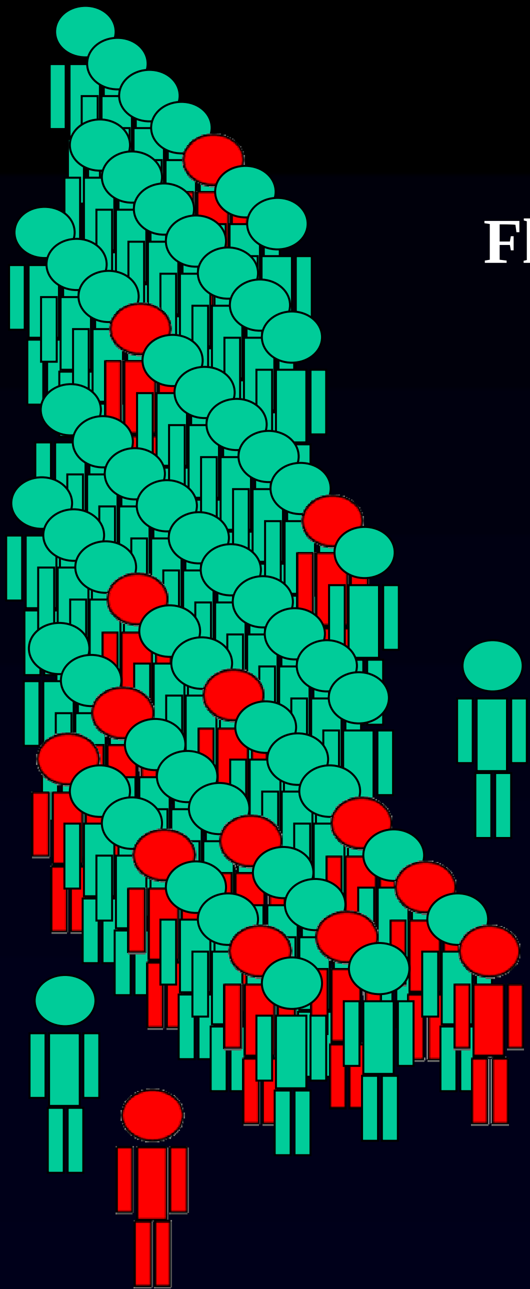


PiCCO vs PAC

20 pts OPCAB

FloTrac 3rd generation

G3



1. More patients in the human database
2. Higher proportion of vasoplegic states
3. More shape variables to calculate χ

$$CO = \text{pulse rate} \,.\, AP_{sd} \,.\, \chi$$

CO G3: Validation study

58 patients with sepsis *
401 cardiac output (CO) measurements

Pulmonary artery catheter to measure iCO and CCO
Reference CO = iCO

Radial (n=32) or femoral (n=26) arterial line
Arterial pressure recorded on a computer and analyzed using CO_{G2} and CO_{G3}

*** Cohort independent from that used to develop the G3 algorithm**

CO G3: Validation study

Methods:

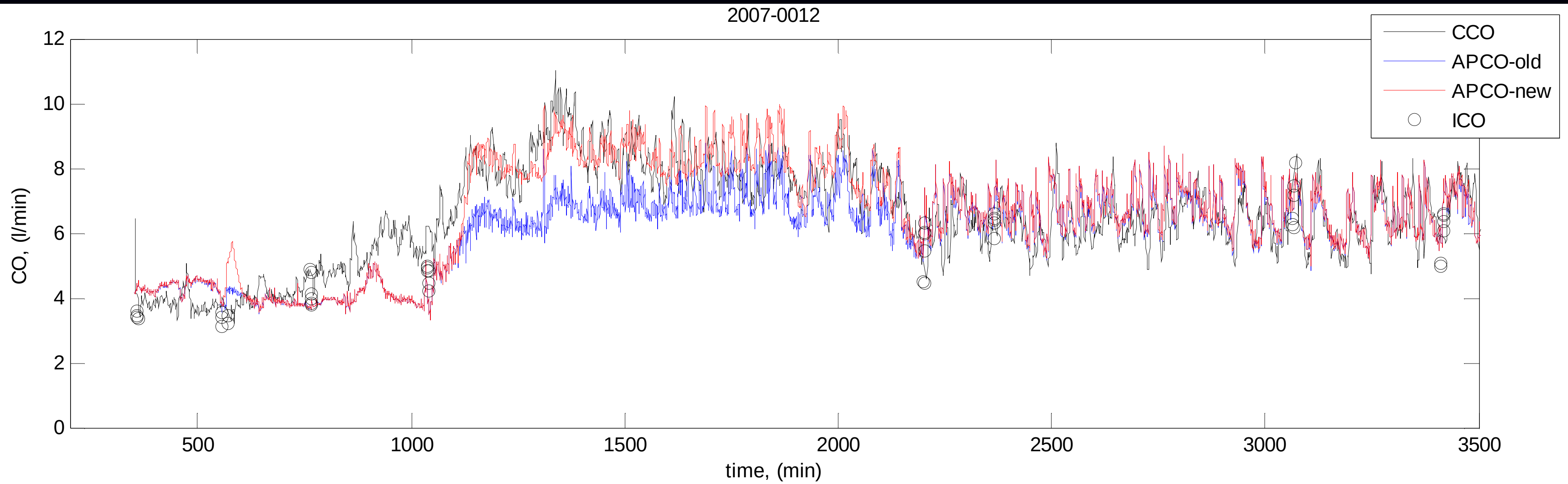
- ICO 3-5 boluses averaged*
- CCO: 2 before and 3 after ICO boluses (~5min)
- CO G2/G3: averaged for 5 min (7 values before and 8 values after ICO measurement)

