# Affordable Cardiac Output Monitoring for the Anaesthetist


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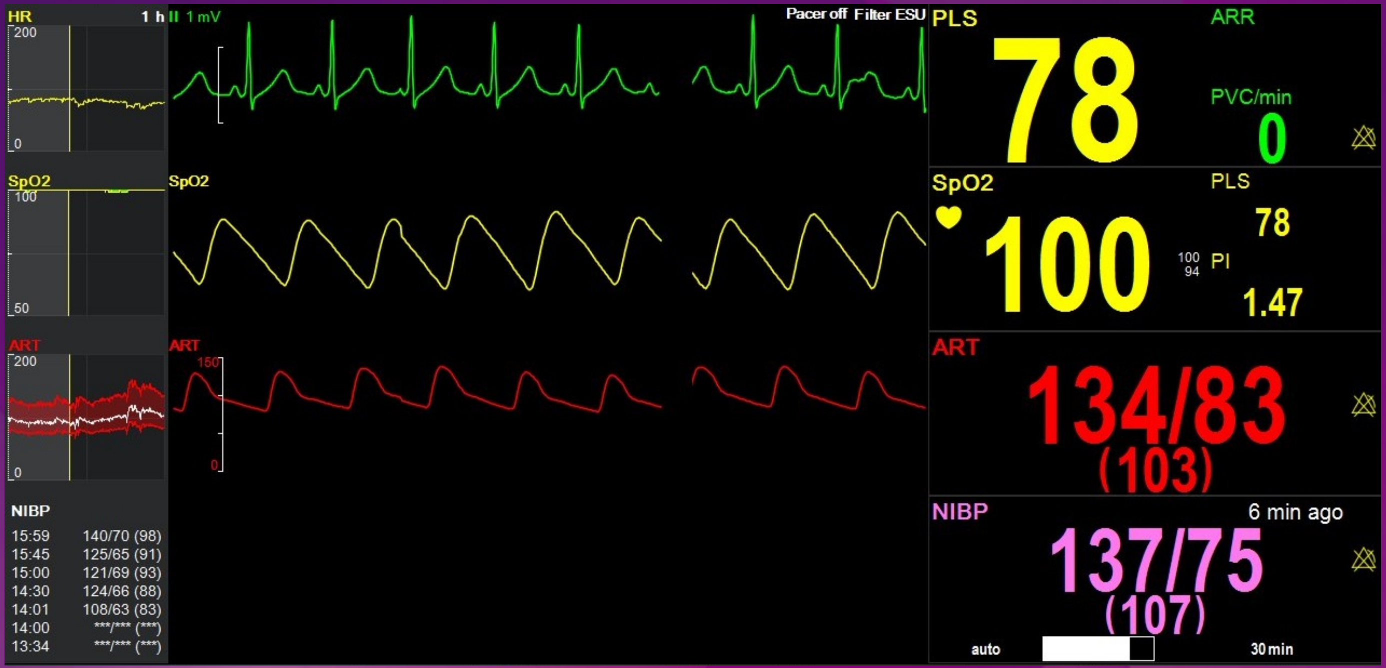
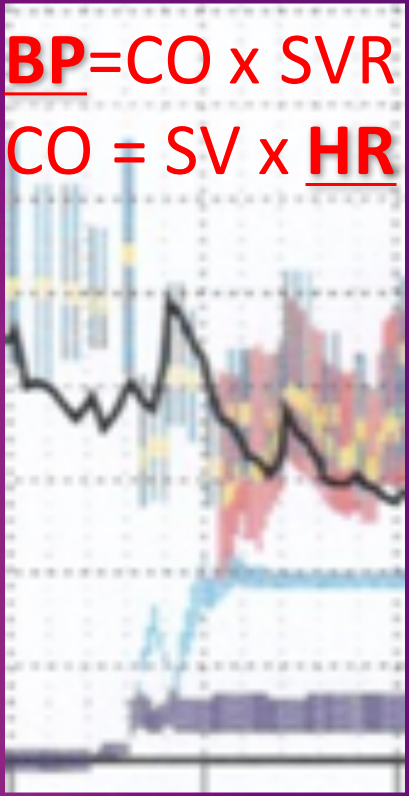



# BLOOD PRESSURE (BP) AND HEART RATE (HR) MONITORING

## Key role played in managing anaesthesia

# Anaesthesia scenario:




- After induction BP drop to 60/30mmHg
- Treatment:
  - Fluids or Vasopressor
  - But which & how much?
- *Knowing stroke volume would help*
  - *But how do you measure SV or CO?*

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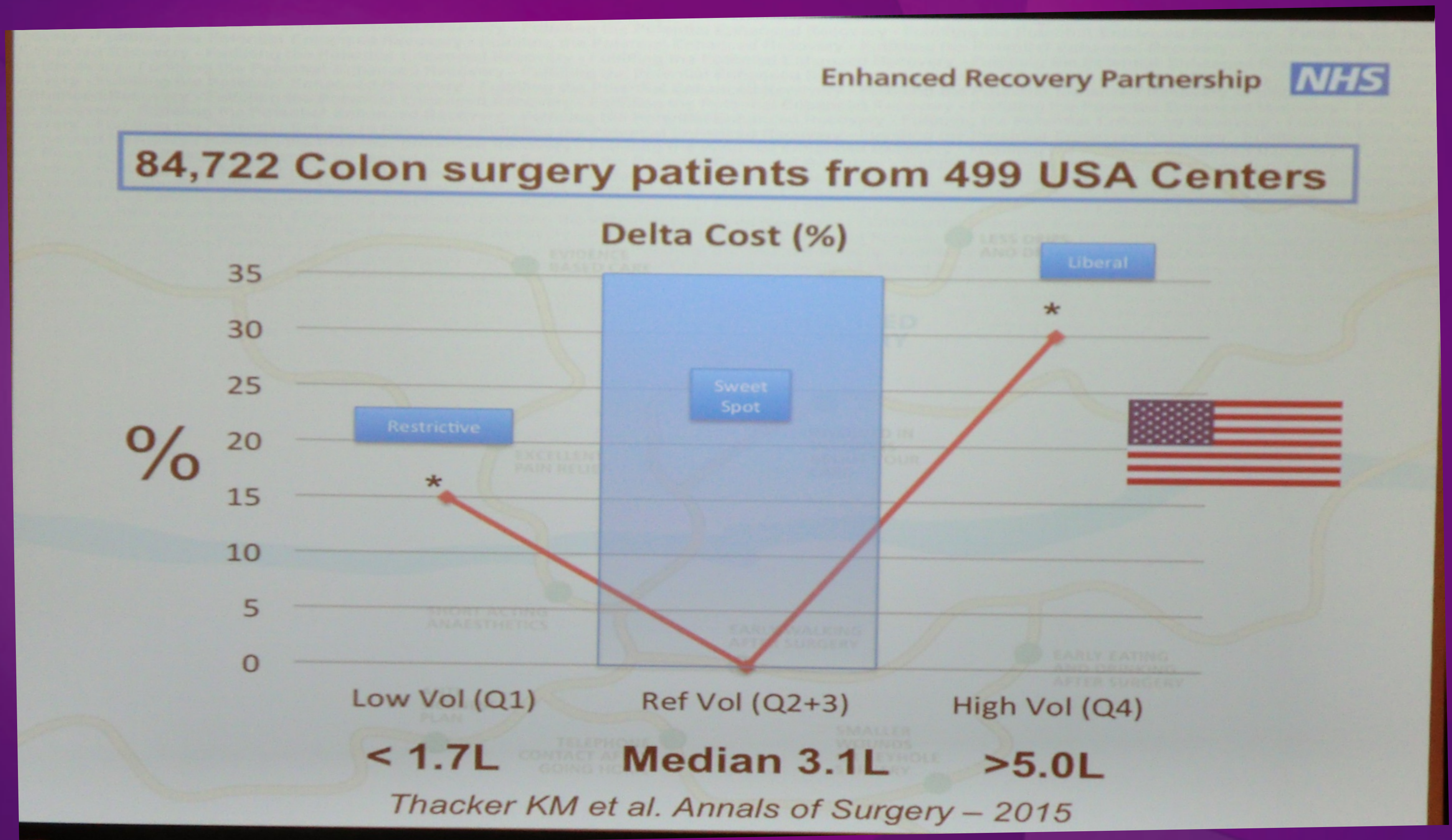
# Perioperative fluid administration: Recent outcome data from the USA

