Heart Rate Variability: A Clinician's POV

Group 31

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Overview

Monitors from Siemens/Dräger

Cardiac and bedside monitors comparison

WHDs

Respiratory/hemodynamic monitoring

Relationship between parameters

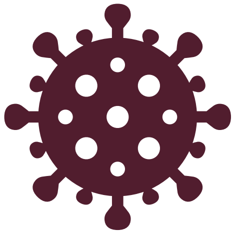
End users and testing criteria

Collaboration with clinicians and designers

Real-life: Covid-19

Share prices

… and more research



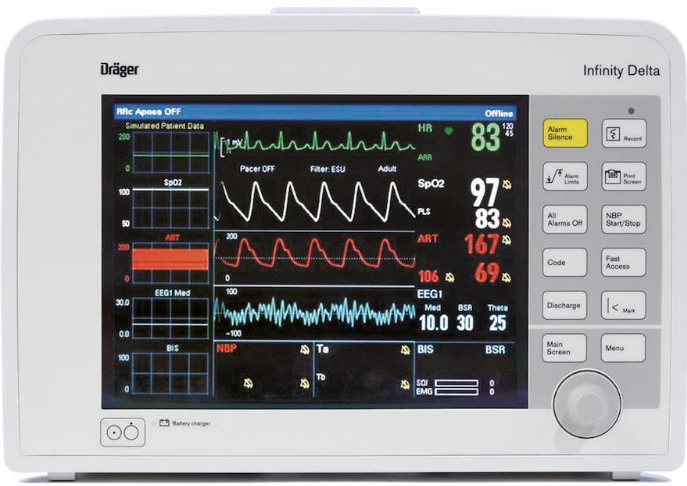
Siemens

ACUSON SC2000 PRIME Ultrasound System

- Echocardiography
- **Function:** Diagnosis for treatment of SHD (structural heart disease) patients
- **Features:**
    - Blood Flow visualization
    - Colour doppler for 4D volume imaging
    - Septal Guide
    - ESie Valves, Measure and LVA volume analysis
    - Real-time volume imaging
    - AI-powered measurements

Dräger

Infinity Delta and Delta XL Monitor



Function

- Constantly monitor adult, paediatric and neonatal patients at the bedside and during transport
- Used in: all hospital departments and acute care environments

Features

- Parameters: ECG, ST segment analysis, etCO2, BISx, EEG, Temperature, Blood pressure and arrhythmia
- Pick and Go technology
- Wired-to-wireless networking using Infinity network, Infinity CentralStation or Infinity OneNet

Types of Cardiac Monitors

	Holter	Event	MCT	TCAT3
Leads	5	2-3	3	4
Channels	3	1 or 2	2	2
Study Duration	24-48 hrs	3 - 30 days	3 - 30 days	3 - 30 days
Symptomatic Events	●	●	●	●
Auto Triggered Events (tachy, brady, pause, AF)		●	●	●
Immediate Data Delivery		◒	●	●
Full Disclosure Analysis	●			●
100% Beat AF Burden			◒	●
24/7/365 Monitoring	N/A	●	●	●

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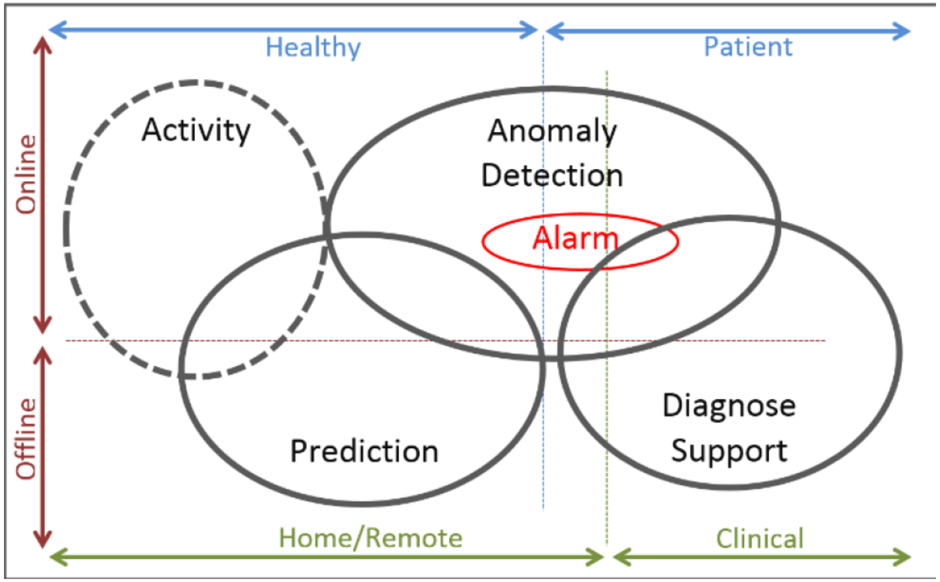
Bedside Monitor Comparison

CARESCAPE B850 Monitor (GE Healthcare)	IntelliVue X3 (Philips)
4 leads (I, II, III and V1)	2 leads (I and II) and configuring options
Fixed QRS sensitivity	Adjustable setting for QRS sensitivity
No ECG processing delay	0.7-1s ECG processing delay
Fixed 5s delay for asystole	Configurable 2-4s delay for asystole
Wait 5s after last detected beat to sound alarm	Filtering delay of 1s and waits up to 4s to alarm
No false asystole alarms	One false asystole alarms for every 210 monitoring hours
More false tachycardia alarms	More false ventricular tachycardia alarms

Wearable Health Devices (WHDs)

Functions:

- Self-health tracking of activity/fitness/sleep level
- Help clinicians in earlier diagnosis and guide treatment of patients
- Continuous real-time monitoring of vital signs during daily activities and outside the clinical environment
- Ambulatory monitoring for first responders
- Potentially to gather data in the military and space



