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Computer assisted pantropic urethral pressure profile

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Summary. A computerized method for urethral pressure measurement along the whole length and at every angle of the urethra is presented. The main advantage is the exact study of physiological versus artificial factors in pressure distribution in the urethra. Details of the technique are presented.

Key words: Urethral pressure profile – Urodynamics – Microtip transducers

Introduction

The urethral pressure profile, as a graphic representation of the wall tension along the urethra, has become a very popular clinical tool for the investigation of problems associated with urinary incontinence [6, 17, 18]. It is also being used in the evaluation of drug effects on the urethral tone [13] and in the evaluation of urinary outflow obstruction [2]. Many techniques of urethral pressure measuring have been developed. Balloon catheters did not gain much popularity because of difficulties of calibration, construction and handling [20]. They measure pressures over a large area, and cause a non physiological dilatation of the urethra. Membrane catheters, developed to overcome the shortcomings of the balloon catheters, proved to be more accurate than the perfusion techniques [28]. The water-perfusion technique, the Brown and Wiekham procedure [8] modified by Harrison and Constable [21], is widely used. Simultaneous measurement of intravesical and intraurethral pressure are routine procedures [18, 27, 33]. Easier to perform, but less accurate, are the gas urethral pressure profile measurements [25]. Some authors [5, 14] perform a combined electromyography and gas urethral pressure profile, using a specially designed catheter. Shelley and Warrel [30] popularized the use of micro-tip transducers in experimental work, which were also used by Asmussen in clinical work [4]. These catheters proved to be very sensitive, but they are very expensive, and caused problems with calibration.

Profile parameters [1, 12], short-term and long-term reproducibility [24], comparison of the different techniques [23–32] and errors in measurement [7] have been described extensively. One of the main problems is the long-term reproducibility of the profile. This is partially due to an unstable urethra, but using micro tip transducers, rotational variation possibly is one of the contributing factors, as was recently suggested by some authors [3, 10, 34].

In this study we propose a new technique for measuring urethral pressures around the whole axis and along the whole length of the urethra.

Methods

In this new technique, a semi-flexible catheter (Ch6) equipped with two solid-state sensors was used. As in classical urethral pressure profiles (UPP), the microtransducer at the top measured the intravesical pressure continuously and the one at 6 cm from the top measured urethral pressures.

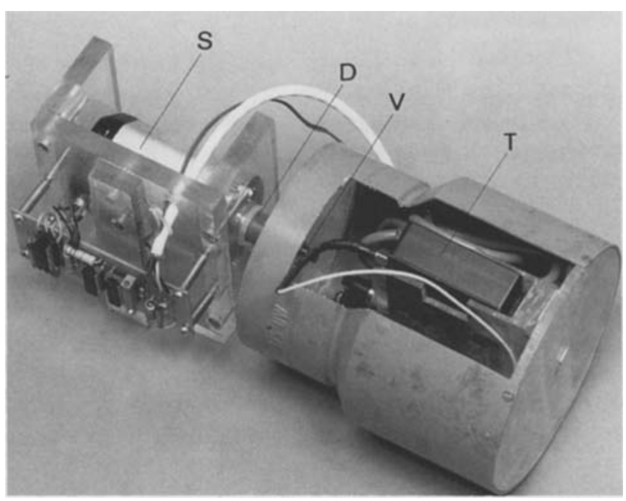

Fig. 1. The Capupp (Computer Assisted Pantropic Urethral Pressure Profile) withdrawal apparatus. T = telemetric signal transmitter; S = step per motor; V = screw thread; D = hollow bar

A computer controlled withdrawal unit which makes the catheter move along a helical path, has been designed and a prototype was built by the authors. The stepper motor S makes the thread-bar D rotate in the fixed (fast) screw-thread V (Fig. 1). In this way the bar D as well as the stepper motor S and the telemetry-transmitter T shift horizontally during the rotation of the bar. The catheter which is fastened inside the hollow bar, is thus withdrawn at a constant velocity through the urethra while rotating around its axis at the same time.

