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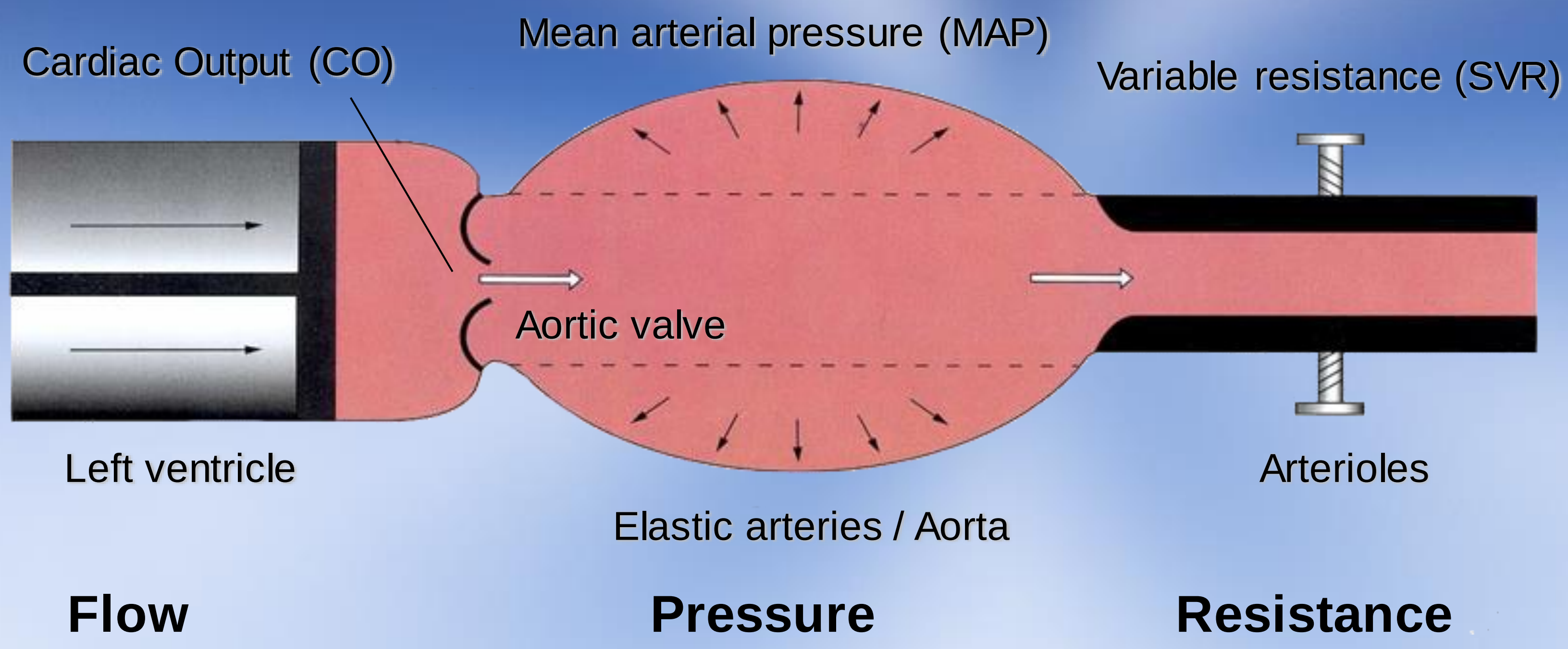
Impedance Cardiography (ICG)

Method, Technology and Validity

Hemodynamic Basics

Cardiovascular System



SVR = MAP / CO
MAP = CO x SVR
CO = MAP / SVR

Hemodynamic Basics

Parameters of Hemodynamics

Pressure

Blood Pressure (BP)

Force against vessel walls

Flow

Cardiac Output (CO)

Liters of blood pumped by heart in one minute

Resistance

Systemic Vascular Resistance (SVR)