Wearable Health Devices (WHDs)

Examples of some wearable health devices. (1)—SensoTRACK ear sensor; (2)—Google
Contact Lens; (3)—BioPatchTM; (4)—Smartwatch Basis PEAKTM; (5)—QardioCore; (6)—Vital Jacket®
t-shirt; (7)—Moov (activity tracker)

Benefits:

- Minimise discomfort and interference of daily activities
- Improvement of AF early detection
- Wireless communication or centralised data
- Patient monitoring in all environments
- Faster response during emergencies

Parameters monitored:

- Heart rate, blood pressure, respiratory rate, blood oxygen saturation, capnography, stroke volume, ECG, glucose monitoring

Types:

- Glasses/contact lens, ear sensor, chest straps, adhesive patches, watch, t-shirt, ankle tracker

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Smartwatches

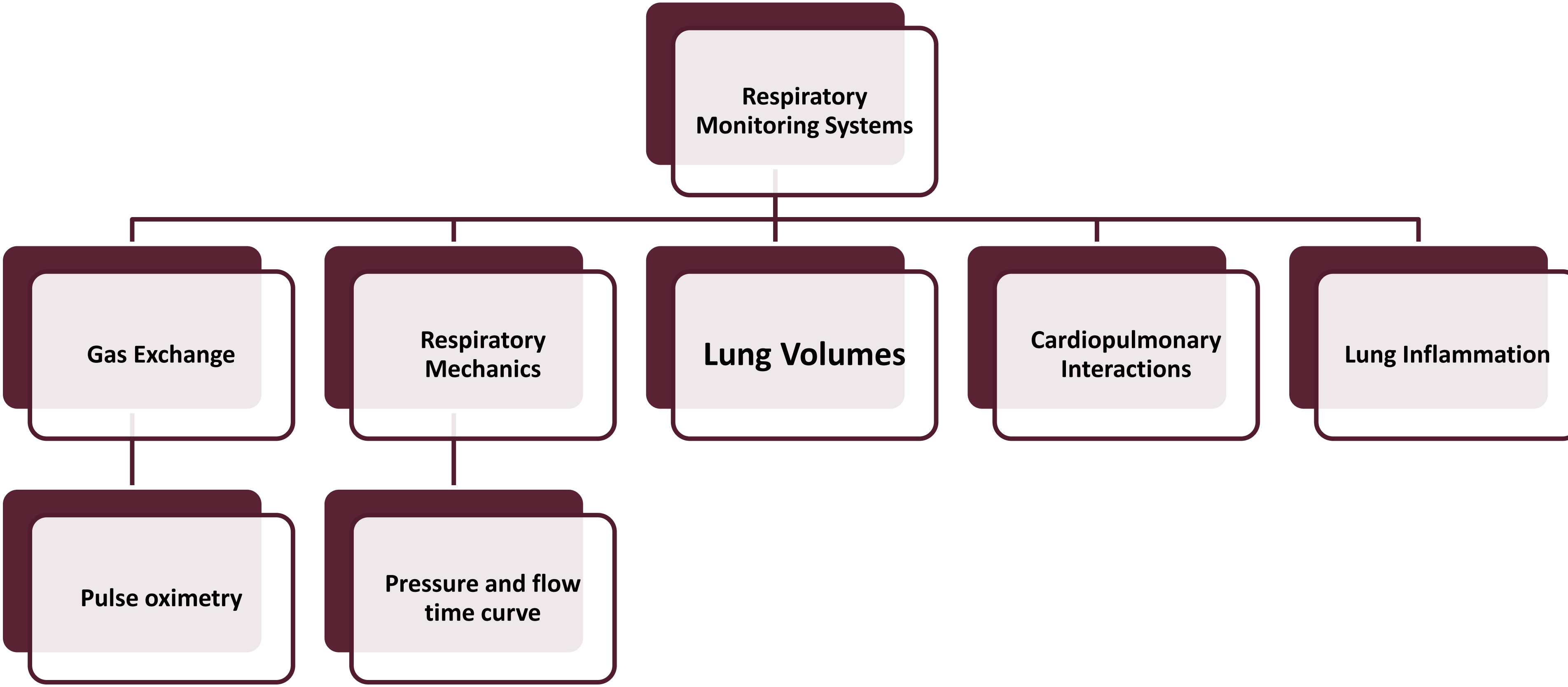
Apple Watch Series 4 (AW) vs Philips Page-Writer TC70 ECG machine

- Assess accuracy of the ECG interval measurements between 1 lead and 12 lead
- **AW technology**: green light-based photoplethysmography (PPG) and electrodes on the back and crown of the watch
- **AW ECG classification:** sinus rhythm, atrial fibrillation, low heart rate (sinus bradycardia), high heart rate and inconclusive
- 98.3% sensitivity and 99.6% specificity in detecting AF
- Study by *Saghir et al.* showed:
  - 100% concordance rate for automated sinus rhythm interpretation
  - No false positives of AF or high heart rate
  - Strong correlation in PR and QRS intervals
  - Moderate correlation in RR< QT and QTc intervals
  - AW is sensitive to movements and muscle contractions (noise)