* ICO measurements: average values were included only when total variability of the 3-5 bolus was < 15%

Hear rate (bpm)	**97 ± 19**
Mean arterial pressure (mmHg)	**76 ± 11**
iCO (l/min)	**7.5 ± 2.0**
CO_{G2} (l/min)	**6.5 ± 1.5**
CO_{G3} (l/min)	**7.3 ± 2.1**
CCO (l/min)	**8.1 ± 2.1**
SVR (dynes/sec/cm^5)	**875 ± 283**

Erasme pt12

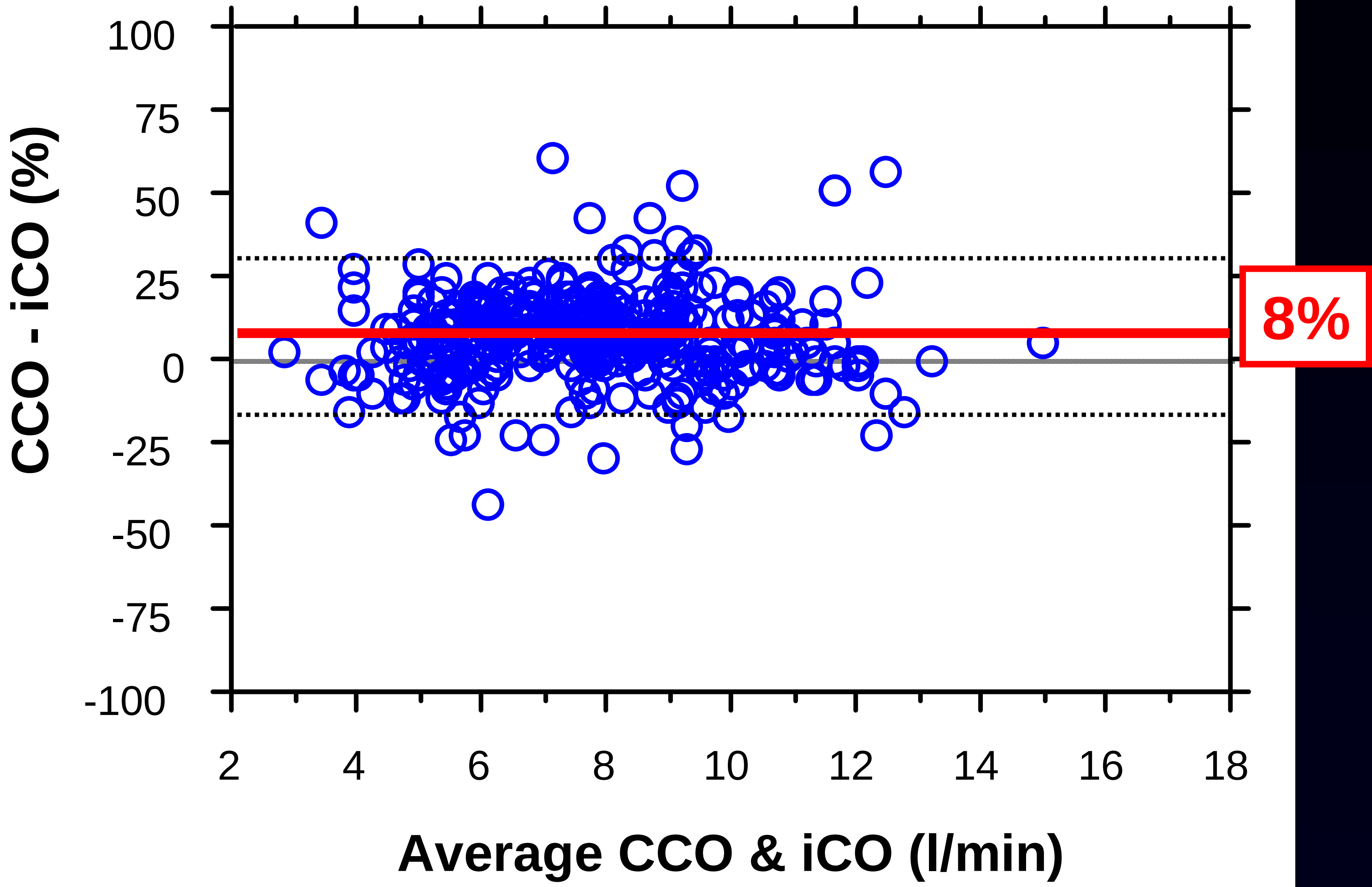
CO G3: Validation study



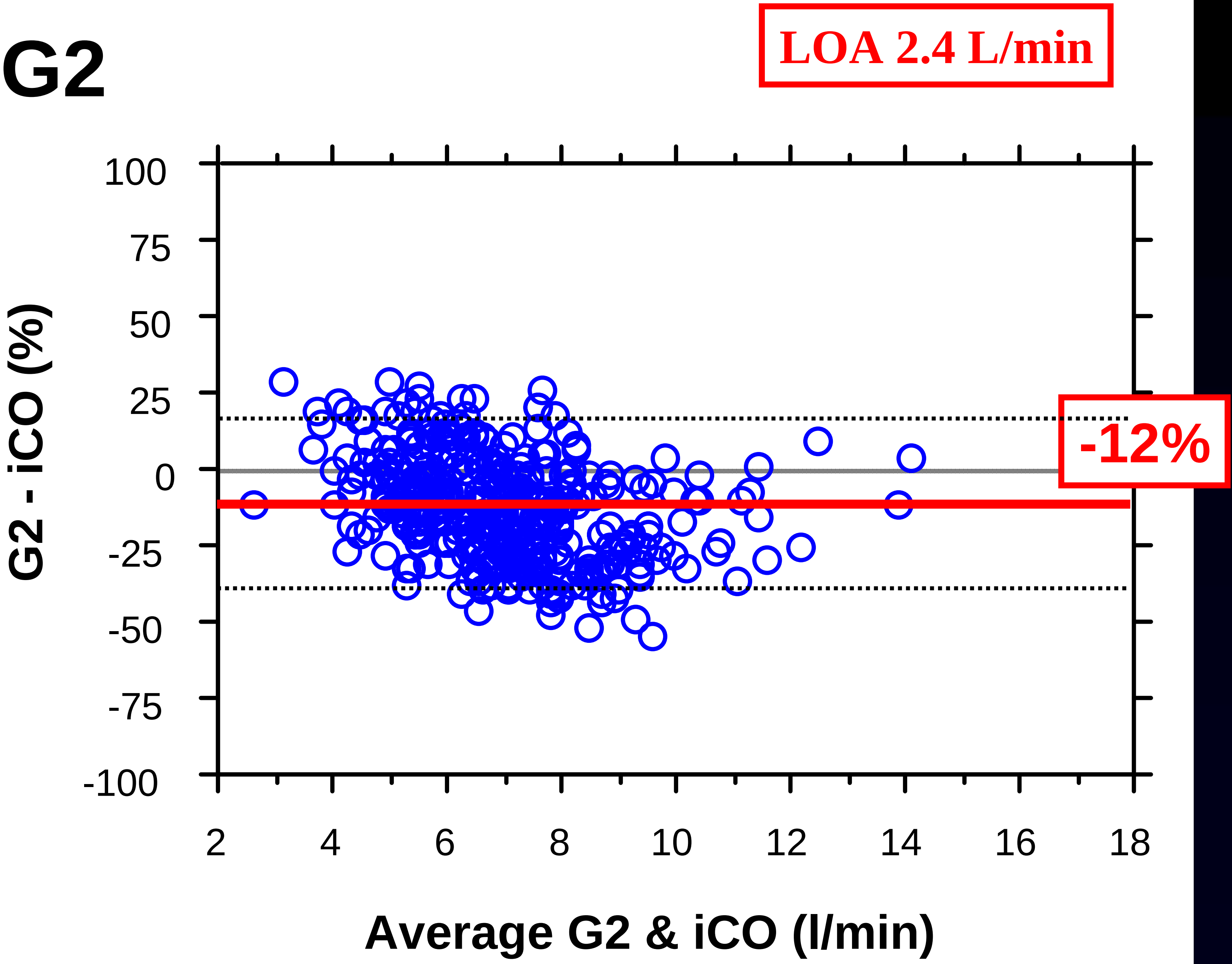
○ **ICO from Swan-Ganz** **CCO from Swan-Ganz** **2nd Generation** **3rd Generation**