In order to minimize artefacts caused by the moving object in the urethra, the velocity of the catheter with respect to the wall of the urethra should not exceed 5 mm/s. The absolute velocity of every point of the catheter can be divided into two components: a linear movement and a rotation.

The linear movement $V{\downarrow}l{\uparrow}$ is given by:

$$V{\downarrow}l{\uparrow} = N \cdot p (mm/s)$$

with N the number of revolutions per second (s^{-1}), p the pitch of screw-thread (mm).

The calculation of the rotational component V_r yields:

$$V_r = \Pi D \cdot N$$

with N the number of revolutions per second ($s^{-1}{\downarrow}$), D the diameter of the catheter (mm). The value of the absolute velocity V_a is:

$$V_a = (V_l^2 + V_r^2 + 2V_r Vl \cos \Pi)^{1/2}$$

with Π the angle between the vectors of both velocities V_r and $V{\downarrow}l{\uparrow}$. The last term in this expression is reduced to zero since both components are perpendicular.

This yields:

$$V_a = (V_l^2 + V_r^2)^{1/2} = N(p^2 + \Pi^2 D^2)^{1/2}$$

with p = 1 mm, D = 3 mm, N = 0.4167/s. V_a isless than the 5 mm/s limit, i.e. $V_a = 3.95$ mm/s.

The value of the pitch p turns out to be almost insignificant with regard to the absolute velocity.

The pitch p is determined for both the horizontal distance d_l between two immediately successive measurements ($d_l = p/NM$) and the distance d_2 between two successive measurements with the same angular position ($d_2 = p$). The symbol N_m stands for the measuring-frequency, i.e. the number of measurements per revolution. In this way the pitch is equal to the reciprocal of the spatial sampling-frequency.

The value of p is also important for the duration t of the whole measurement which equals: $t = l/Vl = l/N \cdot p$ with l the length of the urethra.

The computer controls the helical movement through the drive of the stepper motor. The driving circuitry converts the signal of the computer into drive-pulses for the coils of the stepper motor. A part of it is mounted directly under the motor (see photograph). This part also contains two reed-relais which are switched by the magnet M to detect the extreme positions of the moving system. In this way the movement is interrupted automatically if the maximum backward or forward position has been reached. The pulse-frequency f_p applied to the stepper motor equals 20 Hz. Since one step of the stepper motor corresponds to 360/48 = 7.5 degree of revolution, the number of revolutions per second N equals:

$$N = f_p/48 = 20 \text{ Hz}/48 = 0.4167/s$$

Furthermore, both pressures are registered in each position, i.e. immediately before each step. So the measuring-frequency Nm(cf. supra) equals 48.

The pulse rate f_p applied to the stepper motor determines, together with the pitch p of the screw-thread, both the absolute velocity of the distal sensor with regard to the wall of the urethra:

$$V_a = N(\Pi^2 D^2 + p^2)^{1/2} = 1/48\, f_p(\Pi^2 D^2 + p^2)^{1/2}$$

and the withdrawal velocity at which the catheter moves out of the urethra, i.e. the linear component $V{\downarrow}l{\uparrow}$ of the absolute velocity:

$$V{\downarrow}l{\uparrow} = N \cdot p = 1/48 \cdot f_p \cdot p$$

Both pressure signals are transmitted by the telemetry-system T to the receiver which is connected with the data-acquisition unit. At first the acquired data are stored in the computer memory and afterwards on flexible discs. The stored data which are measured voltages, are converted into pressurevalues taking account of the calibration.

In order to exclude artefacts further processing is done on the difference of both pressures, i.e. $p_d = -p_{intravesical} + p_{urethral}$.