Respiratory Monitoring in the ICU

Monitoring technique	Continuous versus intermittent	Specific situations	Potential usefulness	Limitations
Pulse oximetry	Continuous	All patients receiving MV	Detection of hypoxemia	
Ventilator pressures	Continuous	All patients receiving volume-controlled modes		Less reliable when patient is breathing actively
Ventilator traces	Continuous	All patients receiving MV		Clinicians need to learn how to read traces (no automatic detection)
Respiratory mechanics	Intermittent	Passive patients	ARDS, COPD	Less reliable when patient is awake
Pressure/volume curves	Intermittent	Passive patients	ARDS	Complex and need sedation and relatively homogeneous lungs
Work of breathing, pressure-time product	Intermittent	Respiratory distress, ventilator setting, weaning	Research	No automated measurement; needs esophageal pressure
Extravascular lung water	Intermittent	Pulmonary edema	Diagnosis of pulmonary edema	Complex and needs invasive devices
Lung volumes	Intermittent	ARDS	Could help to define risks of ventilation and assess recruitment	Need a passive patient
Electric impedance tomography	Continuous	ARDS	Could help to visualize regional ventilation	Needs a specific tool
Hemodynamic monitoring	Continuous or intermittent	Patients who have hemodynamic impairment and who are receiving MV	Helps to understand hypoxemia and its consequences	More or less invasive
Volumetric capnography	Continuous	ARDS		Complex analysis
Esophageal and transpulmonary pressure	Continuous or intermittent	ARDS	Could help to titrate ventilator pressures	Complex interpretation and difficult placement
Diaphragmatic electromyography	Continuous	Patients receiving assisted ventilation		Needs specific catheter, no absolute value

Respiratory Monitoring in the ICU



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Pulse Oximetry

- Widely used in anesthesiology and ICU
- Non-invasive and painless test that measures oxygen saturation in the blood

Oxygen Saturation %

Pulse rate (beats per minute)

Pulse Oximetry

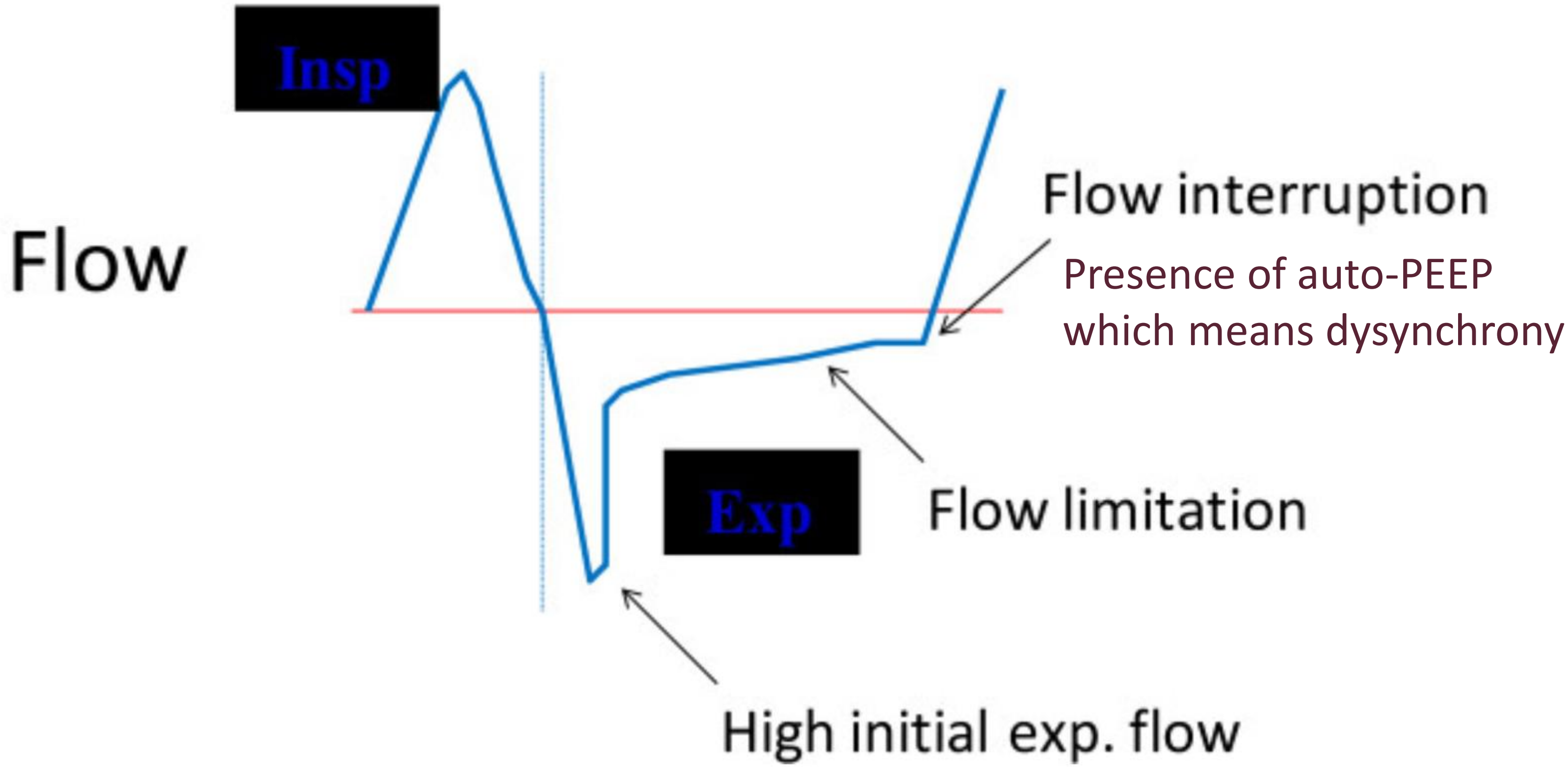
Intrinsic limitations?

