

*3<sup>rd</sup> Healthcare Without Walls: Rehabilitation Conference*

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# **Impedance Cardiography: in a Community Heart Failure Service**

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# Heart Failure Nursing Service

- Service began 2004
- Community-based with hospital in-reach
- Area covers 500 000 population
- Current caseload 500 patients
- Nurse-led service
- 2 specialist nurses, 1 p/t physiotherapist and 1 secretary
- Access to exercise training classes, dieticians, clinical psychology and palliative care services

# Heart Failure Nursing Service

- Patient Outcomes
  - Reduced hospital admissions
  - Improved drug concordance
  - Reduced CVD risk factors
  - High patient satisfaction
- Other Outcomes
  - Cost-effectiveness
  - Research Active
  - Regular Publications
  - Innovative technologies

# Heart Failure Challenges

- Recognising unwell patients early
  - Fluid Retention
  - Reduced cardiac output
- Adjusting treatments to
  - Avoid complications
  - Produce optimal quality of life
  - Keep patients healthy at home
- Recognising end-stage heart failure



# Community Assessment

- History and Examination
- Clinician Experience
  
- Technology
  - Impedance Cardiograph (ICG)

# Using ICG in Heart Failure

- Problems of clinical assessment
  - Clinician skill/experience
  - Patient variability
  - Diagnostic accuracy of signs and symptoms
  - Confusing co-morbidities

# What is an ICG?

A non-invasive method of gaining real-time haemodynamic and cardiac contractility data on patients...