Force that must be overcome to expel blood from the heart

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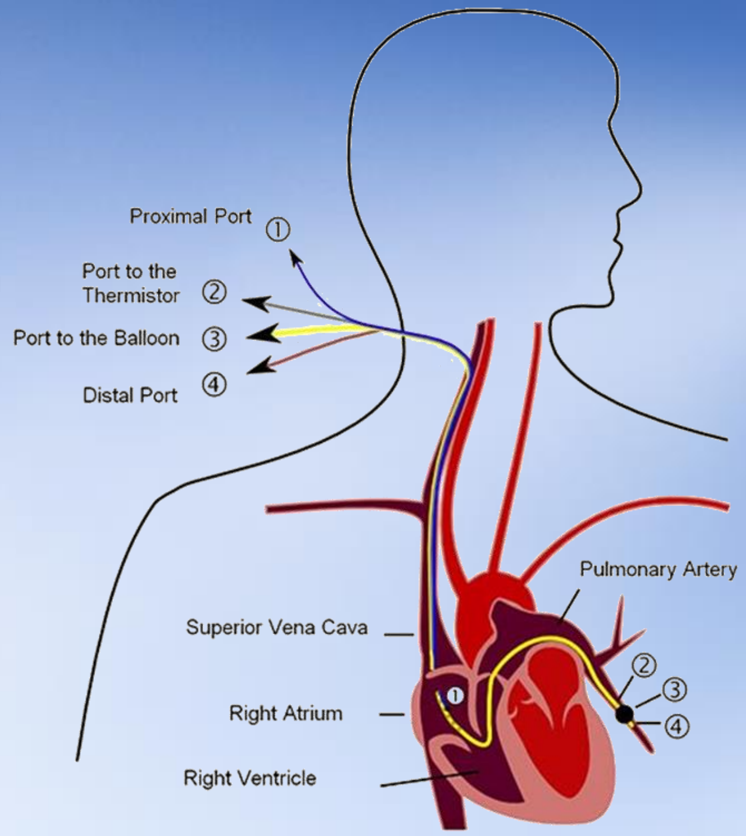
Thermodilution

Typical Invasive Hemodynamic Monitoring



Application:

- Pulmonary artery catheter (PAC)
- Bolus application with cold water (10°C, 5-10 ml) into right atrium
- Recording of temperature in the pulmonary artery

Problems:

- Highly invasive (risk of bleedings, thrombosis and ruptures)
- Non continuous
- Cost-intensive

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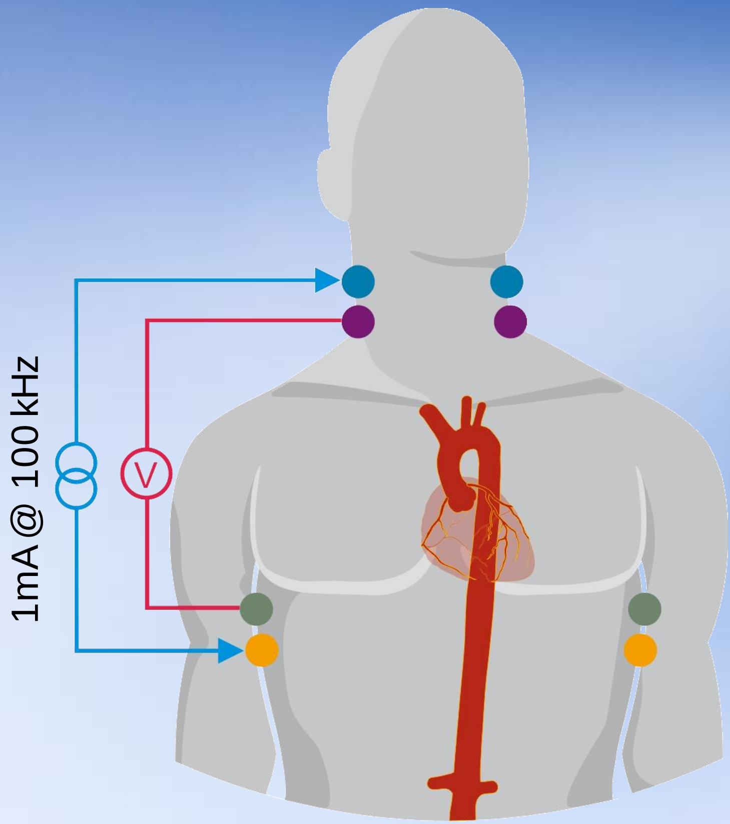
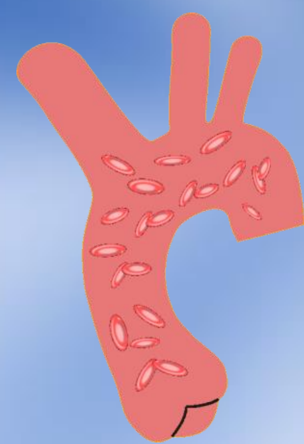
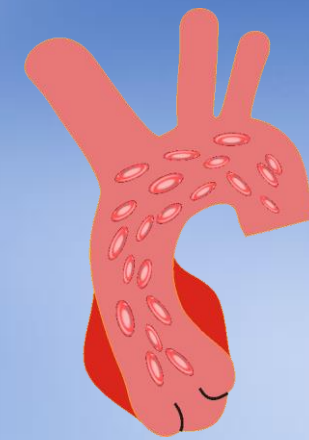
Non-invasive Beat-to-beat Hemodynamic Monitoring



