Cardiac Mechanics - Overview of Lectures and Exercises

Deformation (3-4 hours lecture + 3 hours exercises)

- Wiggers diagram
- Volume time trace
- Reciprocal volume changes of the atria and ventricles
- Ejection fraction
- Segment length time trace
- Strain
- Longitudinal and circumferential strains
- Incompressibility and wall thickening
- Geometric relation between EF and strains
- Transmural gradient in strains
- Shear strains
- Myocardial fiber and sheet structure
- Rotation, Twist, Torsion, Circumferential-longitudinal shear strain
- MAPSE and TAPSE
- Left atrial strain
- Tissue velocity and strain rate
- Preload and afterload dependence of shortening
- Pressure-strain loops
- Non-invasive estimation of LVP for LVP-strain loops
- Examples of strain traces and loops during:
    - Ischemia
    - LBBB
- Mechanical dispersion
- Waveform features related to valve events
- Definition of ED and ES

Tau – the time constant of exponential pressure decay (1 hour lecture + 1 hour exercises)

- Lusitropy
- *Tau* vs minimum dP/dt
- Mathematics – calculation of *tau*
- Zero-asymptote
- Non-zero asymptote
- Residual pressure
- Increased heart rate
- Response to activity

End diastolic pressure volume relation (1 hour lecture + 1 hour exercises)

- Hooke’s law
- Spring analogy
- Compliance and elastance
- Incomplete relaxation
- Pericardial and external constraints
- Measurement of pericardial pressure
- Factors altering myocardial stiffness
- Changes with acute ischemia

- Diastolic heart failure
- Normalization with respect to size

Contractility & end systolic pressure volume relation (1 hour lecture + 1 hour exercises)

- Systolic stiffness
- Time varying elastance
- ESPVR vs Emax vs Es
- Slope vs V_0
- Linear vs curved ESPVR
- Preload recruitable stroke work
- Relationship between dP/dt_{max} and end diastolic volume
- Single-beat contractility indices

Preload (1 hour lecture + 1 hour exercises)

- Definitions: LV pressure, transmural pressure, wall stress
- Wall stress by Laplace
- External constraint – pericardium
- External constraint – right ventricle
- ED volume as measure of preload
- Respiration and preload
- PEEP and preload

Afterload (1.5 hours lecture + 2 hours exercises)

- Afterload dependency of shortening and velocity
- Afterload from the perspective of the ventricle vs myocardium
- Wall stress by Laplace
- Systemic vascular resistance
- Resistance, compliance, inertia
- Frequency content of the pressure wave
- Windkessel model – impedance
- Pulse wave velocity
- Wave reflections
- Bonus material in relation to frequency content: The Nyquist sampling theorem

Suction and restoring forces (1 hour lecture + 1 hour exercises)

- Definition of restoring forces
- Restoring forces vs conventional strain, segment length, and volume
- Quantifying restoring forces
    - Estimating the fully relaxed pressure from EDPVR
    - Estimating changes in restoring forces with unknown resting state
    - Estimating the fully relaxed pressure using tau
- Suction, different definitions
    - Reduction of pressure in LV relative to LA
    - Filling during falling pressure
    - Negative transmural pressure
- Is blood pushed or pulled into the LV

Frank-Starling Effect (1 hour lecture + 1 hour exercises)

- Mechanisms of increased systolic function
- The Frank-Starling mechanism (Starlings law of the heart) 1912
    - Definition
    - Purpose
- Ventricular function curves
- Autoregulation -Venous return and Guyton curves
- Frank-Starling mechanism – 1970s
    - Structure of cardiac muscle
    - Contractile components of the muscle
    - The sliding filament hypothesis
- Contractile components of muscle
- Length-tension relationship

Myocardial and ventricular efficiency (1 hour lecture + 1 hour exercises)

- Current parameters of systolic function
- Heart – O2 consumption and efficiency
- Pressure-volume analysis
    - PVA
    - PE and SW
    - PVA and VO2
    - Unloaded VO2 /Excess VO2
- Changes in contractility and O2 consumption
- Should we abandon PV-analysis? Simulation
- Myocardial efficiency in PET
- Renewed interest in myocardial efficiency

