Per Bagi

Pressure/cross-sectional area relations in the proximal urethra of healthy males

Part III: The time dependent pressure response following forced dilation: standardization of a technique

Abstract The urethral response to a sudden forced dilation was studied in ten healthy male volunteers aged from 27 to 71 years. Measurements were performed from the bladder neck and beyond the region of high pressure using a specially designed probe. The pressure response after dilation showed a characteristic course, which could be described by a double exponential function of the form: \( P_t = P_{equ} + P_a e^{-\tau_a t} + P_b e^{-\tau_b t} \), where \( P_t \) is pressure at time \( t \), \( P_{equ} \) is equilibrium pressure after dilation, \( P_a \) and \( P_b \) are pressure decay, and \( \tau_a \) and \( \tau_b \) are time constants. The size and velocity of dilation, as well as the degree of distension before dilation, proved of significance for the magnitude of the pressure response. The characteristics of the pressure response are given by the properties of the periluminal structures strained during dilation, and are thus predominantly determined of elastic, collagen, muscular, and glandular components. However, a high degree of relaxation after straining, and a modest stiffness, indicates that the muscular component dominates the response. The significance of the prostatic tissues remains unclear.

Keywords Male urethra · Stress-relaxation · Pressure · Cross-sectional area

Introduction

The distensibility of the urethra has major implications for its normal physiological function, but the urethral resistance against dilation is a complex phenomenon which is highly dependent on the circumstances under which it is evaluated. The urethral response to dilation at rest during the reservoir phase has been extensively studied, but mainly under static conditions as evaluated at steady-state following distension. The time-dependent response has only gained limited attention, and seems not to have been studied in men [11, 13, 24, 27, 28]. The dynamic properties of the urethra may be studied by means of forced dilations, in terms of urethral pressure and cross-sectional area as related to time. This procedure induces an increase in urethral cross-sectional area, and thereby a stretch of the periluminal structures, and a concomitant pressure response characterized by a steep initial pressure increase followed by a slower decay over the next seconds. Similar reactions are well known from other hollow organs, and the character of these responses may reflect alterations associated with disease [6, 15, 22].

The aims of the present study were 1) to evaluate the character of the dynamic pressure response of the prostatic urethra to forced dilation, 2) to evaluate the significance of the size and velocity of the individual dilation, 3) to evaluate the significance of the degree of distension as studied during continued stepwise dilations, and finally 4) to evaluate the reproducibility of the method. All were investigated at rest during the reservoir phase.

Materials and methods

Ten male volunteers aged 27 to 71 years (median, 38 years) without past or present urological complaints participated in the study. Urinalysis (dipstick) and blood tests (haemoglobin, sodium, potassium, and creatinine) were normal in all individuals. Informed consent was obtained and the study was approved by the local ethics committee.

Symptoms of benign prostatic hyperplasia (BPH) were evaluated by filling in a patient weighted symptom score (DAN-PSS) [16], and prostatic volume was determined by transrectal ultrasonography (7 MHz rectalscanner, type 8551, Bruel and Kjaer, Denmark) according to the formula: \( \text{volume} = 0.52 \times \text{width} \times \text{height} \times \text{length} \) [23]. In addition all subjects had an urodynamic examination including flowmetry (standing, filling by diureses), resting urethral
pressure profile (UPP) (8 F catheter, two sideholes, retraction rate 3 mm s⁻¹, perfusion rate 2 ml min⁻¹), cystometry (supine, saline, transurethral filling, 5 F catheter, filling rate 50 ml min⁻¹), and pressure-flow. Results were recorded on DISA UROsystem 21F16 2100 (Dantec, Denmark) (flowmetry, UPP, cystometry, and pressure-flow) or Urodyn 1000 G22 01 (Dantec, Denmark) (flowmetry). The results of these examinations are given in Table 1.

The relationship between intraurethral pressure and cross-sectional area was determined using a specially designed retraction device, which allows the change in cross-sectional area (ΔCA), to be freely adjusted [28]. The velocity of dilation was adjusted by interposing one of three tubes (Q₁, Q₂, and Q₃) between the pump and the infusion line. The corresponding median velocities of dilation were determined to be 65 mm²/s (Q₁), and 135 mm²/s (Q₂) in the full range of dilation applied (ΔCA 10–40 mm²), whereas the velocity with the last tube interposed (Q₃) increased slightly from 215 mm²/s (ΔCA 10 mm²), to 235 mm²/s (ΔCA 20 mm²), and 250 mm²/s (ΔCA ≥30 mm²) [28].