Diastole



Systole



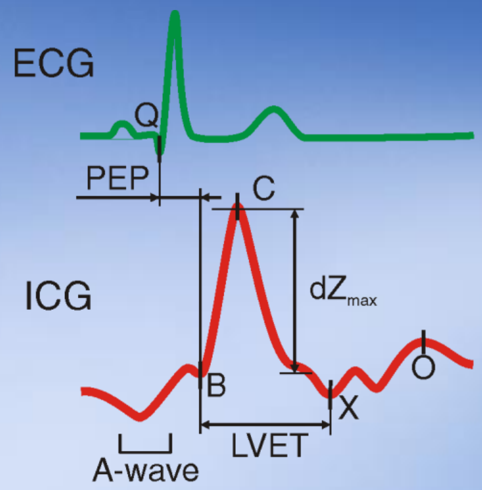
- Aortic valve is closed
- No blood flow in the aorta
- Red blood cells are orientated randomly

- Aortic valve opens
- Blood flow in the aorta (Windkessel function)
- Alignment of red blood cells

Sources of the measured impedance change

Impedance Cardiography (ICG)

ICG waveform and fiducial points



A-wave	-	Contraction of atrium
B	-	Opening of aortic valve
C	-	Max. systolic flow
X	-	Closing of aortic valve
O	-	Opening of mitral valve
PEP	-	Pre-Ejection Period
LVET	-	Left Ventricular Ejection Time
dZ_{max}	-	ICG Amplitude

- Automatic detection of fiducial points
- Calculation of hemodynamic parameters (e.g. Stroke Volume [SV], Cardiac Output [CO], Thoracic Fluid Content [TFC])

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Impedance Cardiography (ICG)

Equation for Stroke Volume Estimation

$$SV = V_{EPT} \cdot \frac{dZ_{max}}{Z_0} \cdot LVET$$

$$V_{EPT}(male) = \frac{(0.17 \cdot H)^3}{4.25} \cdot \frac{W}{0.524 \cdot H - 16.58}$$

$$V_{EPT}(female) = \frac{(0.17 \cdot H)^3}{4.25} \cdot \frac{W}{0.524 \cdot H - 26.58}$$

SV	Stroke Volume
V_{EPT}	Patient related parameter (depending on weight, height, gender, ACM)
dZ_{max}	Amplitude of the systolic wave of the ICG
Z_0	Base impedance (overall impedance of the thorax)
LVET	Left Ventricular Ejection Time: time interval between opening and closing of the aortic valve, validated by ACM [ms]
W	Weight of patient [kg]
H	Height of patient [cm]

