**95**

Chuong C[1], Towns R[1], Eberhart R[1], Mosier E[1], Zimmern P[1]
***1.*** *UT Southwestern Medical Center*

# DEVELOPMENT OF A BIOMECHANICAL FINITE ELEMENT MODEL TO PREDICT PROLAPSED ANTERIOR VAGINAL WALL COMPARTMENT PROPERTIES

## Hypothesis / aims of study

Estimation of the biomechanical properties of human prolapsed vaginal wall tissue has benefited from *in-vitro* uni- and biaxial tensiometry (1). *In-vivo* biomechanical data have recently been obtained using a suction device (Cutometer, SRLI Technologies), documenting strong intra- and inter-rater reliability (2). Our goal is now to develop a computational model that simulates the *in-vivo* mechanical responses of the prolapsed anterior vaginal wall (PAVW), comparing results with data from the cited *in-vitro* tensile tests to improve mesh design in the repair of anterior compartment prolapse.

## Study design, materials and methods

Following IRB approval, women with symptomatic grade 2-3 anterior vaginal wall prolapse requiring surgical repair were consented for dual measurements. Under anesthesia and with an empty bladder, a suctioning pressure ramp was applied via a Cutometer (BTC-2000™, SRLI Technologies) 10-mm diameter probe to the anterior vaginal wall below the bladder neck area. Tissue uplift was measured by scanning laser light within the Cutometer probe, and the elastic tangent modulus of the tissue at peak pressure load was calculated. During prolapse repair, 1x 3 cm strips of vaginal tissue along the anterior-posterior axis were harvested and tested within 2 hours of harvest according to a standard methodology (1). An initial mathematical analysis indicated that a maximum tissue strain of 23% is associated with an uplift of 3 mm, suggesting the nonlinear stress-strain data from 0 through 25% strain is most relevant to real lifetime tissue response under Cutometer load. Using an Instron (model 5565) with 100 N load cell, a cyclic load stretched these vaginal strips three times in a row to 25% strain, following which the strip was stretched to maximum load to determine its failure strength. Instantaneous tissue strain was calculated between two reference marks in the center region of the strip. Tensile stress-strain data were fit to a Mooney-Rivlin strain energy function for material description. The finite element model (FEM, ANSYS,v.11,) was used to simulate tissue uplift under applied Cutometer suction pressure. Model predictions were compared to the *in-vivo* tissue uplift measurements at peak Cutometer suction pressure.

## Results

Paired tissue data from Instron and Cutometer measurements were obtained from 6 post-menopausal patients (mean age:59) who underwent prolapse repair. Fig. 1A shows Instron uniaxial stress-strain responses; tissue strips were stretched in three cycles to 25% strain followed by stretching to failure. Fig. 1B shows the zoom-in view of the first three successive loading-unloading cycles, with hysteresis loops. The second and the third loops converged after preconditioning (3). Fig. 2 illustrates the computer model of the tissue wall and Cutometer. A schematic of tissue uplift under suction load is presented in Fig. 3. Fig. 4 shows the FEM mesh (a sector of the model is removed) for unloaded & loaded states. Table 1 presents Instron and Cutometer data. It indicates that, despite some small variations, the predicted Cutometer uplift is promising for ultimate model validation.

## Interpretation of results

Rather than removing tissue strips and obtaining secondary information after prolapse repair, we focused on *in-vivo* properties assessment, adapting the Cutometer to pelvic organ prolapse measurement. Stress-strain data from *in-vitro* tensile tests provided input for the FEM model. Comparison between these two techniques was made possible by theoretical calculations taking into account a reversible tissue cycling process from the tensile test, comparing it to a brief suctioning perturbation by the Cutometer. The PAVW biomechanical properties (tensile test data) allowed computational modeling of the Cutometer data for the same patients. Refinements in the model will come from a larger series of patients, improvement in model surfacing (smaller pressure units), and studies of tissue viscoelasticity, including relaxation and creep.

## Concluding message

We have developed a FEM model, employing nonlinear material properties from human *in vitro* tensile measurements, to predict the pressure-uplift data from an *in vivo* (Cutometer) test of the human PAVW.

