Effect of left-ventricular aneurysm on human ventricular mechanics: A patient-specific simulation model study

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Introduction
Facts about Heart Failure (HF)

• UK’s biggest killer - affects at least one in every 100 \([1,2]\)
• Cost to NHS - £625 million per year \([1]\)
• Within the year of admission for HF, 32% of patients died \([2]\)
• LV dysfunction associated with myocardial infarction has a significantly worse 3-years survival in patients \([3]\)

Normal vs Aneurysm

- **Myocardial infarction** could lead to **LV aneurysm** & consequently **heart failure** (HF)

- Surgical Ventricular Restoration (**SVR**) – still not effective

Why Simulation

- Non-invasive procedure

- Measuring myocardium stress in-vivo still not possible

- Can investigate and examine the effects of various factors on ventricular mechanism which are technologically and ethically complex to perform on real patient

- Can lead to patient-specific treatment plan
Research Objectives
• To identify and investigate on patient-specific diastolic mechanics of normal left ventricle

• To identify and examine on patient-specific systolic mechanics of normal left ventricle

• To identify the changes in mechanical characteristics between normal LV and LV with an aneurysm in diastole and systole
Materials and Methods
Finite Element Analysis (FEA)

**Input**
1. Mesh Geometry
2. Boundary Condition
3. Load
4. Material Property

**Output**
1. Displacement
2. Pressure/volume
3. Stress/strain
3D Mesh geometry construction

1. Short Axis Image
2. Preliminary 3D Geometry
3. Long Axis Image
4. Create basal-atrium intersection plane
5. Remove extra volume by cutting preliminary 3D geometry in basal-atrium intersection plane
6. Final 3D biventricular geometry
Normal vs Aneurysm
Fibre-sheet structure

Myocardial fibre angle varies from $+50^\circ$ to $+70^\circ$ in the sub-endocardial to almost $0^\circ$ in the mid-wall to $-50^\circ$ to $-70^\circ$ at sub-epicardial with respect to the local circumferential direction.

Implement Fibre-sheet structure on mesh

Geometry:

- \((f, s, n)\) : fibre, sheet, fibre-sheet normal
- \((e_z, e_c, e_n)\) : local longitudinal, circumferential and radial directions
- \(\alpha\) : helix or fibre angle
- \(\beta\) : sheet angle
Myocardium Material

- Hyperelastic
- Orthotropic

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<th>a (KPa)</th>
<th>b (KPa)</th>
<th>a_f (KPa)</th>
<th>b_f (KPa)</th>
<th>a_s (KPa)</th>
<th>b_s (KPa)</th>
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Results and Discussion
Validation
Effect of fibre orientation on pressure – volume relation during diastole
Effect of fibre orientation on fibre stress during diastole
Effect of material parameters on pressure-volume relation

- Parameter $b$ has major influence on LV inflation
- Reducing last six parameter's value (from Human) would not increase the LV inflation at EDP
- The PV relation mainly depends on $(b/a)$ value

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<td><strong>Human</strong></td>
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<td>6.000</td>
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Effect of RV topology on LV volume in diastole
Effect of RV topology on LV fibre stress-strain

LV (a) BV

Base Equatorial Apex s-l α-p
Future work

• Diastolic simulations of 5 normal hearts to provide a reference map for ventricular wall stress
• Systolic simulations of 5 normal hearts to provide a reference map for ventricular wall stress
• Simulation of LV with aneurysm and investigate its effect on LV mechanics
Summary

- Research Objectives
- Simulation Methods
- Effect of different factors on LV diastole

- Potential Benefits
  - Improved understanding of the physiology and pathophysiology of human heart in normal and diseased condition
  - These understating will eventually lead to better treatment and patient-specific optimal surgery