659

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DEVELOPMENT OF A FINITE ELEMENT MODEL OF THE URETHRA TO EXPLAIN THE ORIGIN OF URETHRAL NOISE

Hypothesis / aims of study

In men, an enlarging prostate mostly leads to bladder outlet obstruction (BOO). Instead of an invasive pressure/flow study, alternative, non-invasive methods have been proposed to diagnose BOO. One method involves the recording of perineal noise during voiding using a microphone, see fig. 1. Presumably, this noise represents vibration of the urethral wall caused by turbulence in the urethra past the obstruction. It has been shown that the noise correlates with the degree of obstruction, position of the microphone and wall stiffness [1], but its origin is still undefined. The aim of this study was to develop a mathematical model of the urethra to study the velocity / pressure distribution of fluid passing an obstruction. The model uses Finite Element Analysis (FEA) to calculate the response of a fluid filled urethra to a certain loading condition (e.g. bladder pressure).

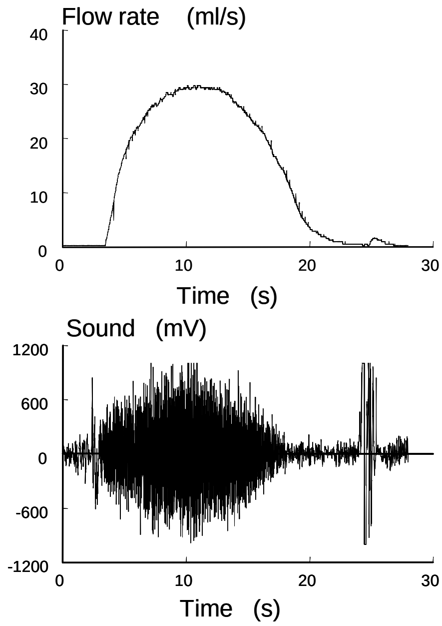

Fig 1 Simultaneous measurement of flow rate (top panel) and noise (lowest panel) using a perineal microphone.

Study design, materials and methods

The urethra was modelled as a two-dimensional pipe (150 mm in length and 25 mm in diameter) and the obstruction by a decreased diameter of the 2nd length quarter of the model, see fig 2. The longitudinal cross-section was divided in ~ 700 discrete building blocks called fluid elements. Each fluid element described flow of urine in terms of velocity and pressure as defined by the laws of conservation of mass (no urine is added or removed via the wall) and momentum (equilibrium between velocity and pressure distribution). We assumed that the fluid flow was stationary, meaning that the solution of each fluid element was independent of time and that the urethral wall did not move (anymore). This latter assumption implied that the visco-elastic urethral wall properties were not included in this first model. The fluid properties were calculated at three degrees of obstruction (low, medium, high) by setting the diameter of the obstruction to 12, 8 and 5 mm. Fluid entered the left side of the model at 0 m/s, reflecting a large filled bladder with relatively static urine. Fluid exited the model at the right side at 2 m/s. To meet these boundary conditions, the entrance pressure was set at 20, 50 and 150 cmH_2O above the atmospheric level and the outlet pressure was kept at atmospheric level. Zero velocity was also set for the fluid elements in contact with the urethral wall to warrant frictionless fluid flow. In each simulation, the pressure distribution along the model wall past the obstruction was calculated to find out the best location for a microphone to record perineal noise.

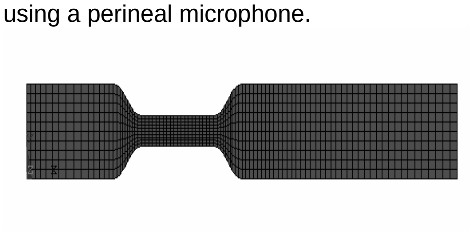

Fig 2 Cross section of the model urethra divided in fluid elements to simulate the velocity / pressure distribution at each location using Finite Element Analysis.