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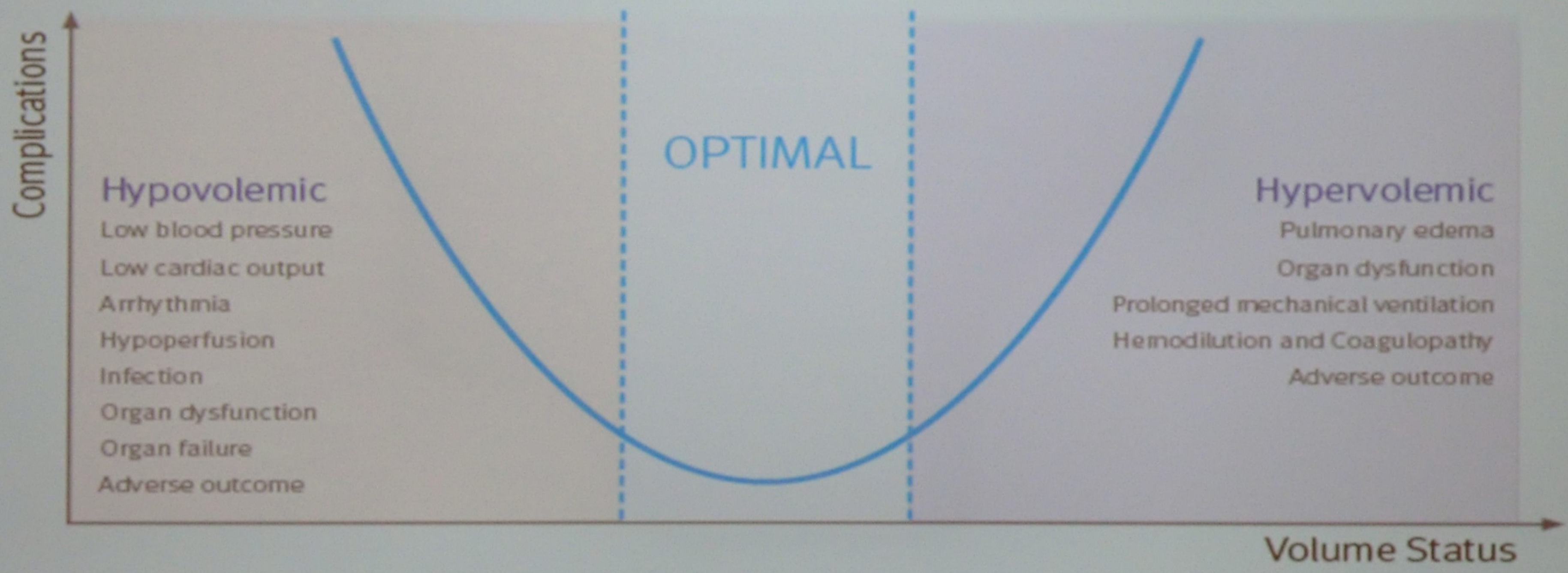
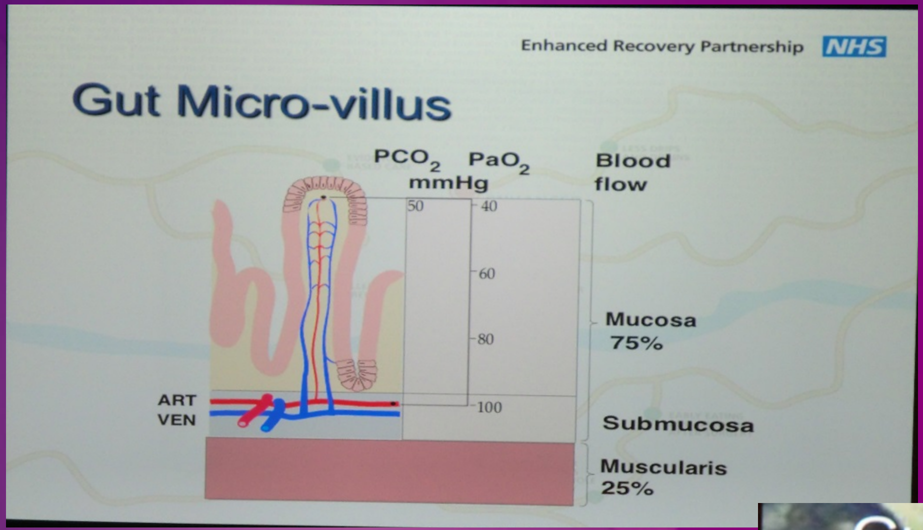
# This slide

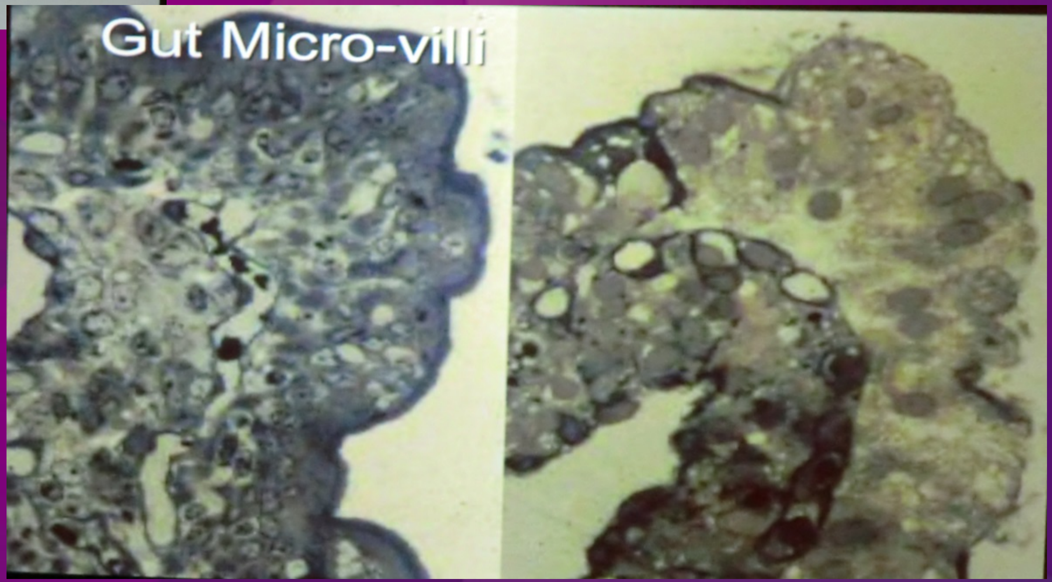
Complications associated with suboptimal fluid therapy




Bellamy, et al. Wet, dry, or something else? Editorial. BJA, 2006

# Poor intra-operative perfusion on gut mucosa causing ileus and leaks



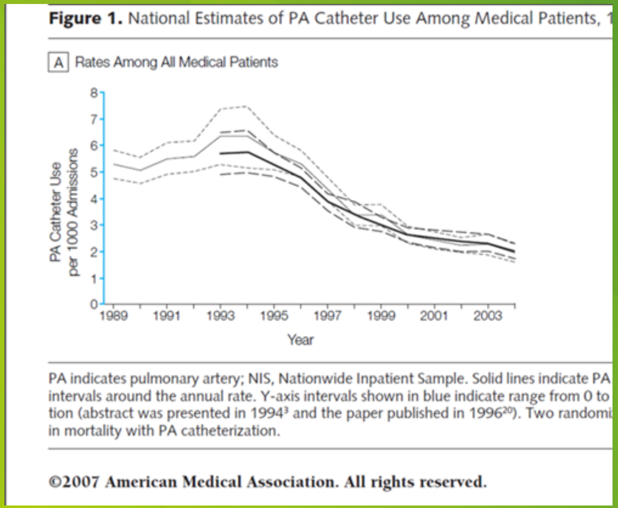




M Mythen's Lecture
Hong Kong April 2016

# Pulmonary Artery Catheter:

- Was the Gold Standard
  - But use has declined worldwide
  - to 1% of the 1990s level

- Not a suitable Point-of-Care monitor for routine anaesthesia
  - Invasive
  - Costly in time & money
  - Reliable?
  - Did not improve outcomes

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# Emerging Technologies:
# *Since 2000 - Continuous CO*

- **Intensive Care:**

  Trans-Oesophageal Echo.

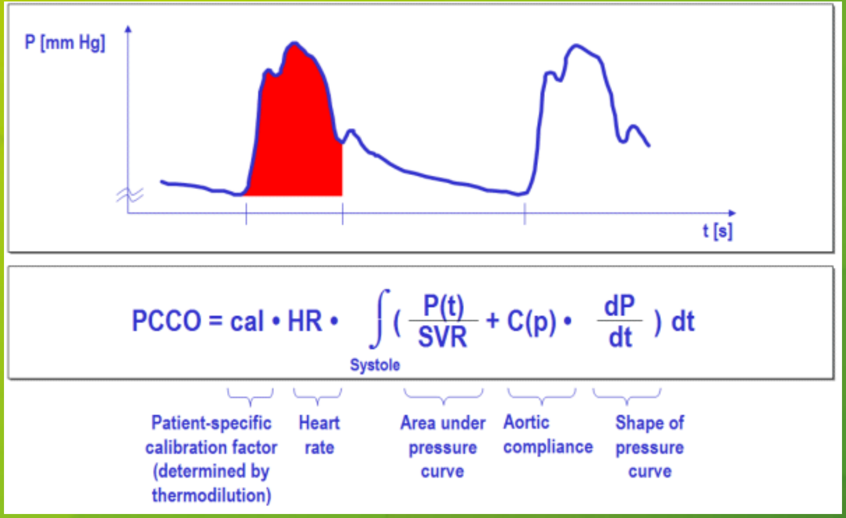
  Too bulky & expensive for regular theatre use

- **Anaesthesia:**

  ***Minimally invasive CO monitors***

  - ❑ Arterial pulse contour analysis
  - ❑ BioImpedance
  - ❑ Continuous wave Doppler