The examinations were directed to evaluate the influence of 1) the size and velocity of dilation, and 2) the degree of distension during continuous stepwise dilation, and were performed on two separate days with an interval of at least 1 week. The insertion and localization of the catheter were identical for the two procedures. Investigations were performed with the subject in the supine position with an empty bladder. The catheter was introduced into the urethra, and placed with the balloon in the bladder. The catheter was then mounted in a specially designed retraction device, and the balloon was connected to a pressure reservoir with a pressure of 10–15 cm H₂O above bladder pressure, then slowly retracted until the sensing electrodes entered the urethra as indicated by a fall in cross-sectional area. Measurements were initiated after the catheter was retracted a further 5 mm from the bladder neck, and repeated at every 5 mm until the high-pressure zone was passed. At each site of measurement the balloon was adjusted to a cross-sectional area of approximately 13 mm² and one of the following procedures was performed.

1. The significance of the size and velocity of dilation. The balloon was inflated a total of six times, using increments in cross-sectional area of 20 mm² and 40 mm². Both cross-sectional area changes were performed at three different rates of inflation by changing the interposed tube (Q₁, Q₂ and Q₃). Once inflation was completed, the balloon was only deflated after pressure equilibrium, as indicated by a constant balloon pressure, had occurred. This was also the case before a new inflation was performed.

2. The significance of the degree of distension during continuous stepwise dilation. The balloon was inflated in steps of approximately 10 mm² at a maximum rate of inflation (Q₃). After each inflation pressure equilibrium was awaited, and the inflation was continued until a cross-sectional area of 80 mm² or a balloon pressure of 150 cm H₂O was reached, before the balloon was deflated.

3. Reproducibility. After approximately 4 weeks, the reproducibility of the technique was evaluated by repeating the examination of the significance of variation in the size and velocity of dilation in five volunteers, aged 27–71 years (median, 44 years).

Anal EMG was registered during all examination procedures using surface electrodes, and recorded simultaneously with cross-sectional area, balloon pressure and bladder pressure on a DISA UROsystem 21F16 2100 (Dantec, Denmark) and analog/digitally converted into a computer.

Localization of measurements

Due to significant variations in the length of the posterior urethra – defined as the distance from the bladder neck to the site of the maximum pressure determined from the UPP – the location of the site of measurement was standardized by dividing the distance from the bladder neck with the length of the posterior urethra and multiplying by 100, thus expressing the measurement location as a percent of the distance from the bladder neck to the site of the maximum pressure. Only measurements performed at a distance of less than 150 percent from the bladder neck were included in the analysis. As major variations in the measurement parameters occurred along the urethra, the investigated part of the urethra (0–150%) was divided into five segments, each of the length of 30 percent (I, 0–30%; II, 31–60%; III, 61–90%; IV, 91–120%; V, 121–150%) before analysis.

Distension parameters

Elastance (ϕ) is defined as the ratio of pressure (dp) to volume (dv) change, and compliance is the inverse of elastance. For a urethral segment between the measuring electrodes with a distance l mm, the change in volume is \( \Delta V = \Delta \text{CA} \cdot l \), where \( \text{CA} \) is cross-sectional area, provided that the slope of the walls is negligible. If the change in pressure is dp (cm H₂O), then the elastance is dp/(\( \Delta \text{CA} \)) (cm H₂O/mm²). It follows that for unity of length (l = 1 mm) the elastance is numerically identical with dp/dCA (ϕ cm H₂O/mm²).

Statistics

The Wilcoxon test was used to compare paired data from two groups and Friedman’s test was applied when more than two paired groups were compared [25]. If Friedman’s test demonstrated a significant difference between groups, the analysis was extended with a multiple test procedure in an attempt to identify the deviating group(s) [25]. The mean value was used for analysis when more than one set of data existed per subject per group. Bonferroni’s method was applied when multiple comparisons were made and \( P < 0.05 \) was defined as the level of significance [3]. Reproducibility was evaluated by calculating the median and quartiles of

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Table 1. Symptom score, prostatic volume and urodynamic findings. Figures given are median and range, or number.

<table>
<thead>
<tr>
<th>Symptom score</th>
<th>Symptom</th>
<th>Bother</th>
<th>Prostatic volume (cm³)</th>
<th>Uroflow (ml s⁻¹)</th>
<th>Voided volume (ml)</th>
<th>Bladder capacity (ml)</th>
<th>Obstructed[a] (No)</th>
<th>Unstable[b] (No)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>0 (0–5)</td>
<td>3 (1–5)</td>
<td>0 (0–4)</td>
<td>21 (13–33)</td>
<td>24 (12–36)</td>
<td>191 (155–500)</td>
<td>360 (254–560)</td>
<td>0</td>
</tr>
</tbody>
</table>

[a] According to the criteria given by Abrams and Griffiths [1].
[b] Detrusor contractions exceeding 15 cm H₂O during cystometry.