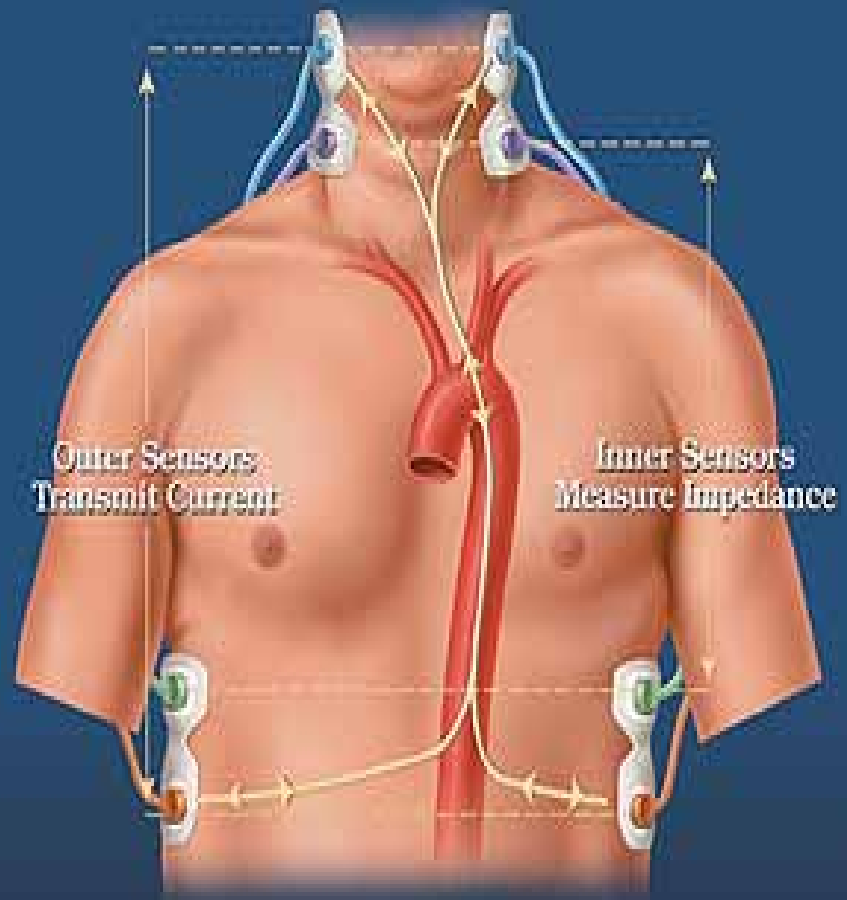
*...‘It’s a monitor’*

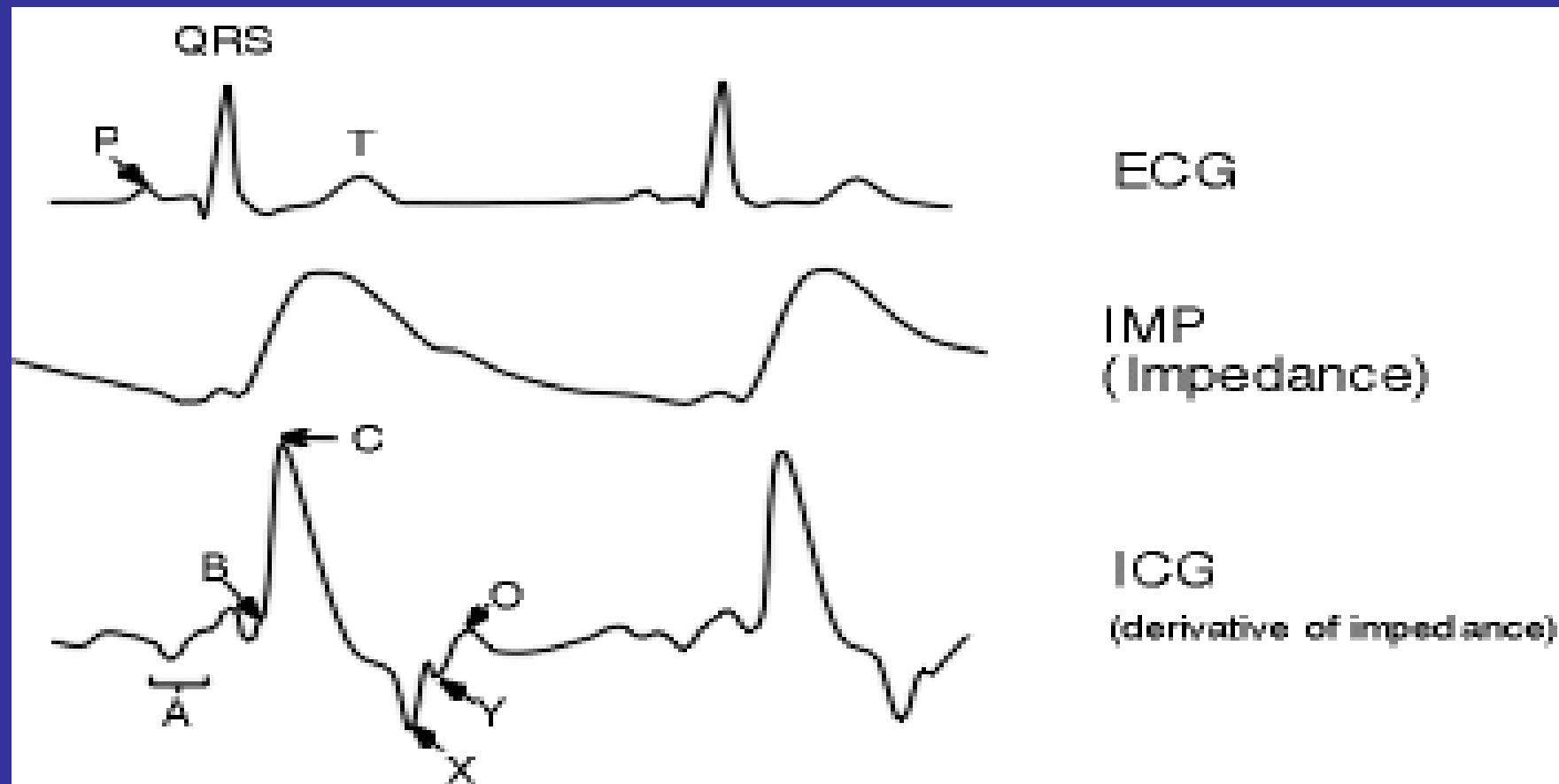
# Background



# How Does it Work?

- A small alternating current is transmitted through the chest.
- The current seeks the path of least resistance: the blood filled aorta.
- Baseline impedance to current is measured.
- Blood volume and velocity in aorta change with each heartbeat.
- Corresponding changes in impedance, tracked to the ECG, provide haemodynamic parameters.