1. Insensitive to changes in PaO_2 at high PaO_2 levels
2. Cannot distinguish between normal Hb and methemoglobin or carboxyHb
3. Slightly underestimate SaO_2 in darkly pigmented skin patients
4. Type of probe – accuracy better for finger than earlobe probes
5. False alarms common - PICU

Pulse Oximetry

- Should still be used to provide an early warning sign
- Beneficial for all patients receiving mechanical ventilation
- Detection of hypoxemia

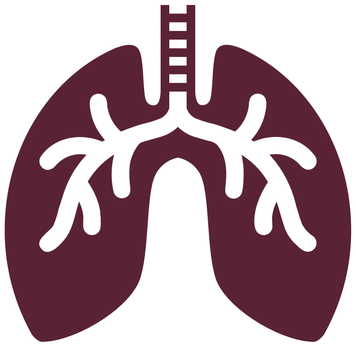
Pressure and Flow Time Curve Analysis



Dysynchrony

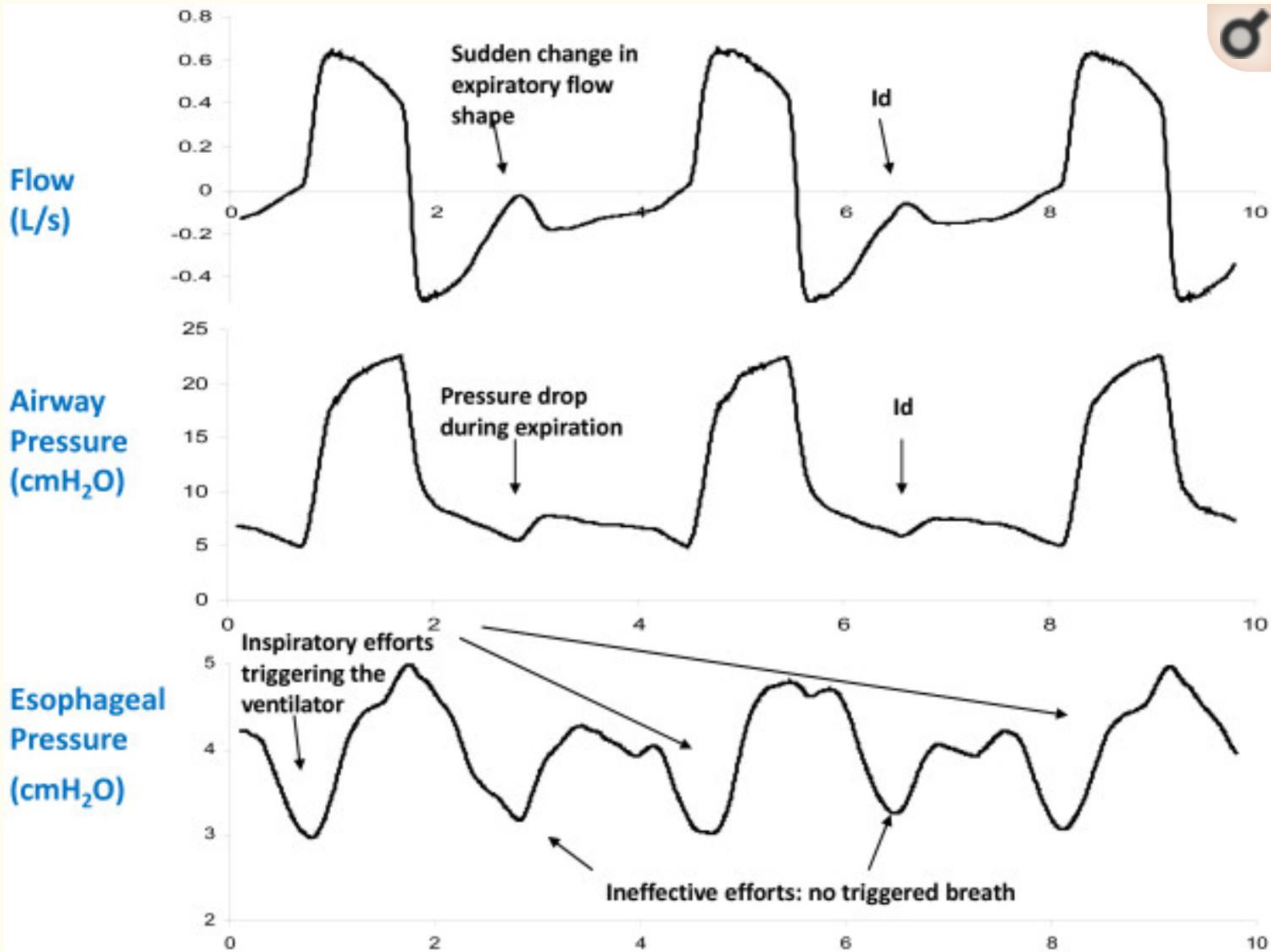
Caused by:

1. Poor or delayed ventilator triggering or cycling or both
2. Excessive levels of pressure support result in ineffective triggering



Important to recognize because:

1. Indicate dynamic hyperinflation
2. May lead to excessive ventilatory assistance
3. Induce delays in weaning from mechanical ventilation
4. Severe sleep disruption



Flow (L/s)
Sudden change in expiratory flow shape
Id
Airway Pressure (cmH_2O)
Pressure drop during expiration
Id
Esophageal Pressure (cmH_2O)
Inspiratory efforts triggering the ventilator
Ineffective efforts: no triggered breath

Respiratory Monitoring in Specific Situations

Acute Respiratory Distress Syndrome (ARDS)

- Oxygenation
- Dead space estimate
- Lung mechanics
- Monitoring of plateau pressure
- Esophageal pressure and lung volume measurements (for severe cases)

Chronic Obstructive Pulmonary Disease (COPD)

- Respiratory mechanics
- Plateau pressure
- Auto – PEEP
- Detection of asynchrony (when switched to triggered breaths)

Non-invasive Ventilation

- Start with full clinical assessment
- Pulse oximetry essential
- Transcutaneous capnometry to monitor alveolar ventilation
- Arterial blood gases
- Shock, measurement of blood lactate levels

Neurological dysfunction

- Pulmonary hyperventilation reduces ICP (short term management only)
- SjO2 or PbrO2 monitoring to evaluate O2 delivery
- Multimodal brain monitoring

Hemodynamic Monitoring in the ICU

Overview of monitoring methods.