Bernstein D.P., *Crit Care Med*, 1986

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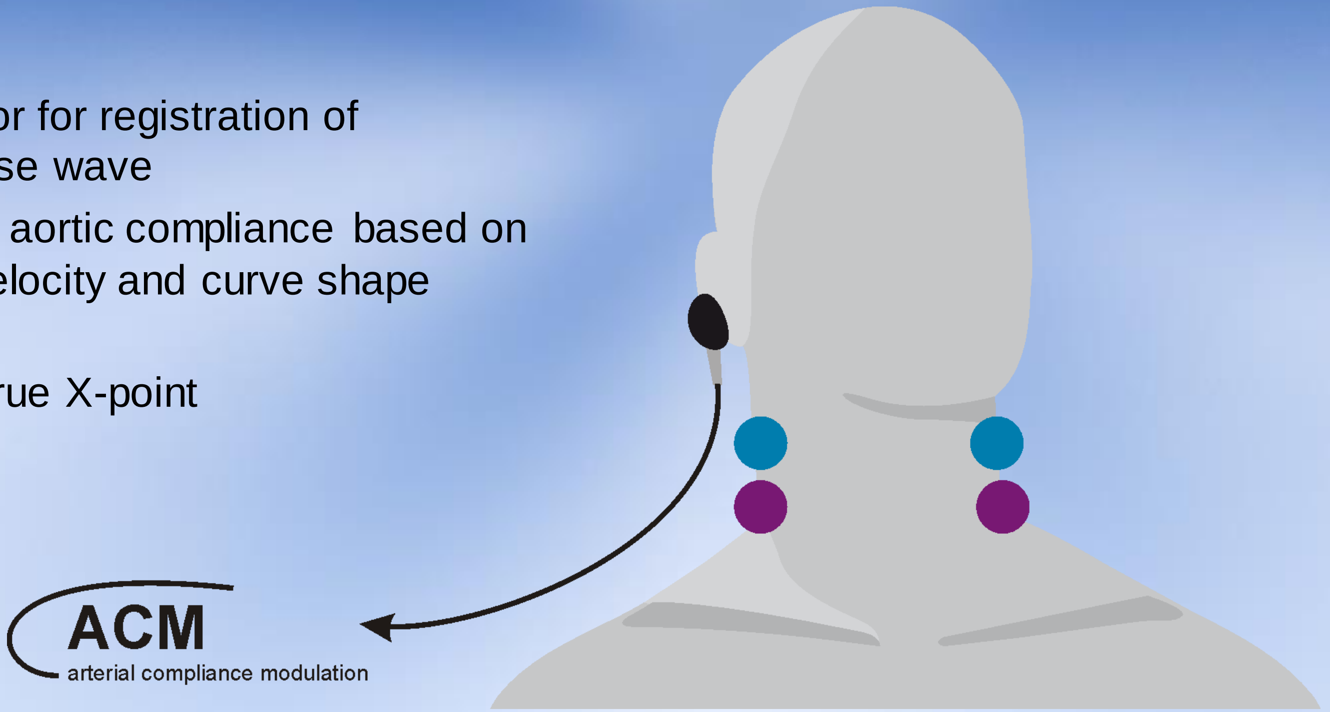
Impedance Cardiography (ICG)