# WHAT IS AVAILABLE AND HOW DO THEY WORK?

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# Currently available systems: Pulse contour analysis

**Direct / arterial-line**

- FloTrac-Vigileo
  - (Edwards, US)
- PiCCO
  - (Pulsion, Germany)
- LiDCO-rapid
  - (England)
- Most-Care
  - (Italy)

**Finger cuff technology**

- Clearsight System
  - (Edwards)
  - [previously Finapres]
- CNAP
  - (CNSystems, Austria)


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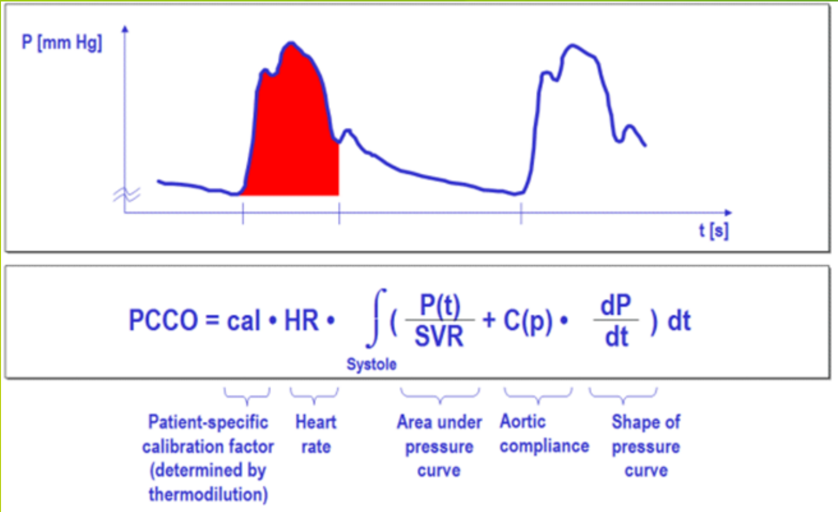
# How does the system work: Pulse contour analysis

- Detects the arterial pressure waveform
- Wrist (radial), finger or major artery (femoral )
- Algorithm used to derived stroke volume (SV) and cardiac output (CO) from the area under the pressure curve
- But many different formulae!



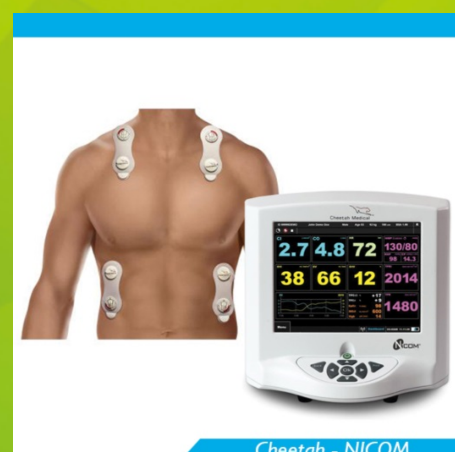

| Formula ($CO = SV \times HR$) | Commercial use* |
|---|---|
| $SV = k \times MAP$ | N/A |
| $SV = k \times PP$ | FloTrac-Vigileo |
| $SV = k \times (PP/(SBP + DBP))$ | CardioQ-ODM+ |
| $SV = k \times \sqrt{\int_T (ABP(t) - MAP)^2 dt}$ | LiDCO |
| $SV = k \times (1 + (T_{sys}/T_{dia})) \times \int_{systole} ABP(t)dt$ | PiCCO |

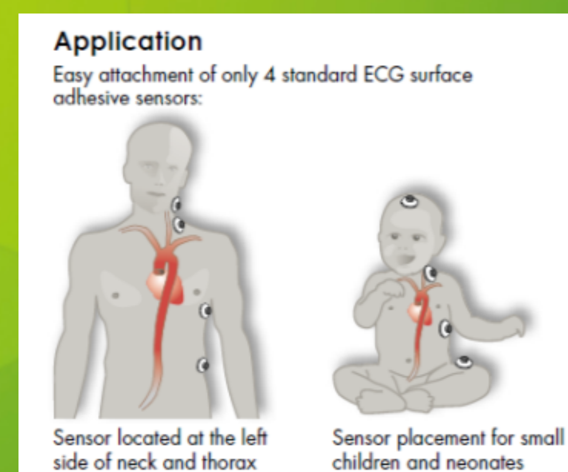
# Currently available systems: BioImpedance / Reactance

- BoMed (1980s)

- 20 years of improvement:
  - Signal detection
    - Electrode design & position
  - Waveform analysis

- **Available systems today:**
  - **NICOM Cheetah**
  - **PhysioFlow**

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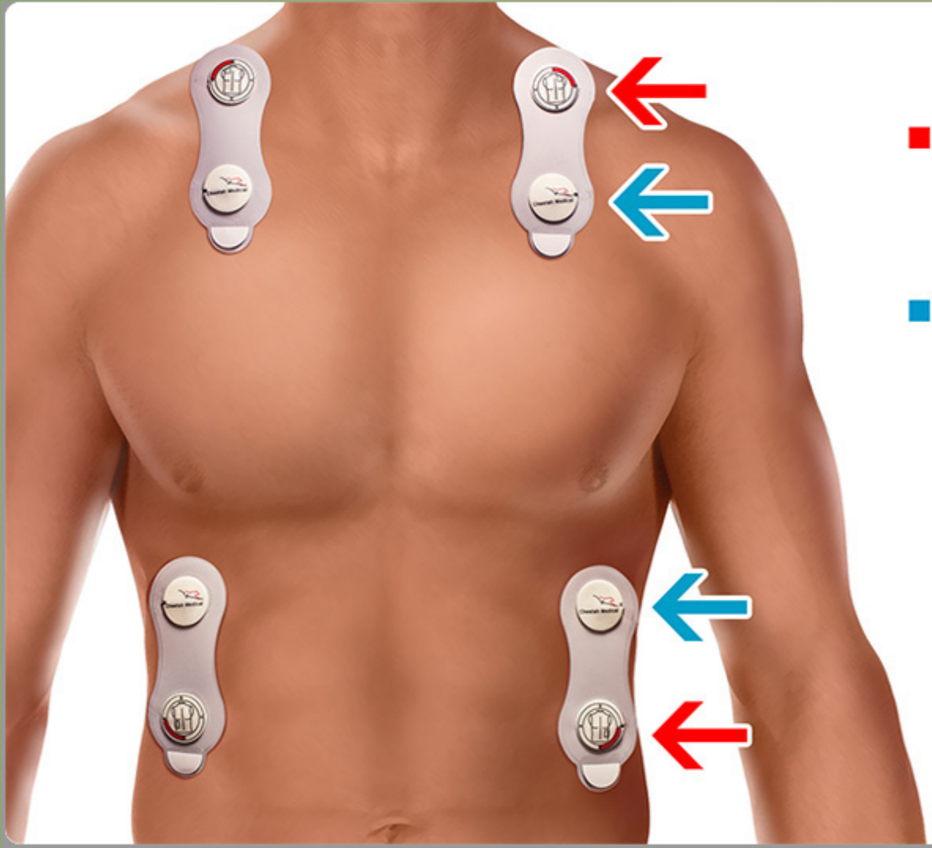
# NICOM
# Cheetah Medical, (Israel)

Cheetah Medical™



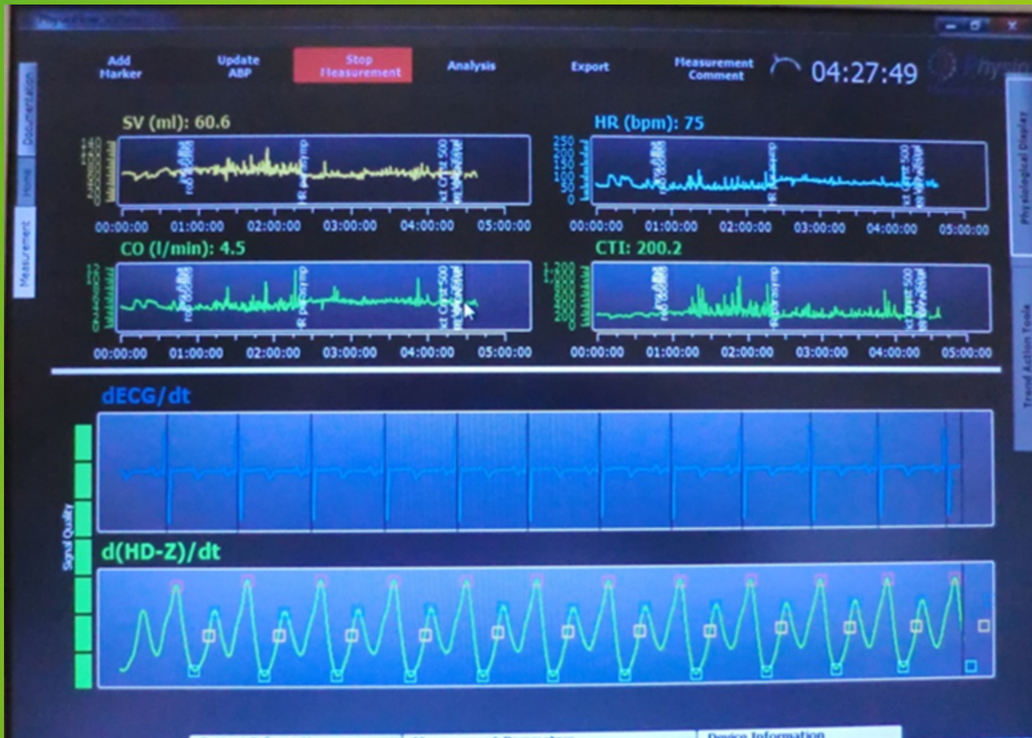
- An electric current of known frequency is applied across the thorax between the outer pair of sensors.
- A signal is recorded between the inner pair of sensors.

