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Idzenga T[1], Arif M[2], van Mastrigt R[2], de Korte C[1]
***1.** Radboud University Nijmegen Medical Center, Nijmegen, The Netherlands, **2.** Erasmus Medical Center, Rotterdam, The Netherlands*

ULTRASOUND STRAIN IMAGING IN THE LOWER URINARY TRACT DURING VOIDING AS A TOOL FOR DIAGNOSING BOO

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. The invasive nature of a pressure flow study 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.

Upon voiding the detrusor contracts and forces urine through the urethra causing an outward force on the urethral wall. At parts of the urethra where the pressure exerted by the surrounding tissue (e.g. an enlarged prostate) is higher, the passage will be narrower. At these locations the radial deformation of the urethral tissue is expected to be smaller. With radiofrequency (RF) ultrasound it is possible to estimate deformation (strain) in biological tissue under compression [1]. In a model of the urethra we have tested the hypothesis that ultrasonic measurement of radial strain at the prostatic urethra with respect to other sections of the urethra could therefore be a measure for the degree of BOO.

Study design, materials and methods

As a flexible model of the lower urinary tract we constructed three phantoms from an aqueous PolyVinyl Alcohol (PVA) solution. One phantom without an obstruction consisted of a flexible tube (inner diameter: 3 mm, outer diameter: 13 mm). Two phantoms with an obstruction consisted of the same tube surrounded by a ring mimicking a 'mild' prostatic obstruction (inner diameter: 10 mm, outer diameter: 29 mm) and a 'severe' obstruction (inner diameter: 7 mm, outer diameter: 29 mm). The tube and the two rings were freeze-thawed twice. 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. Up- and downstream of the urethral phantom the pressure was measured using disposable pressure transducers. The pump was driven by a sinusoidal function. The up-slope of each cycle was used to (repeatedly) simulate the onset of voiding by the opening of the bladder neck. Eight maximum flow rates were applied to the urethral phantom ranging from 3.7 to 17.5 ml/s. We acquired RF ultrasound data 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 applied maximum flow rate at least three cycles of data were acquired and stored for offline analysis. Strain in the phantom tissue during the onset of voiding was estimated from the RF ultrasound data using a coarse-to-fine strain estimation algorithm [3]. Six Regions-Of-Interest (ROI) were drawn and the mean radial strain (i.e. strain in the direction perpendicular to that of the urinary flow) in these ROIs was calculated. The strain in the two ROIs upstream (1 and 4) and in (2 and 5) the obstruction was averaged and for the different flow rates the ratio of these averages was calculated. As an example of clinical applicability we also transperineal acquired RF ultrasound data in an asymptomatic male volunteer during the onset of voiding.

Results

In all three phantoms the difference between the pressure up- and downstream of the phantom increased with the applied flow and the increasing degree of obstruction (no obstruction: 5.2 – 16.5 cmH_2O, 'mild' obstruction: 6.4 – 22.6 cmH_2O, 'severe' obstruction: 8.3 – 47.1 cmH_2O). In the two phantoms with prostate mimicking ring the ratio of the strain up- and downstream of the ring increased with an increasing flow rate to a maximum followed by a decrease to 1 (see Figure 1). The maximum strain ratio appears to vary with the degree of obstruction but is found at the same flow rate value. In the phantom without the ring the strain ratio was 1 at all applied flow rates. In the asymptomatic volunteer axial strain in the bulbous urethra was estimated during the onset of voiding. The strain appeared to increase with urinary flow (see Figure 2).

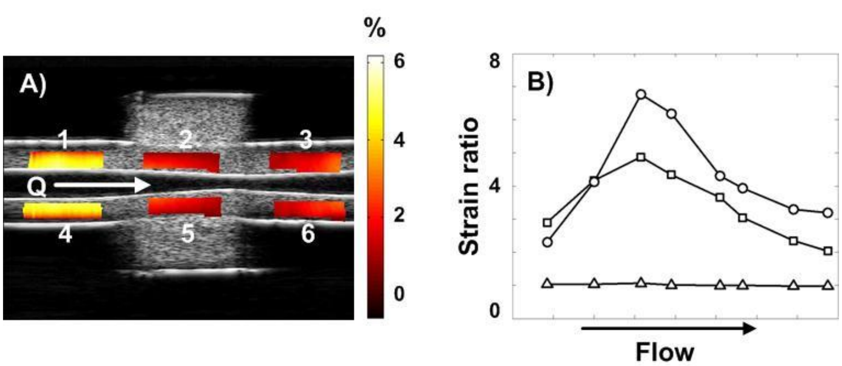

Figure 1: A) B-mode image of the urethral phantom with a prostate mimicking ring with the radial strain in six ROIs at maximum flow rate. B) Ratio of the average radial strain in the ROIs upstream (1 and 4) and at the location of the prostate (2 and 5) for the phantom without obstruction (triangles), a mild obstruction (squares) and a severe obstruction (circles).

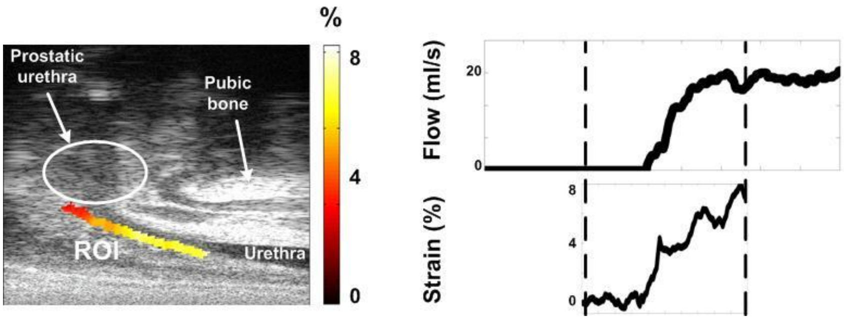

Figure 2: In vivo example of axial strain in the bulbous urethra during the onset of voiding in an asymptomatic male volunteer.

Interpretation of results

In the urethral phantom without a prostate mimicking ring the radial strain in the wall was the same along the length of the phantom. When a ring was placed around the phantom the pressure difference between up- and downstream increased and the strain distribution along the phantom changed. This indicates that at the location of the prostate radial movement of the urethral phantom was limited by the surrounding prostate imitating ring. Estimating the strain pattern in the urethral wall along the lower urinary tract during voiding could therefore possibly be used as a non-invasive method for the diagnosis of BOO. With increasing flow rate the strain ratio upstream and in the obstruction increases to a maximum and decreases to 1 again. This indicates that the proposed technique works best at low flow rates which makes it very suitable for patients with LUTS. The in vivo example shows that it is possible to transperineal image the lower urinary tract and estimate strain in the urethral wall during voiding. This opens the way for the use of ultrasound strain imaging in the lower urinary tract as a tool for diagnosing BOO.

Concluding message

Radial strain in a urethral phantom can be estimated using radiofrequency ultrasound imaging. The strain at the location of an obstruction was lower than the strain upstream. Estimating radial strain along the lower urinary tract during voiding using radiofrequency ultrasound might be used as a non-invasive tool to diagnose BOO in men with LUTS.

References

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