Results

Classical UPP (Urethral Pressure Profile)-measurements are represented in two ways: the graph which shows the variation in time of the pressure-difference (see Fig. 2) and the list of several numerical parameters derived of the UPP-curve (Fig. 3).

In CAPUPP (Computer Assisted Pantropic Urethral Pressure Profile) a subdivision can be made in a similar way although the possibilities for graphical representation are far more numerous.

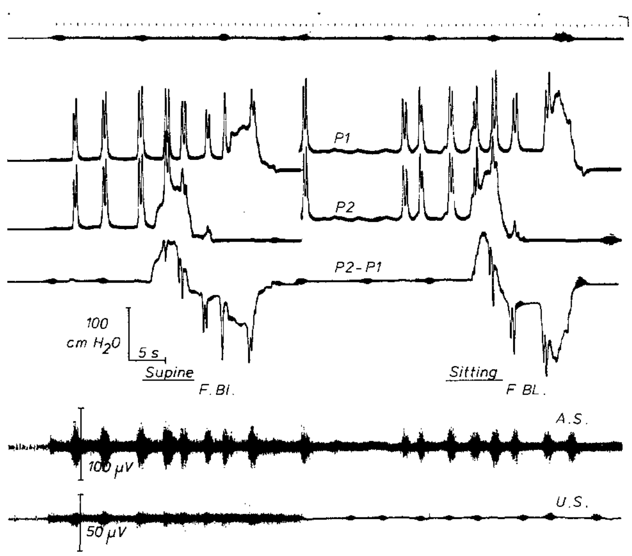

Fig. 2. Classical urethral pressure profile. P_1 = Pressure at proximal sensor; P_2 = Pressure at distal sensor; P_2–P_1 = Urethral closure pressure; A.S. = Electromyography of anal sphincter; U.S. = Electromyography of periurethral striated muscles; F.Bl. = Full bladder

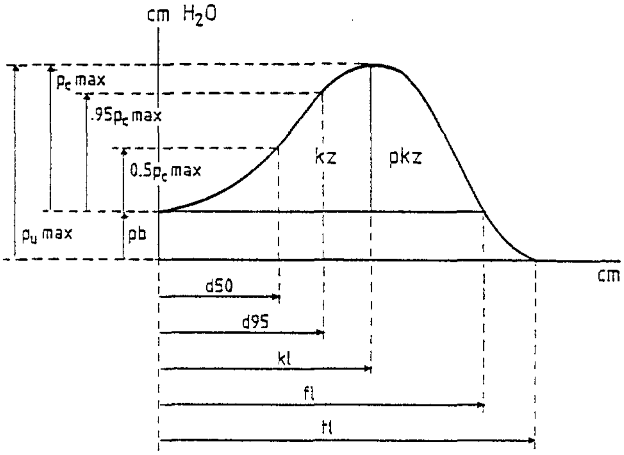

Fig. 3. Classical parameters calculated by computer from a UPP. p_b = bladder pressure; $p_c$max = maximum urethra closure pressure; $p_u$max = maximum urethra pressure; d50 = distance at 50% of $P_c$max; d95 = distance at 95% of $P_c$max; kl = continence line; fl = functional length; tl = total length; kz = continence zone; pkz = postcontinence zone

The band of UPP's and the average UPP

As in the classical UPP all 48 profiles, i.e. one profile in each orientation, could be displayed on one graph versus time. In this way, a band of curves arose of which the average curve could be derived (Fig. 4). For every distinct UPP-profile, the classical parameters (Fig. 3) were calculated.

Pressure "surface"

A three-dimensional representation of the several profiles, with time in the X-direction, pressure in Y and the orientation (0° → 360°) in the third dimension, resulted in a kind of a surface. The graph is interesting for the visual interpretation of pressure variation due to the orientation of the catheter (Fig. 4).