Results

Fig. 3, top panel, shows increased fluid velocity, v_{max}, inside the obstruction as calculated by FEA. At the widening of the urethra after the obstruction, the fluid velocity, v_{min}, was negative, suggesting recirculation of fluid. A streamline plot, middle panel, indeed showed fluid separation at this location resulting in a recirculation zone. More downstream, the fluid streamlines restored. The lowest panel shows the pressure distribution. Negative pressures, P_{min}, were calculated at the obstruction outlet. This area partly coincided with the recirculation zone. Fig. 4, shows the wall pressure in all three simulations as a function of wall length starting from the obstruction outlet, see also fig. 3. Negative wall pressures were found at medium and high degree of obstruction between 0 and ~15 mm. The average location at which wall pressure and fluid velocity towards the wall were maximum, the so-called reattachment point, was 26 ± 10 mm (mean ± 1 SD).

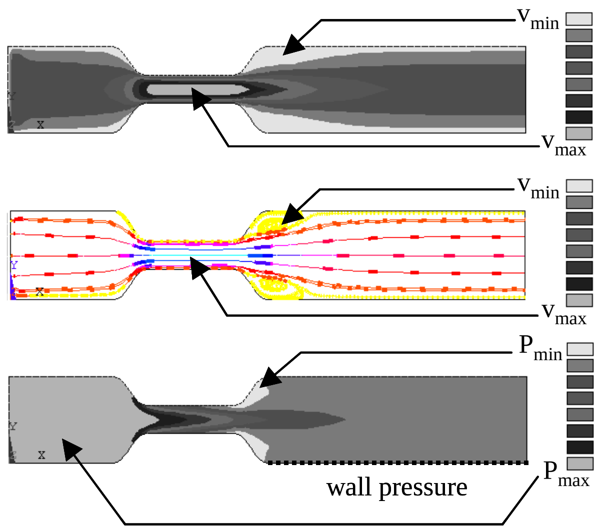

Fig 3 Results of a FEA of fluid flow through a medium obstructed model urethra: top and middle panel show the velocity distribution through the obstruction. Recirculation of fluid occurred when pressure at the obstruction outlet was negative, lowest panel.

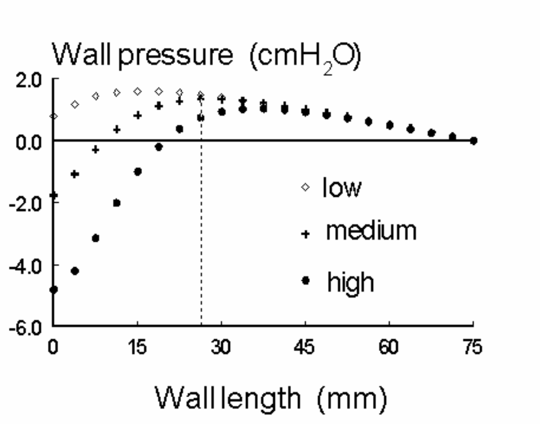

Fig 4 The wall pressure, calculated at three degrees of obstruction, was plotted against the wall length past the obstruction, see also fig. 3. Wall pressures were negative at medium and high obstruction, which indicated fluid recirculation. The point of maximum wall pressure depended slightly on the obstructions applied.

Interpretation of results

Turbulence I the urethra could be explained by a negative pressure after the obstruction, which causes recirculation of urine. The streamlines restored distal from this recirculation zone at the reattachment point. At this point, the impact of constantly streaming urine against the wall was highest. Presumably, flexible tubes, i.e. the urethra, this induces vibrations with the highest amplitude.

Concluding message

We made a model of the urethra based on Finite Element Analysis to study the flow of urine through an obstructed urethra. We found that an obstruction may cause turbulence in the urethra, when past the obstruction a negative pressure develops, inducing recirculation of urine. The streamlines restored at a reattachment point, a location at which presumably vibrations are induced with the highest amplitude. We therefore think that the reattachment point is the best location to non-invasively assess urethral noise. The location seemed to vary slightly with the degree of obstruction applied. This result was confirmed by the outcome of a series of noise measurements in a urethral model of Polyvinyl Alcohol, which was presented in a separate abstract. We hope to extend our urethral model based on FEA by including urethral visco-elastic properties and geometry to develop a non-invasive method for diagnosing BOO based on perineal noise recording.

References

[1] Perineal noise recording as a non-invasive diagnostic method of urinary bladder outlet obstruction: a study in Polyvinyl Alcohol and silicone model urethras. Neurourol.Urodyn. Accepted for publication.

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