CCO

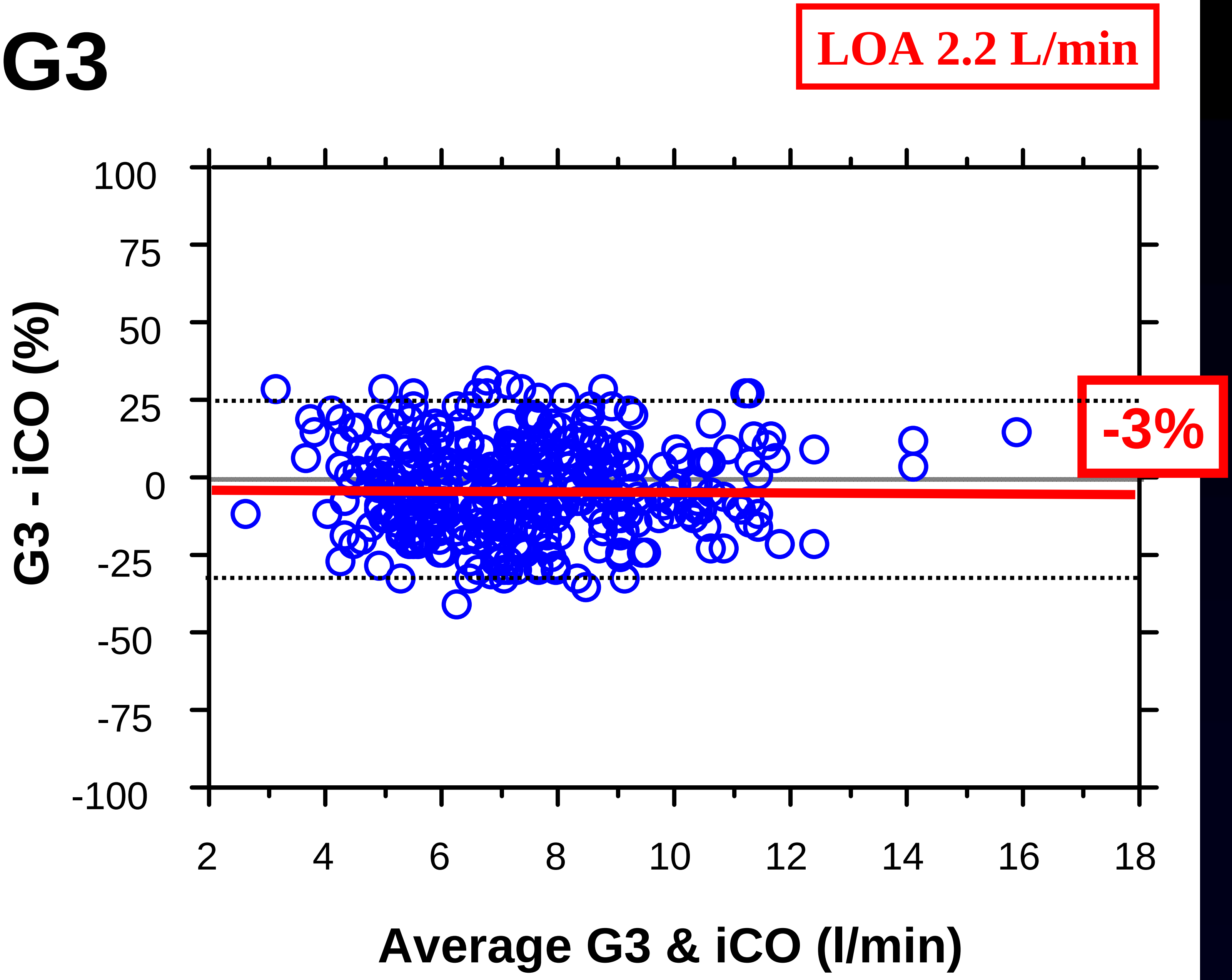
LOA 2.2 L/min

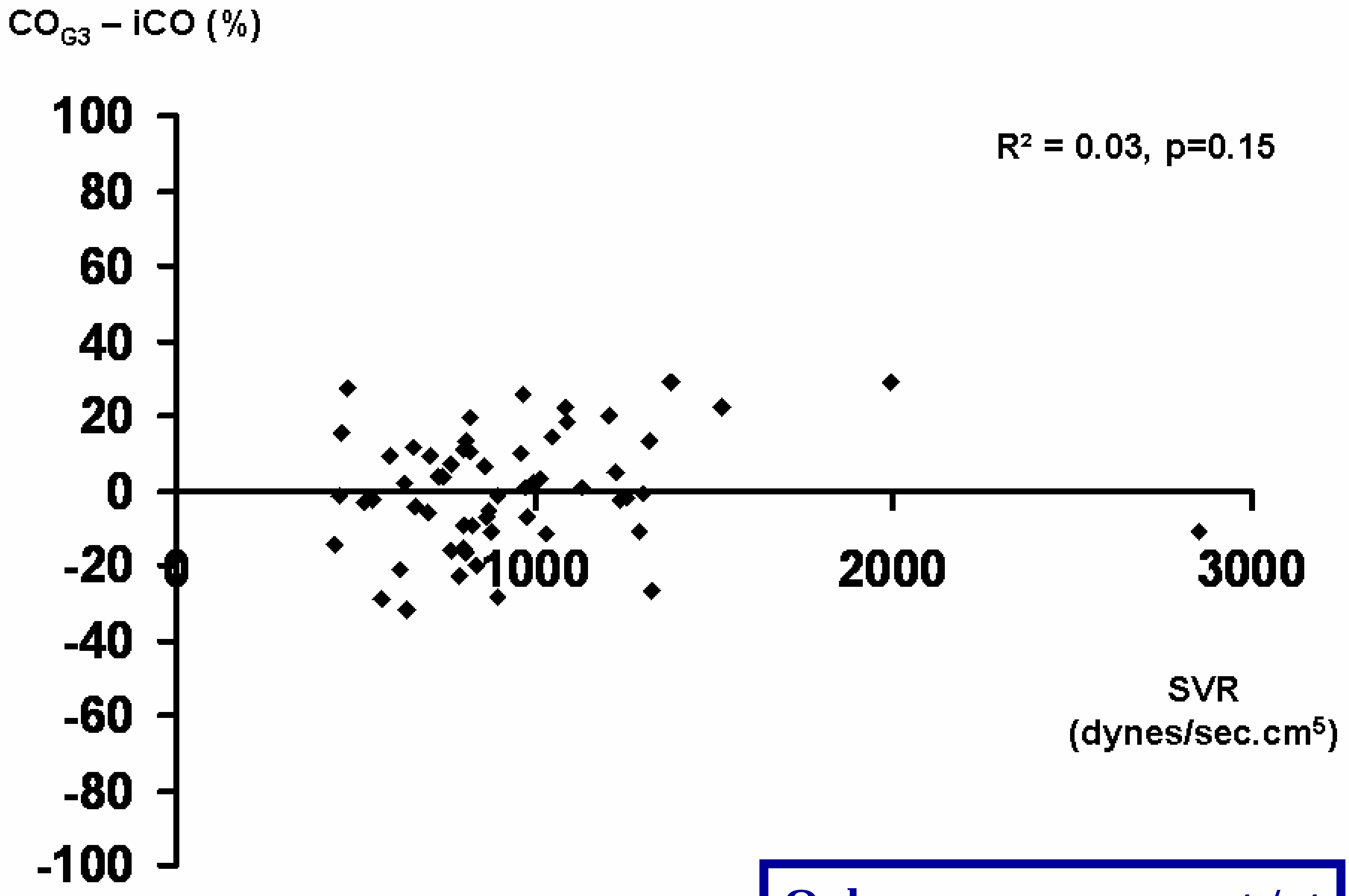


G2


LOA 2.4 L/min
-12%
G2 - iCO (%)
100
75
50
25
0
-25
-50
-75
-100
2
4
6
8
10
12
14
16
18
Average G2 & iCO (l/min)

