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A CLINICALLY-RELEVANT MODEL OF STRESS URINARY INCONTINENCE: WHAT IS THE EFFECT OF MATERIAL PROPERTIES ON THE FINITE ELEMENT SIMULATION OF THE BLADDER, URETHRA AND SUPPORT STRUCTURES DURING A COUGH

Hypothesis / aims of study

The complex geometry of the pelvic floor support structures and insufficient information regarding the properties of these structures have been barriers to clinically-relevant models of female stress urinary incontinence. We used clinical urodynamicdata to create a simplified simulation of the effects of a cough on the bladder and its support structures. In this project, we used the validated simulation to perform a sensitivity analysis of the effects of changing properties of the materials that are involved in pelvic support. The long term goal of this work is to build a clinically-relevant simulation that would be useful for enhancing prediction of an individualized patient's surgical outcome.

Study design, materials and methods

Urodynamics

Urodynamic data was obtained from a continent 28-year-old woman. Cystometry was performed at a fill rate of 80 ml/min with the subject in a birthing chair reclined at 45 degrees. An 8F catheter was placed in the subject's vagina to estimate abdominal pressure. An 8F dual-micro-tipped catheter with infusion port was placed with the distal transducer in the bladder and the proximal transducer in the midurethra facing the 9-o'clock position to record vesical (bladder) pressure and urethral pressure, respectively. Maximum urethral closure pressures and urethral pressure profiles (UPP) were obtained at maximum cystometric capacity, 536 ml in this subject. Urethral pressure was recorded during cough & valsalva events at the location of maximum urethral pressure identified in the UPP. Urodynamic methods, definitions, and units conformed to the standards recommended by the International Continence Society (1). Only data from a cough performed at maximum cystometric capacity was simulated in this initial model.

Simulation

The following assumptions were used for the initial model. The bladder was modelled as a closed sphere with a closed outlet tube (the urethra) attached. The bladder and urethra were modeled as Mooney Rivlin and Blatz Ko hyperelastic materials, respectively, based on the work of Haridas et al (2) The support structure was assumed to be comprised solely of linearly elastic muscle (3). The mesh for all structures was comprised of 8 node hexahedral elements. The loads applied to the model were taken directly from the recorded abdominal pressure data. These loads were applied as pressure loads to the outer surface of the top hemisphere of the sphere representing the bladder.
To prevent unrealistic motion of the model, the rim of the support structure (Fig. 1) was completely constrained for both movement and rotation. The walls of the orifice of the support structure through which the urethra passes, were also constrained to prohibit in-plane motion. To simulate vaginal support of the urethra, the dorsal side of the urethra was constrained for movement and rotation about the z axis. The simulation was carried out by following abdominal pressure changes during a cough using a Lagrangian formulation for all structures. The model was validated by comparing vesical pressure predictions from the simulation to clinical vesical pressure measured simultaneously with the abdominal pressure used to load the model.

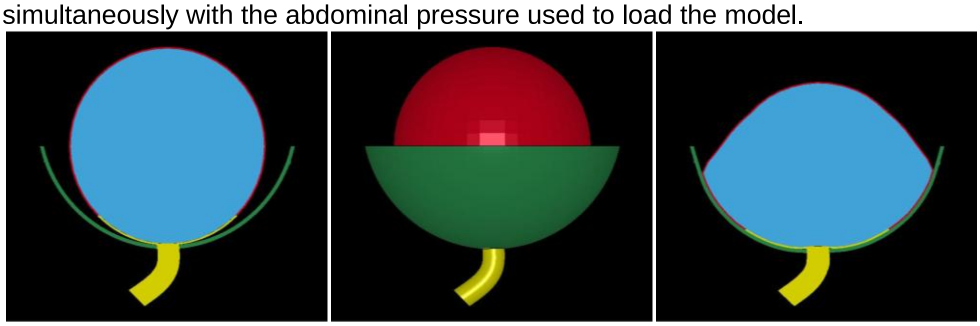

Figure 1. Simplified example model of the bladder and the urethra. Bladder inner diameter: 100.8 mm; bladder outer diameter: 1022.6 mm; urethra length: 33.0 mm; urethra outer diameter: 11.5 mm. **A**. Three-dimensional view of model. **B**. Cross section of the undeformed model. **C**. Cross section of deformed model at time of peak abdominal pressure.

Sensitivity analysis

We performed a sensitivity analysis to determine if changing material properties (more or less stiffness) affects model outcomes. In the first model, we increased the stiffness of all materials to 150% of the published values (the stiff model). In the second model we decreased the stiffness of bladder and urethra to 50% of published values and that of the support structure to 75% of published values (the compliant model). These choices were made by pushing the change in the lower value of the material properties to the lowest values tolerated by the modelling software so as to be able to complete the simulation.

Results

Displacements of the compliant model during a cough were greater than those of the stiff model, implying that the support structure of the compliant model moved down more in response to the cough than the stiff model. The support structure of the compliant model therefore acted more like a trampoline, and the stiff model more like a rigid wall.

Although the material properties are changed dramatically, the predicted bladder or vesical pressures are similar (Figure 2), suggesting that precise characterization of the material properties of the lower urinary tract and support structures is not essential in order to produce a relevant model of pelvic floor mechanics during a cough.

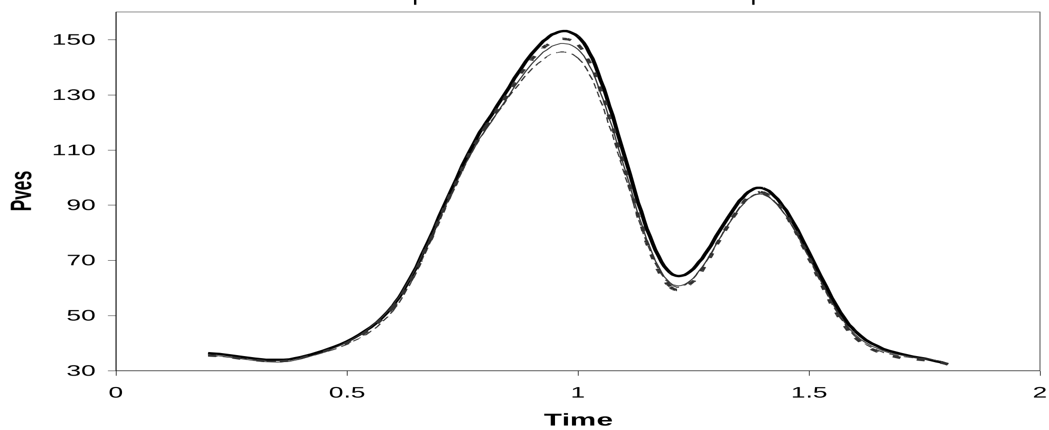

Figure 2. Vesical, or bladder, pressure measured while coughing during a urodynamics exam on a continent woman (heavy solid line) compared to vesical pressures predicted by finite element models using published material property values (solid line), stiff material properties as described above (dashed line line) and compliant material properties as described above (heavy dashedline).

Interpretation of results

Our sensitivity analysis demonstrates that, while stiffness strongly affects displacement, it does not have much impact on bladder pressures generated during a cough. Future work will include application of the model to incontinent women and use the model to better understand biomechanics of the pelvic floor.

Concluding message

Urodynamic pressures can be replicated in FEM models using standardized material properties. Future work will include application of the model to incontinent women and use of the model to better understand biomechanics of the pelvic floor.

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Was the Declaration of Helsinki followed?	**Yes**
Was informed consent obtained from the patients?	**Yes**