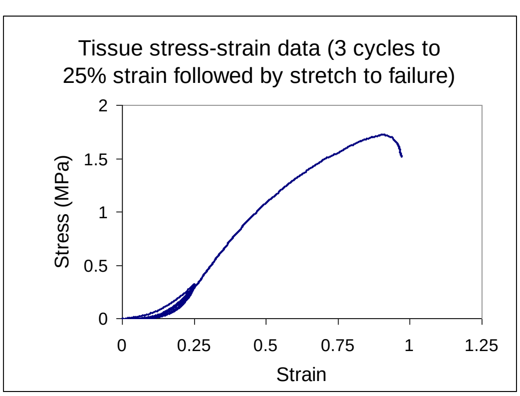


Fig. 1A

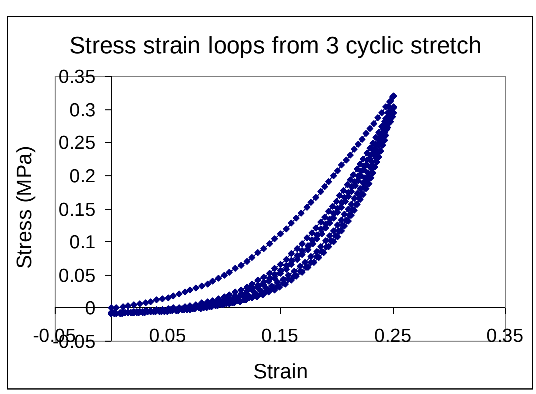


Fig. 1B

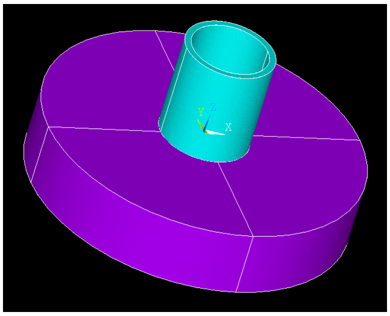

Fig. 2

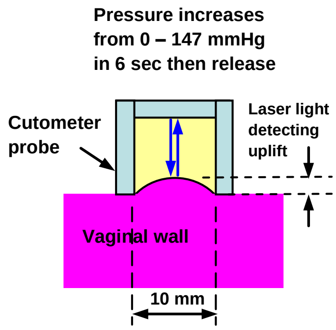


Fig. 3

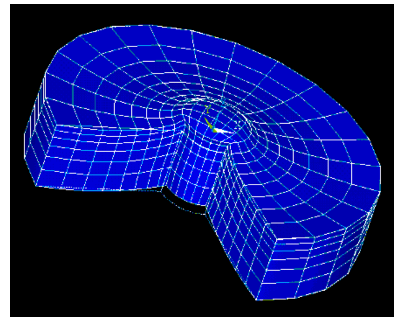

Fig. 4

| Patient # | Pressure (mmHg) | Uplift (mm) | | % differences |
|---|---|---|---|---|
| | | Cutometer | FEM | (FEM-Cutometer)/Cutometer |
| P 1 | 147 | 1.94 | 1.96 | 1.3% |
| P 2 | 147 | 2.10 | 2.35 | 11.9% |
| P 3 | 147 | 1.54 | 1.80 | 16.9% |
| P 4 | 147 | 1.99 | 1.54 | -22.9% |
| P 5 | 147 | 1.46 | 1.65 | 13.1% |
| P 6 | 147 | 0.79 | 0.83 | 5.1% |
| **Average of absolute values in % differences** | | | | **11.8%** |

References
1. NUU 28(4):325-329, 2009
2. NUU 28(4):325-329, 2009
3. Fung, YC, Biomechanics: Mech Prop of Living Tissues, Springer-Verlag, 1993, 2nd ed.

| | |
|---|---|
| *Specify source of funding or grant* | **The Cain Foundation** |
| *Is this a clinical trial?* | **No** |
| *What were the subjects in the study?* | **HUMAN** |
| *Was this study approved by an ethics committee?* | **Yes** |
| *Specify Name of Ethics Committee* | **Institutional Review Board of UT Southwestern** |
| *Was the Declaration of Helsinki followed?* | **Yes** |
| *Was informed consent obtained from the patients?* | **Yes** |