- A: Contraction of atrium
- B: Opening of aortic valve
- C: Maximum flow from left ventricle into aorta
- X: Closing of aortic valve
- Y: Closing of pulmonic valve
- O: Widest open of mitral valve

**Figure 2. Signal curves from the Electrode Sensors**

# Stroke Volume

$$SV = V_{EPT} \cdot dZ_{max} / Z_0 \cdot LV ET$$

$V_{EPT}$  Volume of the thorax electrically participated  
(from weight, height, age and gender)

$dZ_{max}$  Systolic wave amplitude on ICG

$Z_0$  Base impedance

$LV ET$  Left ventricular ejection time

# 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)

# Accuracy

- Electrical Interference to signal quality
- Aortic regurgitation
- High mean arterial pressure
- Aortic prosthesis
- Large thoracic fluid volumes

# Checks

- Is the signal good quality?
- Is there a clear systolic wave?
- Is the TFC too high ( $>65\text{k}\Omega\text{m}^{-1}$ ) or the  $Z_0$  too low ( $<15\ \Omega\text{ms}$ )?
- **Does the readings fit with the clinical impression?**

# Safety

- Tiny AC current not felt by patient
- Electrode skin reaction very rare
- Caution in pacemaker dependent patients

# Evidence Base

- Inpatient precision of cardiac output (CO) calculated by ICG better than that by thermo dilution through pulmonary artery catheter<sup>1</sup>.
- TFC may predict pulmonary fluid earlier than visible on CXR<sup>2</sup>.
- Reproducibility of measurements good<sup>3</sup>.

<sup>1</sup>Van de Water, 2005; <sup>2</sup>Peacock, 2000; <sup>3</sup>Greenburg et al., 2000

# Clinical Profiles of Heart Failure

## Wet/Dry and Cold/Warm

		Congestion (“Wet”)?		
		NO	YES	
Adequate Perfusion (“Cold”) ?	YES	<b>A</b> Warm & Dry	<b>B</b> Warm & Wet	<b>Signs/Symptoms of Congestion</b> Orthopnea / PND JV Distension Hepatomegaly Edema Rales Abd-Jugular Reflex
	NO	(Low Profile) <b>L</b> Cold & Dry	(Complex) <b>C</b> Cold & Wet	
<b>Evidence of Low Perfusion</b>				
Narrow pulse pressure Sleepy / obtunded Low serum sodium		Cool extremities Hypotension with ACE inhibitor Renal/hepatic dysfunction		



**Prospective Evaluation and  
Identification of Cardiac  
Decompensation in Patients with Heart  
Failure by Impedance Cardiography  
Test (PREDICT)**

**Packer M, Abraham WT, Mehra MR, Yancy CW, et al.**

**Utility of Impedance Cardiography for the Identification of Short-Term Risk of Clinical Decompensation In Stable Patients With Chronic Heart Failure. *J Am Coll Cardiol.* 2006;47:2245-52.**

## **PREDICT: Background and Objective**

- Prior studies have shown the prognostic value of hemodynamics over periods too long to allow for immediate intervention to prevent an imminent clinical event
- Purpose of study was to assess the utility of ICG in predicting short-term clinical deterioration in ambulatory patients with HF
- The prespecified primary hypothesis was that changes in ICG variables combined into a composite score would predict the occurrence of a major clinical event