ACM – Arterial Compliance Modulation

Latest ICG technology for higher accuracy

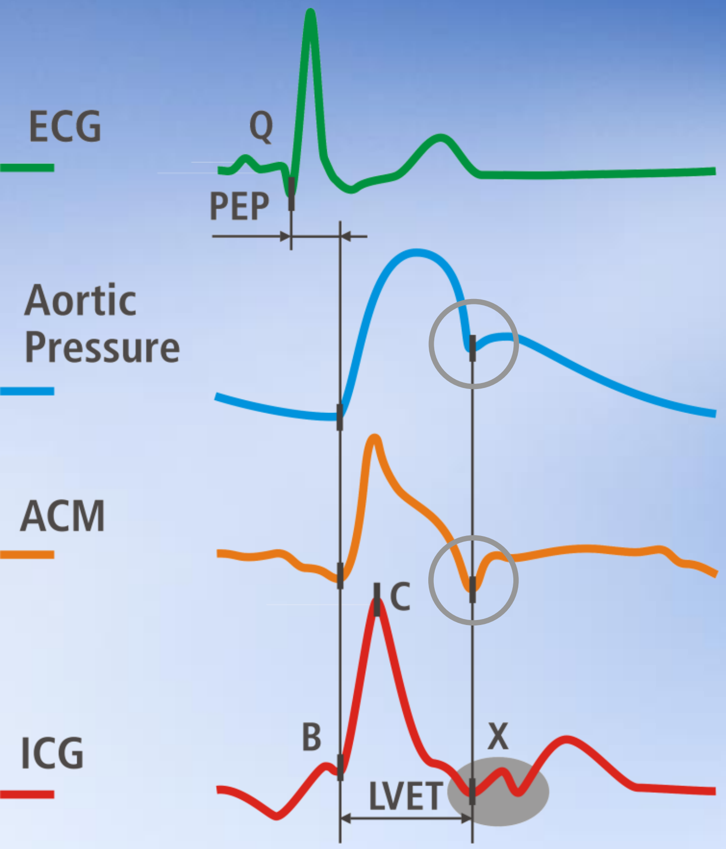
- Earlobe sensor for registration of peripheral pulse wave
- Calculation of aortic compliance based on pulse wave velocity and curve shape parameters
- Detection of true X-point



Impedance Cardiography (ICG)

ACM – Arterial Compliance Modulation

How does ACM work?



Invasive aortic pressure curve allows accurate detection of aortic valve closing

ACM curve clearly reflects the fiducial points of the aortic pressure curve and can be measured non-invasively

Based on ACM the true X-point in the ICG signal can be defined

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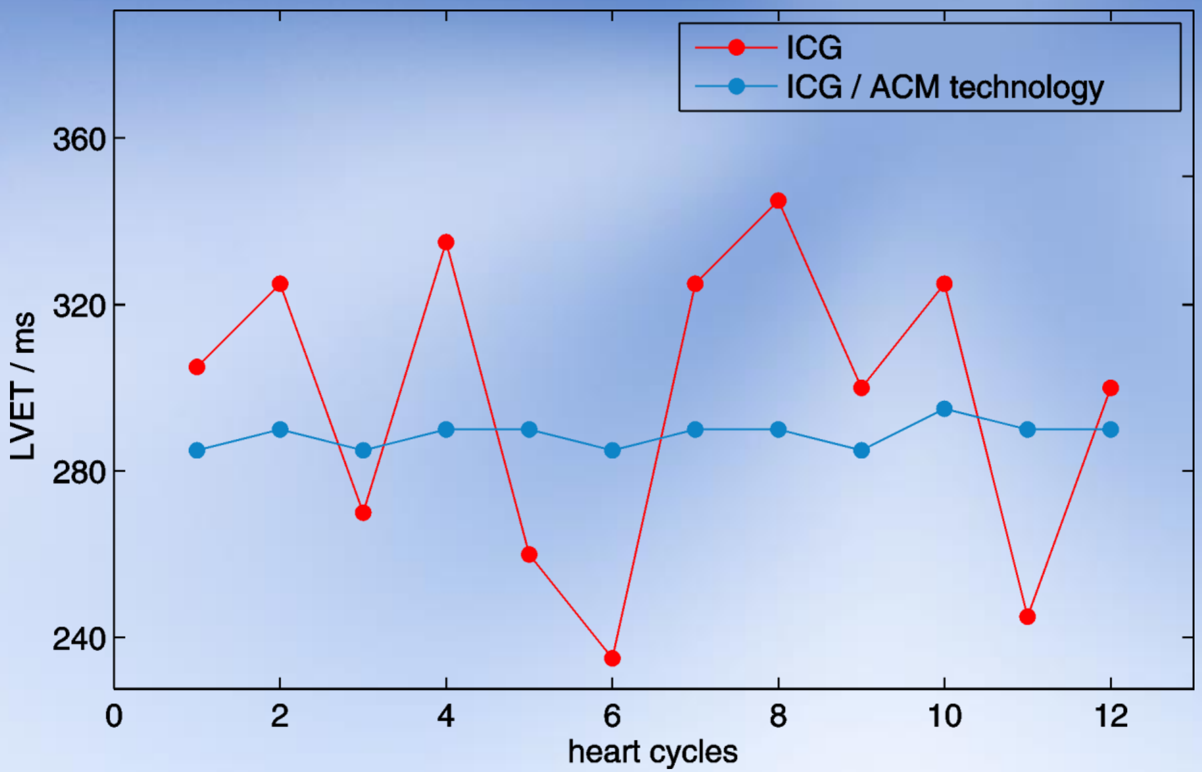
Impedance Cardiography (ICG)

