Biomechanical simulation of mesh surgery: sacropexy and vaginal procedures.

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The mobility of the female pelvic system:
- Mobility: Normal physiology,
- Hypo mobility: Cancer, pelvic endometriosis,
- Hyper mobility: Genital Prolapse, urinary incontinence

Physiology and Physiopathology are not well understood

Pelvic organ mobility
- Physiology
- Necessary for functions

Mobility of organs
- Urinary and rectal evacuation
- Sexual intercourse
- Vaginal delivery

Impaired by pathology and surgery: Mesh?
Pelvic cavity Mobilities: dynamic MRI

Normal mobility

Hyper-mobility

Hypo-mobility

Normal patient

Cystocele grade IV

Endometriosis
Quantification of mobility

- In white: the initial position of organs
- In color: quantification of mobility from 0 to 20 mm

Initial position

After displacement

u(x)
Pelvic tissues properties: hyperelasticity

The mobility of the female pelvic system:
Due to the specific properties of the pelvic tissues

Destructive characterization
Pelvic organs
Fascia
Ligaments

Different situations
Young and old patients
Prolapse patients

Understand histology and biomechanics
Non pathologic population:
25 non pathologic cadavers (caucasian, 60 years old av.)

3 organs:
Vagina, Bladder, Rectum
- anterior & posterior wall
- transversal & longitudinal dir.

3 ligaments:
US, rond, broad

Destructive characterization: hyperelasticity

Mapping of the mechanical properties

Nominal stress (MPa) vs. Strain (%)

- Utero Sacral
- Vagina
- Rond
- Rectum
- Large
- Bladder
Pelvic organ simulation: how is it suspended?

The mobility of the female pelvic system:
Due to the specific anatomy of suspension

Suspension due to
- Fascia
- Ligaments

The proportion of these elements is not well known
- No scientific evidence
- Very different theories

Biomechanical suspension: build a model and compare it to reality (dynamic MRI)
Model Generation | 3D reconstruction to FE model

A | MRI technics
B | Medical imaging
   DICOM + AVIZO
C | 3D model
   AVIZO + DS CATIA
D | Area
   DS CATIA
E | FE model
   ABAQUS
F | Simulation
   ABAQUS

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+ round, broad, omilical lig and paravag susp

MRI reconstruction data + Characterized ligaments & fascia
+ 2 “observed” ligaments: Ombilical fixation, paravaginal suspension

Maximum deviation simulations / MRI measurements = 7.8 mm
Validation of the biomechanical model

- Muscles are added with their properties
- Fasciae and their adhesion to organs
- Zones with or without mobility
- Different ligaments and their respective impact on mobility

- Validation: normal patient without pelvic floor defects
- Build the geometry, add the ligaments
- Comparison of the mobility of the model to dynamic MRI of the patient: less three mm difference / reality

- Long and complex steps:
  4 different publications of the team
<table>
<thead>
<tr>
<th>MODEL</th>
<th>SACROPEXY</th>
<th>VAGINAL MESHES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Build the model</td>
<td>Technical points and mechanical consequences</td>
<td>Mesh kits Number mesh Comparison / sacropexy</td>
</tr>
</tbody>
</table>

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Pelvic biomechanical generic model

- Vagina with content to improve contrast: deformation
- Bladder: possibility to empty bladder or not
- Modify lateralization/uterine size: personalization of the model
PELVIC BIOMECHANICAL GENERIC MODEL

Pressure
Modification of loading conditions

Example:
cough = pressure at 10-3 MPa
45 degree orientation
[Kamina2008]

Geometry
Parametric model of pelvis

Example:
Uterus geometry

Bladder volume
Influence of bladder on organs mobility

Initial geometry
Uterus angle
Uterus dimensions

Initial geometry
Uterus angle
Uterus dimensions
Sacropexy: Anchoring points, mesh and fixation method selection

- Different sizes and properties of meshes
- Polyester or polypropylene
- Resorbable and non-resorbable
- Sutures or staples

Simulators: physical or virtual pedagogic or for personalized medicine
Sacropexy biomechanical simulation

Study the influence of:
- Mesh size
- Anterior or/and posterior meshes
- Number of sutures

Analysis of vagina mobility
Analysis of stress on each suture

Configuration A1
Small or large anterior mesh

Configuration A2
Small or large posterior mesh

Configuration A3
Small and large meshes
Sacropexy biomechanical simulation mobilities

Patient-specific model
Generic Model

Displacement (mm)

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Sacropaexy / analysis of suture stress

**Question**
Best space between sutures on the vagina??

**Conclusion**
1 suture every 2.5 cm...
- 1 sut 1,5 cm > stress 0,005 MPa
- 1 sut 2,5 cm > stress 0,010 MPa x2
- 1 sut 3,5 cm > stress 0,025 MPa x5

Anterior: blue line: closer points
Posterior: red line: more distal points

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Vaginal mesh surgeries / different ant and post kits

Configuration C1
Elevate anterior mesh

Configuration C2
Uphold anterior mesh

Configuration C3
Pinnacle posterior mesh
Vaginal mesh surgeries / different anterior and posterior kits

Stress

Elevate  Uphold  Uphold  Pinnacle  Pinnacle  Elevate

0,012 MPa  0,014 MPa  0,010 MPa

Stress levels:
0  0,005  >0,01
Vaginal mesh surgeries / different ant and post kits

**Step #1**
Comparison of pelvic organ mobility

- **Uphold**
  - Cervix displacement = 5.9 mm
  - Suture stress = 0.014 MPa

- **Pinnacle**
  - Cervix displacement = 4 mm
  - Suture stress = 0.010 MPa

- **Uphold + Pinnacle**
  - Cervix displacement = 2 mm
  - Suture stress = 0.004 MPa

**Step #2**
Analysis of suture stress

- **Uphold**
- **Pinnacle**
- **Uphold + Pinnacle**

Displacement (mm) scale:
- 0mm
- 2mm
- 4mm
- 6mm
- 8mm
- 10mm
- 12mm

Stress scale:
- 0
- 0.005
- >0.01

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Changing physiologic conditions after surgeries / bladder volume

*bladder volume 150 mL to 300 mL*

+ 2 Large meshes

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Changing physiologic conditions after surgeries / local pressures

Pressure variations
+ 2 Small meshes

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Comparison of different mesh surgeries

Step #1
Comparison of pelvic organ mobility

Cervix mobility (mm)

Init 3 Sutures 5 Sutures Small Large Anterior Posterior Coupled Elevate Uphold Pinnacle UH+Pin

NO MESH SACROPEXY VAGINAL MESH

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Comparison of different mesh surgeries

Step #2
Analysis of suture stress

Stress (MPa)

Init 3 Sutures 5 Sutures Small Large Anterior Posterior Coupled Elevate Uphold Pinnacle UH+Pin

NO MESH SACROPEXY VAGINAL MESH
Conclusions

• Biomechanical simulation add original and interesting information
• Large mesh better / small mesh
• SACROPEXY / More sutures, distance between 2 cm for the anterior and 3 cm for the posterior meshes
• BOTH MESHES : better reduction of mobility and mechanical stress
• VAGINAL MESHES / more mobility and more local stress : more fragile ??
• Interest still has to be proved in clinical practice : is it clinically relevant ??

Opens the possibility of personalized preoperative evaluation of different surgical techniques for a specific patient :