Method	Examples of commercial name	Calibrated or not	Major advantages	Major disadvantages
Invasive methods				
Pulmonary artery catheter		Calibrated	Direct measurements in right atrium and pulmonary circulation	Delay in determining CO, most invasive, and risks involved
Less-invasive methods				
Transpulmonary thermodilution	PiCCO ® VolumeView ®/EV1000 ® LiDCO ®	Calibrated	Intermittent and continuous CO, added variables	Need for specialized arterial and central venous line, LIMITS (PiCCO ® system)
Ultrasound flow dilution	COstatus ®	Calibrated	Continuous CO, added variables, can detect intracardiac shunts	Requires AV loop
Pulse contour and pulse pressure variation	FloTrac ®/Vigileo ® ProAQT ®/Pulsioflex ® LiDCOrapid ®/pulseCO ® Most Care ®/PRAM	Non-calibrated	Continuous CO	Lack accuracy in unstable patients or during use of vasoactive drugs
Partial CO_2 -rebreathing	NiCO ®	Non-calibrated	No need for intravascular devices	Only in sedated patients under volume control ventilation, interference from pulmonary disease

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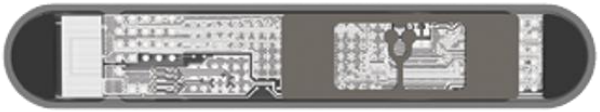
Hemodynamic Monitoring in the ICU

Transesophageal echocardiography		Operator dependent	Real-time images of the cardiac structures and blood flow	Learning curve, (low) risk of complications
Esophageal Doppler		Operator dependent	Real-time CO and afterload data, added variables	Risk of dislocation
Non-invasive methods				
Transthoracic echocardiography		Operator dependent	Direct measurement of CO and visualization of cardiac structures	Ultrasound characteristics often suboptimal in ICU patients
Non-invasive pulse contour systems	T-line ® ClearSight ®/Nexfin ®/ Physiocal ® CNAP ®/VERIFY ®	Non-calibrated	Non-invasive, simple tool	Less accurate, needs more validation
Bioimpedance		Non-calibrated	Simple tool, providing data concerning CO and fluid overload	Changes intrathoracic fluid content and SVR influence measurements
Estimated continuous cardiac output ®	esCCO ®	Non-calibrated	Uses widely available variable to estimate CO	Is only estimate, inadequate accuracy
Ultrasonic cardiac output monitoring ®	USCOM ®	Non-calibrated	Short learning curve and only few risks	Only estimate, uses standard valve areas which can differ

Invasiveness of Specific Monitors

Company	Product	Invasive?	Explanation
Abbott	CardioMEMS HF System	Yes	Implant sensor into PA
Medtronic	LINQ II Insertable Cardiac Monitor (ICM)	Yes	Implant under skin
Hill Rom	Connex Vital Signs Monitor	Presumably not	Wanded



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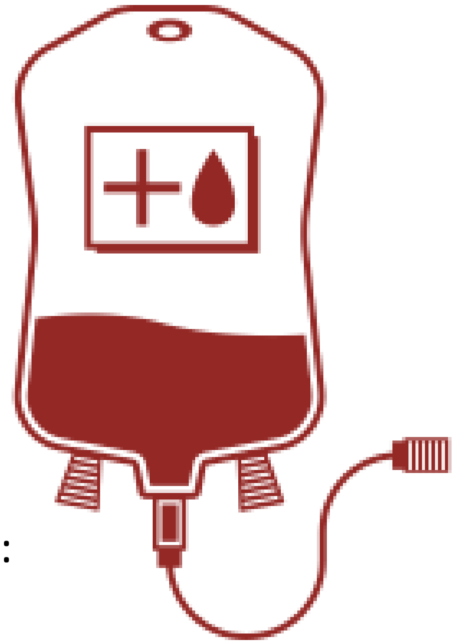
Invasiveness of Specific Monitors

Company	Product	Invasive?	Explanation
Philips Healthcare	IntelliVueMX750	Depends	Detector not included
Getinge	NICCI technology	No	Finger sensors
Omron	HeartGuide TM	No	Inflatable cuff

Hemodynamic Instability

- **Mismatch** between oxygen delivery and demand
- Often monitored by basic vital parameters:

I. Heart rate
II. Blood pressure
III. Central venous pressure (CVP)
IV. Peripheral and central oxygen saturation
V. Respiratory variables
VI. Urine output



BUT when these fail, increased need for hemodynamic monitoring:

I. Cardiac output (CO)
II. Pulmonary arterial occlusion pressure/wedge pressure
III. Pulmonary arterial pressure (PAP)
IV. Mixed venous oxygen saturation (SvO2)
V. Stroke volume variation (SVV)
VI. Extravascular water

Basics of Hemodynamic Monitoring

Fick principle:

$$CO = \frac{VO_2}{CaO_2 - CvO_2}$$

VO_2: Consumption of O_2
CaO_2: Arterial oxygen content
CvO_2: Mixed venous oxygen content

Transpulmonary thermodilution: the PiCCO system

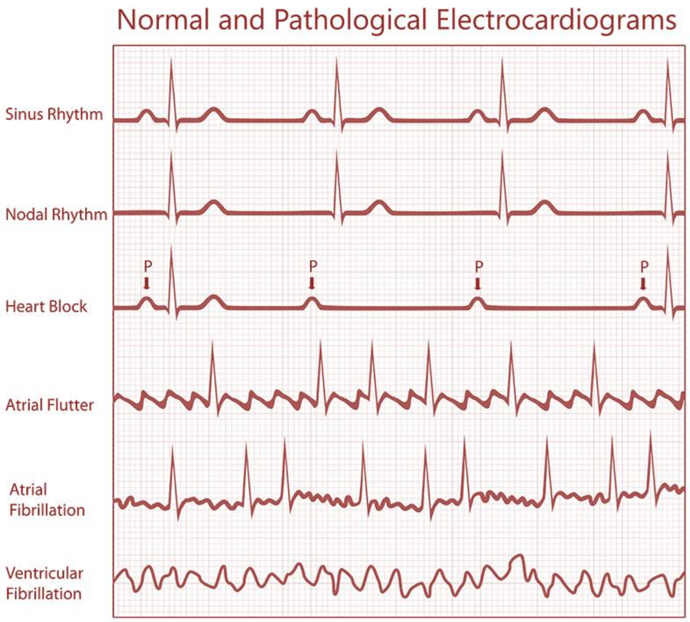
- Less invasive
- Calibrated technique and surrogate gold standard
- Provides intermittent and continuous CO measurement
- Uses an algorithm based on arterial pulse contour analysis – allow assessment of beat-to-beat variations of SV and CO
- SVV and PPV proposed as variables to guide fluid loading in ICU