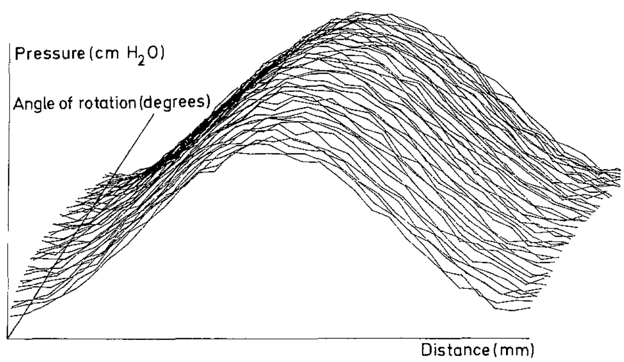

Fig. 4. Band of 48 urethral pressure profiles around the whole axis of urethra

Tables of extreme pressure values

A list of all pressures Pd in the 48 directions was not useful for analysis. Therefore two types of tables have been designed which list minima and maxima.

The first type contained for every orientation both maximal pressure values and the distance at which they occurred, referred to the starting-point (Table 1). The second kind of table lists the minima and maxima of p_d for every rotation, together with the angles of orientation which corresponds to these values (Table 2).

Table 1. Example of table with extreme values per distance

Dist. [mm]	CAPUPP			
	Maximum		Minimum	
	Pressure	Angle	Pressure	Angle
0	36.9	82.5	35	0
1	39.3	97.5	37.8	165
2	41.8	210	40.7	195
3	44.5	240	43.8	247
4	47.3	15	46.9	97.5
5	50	0	50	0
6	53.1	60	52.7	120
7	56.2	210	55.5	307
8	59.3	150	58	233
9	62.2	217	60.6	60
10	65	338	63	278
11	67.6	67.5	65.4	173
12	70.1	173	67.5	188
13	72.3	307	69.3	37.5
14	74.3	45	71	173
15	76	67.5	72.6	165
16	77.4	195	73.8	52.5
17	78.5	338	75.1	150
18	79.3	173	75.5	217
19	79.8	210	76	105
20	80	22.5	76.2	128
21	79.8	203	75.9	75
22	79.3	345	75.4	278
23	78.5	30	74.8	345
24	77.4	233	74.2	15
25	76	60	72.6	113
26	74.3	105	71.1	150
27	72.3	105	69.3	0
28	70.1	120	67.5	285
29	67.6	97.5	65.4	345
30	65	270	63	15
31	62.2	45	60.6	217
32	59.3	255	58	330
33	56.2	165	55.4	210
34	53.1	255	52.7	120
35	50	0	50	0
36	47.3	60	46.9	173
37	44.6	315	43.8	75
38	42	60	40.7	135
39	39.4	30	37.8	240
40	36.7	113	35	67.5

Table 2. Example of table with extreme values per degree of rotation

Angle	CAPUPP			
	Maximum		Minimum	
	Pressure	Distance	Pressure	Distance
0	79.7	21	35	0
7.5	79.3	21	35.2	0
15	79.2	20	35	0
22.5	80	20	35.1	0
30	79.6	20	35	40
37.5	80	20	35	40
45	79.8	21	36.4	0
52.5	79.6	20	35.1	0
60	78.9	21	35.6	40
67.5	78.5	19	35	40
75	79.6	19	35.8	40
82.5	79.6	19	35	40
90	79.8	21	35.3	40
97.5	79.8	21	35	40
105	79	18	35.6	0
112.5	78.4	23	35.3	0
120	79.6	20	35.2	40
127.5	79.3	21	35.3	40
135	78.4	17	35	0
142.5	79.5	19	35	40
150	79.8	21	35.1	0
157.5	79.8	19	35.2	40
165	79.2	22	35.6	0
172.5	79.7	21	35.2	0
180	79	19	35.2	40
187.5	79.9	20	35.6	0
195	79.7	21	35.3	0
202.5	79.8	21	35	40
210	79.8	19	35.2	0
217.5	79.7	19	35.4	0
225	79.2	22	35.1	0
232.5	79.7	21	35.1	40
240	79.5	21	35.7	0
247.5	80	20	35.4	0
255	78.8	22	35.2	0
262.5	79.8	21	36.1	40
270	79.9	20	35.4	0
277.5	79.6	19	35	0
285	79.8	21	35.1	0
292.5	79.8	19	35	40
300	79.5	19	35	40
307.5	79.8	20	35.5	0
315	79.7	21	35	40
322.5	80	20	35.3	40
330	79.8	19	35.1	40
337.5	79.8	19	35	40
345	79.4	20	35	40
352.5	79.5	21	35	0