ACM – Arterial Compliance Modulation

Result of ACM technology – stable and accurate LVET



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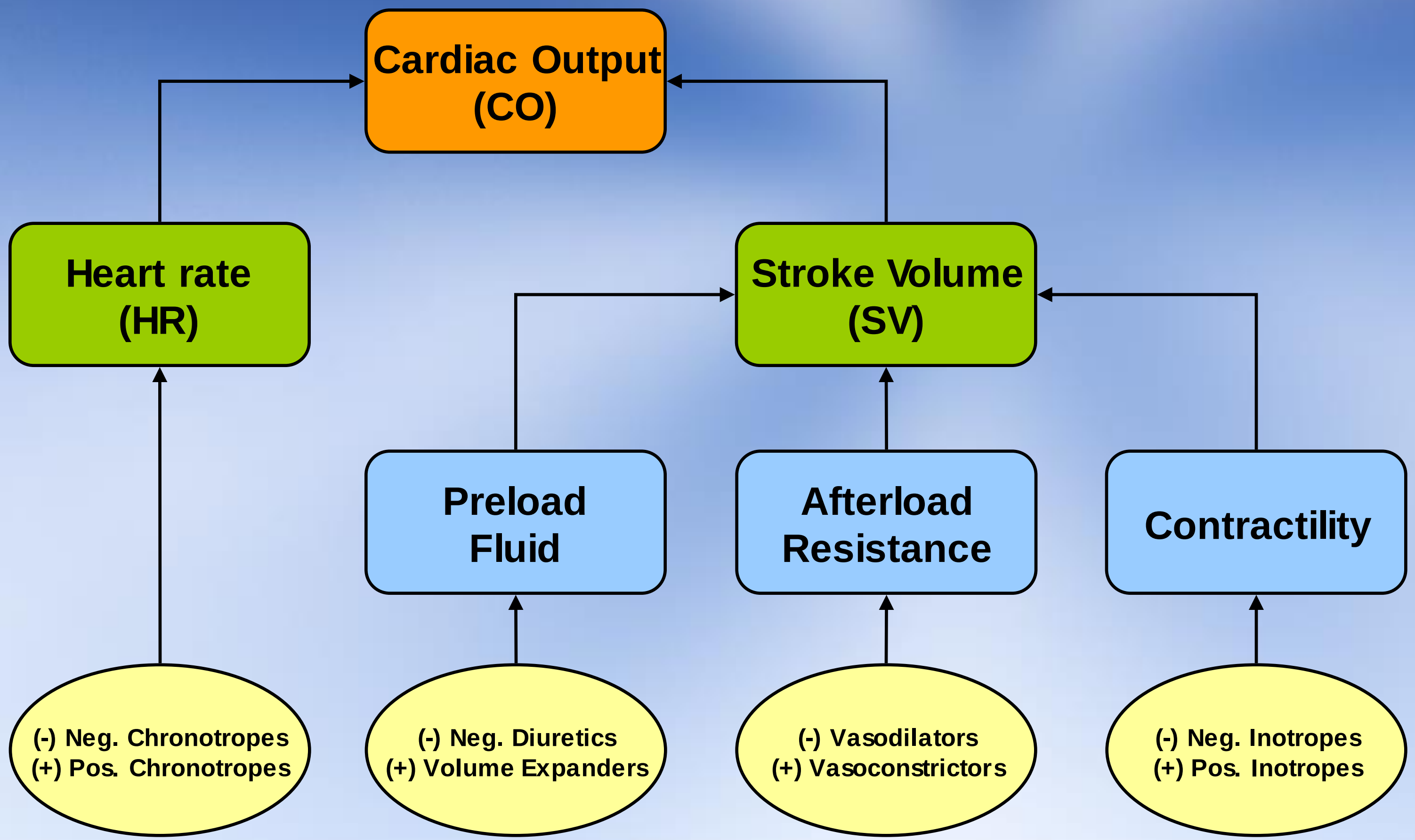
Impedance Cardiography (ICG)

