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DEVELOPMENT OF A BIOPHYSICAL MODEL OF THE URETHRA: COMPARISON OF VISCOELASTIC PROPERTIES BETWEEN PVA MODELS AND PIG URETHRAE.

Aims of study

At present the method for a urodynamic diagnosis of BOO is uncomfortable to the patient and time-consuming. In the past several alternative non-invasive methods have been suggested. One of these was perineal recording of noise produced during voiding [1]. However, the relation between the noise produced and the degree of obstruction of the urethra (e.g. caused by an enlarged prostate) is unclear. To study this relation, we have developed a biophysical model of the urethra made from a cryogel, a 10% solution of PolyVinyl-Alcohol (PVA) that can be polymerised by freezing and thawing.

We hypothesize that the viscoelastic properties of the urethra influence the noise-production during flow. Earlier it was shown that PVA-models are extensible and that the elastic properties of the PVA depend on the number of freeze-thaw cycles [2]. The aim of this study is to compare the elastic and viscoelastic properties of four PVA-models to those of four pig urethrae.

Materials and methods

Each model was made by polymerisation of PVA in a cylindrical mould (450 mm in length, 16 mm in diameter). Two models (U_1 and U_2) were built as a uniform freeze-thawed (1 and 2 times respectively) solid cylinder (diameter is 10 mm). Both were placed in a 3 times freeze-thawed PVA-shell, see Table 1, and had a V-shaped slit along the axis (legs of 5 mm in length) to allow flow through each model. The two other models (U_3 and U_4) had a Y-shaped slit along the axis (legs of 5 mm in length) and were built as a single uniform freeze-thawed (2 and 4 times respectively) solid cylinder. The pig urethrae were extracted from freshly killed female pigs (45 ± 15 mm in length).

One side of each urethra (model/pig) was connected to a 5 ml syringe and by manually injecting a known volume of water strain was applied stepwise. In each urethra stepwise increasing volumes, starting at 0.2 ml with increments of 0.2 ml, were injected. The other side of the urethra was connected to a pressure transducer. The pressure-signal was sampled with a frequency of 1000 Hz and stored on a PC for further analysis using self-written Matlab©-programs.

The elastic and viscoelastic properties of the PVA models and the pig urethrae were calculated by fitting the analytic solution of the step-response (sum of a constant and a bi-exponential function) of a mechanical model (see Fig. 1a) to 1000 samples, selected from the pressure-maximum onwards (see Fig. 1b) of the recorded pressure. The average of elastic modulus E_0 (representing the elastic properties) was calculated by plotting the stress calculated from the fit-coefficients from each measurement and the injected volume, against the applied strain and fit a straight line with the least-squares method through these points for stress-values between 500 and 20000

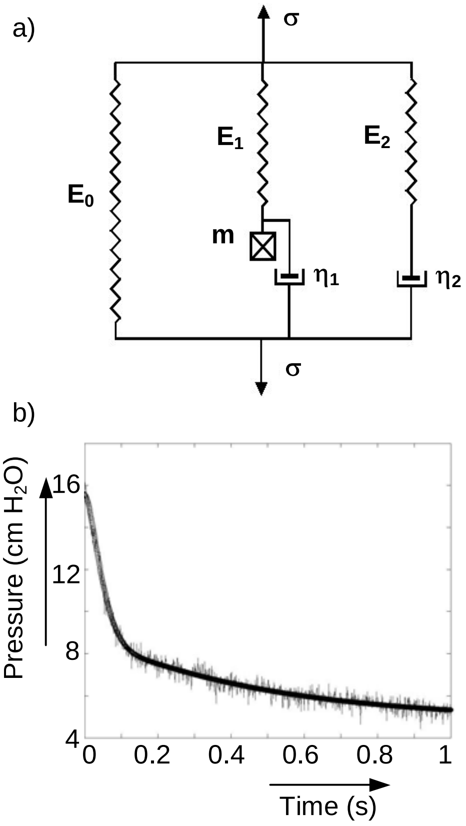

Fig. 1: a) Mechanical model of the urethral wall used for derivation of the step-response function.
b) Selected part of pressure-signal fitted with the analytical step-response function of the mechanical model.

N/m^2. The time-constants τ_1 and τ_2 (representing the viscoelastic properties) were calculated directly from the fit-coefficients from each measurement.

The time constants τ_1 and τ_2 of PVA models and pig urethrae were statistically compared using the Mann-Whitney U-test.

Results

The manual injection of the volumes could be regarded as stepwise since the injection-time of the volumes was short compared to the relaxation time of the urethral wall.

The average values of the elastic modulus E_0 and the time constants τ_1 and τ_2 are presented in Table 1. The time constant τ_1 of the PVA models U_1, U_3 and U_4 was significantly different from that of pig urethrae ($p < 0.05$). And the time constant τ_2 of the PVA models U_1, U_2 and U_3 was significantly different from that of pig urethrae ($p < 0.05$).

Interpretation of results

We have measured the elastic and viscoelastic properties of urethral models, made of PVA, and compared these with pig urethrae. The average of the elastic modulus E_0 of the PVA models was higher than that of the pig urethrae and appeared to increase (independent of the construction of the model and the shape of the slit along the axis) with the number of freeze-thaw cycles. Thus, looking at the elastic properties, the model should be as less freeze-thawed as possible.

The time-constants of the bi-exponential response function appeared not only to depend on the number of freeze-thaw cycles but also on how the model is constructed. In the two groups of models (solid cylinder with/without a shell) τ_1 seemed to decrease with the number of cycles and τ_2 seemed to increase (see Table 1).

For designing the best PVA model the dependence of elastic and viscoelastic properties on the number of freeze-thaw cycles thus seems conflicting. It is not clear which of the two properties most affects the noise-production; therefore more research needs to be done on the effect of viscoelastic properties on noise-production.

References

[1] Towards a noninvasive urodynamic diagnosis of infravesical obstruction, BJU International 84: 195 – 203 (1999);

[2] Polyvinyl Alcohol cryogel: an ideal phantom material for MR studies of flow and elasticity, Magn Reson Med 37: 314-319, 1997.

Table 1: Characteristics of the used PVA models (row 1) and elastic and viscoelastic properties (row 2 through 4) for PVA models / pig urethrae.

Urethra	**U_1**	**U_2**	**U_3**	**U_4**	**U_{pig}**
# Freeze-thaw cycles	Internal: 1 External: 3	Internal: 2 External: 3	Uniform: 2	Uniform: 4	-
$E_{0,avg}$ (x 10^3 N/m^2)	20	43	22	50	10
τ_1 (1/s) Mean ± sd	0.14 ± 0.03	0.04 ± 0.02	0.12 ± 0.03	0.06 ± 0.02	0.04 ± 0.01
τ_2 (1/s) Mean ± sd	0.14 ± 0.11	0.44 ± 0.16	0.13 ± 0.08	0.41 ± 0.14	0.51 ± 0.13

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