Relationship Between Parameters

- **Common:** HR, RR, (NI)BP, CO, SpO2

$$CO = HR \times SV$$

- RR → SpO2, capnography
- ECG: BP/HR affecting heart's activity
  - Atrial flutter
  - Atrial/ventricular defibrillation



Who's Looking at the Monitors?

- Mainly ICU Nurses and occasionally doctors

Problems they experience:

- Alarm Fatigue
- Software-interpretation requires skill, overloaded with information
- Lack of standardisation

Standardization

No Standardisation in :

- Alarm sounds
- Display – colours, numbers or graphical representation
- Location of buttons

While many of these are common between various cardiorespiratory monitors there are differences which negatively impact the health care professional

Testing Criteria

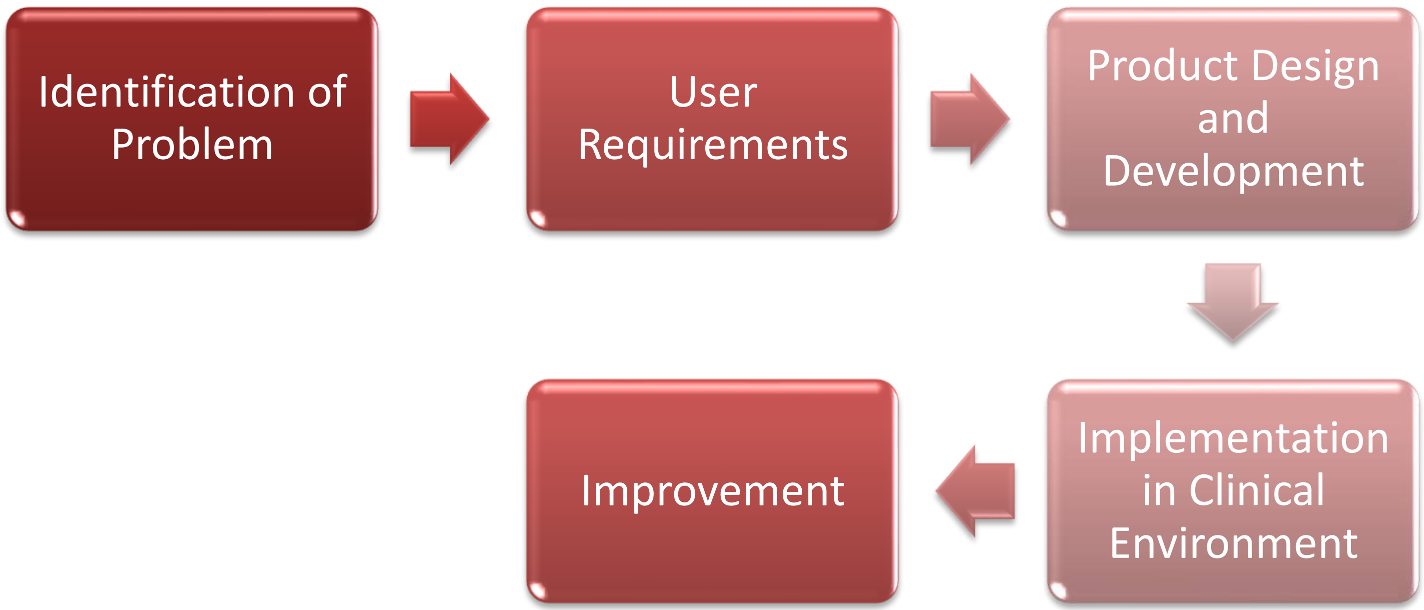
- 510 (K) - FDA Medical Device
- Pre-market Approval
- Class II or Class III

Testing:

1. Comparison testing
   - Safety and effectiveness
   - Worst case and normal conditions
   - Better or equal performance compared to predicate device
   - Intra- device variability
2. Accuracy of device for non-invasive blood pressure monitor must conform to intra-arterial reference standard
3. Electrical safety
4. Electromagnetic compatibility

