Preliminary steps for large scale modelling of heart development

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Introduction

Looping of the Embryological Heart Tube

Most of the earlier studies in heart development focus on a morphological viewpoint which contains both hypertrophic and proliferative signalling models (Fig.1) [1, 2]. Accordingly, Fig.2 illustrates the geometrical variation of the straight heart tube. Extrinsic and intrinsic forces can cause this right/left asymmetry at the end of C-looping. This can be considered as a combination of bending and rotation. Therefore, with respect to Fig.1, we would like to study the morpho-mechanics of cardiac looping. In this regard, a continuum mechanics model which can describe the growth function of this large deformation at the early stages of the heart development will be described during this study.

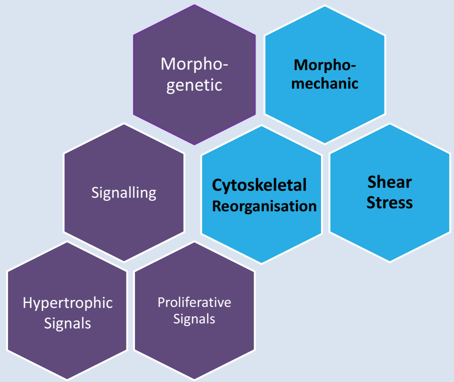

Fig.1: General aspects of the study; Morpho-genetics (purple) and Morphomechanics (blue)

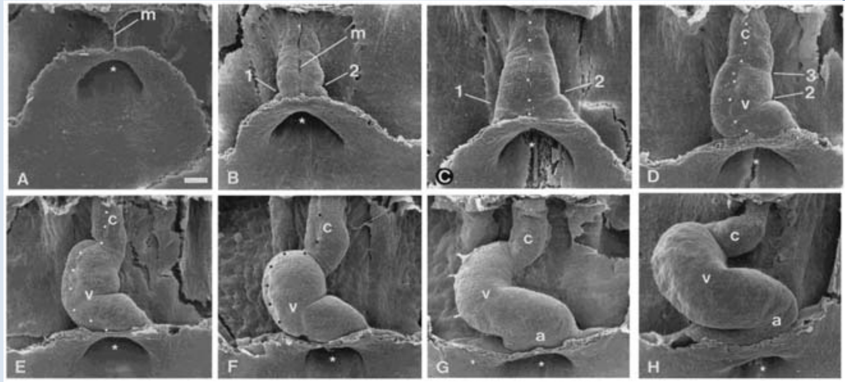

Fig.2 A-H: Geometrical variation in in straight heart tube in early stages of development , (Manner, 2000)

Finite Element Modelling

Geometry Reconstruction/ Meshing Techniques

- High resolution micro-CT (350-nm) of the developing heart from Rat/Mouse/Chicken at key stages of growth
- Image digitisation for geometry reconstruction and consequently completing the physical model
- Defining finite element model with cubic-Hermite elements (with C^0 and C^1 continuity)
- Updating model by host-mesh fitting technique

Rigid body motion in Euclidian Space: Translation + Rotation

Model Deformation in Affine Space: Shearing + Scaling [3]

Finite Element Method

The OpenCMISS software will be used for finite element modelling of early stages of cardiac looping. The mechanism of deformation is not completely obvious yet, however, by using free-form deformation techniques we can derive the later stages of deformation. In this regard, soft tissue deformation can be simulated and understood by Lagrangian mechanics of the motion.

Different constitutive equations can be investigated as a material model in this process. In this step of the study the final goal would be to provide a continuum growth function for the early stages of heart development.

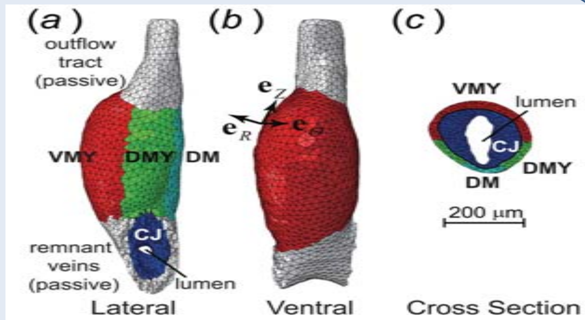

Fig.3: Finite element mesh for one key stage, (a) lateral, (b) ventral and (c) cross-sectional side in a global cylindrical coordination system. Mesh consists: ventral myocardium (VMY), dorsal myocardium (DMY), dorsal mesocardium (DM) & cardiac jelly (CJ) [4].

Study Aims from Mechanical Aspects

- Deformations: Lagrangian mechanics, referential coordinates
- Deformation gradient tensor
- 1st and 2nd Piola-Kichhoff and Cauchy stress tensors
- Modelling of growth kinematics to find growth function
- Volumetric growth, fiber growth and cross-fiber growth
- Balance laws, Field equations, Constitutive equation

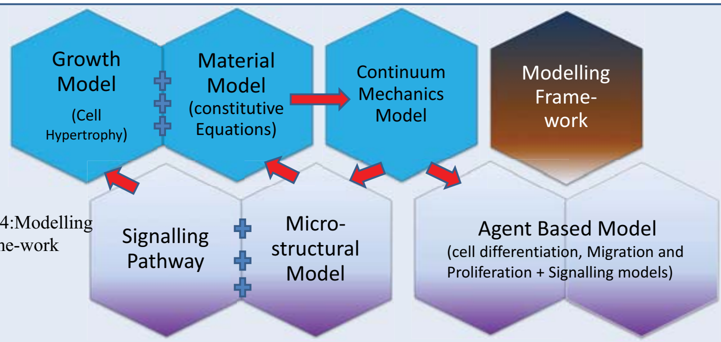

Fig.4:Modelling frame-work

Acknowledgement

The first author would like to acknowledge the Marsden Fund (the Royal Society of New Zealand) for financial support of this study.

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