G3


LOA 2.2 L/min
-3%
100
75
50
25
0
-25
-50
-75
-100
G3 - iCO (%)
2
4
6
8
10
12
14
16
18
Average G3 & iCO (l/min)



Only one measurement /pt (first one)

401 comparisons with iCO-PAC in 58 patients

G2

Bias (l/min) = -1.0
LOA (l/min) = 2.4
Bias (%) = -12 ± 16
%Error = 33%

G3

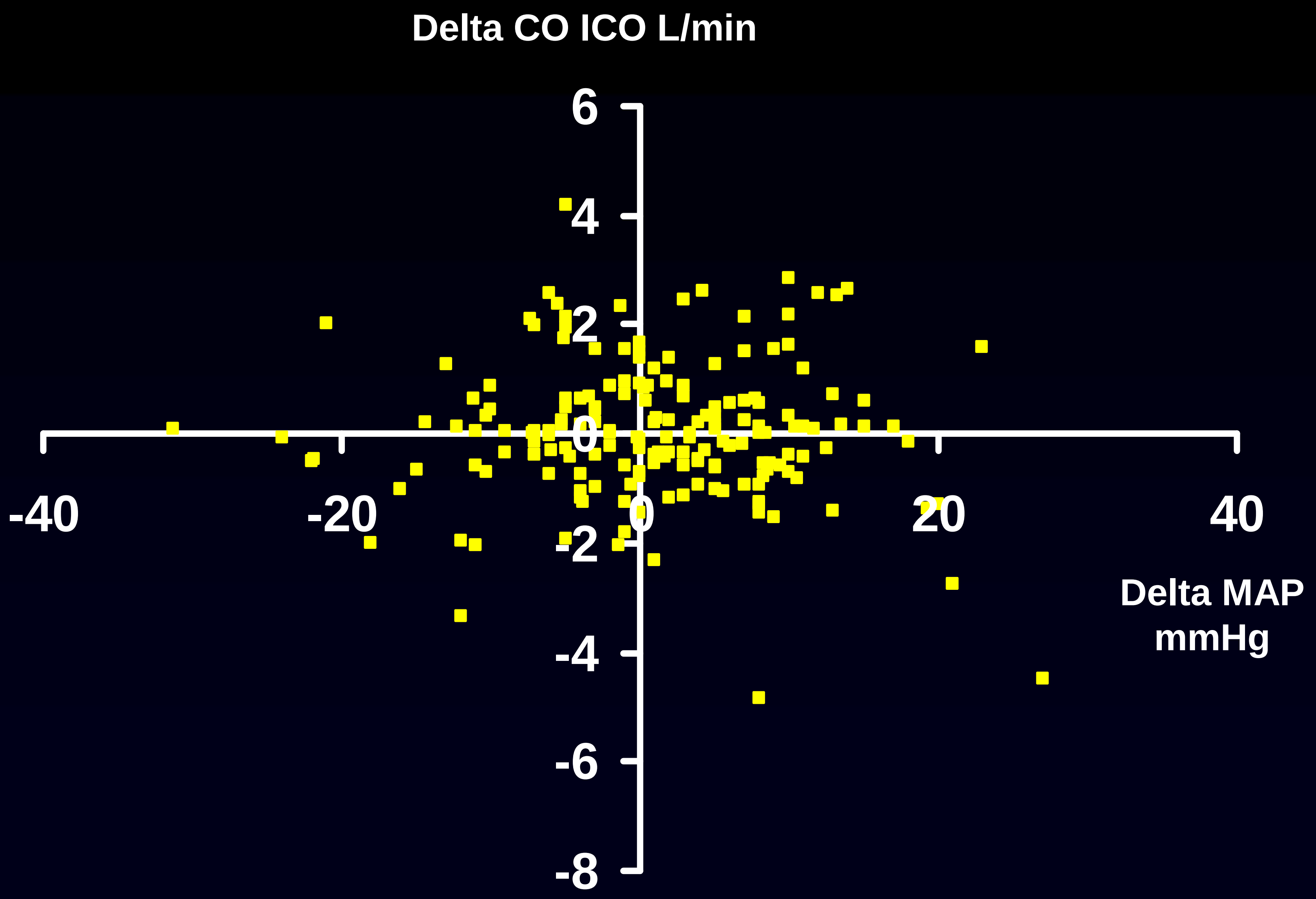
Bias (l/min) = -0.2
LOA (l/min) = 2.2
Bias (%) = -3 ± 15
%Error = 29%

CCO

Bias (l/min) = 0.6
LOA (l/min) = 2.2
Bias (%) = 8 ± 13
%Error = 29%

Detection of changes in CO ?