Planned exercises after the different lectures

Deformation

Sonomicrometry:
Calculate strain from sono, strain rate, define events/phases/waves
Strain: absolute length vs relative to ED (loading cases)
Sign convention, ambiguities
Echo:
Projections: 4Ch, 2Ch, 3Ch, SAX
Calculation of EDV, ESV, and EF by biplane Simpson
Speckle tracking: calculate longitudinal, circumferential and radial strains + GLS and GCS
Myocardial work analysis
Calculate rotation from apical SAX image
Tissue velocity imaging: identify s', e', and a' and spikes related to valve closures
Calculate strain rate
Transmural variation in strains, vary transmural placement of ROI in HCM heart in both LAX and SAX
Strains and work in ischemic and LBBB hearts + mechanical dispersion.

Tau – the time constant of exponential pressure decay

Calculate tau for different cases using

- zero-asymptote method (Weiss)
- Non-zero asymptote derivative method (Craig and Murgo)
- Non-zero asymptote nonlinear optimization method
- Calculate residual pressure
- What is the effect on tau calculated using zero-asymptote assumption when the asymptote is 1) positive and 2) negative?

Compare to minimum LV dP/dt

End diastolic pressure volume relation

Explain the different terms:

- End diastolic pressure volume relation (EDPVR)
- Diastolic stiffness
- Diastolic pressure volume relation
- LV operating stiffness
- Compliance = ?
- Elastance = ?

Discuss factors that alter myocardial stiffness
Extract the EDPVR from the excel-file for LBBB-EB5241

- Calculate the LV operating stiffness

Contractility & end systolic pressure volume relation

- What is ESPVR?
- What is the difference between Emax and end systolic elastance (E_{ES})?
- What is V_0?
- What is time varying elastance?
- Define contractility
- What is PVA
  - Define the different components of PVA
- How can efficiency be calculated
- Derive the ESPVR, including E_{ES} and V0 from the data in the file
- Also find the time varying elastance from time points 20, 100, 250, 260, 270, 310 ms.
- What is the value of Emax?

Preload

For one beat during normal preload and one beat during reduced preload, plot

- transmural LV EDP (=LVP- 0.67*Pericardial pressure – 0.33*RVP)
- Intracavitary LV pressure
- LV volume
- segment length
- segment strain
- pressure-volume loop

Extract

- Transmural LV EDP
- Intracavitary LV pressure
- LV ED volume
- Minimum segment length and strain

Afterload

- Define afterload
    - Myocardial perspective/ Ventricular perspective
- What is «Systemic vascular resistance»?
    - What's a normal value?
- What is arterial elastance, E_a?
- What is input impedance?
- What is characteristic impedance?
- What is meant by the frequency components of a signal?
- What is the Nyquist- or sampling theorem?
- What are lowpass, highpass, and bandpass filters.
    - What are the impedances at high and low frequencies for the different filters?
- Calculate the windkessel parameters for 10 patients
    - Can you classify them into two groups with normal and increased afterload?
    - Decode excel-file and add frequency components

Suction and restoring forces

- Definition of suction
    - What are 3 common definitions?
    - For which of these methods does the LV wall perform work to «fill itself»?
    - Why?
- What are restoring forces?
    - How can they be estimated in terms of pressure or deformation if you know the unloaded resting dimension?
    - How can changes in restoring forces be estimated if you don't know the unloaded resting dimension?

Frank-Starling Effect

- Construct different ventricular function curves for the 4 recordings (LBBB, LBBB+CRT, LBBB_dobutamine and LBBB+CRT_dobutamine) using PRSW and at least one other form of ventricular function curve
- From the PRSW curves, construct linear regression lines for the 4 recordings
- Compare differences in SW at the same EDV for the 4 different recordings.
- Evaluating changes in the slope and intercept, how would you describe the change in systolic function by dobutamine vs. CRT?

Myocardial and ventricular efficiency

- Using the example of PV-analysis comparing a normal situation and aortic stenosis, answer the following questions:
    - Why are there minimal changes in SV and EF, while there is a marked increase in SW?
    - PVA and SW are similarly increased by approximately 45% during aortic stenosis, while myocardial VO2 is only increased by 24%. Explain why this difference occurs.
    - What would you expect to happen to PVA, myocardial VO2, efficiency, SV, EDV and EF if you simulated an acute myocardial infarct during aortic stenosis?