In-vivo Measurement of Viscoelastic Properties of the Human Prolapsed Anterior Vaginal Wall

C. Chuong[1], M. Ma[1], M. Yanagisawa[2], R. Eberhart[2], and P. Zimmern[2]
[1] Department of Bioengineering, University of Texas at Arlington
[2] Departments of Surgery and Urology, University of Texas Southwestern Medical Center at Dallas

Introduction

Improvements in surgical repair of pelvic organ prolapse could benefit from quantitative biomechanical property data to better tailor the repair in each patient. Such vaginal wall tissue property measurements have been obtained by *in vitro* uni- and biaxial tensile tests on fresh human anterior vaginal wall tissue samples. Recently, *in vivo* biomechanical data have been obtained at the same site, adapting a cutometer-like device, the *BTC-2000*™ (SRLI, Nashville). We report here on viscoelastic properties derived from the recovery phase of the SRLI instrument measurement in patients undergoing vaginal prolapse repair.

Objectives

To determine the in-vivo viscoelastic properties of human anterior vaginal wall prolapse tissues using pressure-uplift responses recorded by a cutometer-like device, the *BTC-2000*™.

Methods

Study design, materials and methods

1. 23 women with symptomatic stage 2-3 anterior vaginal wall prolapse requiring surgical repair
2. Under anesthesia and with an empty bladder, a 10-mm diameter aperture *BTC-2000*™ probe was applied to the prolapsed anterior vaginal wall at a fixed point (below bladder neck area).
3. A suction pressure ramp (0 to -147 mmHg in 6 seconds) was applied; the corresponding tissue uplift was measured by triangulation, within the probe, of a laser scan pattern (Fig. 1). The chamber was returned to atmospheric pressure while the corresponding laser-measured tissue uplift was recorded for 20 seconds (Fig. 2).
4. Step 3 was repeated at the suprapubic region for data comparison

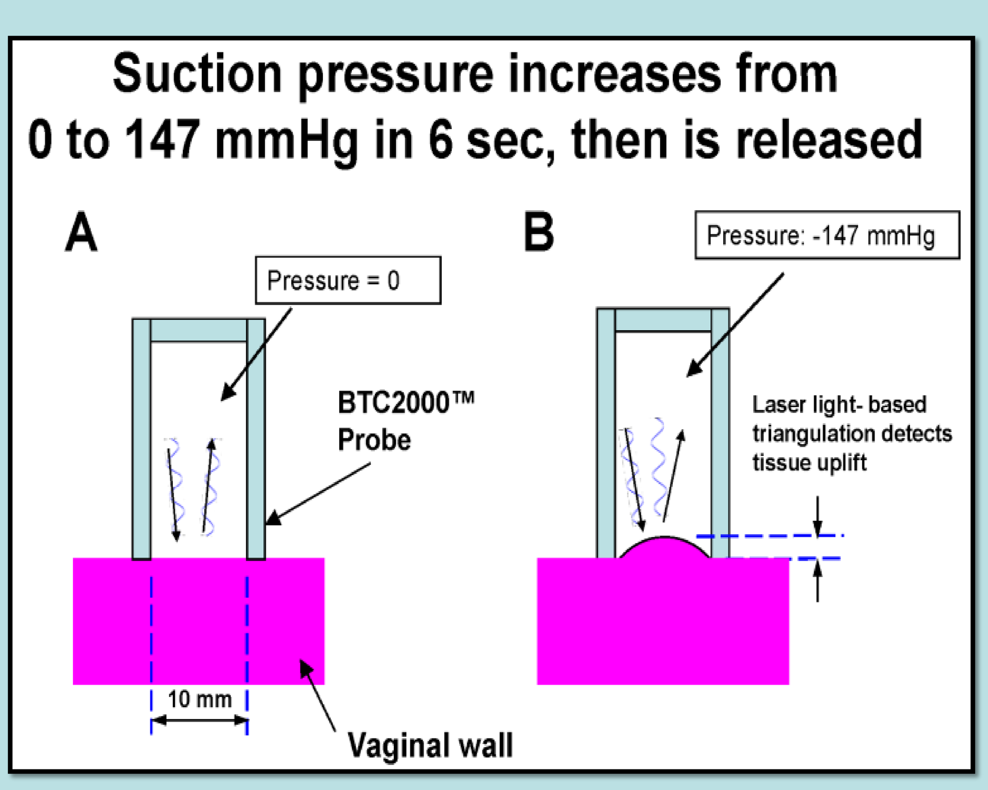

Fig.1. *BTC-2000*™ measurement schematic of tissue uplift in response to suction pressure loading.