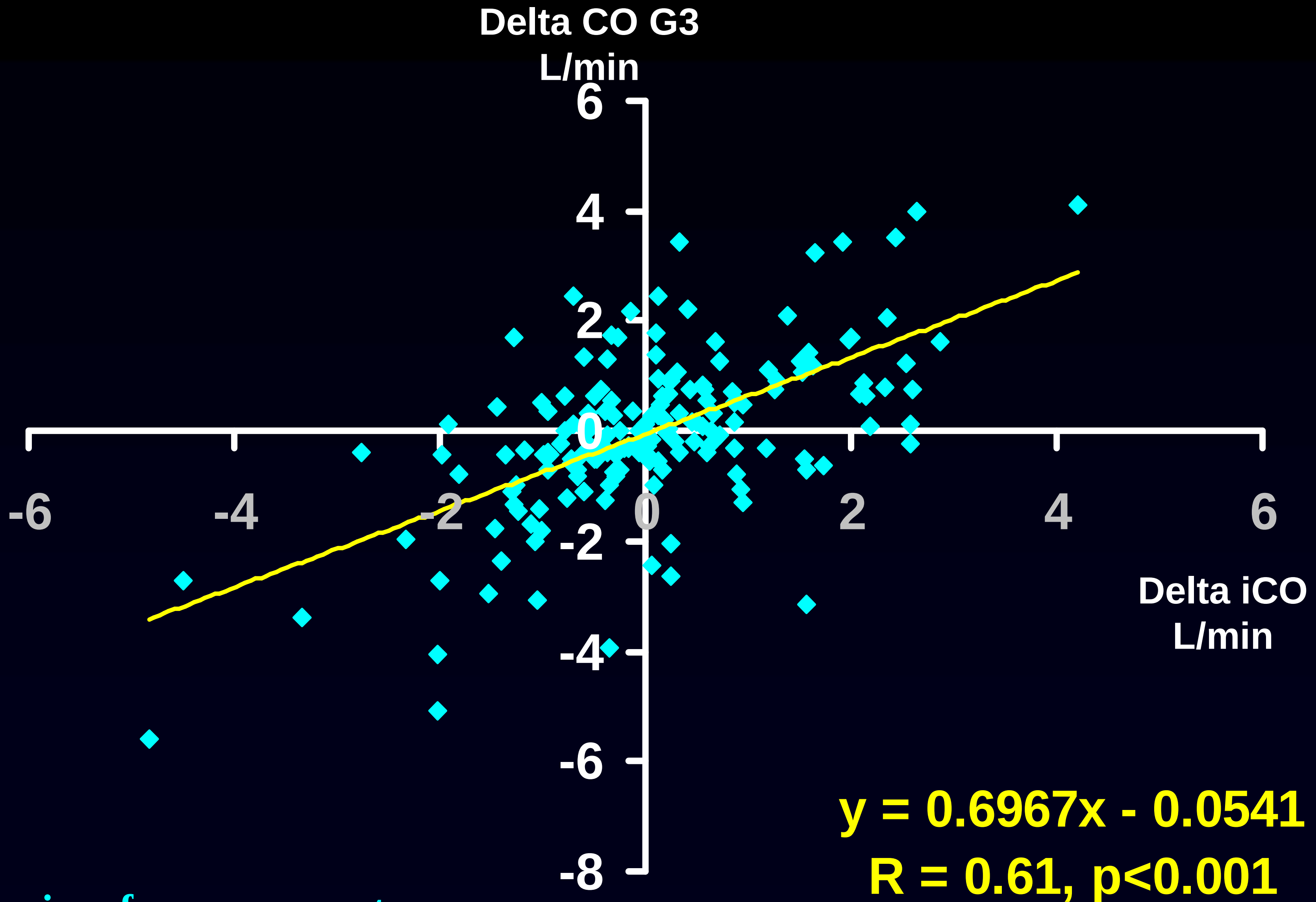
Changes in CO cannot be predicted form changes in arterial pressure