As the heart expands and contracts, a time delay, or phase shift, is created in the current by blood flow.

The monitor then uses this phase shift as a base-line for stroke volume measurement.

# PhysioFlow (France) BioImpedance method

PhysioFlow®
Hemodynamics Redefined™




Wave form morphology analysis

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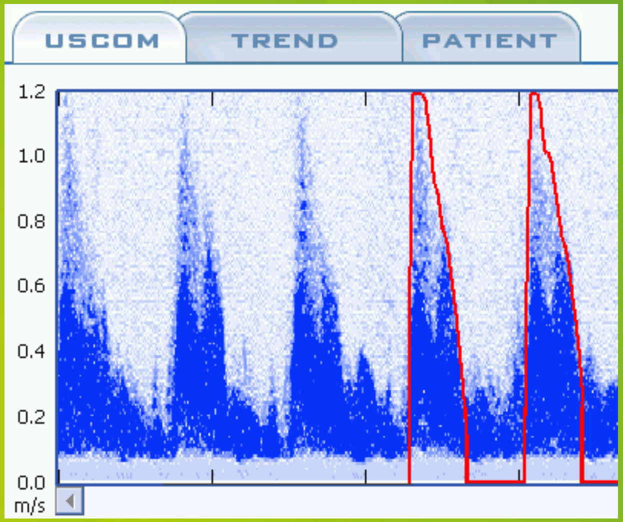
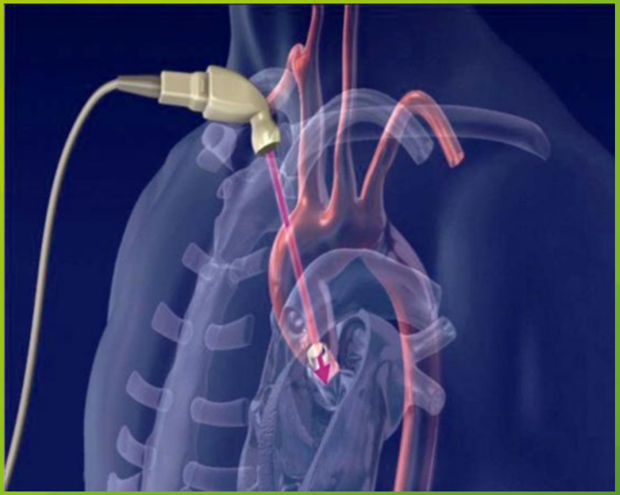
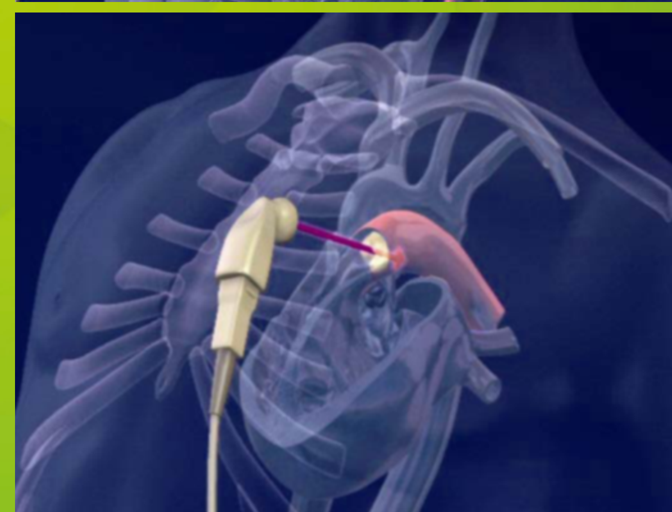
# How does it work: Continuous wave Doppler

- **Not an imaging technique**
- **Requires a probe**
- **Uses ultrasound to detect flow in the aorta**
- **Analyses the flow profiles**



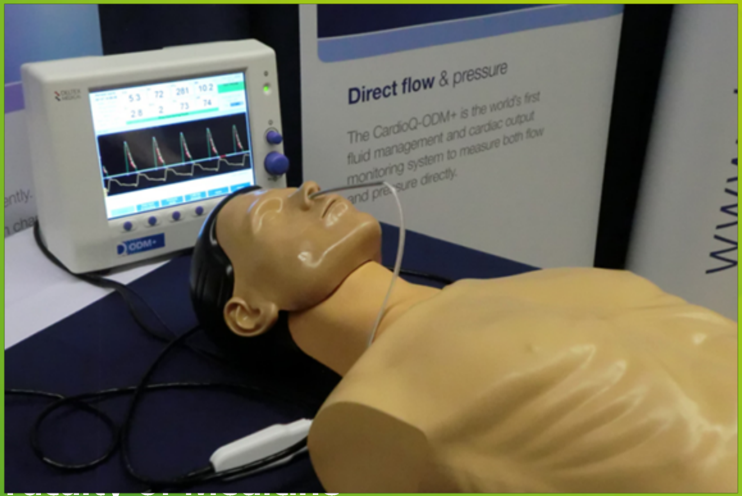



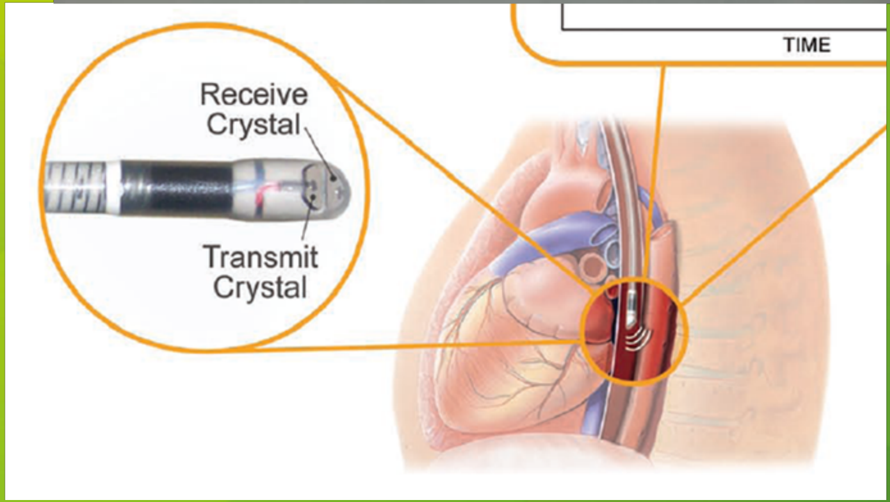
# <u>U</u>ltra<u>S</u>ound <u>C</u>ardiac <u>O</u>utput <u>M</u>onitor *USCOM, (Sydney)*. External Doppler

# Deltex Medical – CardioQ – ODM+ Oesophageal Doppler


New Deltex Oesophageal Doppler Monitor which includes arterial pressure monitoring



# Marketing strategies and affordability:

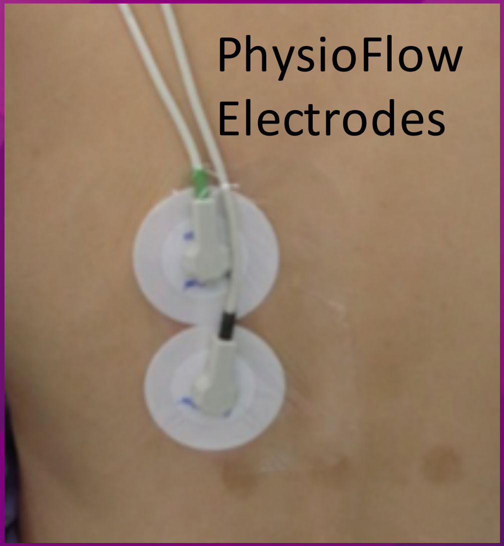
- Research and developments costs money
  - In addition to manufacturing costs
- Why medical devices expensive
  - Return of initial capital outlay
- Cost of buying the equipment
  - Single payment
- Cost of Disposables
  - Where companies make their money

| Technology | Disposable |
| --- | --- |
| Pulse contour | Catheters & Transducer |
| BioImpedance | Electrodes |
| Doppler | Oesophageal probes |

# Examples of consumables:




New Deltex Oesophageal Doppler Monitor which includes arterial pressure monitoring

PhysioFlow Electrodes


Only system with minimal Expenditure on disposables

# Validation studies and reliability:
## *Single centre Random Controlled Clinical Trials*

- **Data from validation studies is poor**
- **Mainly comparisons with single bolus thermodilution (PAC)**
- **Issue of showing accuracy (precision) rather than trending (ability to detect changes)**
- **Good information on reliability and repeatability hard to find**