ICG Hemodynamic Parameters

Flow	Stroke Volume / Index (SV / SI) Cardiac Output / Index (CO / CI)
Resistance	Systemic Vascular Resistance / Index (SVR / SVRI)
Contractility	Systolic Time Ratio (STR) Pre-ejection Period (PEP) LV Ejection Time (LVET) Velocity Index (VI) Acceleration Index (ACI)
Fluid	Thoracic Fluid Content (TFC)

Impedance Cardiography (ICG)

Hemodynamic Components and Implications for Treatment



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Impedance Cardiography (ICG)

Accuracy

Richard Summers, et al. / Academic Emergency Medicine, 2003

- Multicenter study including 680 patients comparing TD and ICG
- CO mean bias ± SD: -0.124 ± 0.75 (l/min)

Albert, et al. / America Journal of Critical Care, 2004

- Study including 29 patients with CHF comparing TD and ICG
- CO mean bias ± SD: -0.08 ± 0.26 (l/min) and correlation of r=0.89 to TD

Van de Water, et al. / Chest, 2003

- Study including 53 patients comparing TD and ICG
- CO mean bias ± SD: -0.18 ± 1.09 (l/min) and correlation of r=0.81 to TD

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Impedance Cardiography (ICG)

ICG Reproducibility

N = 96 stable outpatient cardiac rehab patients

"…highly reproducible on same-day…show device sensitivity to normal hemodynamic changes on inter-day measurements...provides a baseline for objective determination of responses to therapeutic interventions."

Parameter	Day 1 vs. Day 2	
	95% conf. int.	Variability (%)
SI	39.9 – 44.3	± 5%
CI	2.7 – 3.0	± 6%
VI	40 – 50	± 10%
SVRI	1921 – 2235	± 7%
TFC	32 – 34	± 3%

Verhoeve PE, et al. *J Card Fail.* 1998;4(3 suppl):53.

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Impedance Cardiography (ICG)

Reproducibility: ICG vs. Thermodilution (TD)

N = 52 post-CABG patients with 3 sequential TD and ICG measurements

"…superior intrapatient reproducibility compared with thermodilution via PAC."

	Comparison	Correlation (R value)	Stand. Dev. (l/min)
TD vs. TD	TD 2 vs. TD 1	0.83	1.02
	TD 3 vs. TD 2	0.84	1.01
	TD 3 vs. TD 1	0.83	1.07
ICG vs. ICG	ICG 2 vs. ICG 1	0.97	0.44
	ICG 3 vs. ICG 2	0.98	0.39
	ICG 3 vs. ICG 1	0.97	0.43

Van De Water JM, Miller TW. *Chest*. 2003;123(6): 2028-2033.

Impedance Cardiography (ICG)

ICG Limitations

Physical

- Height: between 1.20 m and 2.30 m
- Weight: between 30 kg and 155 kg
  (Note: No age limit, just height and weight)

Precautions

- HR > 250 bpm
- Septic shock (end stage sepsis)
- Severe aortic sclerosis
- Severe aortic valve regurgitation
- Extremely high blood pressure (MAP > 130)
- Cardiac arrhythmia
- Intra-aortic balloon pump

Impedance Cardiography (ICG)
Applications of ICG