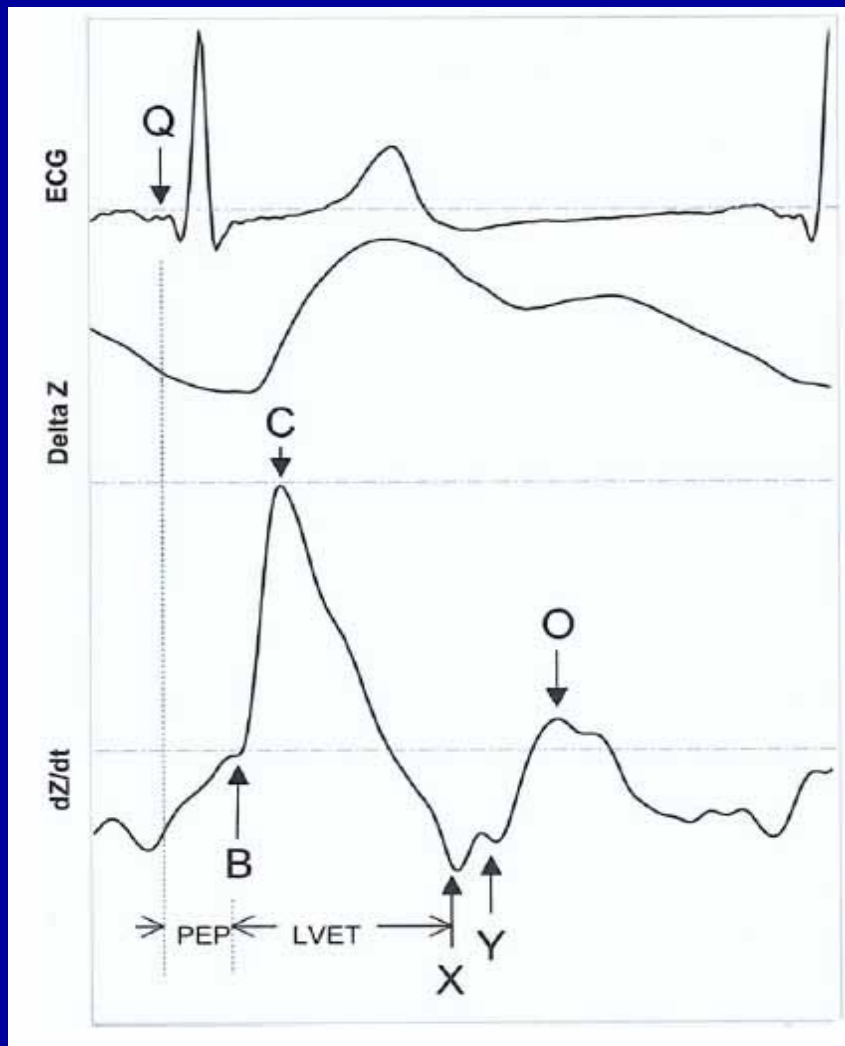
# PREDICT: Inclusion and Exclusion Criteria

- Men or women, aged 18 and over, NYHA Class II, III, or IV with chronic HF ? 2 months duration
- Emergency department visit, unscheduled clinic visit, or hospitalization for HF < 3 months
- Clinically stable, receiving medications for HF at doses considered appropriate
- Main exclusion criteria:
  - Height < 47" or > 91"; weight < 66 lbs or > 342 lbs
  - Hemodynamically significant aortic regurgitation
  - Myocarditis, cor pulmonale, hypertrophic/restrictive myopathies
  - Severe renal (Cr > 5 mg/dl) or liver disease (ALT, AST > 3X nl)
  - Planned CRT, LVAD therapy
  - Recent ACS, MI, sustained VT without ICD

# PREDICT: Baseline Characteristics

<u>Characteristic</u>	<u>Value</u>
N	212
Age	58.5 ± 14.7
Sex - male	145 (68.4%)
Race – white	132 (62.3%)
Race – black	74 (34.9%)
Ischemic etiology	98 (46.2%)
EF	27.1 ± 13.5
NYHA Classification	2.7 ± 0.5
Frequency	Class II 67 (31.6%)
	Class III 139 (65.9%)
	Class IV 6 (2.8%)
<u>Meds</u>	
ACEI or ARB	177 (83.5%)
BB	152 (71.7%)
Aldosterone antagonist	86 (40.6%)
Diuretic	203 (96.2%)

# PREDICT: Derivation of Independent ICG Predictor Variables



- **Thoracic fluid content index**
  - Inverse of baseline impedance, from which pulsatile change (delta Z) originates
- **Velocity index**
  - Maximum deflection of the first derivative of the impedance waveform (C)
- **Left ventricular ejection time**
  - Aortic valve opening (B) to closing (X)

# PREDICT: ICG Score Calculation

- The three independent ICG variables from multivariate analysis were combined into a single composite score
  - Higher thoracic fluid content index = higher risk
  - Lower velocity index = higher risk
  - Shorter left ventricular ejection time = higher risk
- Regression score created and translated to log of odds, probability for HF event, and score value
- Score scale, 0 to 10
  - Low risk = 0 to 3
  - Intermediate risk = 4 to 6
  - High risk = 7 to 10

# PREDICT Results: Hemodynamic Quadrants

High to Low  
Risk Quadrant

RR 7.0

p<0.0001

Thoracic Fluid Content (/kOhm)