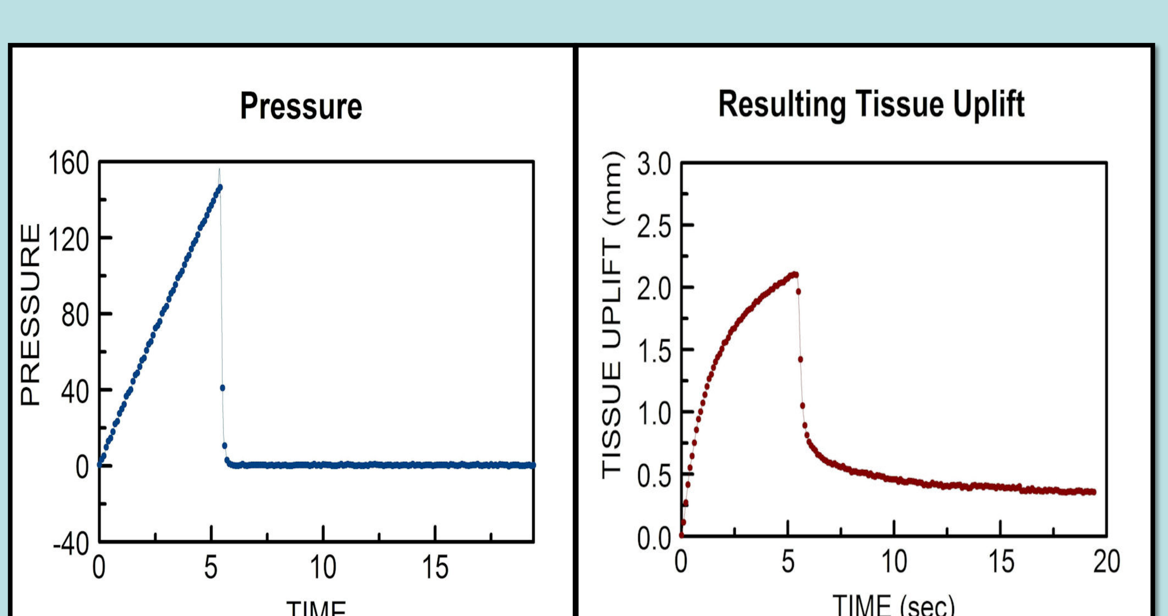

Fig. 2 Suction pressure ramp from 0 to 147 mmHg in 6 seconds and then suddenly released to 0 mmHg. Relaxation of tissue uplift was recorded for 20 seconds.