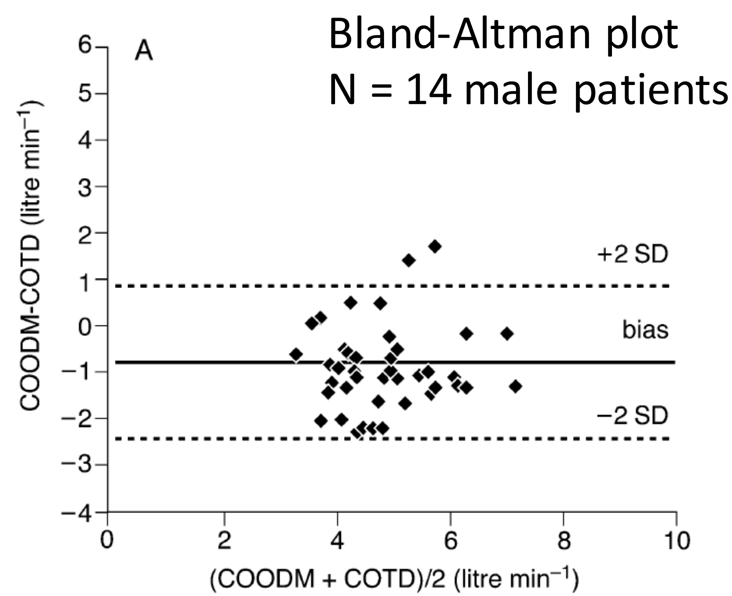



**Fig 2** Bias plot of CO measurements by ODM *vs* TD before (A) and after

Percentage error = 34%
Benchmark <30% for good agreement
"No information regarding how well device measures changes in SV & CO!"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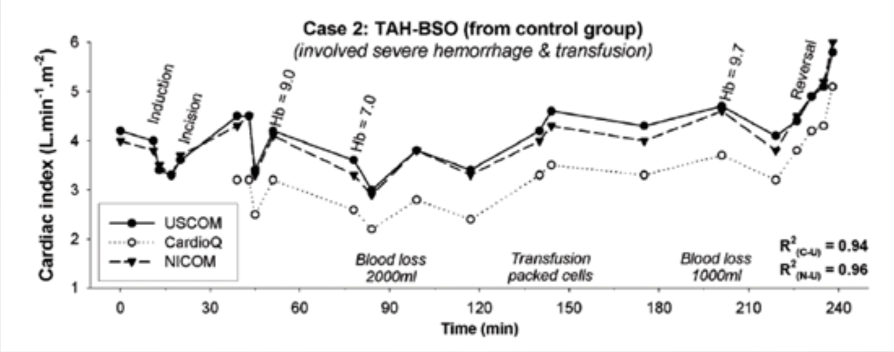
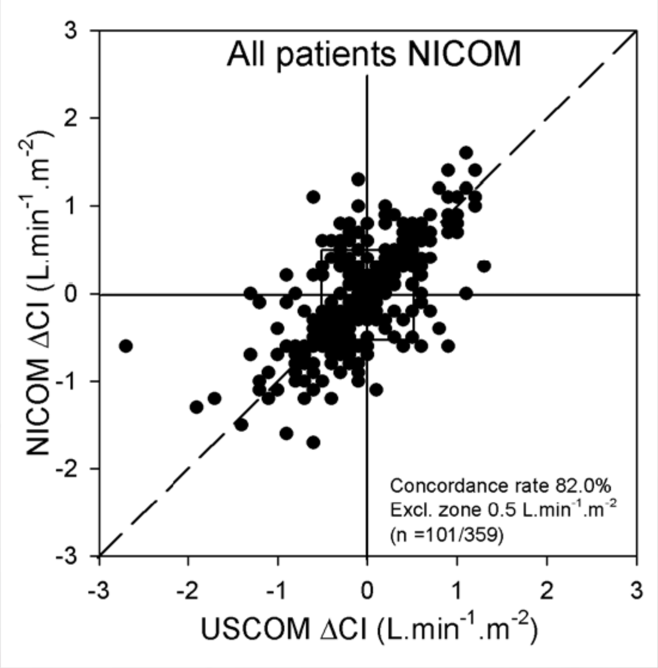
# Validation studies showing trending:

- Need to compare serial changes in SV & CO
  - Statistics only recently established
- Times plots comparing changes in changes
- Multiple patient data studies
  - Serial change in CO - ΔCO
  - Show data on four quadrant plots
  - Concordance analysis
- *Polar plots*



# Validation studies: Pulse Contour

- PCA is not accurate.
- Readings vary by >20%
  - [i.e. range form 4-6L/min for a mean CO of 5L/min]

- CO reading effected by in peripheral resistance

- Unreliable in sepsis and liver cirrhosis, and when vasopressors used

- Should avoid these situations

**Table 1** Summary of recent publications that clinically evaluate the FloTrac/Vigileo™. *Estimated value; †Data include the use of vasopressors; ‡Only postoperative patients; ¶Classical thermodilution not used

| Paper | Year published | Type of cases | Number of patients | Data pairs | Percentage error (%) |
|---|---|---|---|---|---|
| Costa and colleagues[20] | 2006 | Cirrhosis | 14 | 50 | 35 |
| Sander and colleagues[21] | 2006 | Cardiac | 30 | 120 | 54 |
| Breukers and colleagues[22] | 2007 | Cardiac | 20 | 56 | 36 |
| Button and colleagues[23] | 2007 | Cardiac | 31 | 217 | 45* |
| Canesson and colleagues[24] | 2007 | Cardiac | 11 | 166 | 38 |
| †de Waal and colleagues[25] | 2007 | Cardiac | 22 | 184 | <56 |
| Manecke and Auger[26] | 2007 | Cardiac | 50 | 290 | 33* |
| Mayer and colleagues[27] | 2007 | Cardiac | 40 | 320 | 46 |
| ‡Prasser and colleagues[28] | 2007 | Cardiac | 20 | 158 | 26.9 |
| †Lorsomradee and colleagues[29] | 2007 | Cardiac | 52 | 315 | 33–50 |
| Mayer and colleagues[30] | 2008 | Cardiac | 40 | 282 | 24.6 |
| ¶Sakka and colleagues[31] | 2007 | Sepsis | 24 | 24 | 35 |
| Compton and colleagues[32] | 2008 | Cardiac | 25 | 324 | 58.8 |
| Our data | 2009 | Cirrhosis | 29 | 290 | 54 |

Biancofiore et al. Brit J Anaeth 2009:102; 47

# Evidence from trending studies: Swings in Peripheral resistance

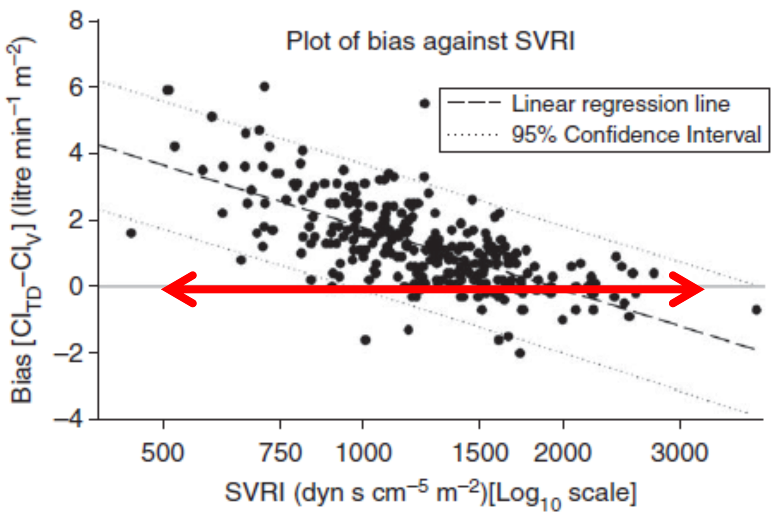



**Fig 3** Bias plotted against SVRI, shown as log scale. A log-linear plot was used to show that as peripheral resistance decreased the discrepancy or bias between CI measurements increased. $CI_{TD}$, thermodilution cardiac index; $CI_V$, Vigileo cardiac index. Data from all 10 time points used (*n*=290).