≤ 35

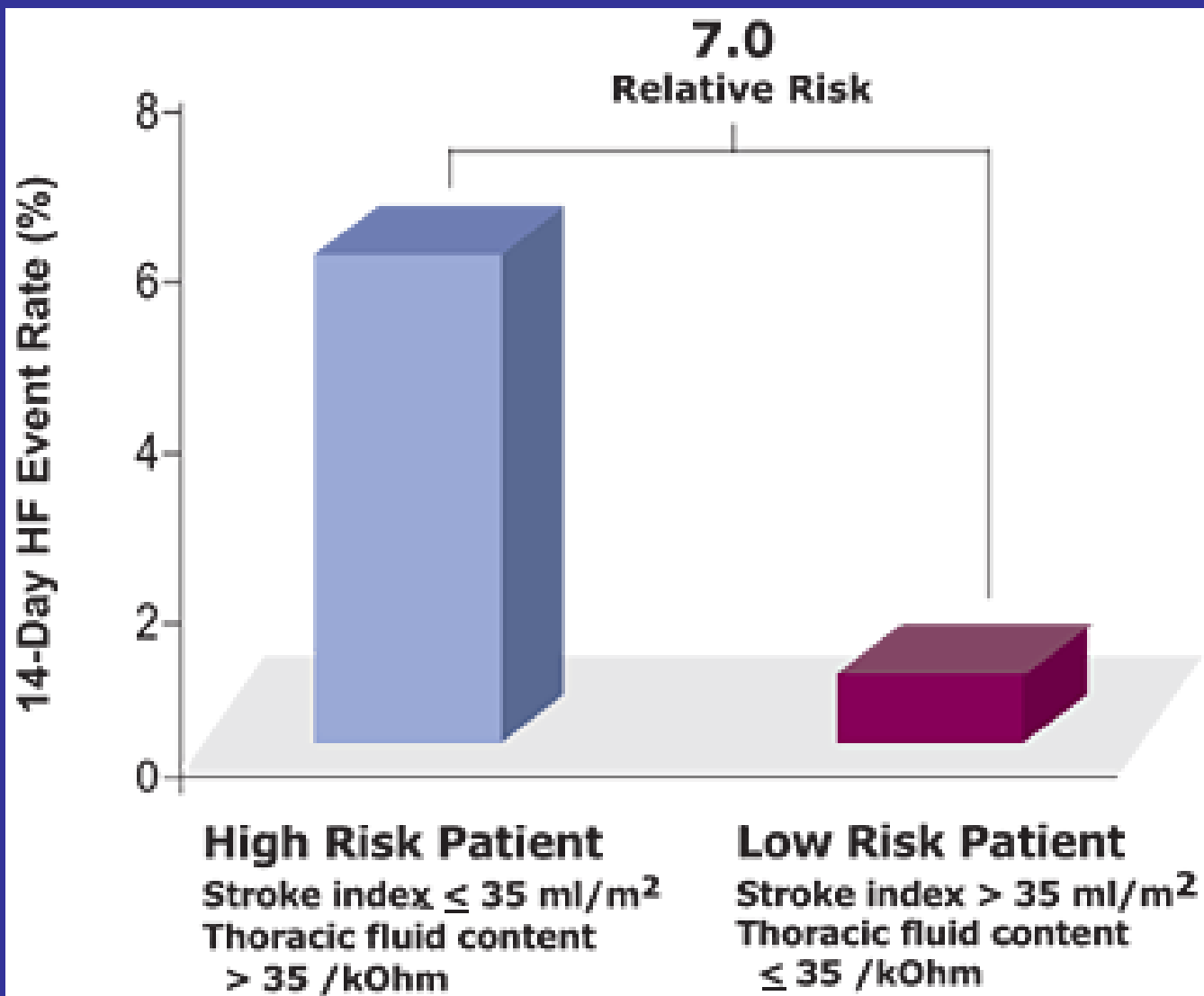
> 35

> 35  
Stroke Index  
(ml/m<sup>2</sup>)

≤ 35

<b>Low Risk</b> (6/649 visits) HF Event Rate <b>0.9%</b>	<b>Intermediate Risk</b> (11/365 visits) HF Event Rate <b>3.0%</b>
<b>Intermediate Risk</b> (31/855 visits) HF Event Rate <b>3.6%</b>	<b>High Risk</b> (29/447 visits) HF Event Rate <b>6.5%</b>