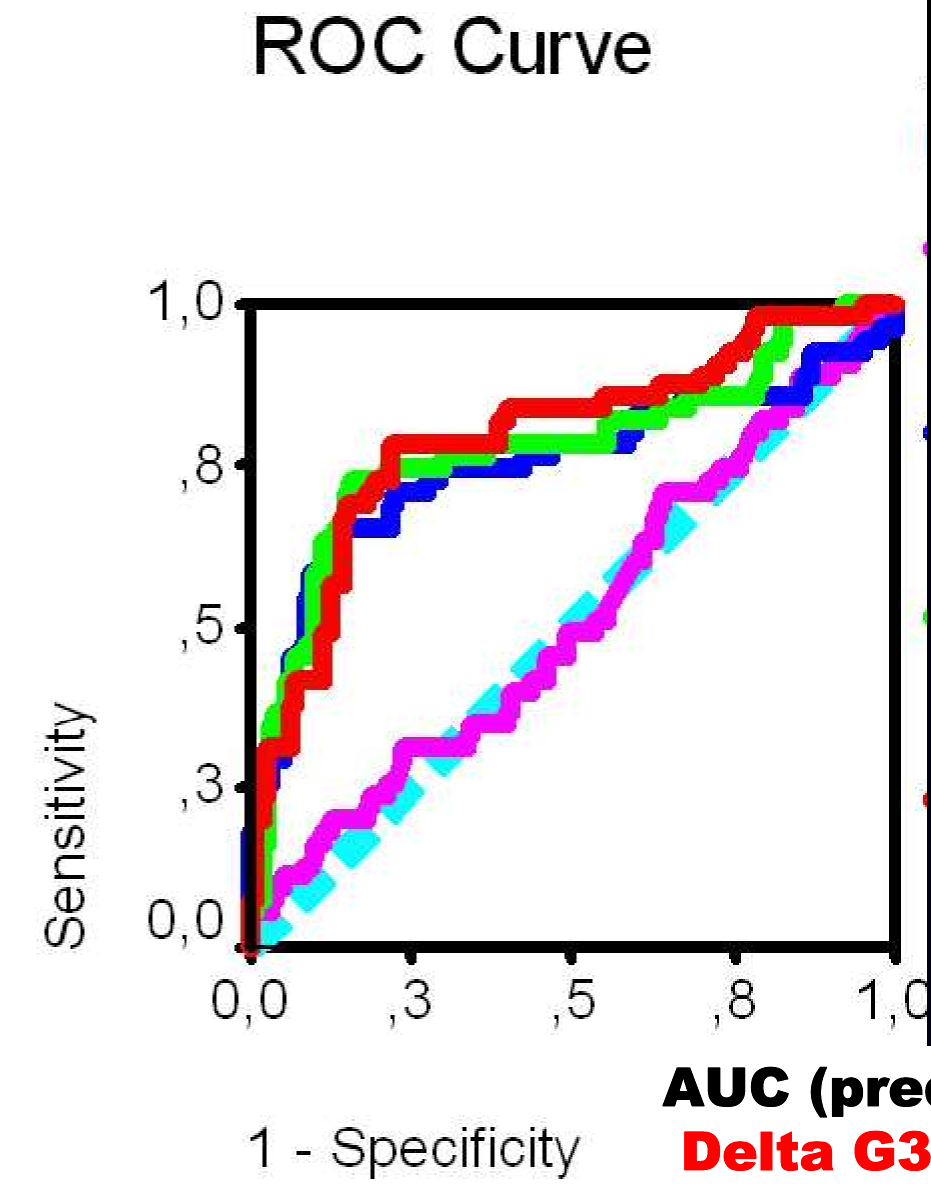
Reference method

183 pairs of measurements
56 pts

Changes in CO are adequately detected by FloTrac G3



183 pairs of measurements
56 pts



183 pairs of measurements
56 pts

AUC (prediction of a 15% change in iCO):

Delta G3 %:	**0.794 (0.719-0.870)**
Delta G2 %:	**0.777 (0.694-0.860)**
Delta CCO %:	**0.751 (0.661-0.842)**
Delta MAP %:	**0.512 (0.419-0.605)**

Conclusions

- **Pulse contour methods reliably estimate cardiac output in most instances.**

- **Depending on the algorithm, calibration may be required.**

- **The choice of the method should be guided by patients characteristics and the potential interest (need?) for additional measurements.**