Biancofiore et al. Brit J Anaeth 2009:102; 47

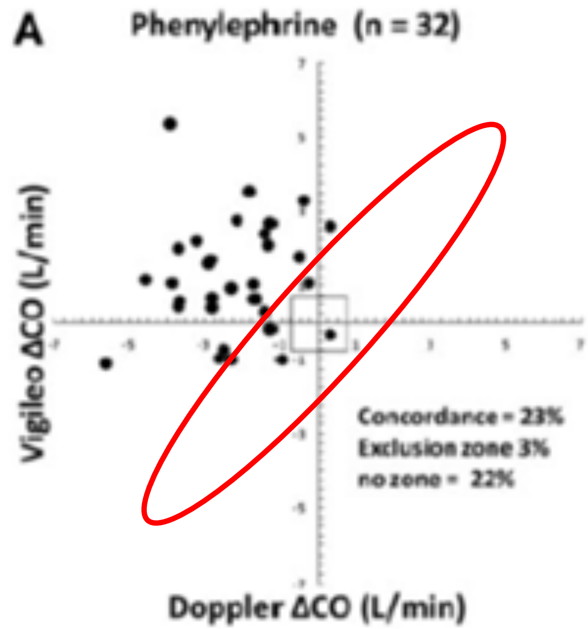
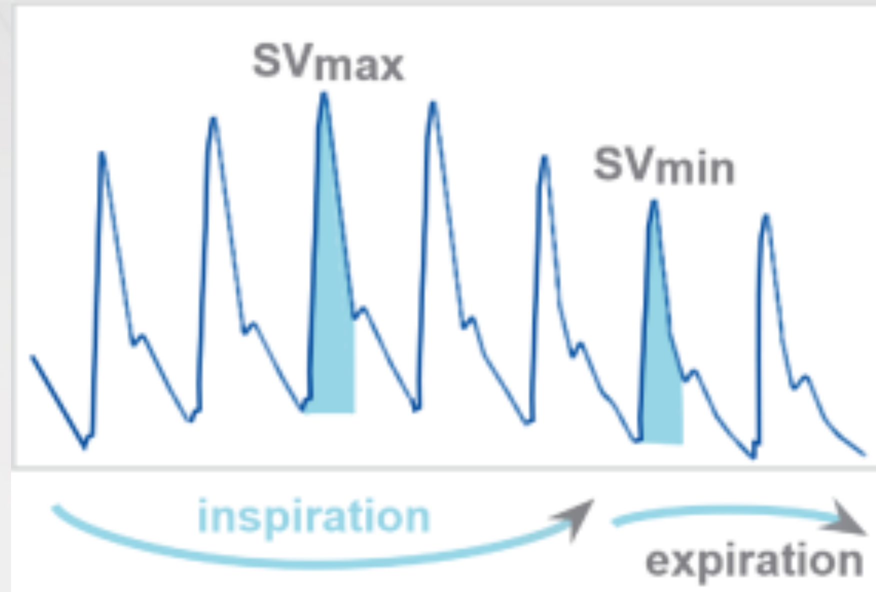


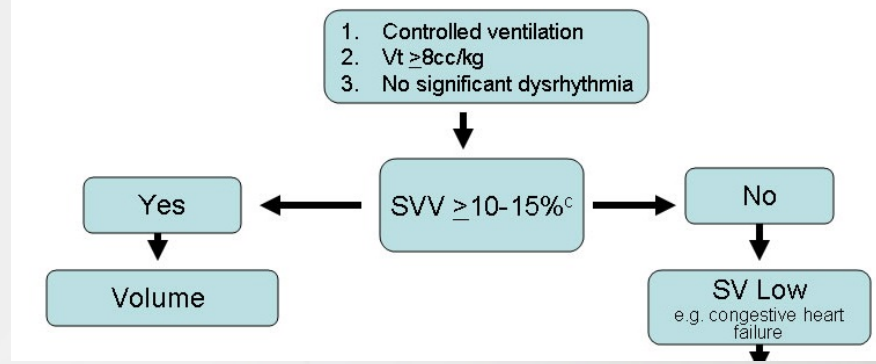

**Figure 3.** Trending ability of Vigileo-FloTrac agai
output (postintervention minus preintervention)

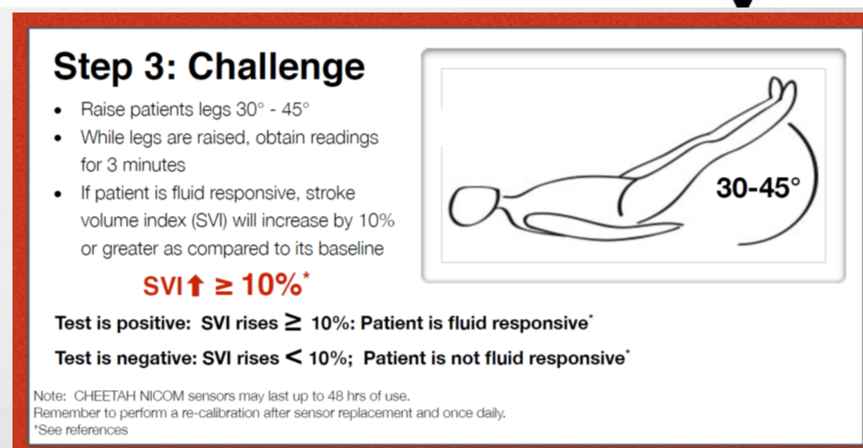
Meng et al. Anesth Analg 2011:113;751

# FloTrac-Vigileo:
# *Dynamic parameters*
# *May be more reliable*

- **Pulse pressure variation [PPV]**
- **IV fluid challenge**
- **Passive leg raise test**

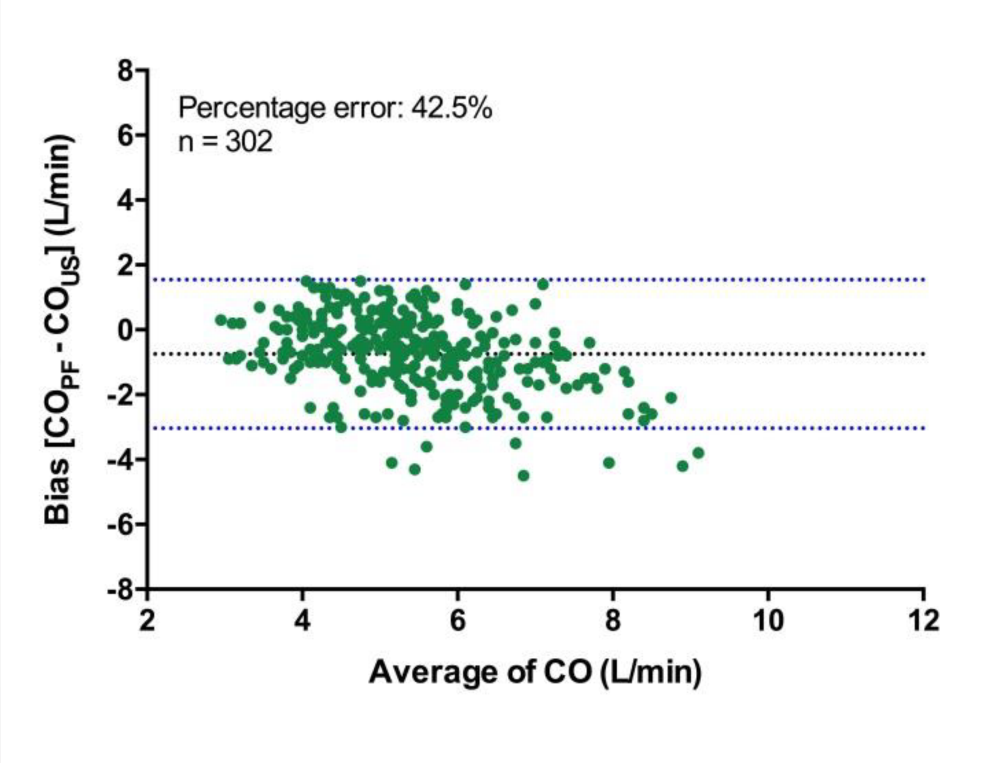


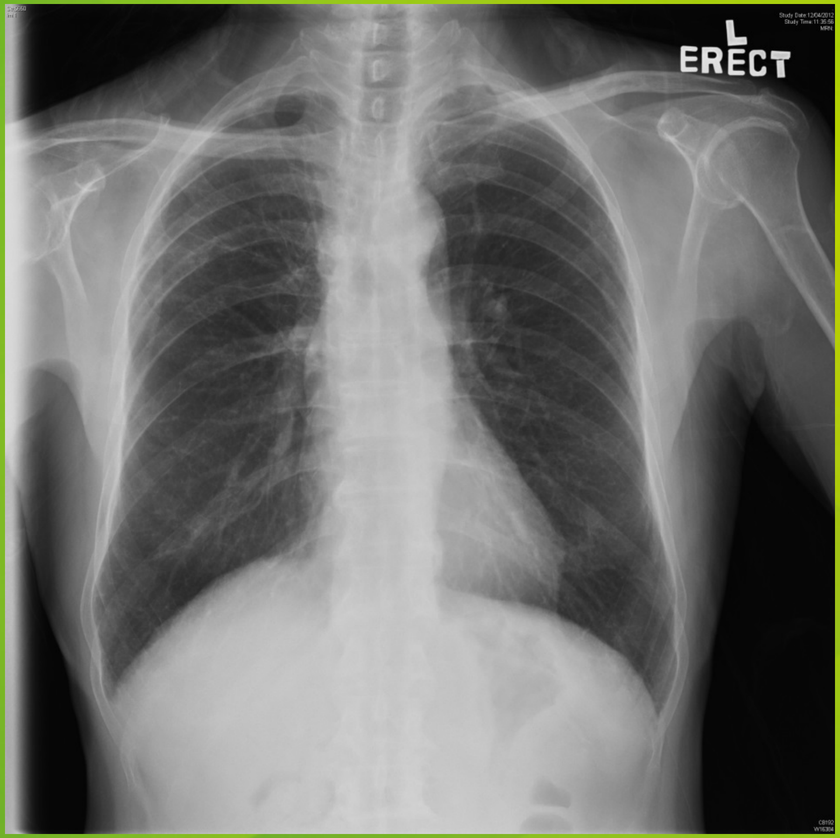
# Validation studies: BioImpedance systems:

