Optimization of material parameters for the constitutive modelling of the female breast based on MRI data, 3-D surface scanning and finite element simulation

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Who is research group CAPS?

Computer Aided Plastic Surgery

Clinic for Plastic Surgery and Hand Surgery
Klinikum rechts der Isar
Technische Universität München

Interdisciplinary research between medicine and engineering

**Medical staff:**

PD Dr. Laszlo Kovacs
Head of the group

Dr. M. Eder
Dr. F. v. Waldenfels

**Engineering staff:**

A. Volf
J. Jalali
S. Raith
Current Situation and Motivation

• Breast cancer is very common: 140,337 surgical interventions in Germany in 2010

• Additionally there are reductions, asymmetry corrections, reconstructions and augmentations

• There is a need for better planning in breast surgery to overcome today’s ad-hoc heuristic approaches
  – Software tools from engineering science might be used for planning
    ➢ Simulations of the mechanical behavior of the breast’s soft tissues is evident
Publications dealing with mechanical behaviour of female breast soft tissue


Theoretical constitutive models utilized by the different authors

<table>
<thead>
<tr>
<th>Publication</th>
<th>Constitutive Model</th>
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<tbody>
<tr>
<td>Krouskop et al. (1998)</td>
<td>Piecewise linear elastic</td>
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<td>Wellman et al. (1999)</td>
<td>Piecewise linear elastic</td>
</tr>
<tr>
<td>Azar et al. (2001)</td>
<td>Exponential Hyperelastic</td>
</tr>
<tr>
<td>Samani et al. (2001)</td>
<td>Polynomial Elastic</td>
</tr>
<tr>
<td>Samani et al. (2004)</td>
<td>Mooney-Rivlin</td>
</tr>
<tr>
<td>Samani et al. (2007)</td>
<td>Linear Elastic</td>
</tr>
<tr>
<td>Tanner et al. (2006)</td>
<td>Various Material Models</td>
</tr>
<tr>
<td>Del Palomar et al. (2008)</td>
<td>Neo-Hookean</td>
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<tr>
<td>Rajagopal et al. (2008)</td>
<td>Neo-Hookean</td>
</tr>
<tr>
<td>Lapuebla-F. et al. (2011)</td>
<td>Neo-Hookean</td>
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</table>

Different testing methods such as ex vivo material tests (uni- or biaxial tension, shear) or numerical simulations (FEA)
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Stress – Strain Curves

- Uniaxial Test
- Biaxial Test
- Shear Test

Graphs showing stress-strain curves for different tests and materials.
Method for in vivo calculation of the breast’s material parameters

- Taking advantage of modern imaging technologies
  - MRI imaging
    - inner anatomy of the test persons’ chests
    - possible in prone or supine position
  - 3-D surface scanning
    - possible in standing position
Method for in vivo calculation of the breast’s material parameters

• Taking advantage of modern imaging technologies

MRI prone position
3-D surface scan
Standing position
MRI supine position
Principle workflow of the material model validation

1. MRI imaging in prone position
2. Finite Element Meshing
3. Simulation of upright position
4. 3-D surface scan
5. Validation
3-D Laser Scan im Brustbereich

scanning device: Konica Minolta Vivid 900i
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3-D laser scans of the breast region

stitching and merging of the 3 separate surface scan data

Utilized software tool: geomagic®
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Segmentation of the relevant anatomical compartments

- 3 different compartments are defined:
- thorax wall, pectoral muscle and soft tissue (fat and glandular)
Finite element mesh for simulation
Finite element mesh for simulation

System boundaries (green)
Thorax treated as rigid -> fixed boundary condition
Muscle also considered to be rigid -> fixed boundary condition
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Consideration of initial deformations

- Apparent deformation due to gravity loading is non-negligible
- -> for physically meaningful calculations a stress-free starting configuration has to be found
Inverse algorithm for the determination of the unloaded breast shape

First estimation of the unloaded configuration

Comparison

defomed configuration segmented from MRI data

new forward calculation of the deformed shape
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reaction forces may be determined from the comparison to the undeformed configuration

better approximation of the undeformed configuration

forward calculation
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Iterativer Prozess
Simulation results with different sets of material properties

variation of material parameters according to Tanner et al. and further Neo Hookean (Young’s modulus varying, PR=0.49)

Registration of surfaces in one common coordinate system
3-D surface comparison

• Coordinate systems of simulation and scans have to be registered for the comparison.
• Calculation of 3D deviation (so called Hausdorff distance) and summed over the surface as one scalar value.
Comparison of different simulation results with

- material parameters too stiff
- matching material parameters
Principle workflow of the parameter identification loop

Preprocessing
- MR Imaging
- 3-D surface scan

FEA Mesh
- merged surface

Optimization loop
- Material parameters
- Scalar value of accordance
- 3D compare
- FEA result

ICEM CFD
- geomagic

optiSLang
- ANSYS
Results: clearly defined optimal set of parameters
Results:
clearly defined optimal set of parameters

Patient individual optimal material parameters:
Young’s modulus: 0.000827 MPa (Factor 1.06 to Tanner et al.)
Poisson’s ratio: 0.5 (perfectly incompressible material)
Results:

clearly defined optimal set of parameters

Material parameters:

- Poisson’s ratio always at 0.5
- Young’s Modulus as a factor to the parameters of Tanner et al.

Output: average deviation in mm
Conclusion

- In vivo approximation of material properties is feasible
  - Based on a combination of:
    - 3-D surface scans of standing position
    - MRI in prone lying position
      - non-invasive approach for material parameter determination
      - Patient individual determination of material parameters is possible
- Acquired material parameters may be used for surgical planning and operation simulations
Outlook

• application to training set of test persons to get better statistical evidence (18 are yet available)

• using more complex material models
  – Mooney-Rivlin, Ogden etc...
  – with more parameters than E and nu (or G and K, respectively)

• material is yet considered to be homogeneous and isotropic
  – glandular tissue is not considered
Determined material parameters may be used in clinical surgery planning e.g. breast reconstruction
Thank you for your attention