Study design, materials and methods
A soft tissue mimicking urethral model representing the lower urinary tract of a male was made from a 10% aqueous solution of Polyvinyl Alcohol (PVA) cryogel. To create different degrees of obstruction two flexible PVA rings (modelling the prostate) were placed around the model urethra, which was placed in a water filled container to prevent evaporation. To generate flow through the model one end was connected to a water column generating the bladder pressure. The other end was connected to an outflow tube draining into a fluid filled expansion barrel through a rotating disk flow meter (Disa Electronic, Denmark). The fluid from the barrel was pumped back into the water column through a roller pump (Verder B.V. The Netherlands). For different water column pressures (i.e. bladder pressures) the pressure drop (p1-p2) over the model urethra and the corresponding flow rate (Q) were recorded with and without rings. The measured pressure drop values and the corresponding flow rate values were plotted in a pressure-flow plot to define the different degrees of obstruction.

An ultrasound system (BK-Medical, Pro Focus UltraView 2202) with a custom designed RF-interface was used to acquire RF data. Silica gel particles of size 15µm-40µm (Sigma-Aldrich, USA) were added to the water circulating through the model to simulate urine and generate ultrasound reflections. To get maximum decorrelation the probe was positioned parallel to the flow direction with ultrasound beam orthogonal to the flow. We acquired 10 subsequent RF-data frames at a Pulse Repetition Frequency (PRF) of 11.4 kHz. Each frame consisted of 144 adjacent RF-signals. We calculated the correlation coefficients between the first and subsequent nine RF-data frames (i.e. 1 with 2, 1 with 3, etc.) for all 144 RF-signals to make correlation images. In each correlation image, we selected a Region of Interest (ROI) in which we calculated the mean correlation coefficient values for three degrees of obstruction. The decorrelation curve was obtained by plotting the resulting mean cross-correlation coefficient value as a function of the time interval between the frames. The decorrelation slope [2] was calculated for each decorrelation curve by taking the decrease in correlation during the time interval between two subsequent RF-signals (87µs). The decorrelation slope in urethral models was studied at three different ultrasound transducer positions: at the obstruction and at 2cm and 4cm downstream of it. The calculated decorrelation slope values were plotted at the different degrees of obstruction.

Results
Figure (A) shows the pressure-flow plots of the urethral models for the three degrees of obstruction. The two straight lines represent the categorization of the pressure-flow data into: unobstructed, equivocal and obstructed according to the Bladder Outlet Obstruction Index (BOOI) [3]. The decorrelation slope for each of the three obstruction at three different positions are shown in Figure (B).
Interpretation of results
The pressure-flow plot (Figure A) demonstrates the degree of obstruction of the three different urethral models. We can see that with increasing flow rate the pressure drops increases smoothly for each urethral model. The plot also shows that the pressure-flow relation in our model is not in accordance with the linear relation assumed in the BOOI analysis model [3]. For that reason we have not used BOOI to characterize the degree of obstruction in our models. At a flow rate of 12ml/s we calculated the decorrelation slope in each urethral model at three different positions. In obstructed region and at 2cm downstream of the obstruction the decorrelation slope increases linearly by increasing degree of obstruction. However at 2cm downstream of the obstruction the decorrelation slope increased most with the degrees of obstruction. This is due to turbulence created by the obstruction. A higher degree of obstruction creates more turbulence and results in higher decorrelation slope. At 4cm downstream of the obstruction the flow becomes laminar again and the change in decorrelation slope is not very significant.

Concluding message
In this study, we applied a decorrelation method to RF ultrasound signals measured in urethral models with different degree of obstruction. The results show that the decorrelation slope increased strongly with the different degree of obstruction at 2cm downstream of the obstruction. At other measuring positions (in the obstruction and at 4cm downstream) the relation was weak. We conclude that the decorrelation of ultrasound images may be a new technique to noninvasively diagnose bladder outlet obstruction.

References

Disclosures
Funding: This research is supported by the Dutch Technology Foundation STW (NIG 10896), applied science division of NWO and the Technology Program of the Ministry of Economic Affairs. Clinical Trial: No Subjects: NONE