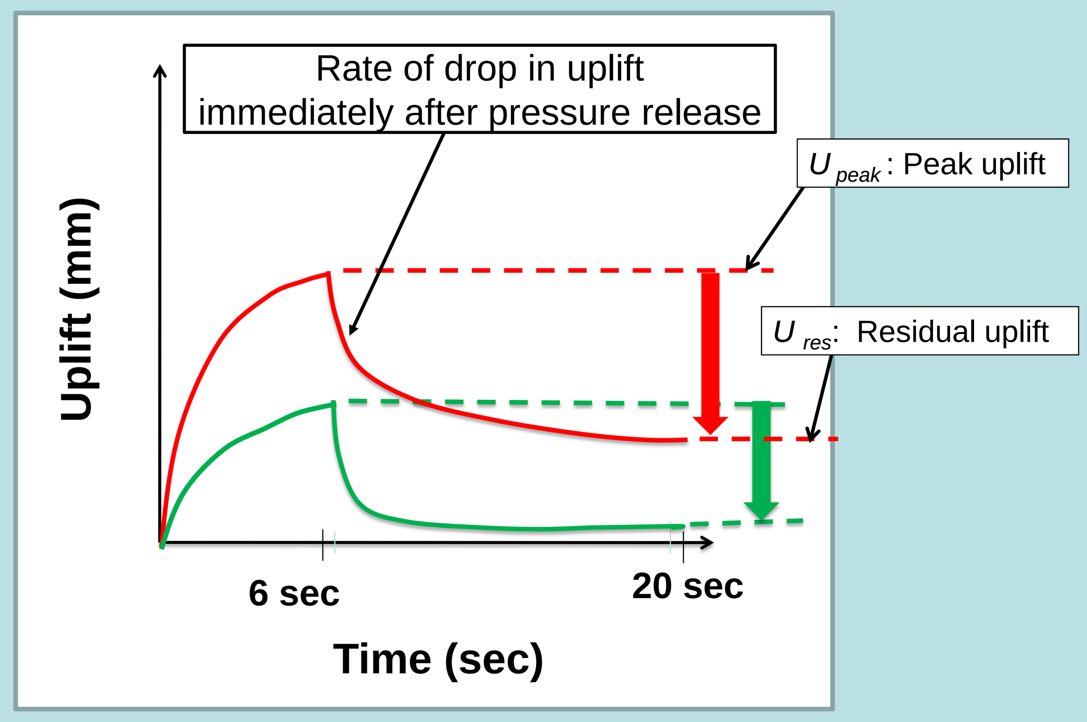

Fig. 3 Uplift recordings reveal two groups of responses. Those in Group 1 (green) exhibit a lower peak uplift and a faster recovery. Those in Group 2 (red) exhibit higher peak uplift and slower recovery.

Tissue viscoelastic parameters measured

1. Peak uplift when time = 6 sec
2. Residual uplift after 20 sec of relaxation time
3. Percentage elastic recovery = $\frac{u_{peak} - u_{residual}}{u_{peak}}$
4. Rate of tissue recovery in terms of E/η ratio.

   Considering the tissue recovery can be modeled by a visco-elastic Voigt creep model consists of an elastic spring (spring constant E) and a dashpot (viscosity η) connected in parallel. To do this, the timed recording of tissue recovery was fit to the model equation simulating the event, expressed in terms of a visco-elasticity parameter, the E/η ratio. The instantaneous uplift u at time t can be evaluated from

$$u(t-6) = u_{peak} - \frac{p_{peak}}{E}\left(1-\exp^{-\left(E/\eta\right)(t-6)}\right)$$

where $\frac{p_{peak}}{E} = u_{peak} - u_{residual}$

E: elastic spring constant

η: dashpot damping coefficient

E/η: Relative contribution between elastic and damping responses

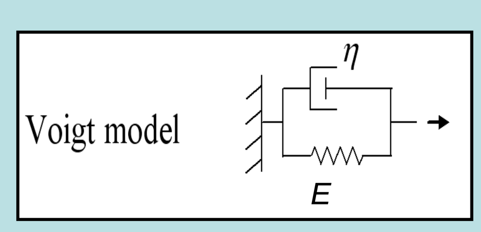

Fig. 4 A Voigt model consists of an elastic spring and a dashpot, mechanically connected in parallel.

