16 - examples - volume growth

the potato equations - kinematics

mass source

growth tensor

mass flux

multiplicative decomposition


example - growth of aortic wall

kinematics of finite growth

$$F = F_e \cdot F_g$$

mass source

mass flux

growth tensor

multiplicative decomposition


example - growth of aortic wall

volume growth at constant density

- free energy $$\psi_0 = \psi_{00}^{(e)}(F_e)$$
- stress $$P_e = P_{e0}^{(e)}(F_e)$$
- growth tensor $$F_g = \dot{\theta} I$$ $$D \dot{\theta} = k_\theta(\dot{\theta}) \text{tr}(C_e \cdot S_e)$$
- mass source $$K_0 = 3 \rho_0^s \dot{\theta}^2 D \dot{\theta}$$

kinematic coupling of growth and deformation


example - growth of aortic wall

volume growth of aortic wall

wall thickening-thickening of musculoelastic fascicles
Matsumoto & Hayashi [1998], Humphray [2002]

example - growth of aortic wall

volume evolution in cylindrical tube

stress-induced volume growth
Himpel, Kuhl, Menzel & Steinmann [2006]

example - growth of aortic wall

stress-induced cross sectional growth
Himpel, Kuhl, Menzel & Steinmann [2006]

example - growth of aortic wall
example - growth of aortic wall

qualitative simulation of stent implantation

initial conditions

- adiposis $E_{fat} = 0.03 E_{tissue}$
- calcification $E_{calc} = 3000 E_{tissue}$
- growing plaque $E_{plaque} = E_{tissue}$

early stage

soft plaque pressed into wall

stiff plaque induces high stress

overall thickening - thickening of individual fascicles

Holzapfel [2001], Holzapfel & Ogden [2003], Kuhl, Maas, Himpel & Menzel [2007]

example - growth of aortic wall

generation of patient specific model

computer tomography - typical cross section

example - growth of aortic wall

qualitative simulation of stent implantation

stretch ratio $\gamma$

restenotic conditions

re-narrowing of x-section in response to high stress

generation of patient specific model

outline of ct image - typical cross section

example - growth of aortic wall
example - growth of aortic wall

generation of patient specific model

from computer tomography to finite element model

stent implantation - patient specific model

tissue growth-response to virtual stent implantation

example - growth of aortic wall

Kuhl, Maas, Himpel & Menzel [2007]