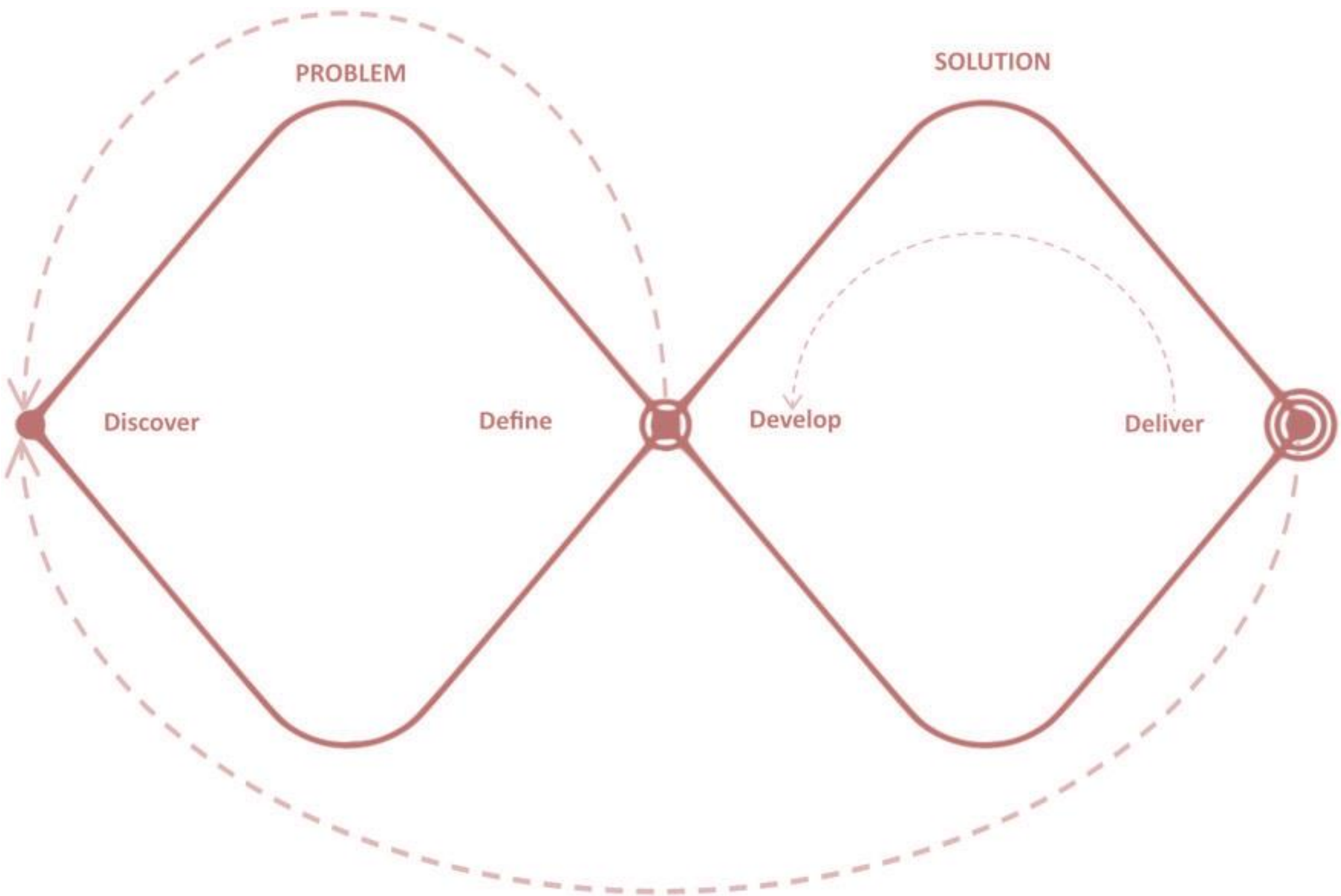
Collaboration Between Clinicians and Designers

Process:



Case studies: Innovation in Paediatric anal dilator design (2002) and Improving accessibility of patient-controlled analgesia (2012)

Design Methodology



Double Diamond Model (adapted from Clarkson (2016) and Design Council (2019))