Results

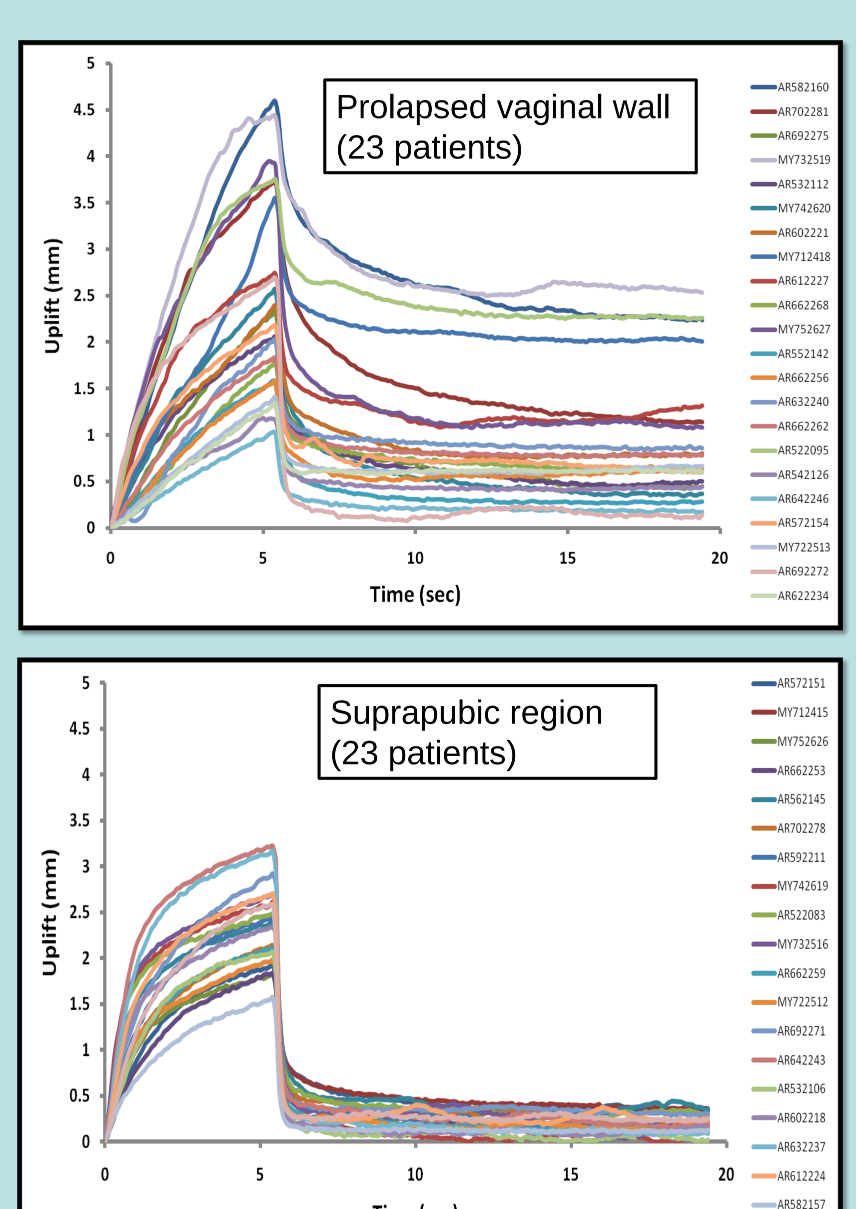

Fig. 5. BTC2000 uplift and recovery data, obtained for tissues from prolapsed vaginal wall (A) and suprapubic regions (B)