HF Event ≤ 14 Days



# Conclusions

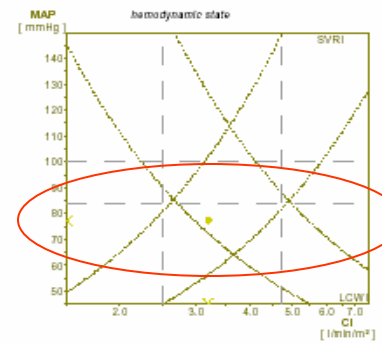
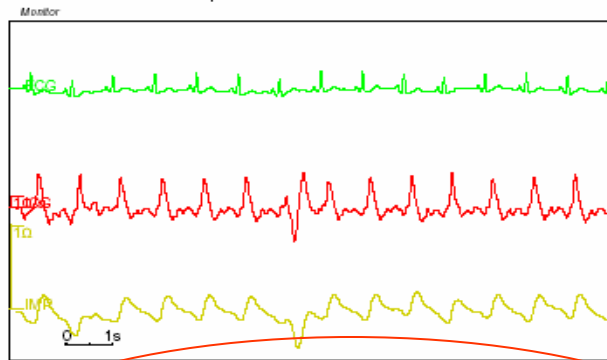
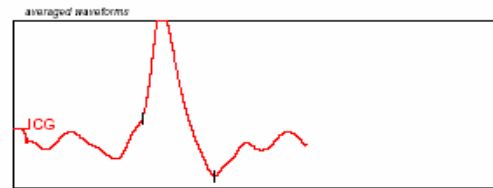
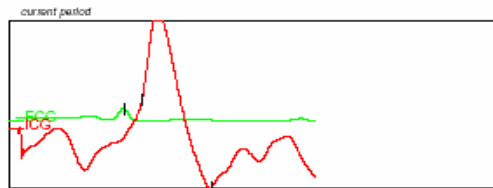
- The ICG composite score was the most powerful predictor of a short-term HF event in the study
  - True even when baseline characteristics, clinical variables, and changes in clinical variables were considered first
- Patients with a low stroke index and high thoracic fluid content identified those at seven-fold risk of a HF event within 14 days

# Case One: JN

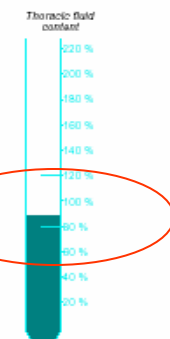
- Female. 51 years old.
- Ischaemic Dilated Cardiomyopathy (NSTEMI). CABG. Moderate-Severe LVSD.
- NYHA Class I. Asymptomatic except mild generalised fatigue.

<small>nicosmo® v1.0 © med. GmbH Germany (<a href="http://www.nicosmo.com">www.nicosmo.com</a>; <a href="http://www.med1.de">www.med1.de</a>)</small> <b>Impedance cardiography with cardioscreen 1000 20/09/2006 14:21</b>				Facility Name
[Redacted]			Pat-ID	498 205604
Date of Birth	Height	Weight	Gender	
11.4.1955	164 cm	60 kg	female	

ACI.....122 1/100/s <sup>2</sup>	LCWI.....3.2 kg*m/m <sup>2</sup>	SpO <sub>2</sub> .....%
CI.....3.19 l/min/m <sup>2</sup>	Load.....0 W	STR.....0.27
CO.....5.27 l/min	LVET.....286 ms	SV.....78.4 ml
CVP.....3 mmHg	MAP.....77 mmHg	SVR.....1126
DBP.....66 mmHg	O/C.....54 %	SVRI.....1860
DO <sub>2</sub> .....ml/min/m <sup>2</sup>	PAWP.....7 mmHg	TFC.....23.8 1/kOhm
ETR.....32 %	PEP.....77 ms	VI.....73.0 1/1000/s
Heather.....21.3 Ohm/s <sup>2</sup>	QI-ICG.....97 %	Z <sub>0</sub> .....42.0 Ohm
HR.....67 1/min	SBP.....100 mmHg	
LCW.....5.3 kg*m	SI.....47.5 ml/m <sup>2</sup>	