Dynamic pantropic representation

This representation (Fig. 5) implied a dynamic sequence of graphs. Each revolution corresponded to a closed curve in which the pressure values p_d were depicted circularly in the same direction as they were measured. These graphs are consecutively shown on the computer screen starting with the plot for $d = 0$. This yields a dynamic representation of the urethral pressure.

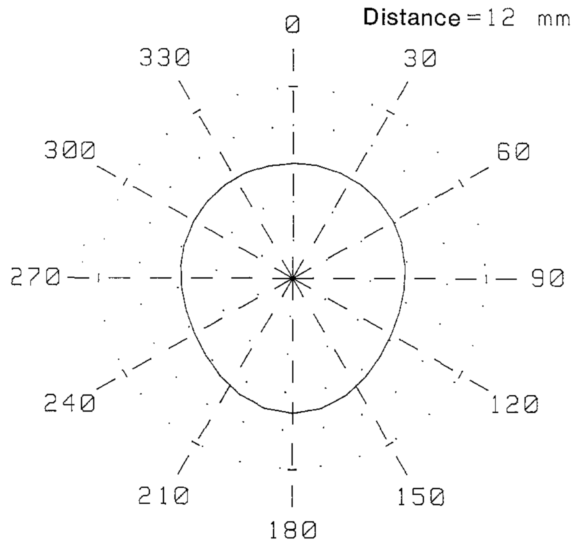

Fig. 5. Moment of a dynamic pantropic presentation of pressures around the urethra

Discussion

Several techniques have been used to quantify the role of the urethra for continence. Although transmural tension measurement should be the best way, this technique is difficult to realize in clinical practice. Therefore, intraluminal pressures along the urethra are measured. However, several factors influence such pressure measurement: compliance of the urethra [16, 26], diameter of the catheter and withdrawal speed for all techniques; perfusion speed, fluid temperature, site, number and diameter of catheter holes in fluid and gas perfusion techniques [15], rotation of the catheter and tip or side orientation in solid state sensor techniques; thickness, sensitiveness, hysteresis, surface and diameter of balloons. In micturitional urethral pressure profiles still more problems arise.

These numerous variables explain why comparison of urethral pressure profiles, especially their absolute values, between different centers is difficult.

The method presented is a variation on the microsensor technique. It has the advantage of allowing pressure measurement at any point around the whole circumference and whole length of the urethra using only one sensor. The necessity to measure pressures in the urethra at different points has been stressed by others. Kramer [22] used a catheter on which not one, but three sensors were mounted in the same axis or rotated by 60 degrees between each other. Constantinou and Govan [10] used a four-channel perfused gap catheter; their data indicated an active mechanism for urethral closure to stress rather than a passive transmission; in this way it was possible to detect pressure differences at the anterior and posterior side of the urethra. Pressure differences between anterior and dorsal side have been observed by Constantinou et al.[10] and by us [34]; but were considered as artifacts by Schäfer et al. [29]. The present method will give unequivocal answers to these different interpretations. Indeed a physiological explanation is possible, because the muscle density of the external sphincter and puborectal muscle is higher ventrally [19].

Computer technology was adapted to urethral pressure profiles by Desmond and Ramayya [12] in combination with the fluid bridge test; they proved an enhanced accuracy of these tests.

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