Computational modeling of volumetric tissue growth: application to the cardiac left ventricle

Citation for published version (APA):

Document status and date:
Published: 01/01/2007

Document Version:
Publisher’s PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:
• A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
• The final author version and the galley proof are versions of the publication after peer review.
• The final published version features the final layout of the paper including the volume, issue and page numbers.

Link to publication

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

• Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
• You may not further distribute the material or use it for any profit-making activity or commercial gain
• You may freely distribute the URL identifying the publication in the public portal.

If the publication is distributed under the terms of Article 25fa of the Dutch Copyright Act, indicated by the “Taverne” license above, please follow below link for the End User Agreement:
www.tue.nl/taverne

Take down policy
If you believe that this document breaches copyright please contact us at:
openaccess@tue.nl
providing details and we will investigate your claim.
Computational modeling of volumetric tissue growth
Application to the cardiac left ventricle

W. Kroon¹, T. Delhaas¹, T. Arts² and P.H.M. Bovendeerd³
Cardiovascular Research Institute Maastricht, Maastricht University, Department of ¹Physiology and ²Biophysics
Eindhoven University of Technology, Department of Biomedical Engineering³

Introduction
Local volumetric tissue growth is a fundamental aspect of cardiovascular tissue development and maintenance, affecting morphology and physiology of the organ. Computational modeling may provide additional insights in the relation between the local tissue stimulus and the local growth. Currently, however, no method is available to simulate volumetric growth in realistic cardiovascular geometries.

Objective
Develop a finite element (FE) based method that enables simulation of three-dimensional inhomogeneous volumetric soft tissue growth.

Materials and methods
Growth is assumed to plastically deform the unloaded tissue geometry based on a mechanical stimulus. Figure 1 shows the steps involved in a growth cycle.

Step 1: Determining the mechanical stimulus. External pressure is applied on the inner surface, simulating diastolic filling. The tissue deforms, behaving transversely isotropic, non-linear elastic and nearly incompressible, as described by the strain energy density $W_{stim}$ [1,2]:

$$W_{stim} = \Psi_{shape} + \Psi_{vol}$$

with $J$ the achieved volume change and $\kappa$ the bulk modulus. The equations of linear momentum that govern the tissue deformation are solved with a FE method.

Step 2: Determining the desired volume change. The end-diastolic linear myofiber strain $\varepsilon$ is translated into a desired local volume change $J_g$,

$$J_g = \frac{V(t + \Delta t)}{V(t)} = \beta(\varepsilon - \varepsilon_{hom})\Delta t + 1$$

with $\varepsilon_{hom}$ the homeostatic myofiber strain, $\Delta t$ the period of growth and $\beta$ a rate constant.

Step 3 Determining the grown tissue geometry. The volume change $J_g$ is applied as internal load in the unloaded tissue. The tissue deforms, behaving isotropic and compressible (isotropic growth):

$$W_{growth} = \Phi_{shape} + \Phi_{vol}$$

$$\Phi_{vol} = \kappa(J^2 - J_g^2)^2$$

Step 4 Updating the unloaded tissue geometry. The grown tissue geometry is adopted as the new unloaded tissue geometry.

Results

Figure 1. Schematic overview of a growth cycle.

Figure 2. The local volume changes and their effect on the transmural distribution of myofiber strain after 160 growth cycles.

Conclusions
A novel method has been developed to simulate 3D inhomogeneous volumetric growth.

Adaptation of the cardiac left ventricle through inhomogeneous changes in wall volume of up to 30% successfully reduced heterogeneity in tissue strain.

References