HR.....67 1/min	50	80
SV.....78.4 ml	57.9	107.3
CO.....5.27 l/min	4.13	8.94
CI.....3.19 l/min/m <sup>2</sup>	2.50	4.20
PEP.....77 ms	50	100
LVET.....286 ms	200	300
SVRI...1860	1000	2500



Notes:

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# Summary: JN

- SI > 35 ('Warm')
- TFC < 35 ('Dry')
  
- STABLE, LOW RISK
  
- Outcome... Still fine 2 years later; echo slight improvement to moderate LVSD

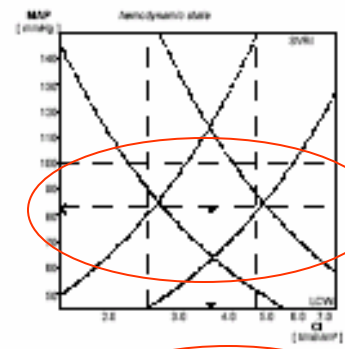
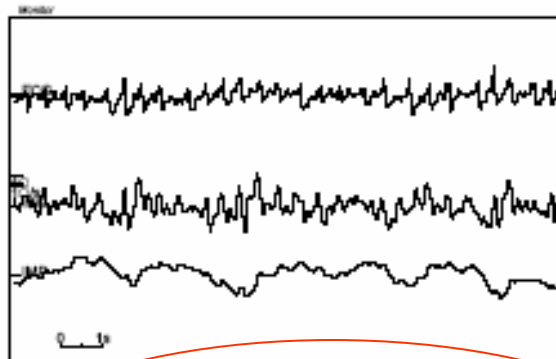
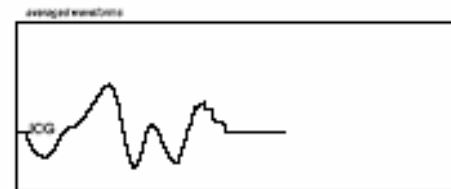
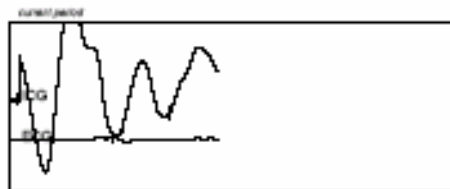
# Case Two: JP



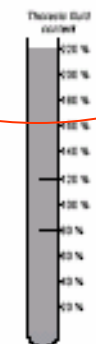
- Female. 82 years old.
- No cardiac history except hypertension.
- Calcium Channel Blocker started by GP for hypertension. Rapid onset SOB on exertion and SOA. CCB stopped.
- Sudden deterioration last week. Now SOB at rest, SOB++ on exertion, SOA++, PND, orthopnoea. GP increased diuretics and referred to HFSN.
- O/E: Obese, weeping SOA++ to knees, sacral oedema+, SOB at rest, hypotensive, tachycardic, irregularly irregular pulse.

<small>ACCOSON® VI 2 © Masimo, SIMON Software <a href="http://www.masimo.com">www.masimo.com</a> <a href="http://www.simon.ch">www.simon.ch</a></small> <b>Impedance cardiography with oadiscscreen 1000 18/12/2007 08:42</b>				Facility Name
Last name, first name		Pat. ID		
p [REDACTED]		nhs470909:		
Date of birth	Height	Weight	Gender	
4.9.1921	160 cm	80 kg	female	

ACI.....75 1/100W <sup>2</sup>	LCW.....3.9 kg*min <sup>2</sup>	SpO <sub>2</sub> .....%
CI.....3.62 l/min/m <sup>2</sup>	Load.....0 W	STR.....1.09
CO.....8.63 l/min	LVET.....195 ms	SV.....49.7 ml
CVP.....3 mmHg	MAP.....83 mmHg	SVR.....961
DBP.....78 mmHg	OVC.....99 %	SVRI.....1781
DO <sub>2</sub> .....ml/min/m <sup>2</sup>	PAWP.....7 mmHg	TFC.....59.5 1k/Ohm
ETR.....43 %	PEP.....212 ms	VI.....36.6 1/1000/s
Heather.....2.0 Ohm/s <sup>2</sup>	Q-ICG.....60 %	Za.....16.8 Ohm
HR.....133 1/min	SBP.....92 mmHg	
LCW.....7.2 kg*min	SI.....27.1 ml/m <sup>2</sup>	