- **Not accurate in studies (c.f. pulse contour)**
  - **Calibrated using patient demographic**
  - **Assumptions about "volume of electrically participating tissue"**



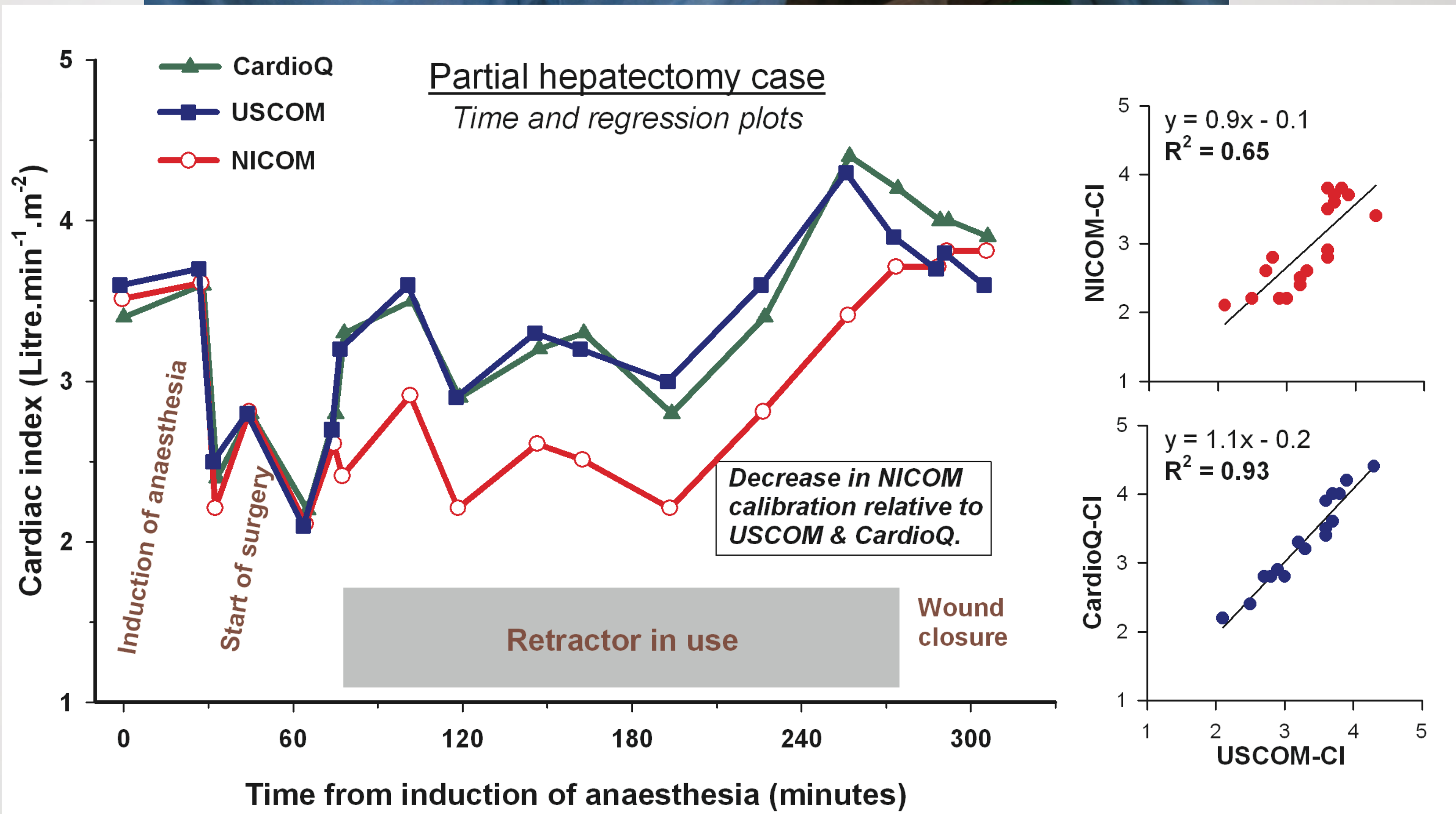
# Pathway of electrical flux:
# *Volume of electrically participating tissue*
# *Not a homogenously perfused thorax!!!*