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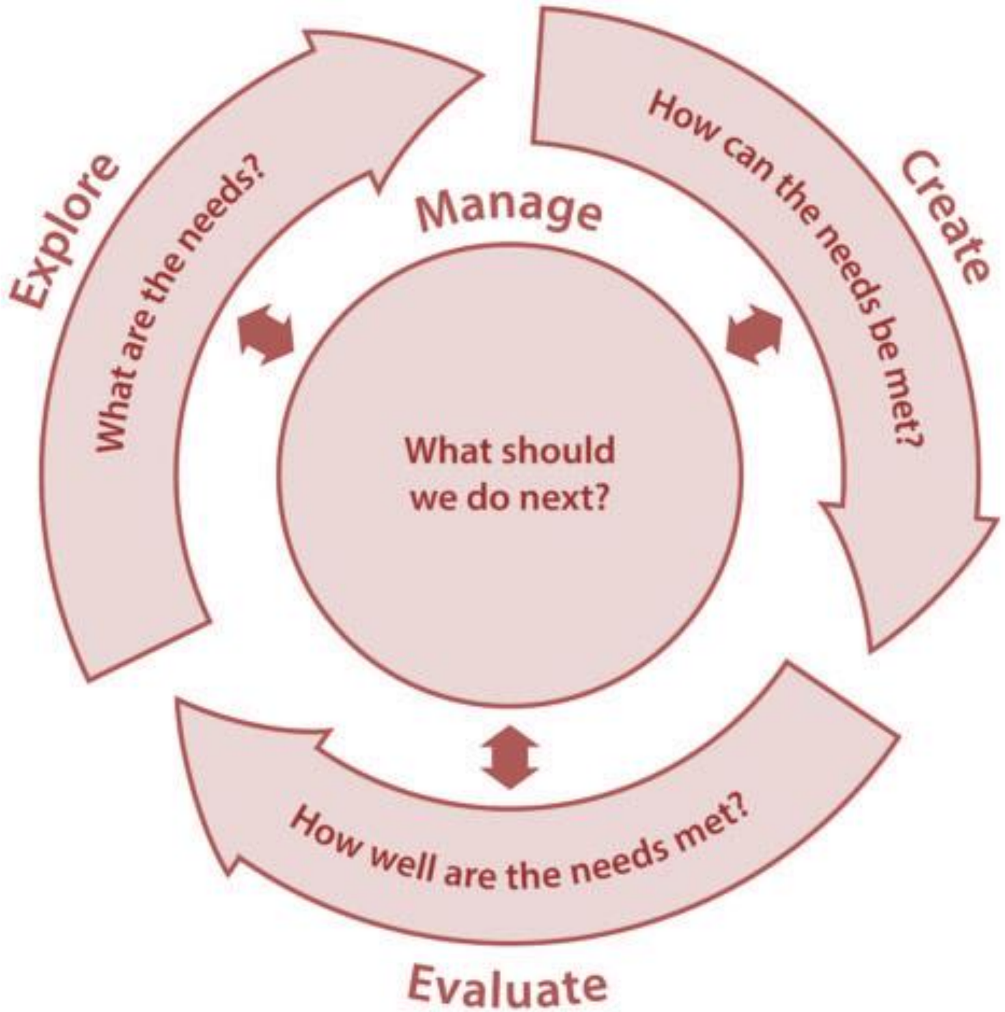
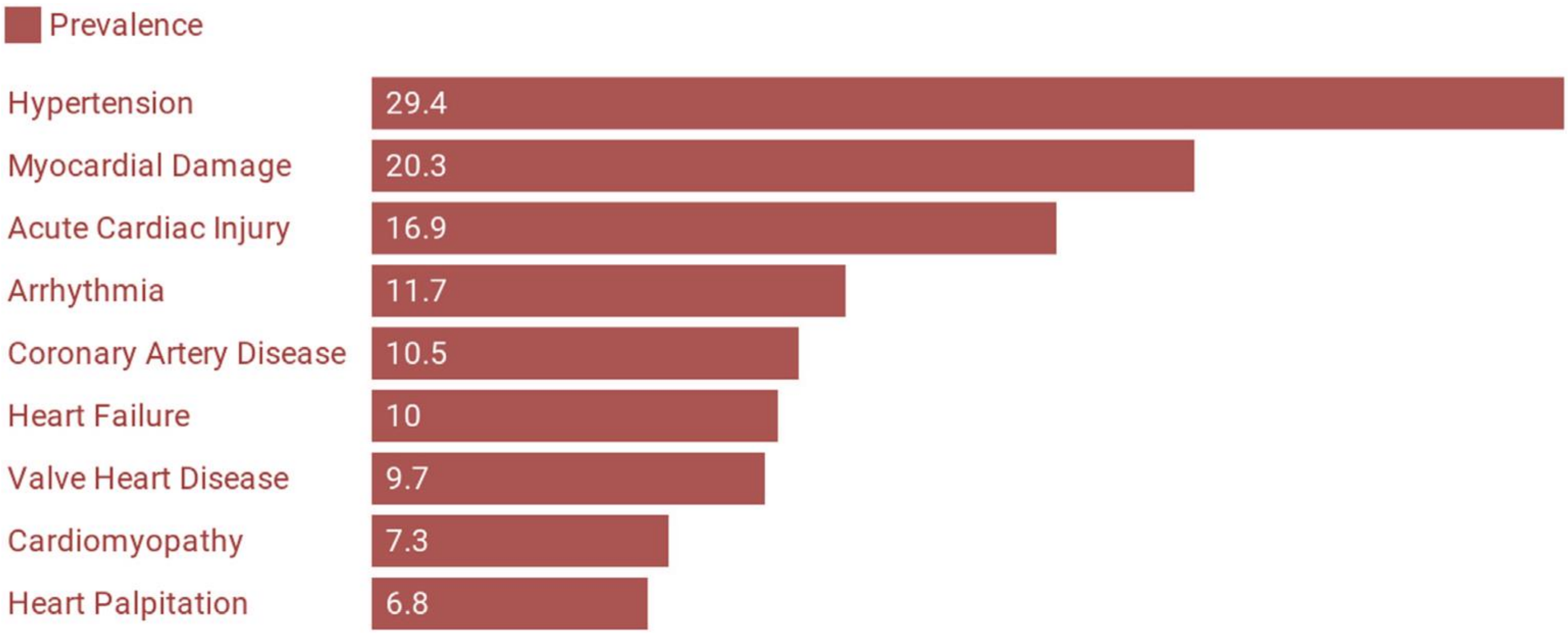
Design Methodology



Design wheel (Engineering Design Centre, University of Cambridge, 2007).

Real-life Monitoring: Covid-19

- SARS-CoV-2 infects patients by binding to ACE2.
- **ACE2** is mostly found in the lungs and is highly present in the heart.
- **High burden of CVDs among Covid-19 patients.**
- Existing CV diseases and further implications require hospitalisation and result in a worse prognosis and higher mortality rate.



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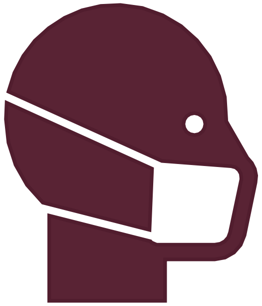
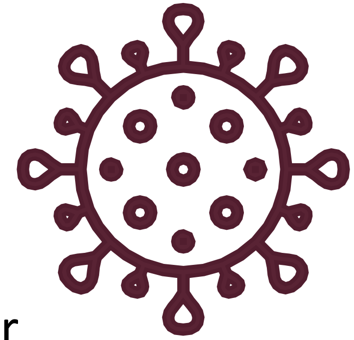
Real-life Monitoring: Covid-19



- Low SpO_2 (hypoxemia) indicates more severe case
- Worst cases in the elderly due to hypertension and diabetes
- **Troponin** as a marker for prognosis and mortality rate
- **Other symptoms**: presence of hypotension, tachycardia, tachypnea, low cardiac output and a third heart sound
- **ECG:** diffuse ST segment elevation, T-wave inversion, arrhythmias, QT elongation
- **Treatment options:**
  - hydroxychloroquine (HCQ) and azithromycin prolong the QT interval
  - Antimalarial drugs, macrolides, ribavirin and lopinavir/ritonavir block rapidly activating delayed rectifier potassium current (IKr)
    - Malignant ventricular arrhythmias, polymorphic ventricular tachycardia (Torsades des Pointes)



Further Research

ECG T-Shirt

Electronic Medical Records

Monitoring parameters and related artifacts causing false alarms

Types of approaches for false alarm reduction

Clinical-driven design of an intelligent monitoring and communication device

Thank you for listening!

Questions?