HR.....133 1/min	50	150
SV.....49.7 ml	66.2	119.1
CO.....8.63 l/min	4.58	7.75
CI.....3.62 l/min/m <sup>2</sup>	2.58	4.25
PEP.....212 ms	50	100
LVET.....195 ms	200	300
SVRI.....1781	1800	2500



Notes:

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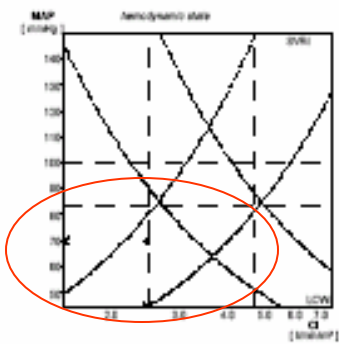
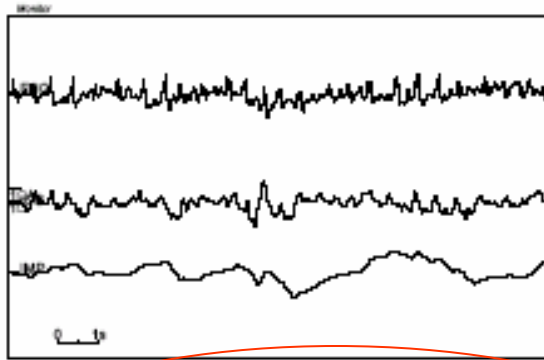
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<small>© 2006 Philips Medical Systems</small> <b>Impedance cardiography with cardiocreen 1000 21/12/2007 14:10</b>				Facility Name  
Patient ID nhs470909:			Date of Birth 4.9.1921	
Height 160 cm	Weight 80 kg	Gender female		

ACI.....39 1/l00s <sup>2</sup>	LCWI.....2.2 kg <sup>3</sup> /min <sup>2</sup>	SpO <sub>2</sub> .....%
CI.....2.47 l/min/m <sup>2</sup>	Load.....0 W	STR.....0.90
CO.....4.53 l/min	LVET.....213 ms	SV.....40.3 ml
CVP.....3 mmHg	MAP.....70 mmHg	SVR.....1184
DBP.....80 mmHg	Ox.....107 %	SVRI.....2171
DO <sub>2</sub> i.....ml/min/m <sup>2</sup>	PAWP.....7 mmHg	TFC.....42.2 1/s/Ohm
ETR.....40 %	PEP.....191 ms	VI.....14.0 1/l000s
Heather.....1.7 Ohm/s <sup>2</sup>	Q1-ICG.....36 %	Za.....23.7 Ohm
HR.....112 l/min	SBP.....90 mmHg	
LCW.....4.1 kg <sup>3</sup> /m	SI.....22.0 ml/m <sup>2</sup>	



HR.....112 1/min	80	160
SV.....40.3 ml	80.0	150.1
CO.....4.53 l/min	4.00	7.25
CI.....2.47 l/min/m <sup>2</sup>	2.00	4.20
PEP.....191 ms	90	190
LVET.....213 ms	200	300
SVRI.....2171	1800	2500

Therapy goal  
 100 %  
 90 %  
 80 %  
 70 %  
 60 %  
 50 %  
 40 %  
 30 %  
 20 %  
 10 %

Notes:  
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# Summary: Using ICG in heart failure

1. Assessing unwell patients
  - Fluid Congestion
  - Poor Perfusion
2. Guiding treatment<sup>1</sup>
3. Prognostification<sup>2</sup>

# Summary: JP

- 1<sup>st</sup> Reading
  - SI < 35 ('Cold')
  - TFC > 35 ('Wet')
- 2<sup>nd</sup> Reading
  - SI < 35 ('Cold') ... *SI worse than 1st reading*
  - TFC > 35 ('Wet') ... *TFC improved from 1<sup>st</sup> reading*
- UNSTABLE, HIGH RISK

Outcome: BP dropped, acute renal failure, admission, death.

# Summary: Community ICG use in heart failure

## Advantages

- Portable
- Repeatable
- Non Invasive
- Easy to use
- Quick (ish)

## Disadvantages

- Initial Cost
- Ongoing electrode costs
- Information has to be interpreted

Thank You!