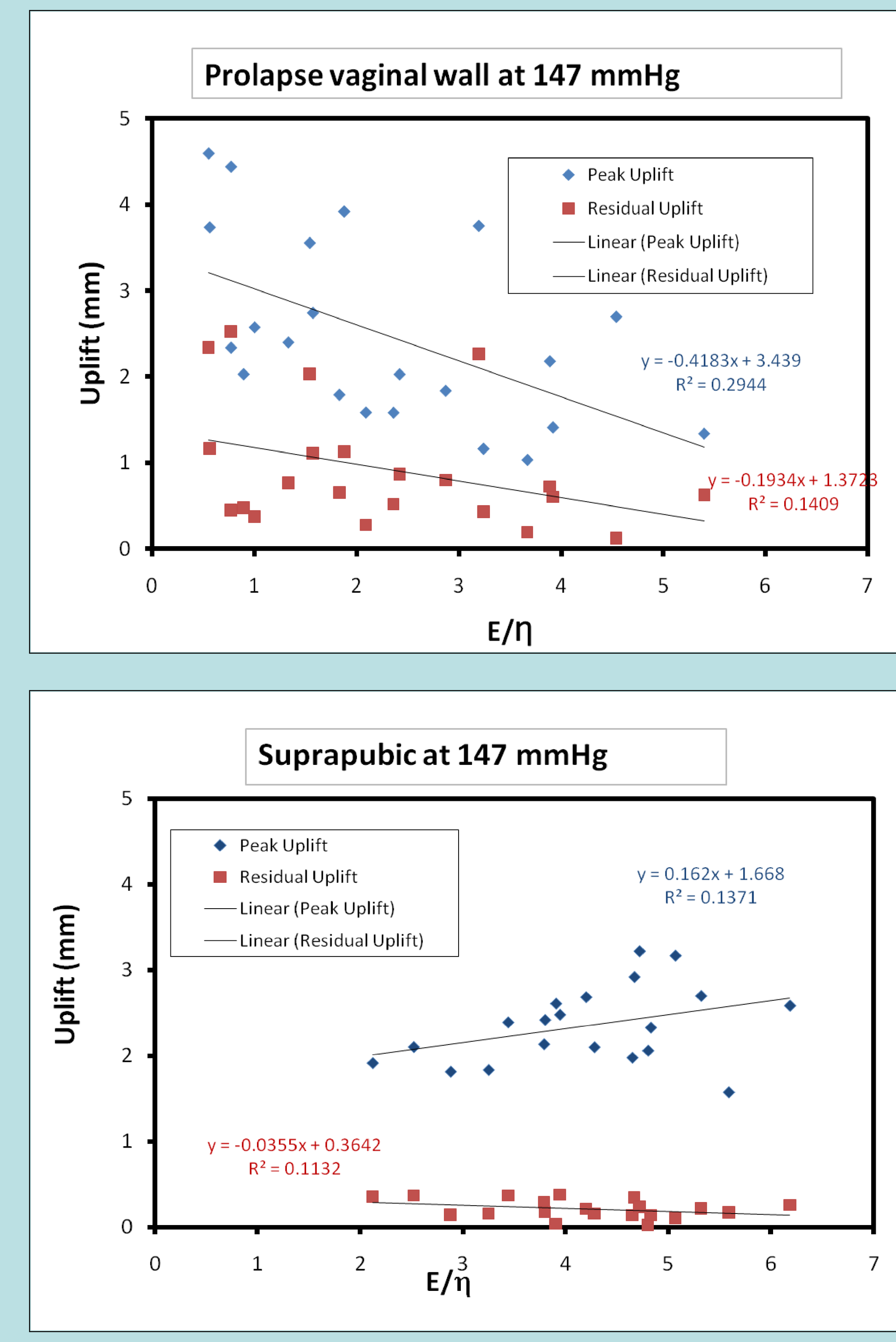

Fig. 6 A) Both peak (blue) and residual (red) uplift are plotted vs. the E/η ratio for prolapsed vaginal wall tissue when pressure is released to 0 from 147 mmHg, with linear regression lines. B) Similar plot for the suprapubic region.

Prolapsed vaginal wall tissues

- Higher E/η ratio means faster tissue recovery upon (negative) pressure release from 147 to 0 mmHg at 6 sec. Patients with faster tissue recovery exhibit lower peak uplift and residual uplift.
- Lower E/η ratio means slower tissue recovery after negative pressure release. Patients with slower tissue recovery exhibit higher peak uplift and residual uplift.
- The percentage of elastic energy released during recovery was found to be insensitive to the rate of tissue recovery.
- A lower percentage of elastic energy stored during uplift (60%), is recovered during relaxation after pressure release.

Tissues at suprapubic region

- Tissue recovery rates during relaxation are relatively higher.
- Both peak uplift and residual uplift are insensitive to recovery rate
- A higher percentage of elastic energy stored during uplift (90%), is recovered during relaxation after pressure release.

Conclusions

- Different biomechanical behavior was observed for prolapse tissues compared with suprapubic region tissues, based on *in-vivo BTC-2000* measurements in women with anterior vaginal wall prolapse and employing a Voigt model. The prolapse tissues were more compliant.
- Refinements of this promising model, data collected from a larger population, and clinical correlations will be used to determine risk factors influencing the viscoelastic properties of prolapse tissues.

References

1. Fung, Y.C., Biomechanics: Mechanical properties of living tissues, 2nd ed. Springer-Verlag, 1993, NY.
2. Zimmern PE, Eberhart RC, Bhatt A: Methodology for biomechanical testing of fresh anterior wall vaginal samples from postmenopausal women undergoing cystocele repair. Neurourology and Urodynamics 28:325-329, 2009/
3. Chuong C, Towns R, Eberhart R, Mosier E, Zimmern P: Development of a biomechanical finite element model to predict prolapsed anterior vaginal wall compartment properties. Abstract 95. NUU 29 (6):944-946, 2010.
4. Mosier E, Jerome R, Chuong C, Eberhart R, Zimmern P. In vivo measurement of the anterior vaginal wall biomechanical properties in prolapse patients undergoing surgical repair. Podium #21. NUU 29(2):315, 2010.

ICS 2011, Glasgow