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ULTRASOUND DEFORMATION IMAGING IN THE LOWER URINARY TRACT TO ESTIMATE PRESSURE IN THE URETHRA

Hypothesis / aims of study

With increasing age men often develop lower urinary tract symptoms (LUTS) such as frequent voiding, a low flow rate and incomplete emptying of the bladder. A possible cause of these symptoms is bladder outlet obstruction (BOO), defined by a high detrusor pressure in combination with a low urine flow rate. Both parameters are measured during a urodynamic pressure flow study. The invasive nature of these studies can lead to morbidity such as urinary tract infections, discomfort and pain. Therefore, there is an apparent necessity for non-invasive techniques to diagnose BOO, ultrasound imaging of tissue deformation can possibly provide in this.

Upon voiding the detrusor contracts and propels urine through the urethra. This results in a radial force on the urethral wall that leads to deformation of the urethral tissue. At parts of the urethra where it is surrounded by tissue (e.g. an enlarged prostate) that prevents this radial expansion, the passage will be narrower. This results in a decrease in urethral pressure and reduced radial deformation. With radiofrequency (RF) ultrasound it is possible to estimate deformation (strain) in biological tissue under compression [1]. Ultrasonic estimation of deformation up- and downstream of the prostatic urethra could therefore be a measure for the differences in local urethral pressure. In a model of the urinary tract we have tested this hypothesis.

Study design, materials and methods

As a flexible model of the lower urinary tract we constructed two phantoms from an aqueous PolyVinyl Alcohol (PVA) solution. The phantoms consisted of a flexible tube (inner diameter: 3 mm, outer diameter: 13 mm). Two degrees of obstruction were created by surrounding the tube with a PVA ring mimicking a 'mild' prostatic obstruction (inner diameter: 13 mm, outer diameter: 29 mm) and a 'severe' obstruction (inner diameter: 7 mm, outer diameter: 29 mm). Both rings were 12 mm thick. The tube and the two rings were freeze-thawed two times at –20 ºC. With increasing number of freeze-thaw cycles the stiffness of the PVA increased [2]. The phantom was placed in a water-filled container, one side was connected to a centrifugal pump and the other side to a flow meter. The pump was driven by a sinusoidal function at a frequency of 30 cycles/minute. The up-slope of each cycle was used to (repeatedly) simulate the onset of voiding by the opening of the bladder neck. In the first phantom a maximum flow rate of 6.7 ml/s and in the second phantom a flow rate of 5 ml/s was applied.

At 22 positions along the length of both urethral phantoms (positions were 2 mm spaced) RF ultrasound data was acquired during flow using a linear array transducer (11-3L) and a Philips SONOS 7500 ultrasound system (Philips Medical Systems, Bothell, WA, USA) with a custom designed RF-interface. At each position at least two cycles of data were acquired and stored for offline analysis. From the RF US data we estimated circumferential strain in the phantom tissue at each position during the onset of voiding using a coarse-to-fine strain estimation algorithm and the diameter change of the urethral lumen. Strain estimation was corrected for movements during the voiding cycle using a tracking algorithm. Also at each position the urethral pressure was recorded simultaneous to the US acquisition using a fluid filled pressure catheter.

At each position along the length of the phantom we calculated the increase in stress in the phantom tissue during the onset of voiding from the urethral pressure and the lumen diameter using Laplace's Law for a thick walled tube [2]. This was done at three locations in the urethra mimicking wall with increasing radial distance from the lumen (Region-Of-Interest (ROI) 1, 2 and 3). At each of these positions we also averaged the circumferential strain and correlated the circumferential strain with the applied stress using Spearman's correlation coefficient. From the circumferential strain and stress we derived the elastic modulus for the two phantoms separately using Linear Regression. Also circumferential strains up- and downstream of the obstruction were compared using Student's t-test.

Results

In both phantoms the estimated circumferential strain in the urethral wall correlated significantly positive with the applied stress ('mild' obstruction: Spearman's = 0.91, $p < .05$, 'severe' obstruction: Spearman's = 0.85, $p < .05$). In the 'mild' obstruction the estimated elastic modulus was ~2.8×10^2 N/m^2 and there was no significant difference in circumferential strain and in urethral pressure between up- and downstream of the obstruction ($p = .19$). In the 'severe' obstruction the estimated elastic modulus was ~2.3×10^2 N/m^2 and the measured urethral pressure and the estimated circumferential strain upstream were significantly higher ($p<.05$) than downstream the obstruction.

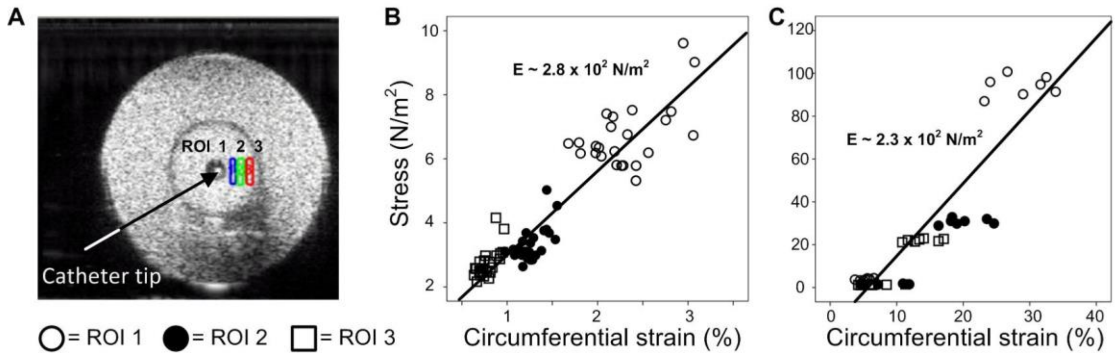

Figure 1: A) Cross sectional area of the 'severe' obstructed urethral phantom with the three ROIs indicated. In B) and C) the stress at the three radial position is plotted versus the circumferential strain in the urethral phantom wall for the 'mild' (B) and 'severe' (C) obstruction.

Interpretation of results

In general, circumferential strain in the model urethral wall was related to the applied stress that results from the local urethral pressure. This relation is characterized by the elastic properties of the model. Assuming these elastic properties to be the same at two positions in the urethra (for example up- and downstream of the prostatic urethra), then in combination with the estimated circumferential strain, the diameter of the lumen and urinary flow rate opens the way to a noninvasive technique for urethral pressure measurement. Measuring these 'relative' pressures could possibly be used to assess to what degree that section obstructs the bladder outlet. Knowledge of the pressure proximal and distal to the obstruction also allows to calculate the pressure profile in the obstructed region and subsequently allows to determine the mechanical properties of the obstruction.

Concluding message

Circumferential strain in a urethral phantom wall and the diameter of the urethral lumen can be estimated using radiofrequency ultrasound imaging. This, in combination the urinary flow rate, could potentially be used as a novel technique to estimate relative urethral pressures and determine mechanical properties of the obstruction.

References

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Disclosures

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