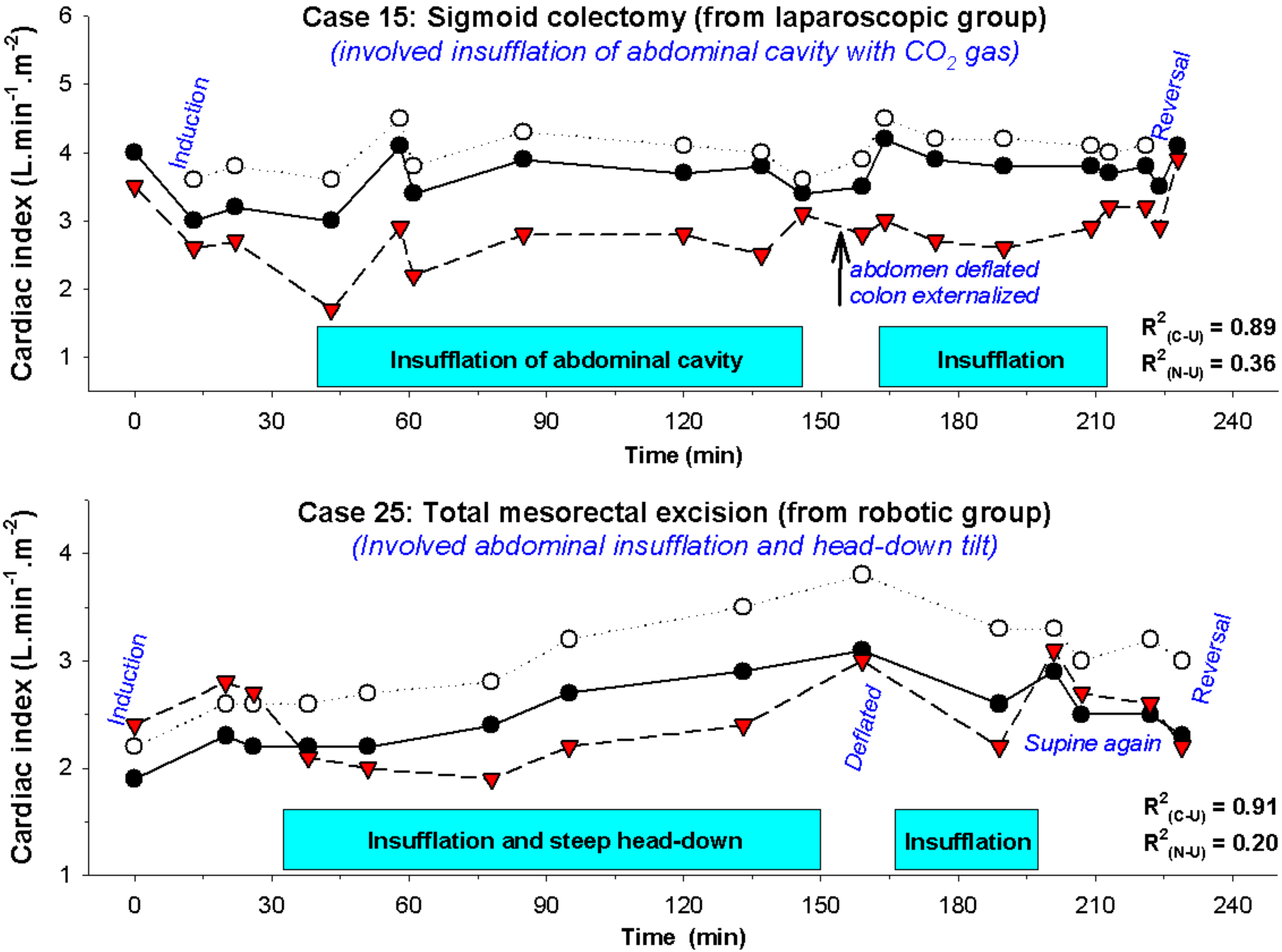
**PA chest X-ray**




**Electrical flux pathways**

# Liver resection open surgery case: *Effect of inserting large retractor*

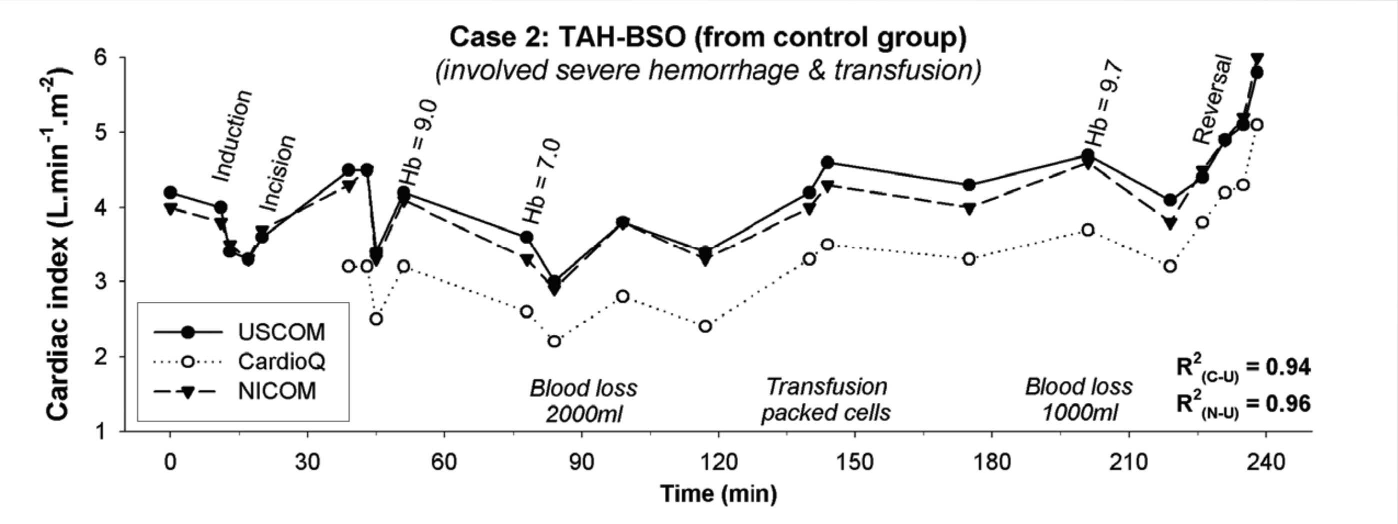




Case 15: Sigmoid colectomy (from laparoscopic group)
(involved insufflation of abdominal cavity with $CO_2$ gas)
Cardiac index (L.min$^{-1}$.m$^{-2}$)
Induction
Reversal
abdomen deflated
colon externalized
Insufflation of abdominal cavity
Insufflation
$R^2_{(C-U)}$ = 0.89
$R^2_{(N-U)}$ = 0.36
Time (min)
Case 25: Total mesorectal excision (from robotic group)
(Involved abdominal insufflation and head-down tilt)
Cardiac index (L.min$^{-1}$.m$^{-2}$)
Induction
Deflated
Supine again
Reversal
Insufflation and steep head-down
Insufflation
$R^2_{(C-U)}$ = 0.91
$R^2_{(N-U)}$ = 0.20
Time (min)

# Validation studies: BioImpedance systems:

- Does trend changes in CO reliably *most of the time* intra-operatively
  - NICOM Cheetah (Hung et al. Anesth Analg 2015:121;936
  - PhysioFlow (Zhang and Critchley [unpublished])
- Can be effected by factors that alter geometry of the upper abdomen.
  - Laparoscopy
  - Surgical retractors
- The Anaesthetist should be aware of these ill effects when using bioImpedance monitoring.



# Validation studies: Doppler systems (Accuracy)

- **In systematic reviews of Bland-Altman studies shown to lack accuracy.**
- **Due to calibration from population studies data that estimate aortic valve and descending thoracic aorta diameter.**

For Oesophageal Doppler **Percentage of Clinical Agreement** (PCA) used which approximate in comparative studies with TDco to a **percentage error of 40-50%**



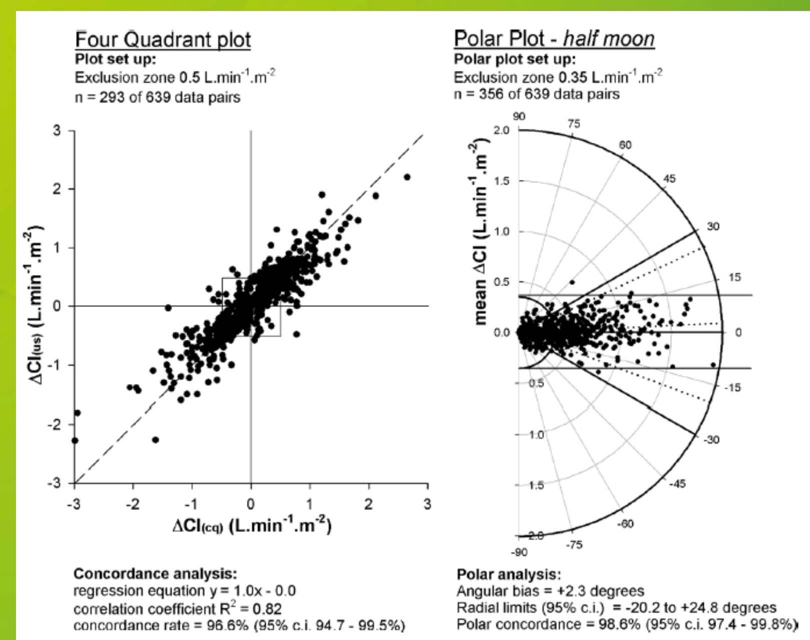
**Table 1** All studies identified in the review.

| Reference | Year | Population | Datasets | Bias $l.min^{-1}$ | Precision $l.min^{-1}$ | % Error |
|---|---|---|---|---|---|---|
| **Studies included in pooled weighted meta-analysis** | | | | | | |
| Boyle et al. [7] | 2009 | Cardiac surgery/ICU (CTX & general) | **78** | **−1.2** | **1.7** | **56*** |
| Thom et al. [5] | 2009 | ICU (tertiary unit) | **89** | **−0.09** | **1.47** | **51.7** |
| Corley et al. [9] | 2009 | Heart failure/pulmonary hypertension | **32** | **0.34** | **0.53** | **25.7** |
| Wong et al. [14] | 2008 | Liver transplant | **71** | **−0.39** | **0.93** | **25.6** |
| Su et al. [11] | 2008 | Liver transplant – overall results | 290 | 0.02 | 0.54 | 12.7 |
| | | After PAC insertion | **10** | **0.04** | **0.58** | **13.6** |
| | | 1 h after incision | 10 | 0.11 | 0.47 | 11 |
| | | 10–15 min before IVC clamping | 10 | −0.11 | 0.65 | 15.2 |
| | | 10–15 min after IVC clamping | 10 | 0.06 | 0.3 | 7.1 |
| | | 10–15 min before portal venous reperfusion | 10 | 0.23 | 0.35 | 8.2 |
| | | Within 3 min of portal venous reperfusion | 10 | 0.14 | 0.47 | 11 |
| | | 10 min after portal venous reperfusion | 10 | −0.05 | 0.40 | 9.3 |
| | | 10–15 min after hepatic artery perfusion | 10 | −0.02 | 0.51 | 11.9 |
| | | At end of biliary reconstruction | 10 | 0.04 | 0.58 | 13.5 |
| | | At end of surgery | 10 | 0.11 | 0.38 | 8.9 |
| Chand et al. [8] | 2006 | Postoperative cardiac surgery | | | | |
| | | Aortic window | **40** | **−0.14** | **0.79** | **33.4** |
| | | Pulmonary window | 45 | −0.03 | 0.55 | 23.1 |
| **Studies excluded from pooled weighted meta-analysis** | | | | | | |
| Knirsch et al. [10] | 2008 | Tertiary paediatric cardiology unit | 72 | 0.13 | 0.67 | 36.4* |
| Van den Oever et al. [13] | 2007 | Cardiac surgery | | | | |
| | | Aortic window: no selection | 20 | 0.79 | 1.43 | 62.3* |
| | | Aortic window: waveform score 6 | 16 | 0.82 | 1.43 | 62.3* |
| | | Aortic window: regular rhythm | 16 | 0.82 | 1.41 | 61.4* |
| | | Pulmonary window: no selection | 36 | 0.17 | 1.57 | 65.5* |
| | | Pulmonary window: waveform score 6 | 21 | 0.15 | 1.8 | 75.1* |
| | | Pulmonary window: regular rhythm | 29 | 0.21 | 1.55 | 64.6* |
| Arora et al. [6] | 2007 | Postoperative cardiac surgery | 120 | 0.13 | 0.36 | 15.1 |
| Tan et al. [12] | 2005 | ICU (tertiary CTX unit) | 40 | −0.18 | 0.82 | 35.7* |

Data for bias and precision included in the pooled weighted meta-analysis are indicated in bold.
*Cardiac output estimated from data.
ICU, intensive care unit; CTX, cardiothoracic; PAC, pulmonary artery catheter; IVC, inferior vena cava.

# Validation studies: Doppler systems (Trending)

- **Measures blood flow directly**
  - Calibration unlikely to change
  - Unlikely to be effected by Peripheral vascular changes
- **Shown to have good trending**
- **Very user dependent**
  - Signal detection needs to be correct and consistent
- **Effected by:**
  - Aging process and
  - aortic changes




Huang et al. J Clin Monit Comput 2016(In press)

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# Summary:

- Clinical need for MICOM in anaesthesia
  - Especially the management IV fluids in major surgery
- Since 2000 several different cardiac output measurement technologies have become available
- Most require disposables that adds to running costs
- Much controversy surrounding validation studies
  - Accuracy and Trending need to be assessed
- Currently, there is no ideal MICOM system for operating theatre use and one needs to know the pros and cons of each

# Thank you