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Comparison Between Bladder Wall's Strain Analysis and CMG in Clinical Urodynamics: Preliminary Report

F. Ronchi[1], V. E. Pricolo[1], P. Rigatti[2], M. Bassani[1], M. Pedesini[1], R. Milesi[1], L. Divieti[3], and P. Bellinzoni[1]

[1] Department of Surgical Anatomy, University of Milan (Head: Prof. A. Bissi), Institute for Biomedical Sciences S. Raffaele, Milan, Italy
[2] Department of Clinical Surgery, University of Milan (Head: Prof. W. Montorsi), Milan, Italy
[3] Department of Electronics, Politecnico of Milan (Head: Prof. L. Divieti), Milan, Italy

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Summary. On the basis of data obtained in previous experimental investigations, the application of a new physical entity, "strain" (σ), was evaluated in bladder dynamics. In this preliminary study 12 cases of urodynamically evaluated subjects are reported; the significance of the traditional P(V) curves is critically compared with the new σ(V) curve, proposed by the authors.

Key words: Bladder – Cystometrogram – Urodynamic evaluation – Micturition.

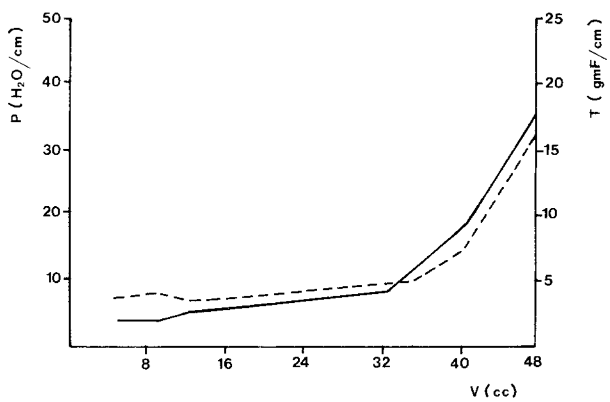

Fig. 1. The P(V) characteristic (– – –) as compared with the T(V) (——) characteristic by Tang and Ruch

Introduction

The urodynamic study of vesical physiology depends upon an interpretation of intraluminal pressure, evaluated during the whole function of micturition [1]. Hence the traditional P(V) (pressure/volume) diagram resulted. In order to interpret the P(V) patterns obtained the term "adaptation" was introduced, meaning a negligible increase in pressure related to measurable increase in the filling volume, probably due to an interaction between an excitatory reflex (tone) and that of an inhibitory one (adaptation) during the filling phase [2].

Sherrington [3] compared the vesical pressure response with the postural reflexes of skeletal muscles, assuming that an interaction with spinal centres was responsible for the activation of a reflex allowing the bladder to maintain almost constant pressure during increases in volume.

Tang and Ruch [4] demonstrated that the central nervous system influences only the voiding reflex and not the filling phase. Therefore, they deduced that the pressure curve is merely related to the physical properties of the bladder wall and introduced a new quantity, tension, i.e. the strength exerted upon the bladder wall to contain a certain amount of fluid at a certain pressure level (Fig. 1)

In their investigations, they applied Laplace's law, assuming the bladder to be a sphere:

$$T = \frac{P}{2} \sqrt[3]{V \frac{3}{4}}$$

approximated to: $T = 0.312\, P \sqrt[3]{V}$

However, in their hypothesis the variation in the bladder wall's thickness during the filling, which may be considerable, is not taken into account.

In fact, in a rabbit, for example, the bladder wall's thickness undergoes a reduction of six times (from 3 to 0.5 mm) during the whole filling phase to maximal distension. This observation is applicable to the human bladder, and this is demonstrable when pre- and postvoid IVP films are compared.

Therefore, it is necessary to determine a measurement of bladder function related to bladder thickness during the filling phase.

In a previous paper [5], referring to Laplace's law and by physicomathematical demonstrations pertaining to the

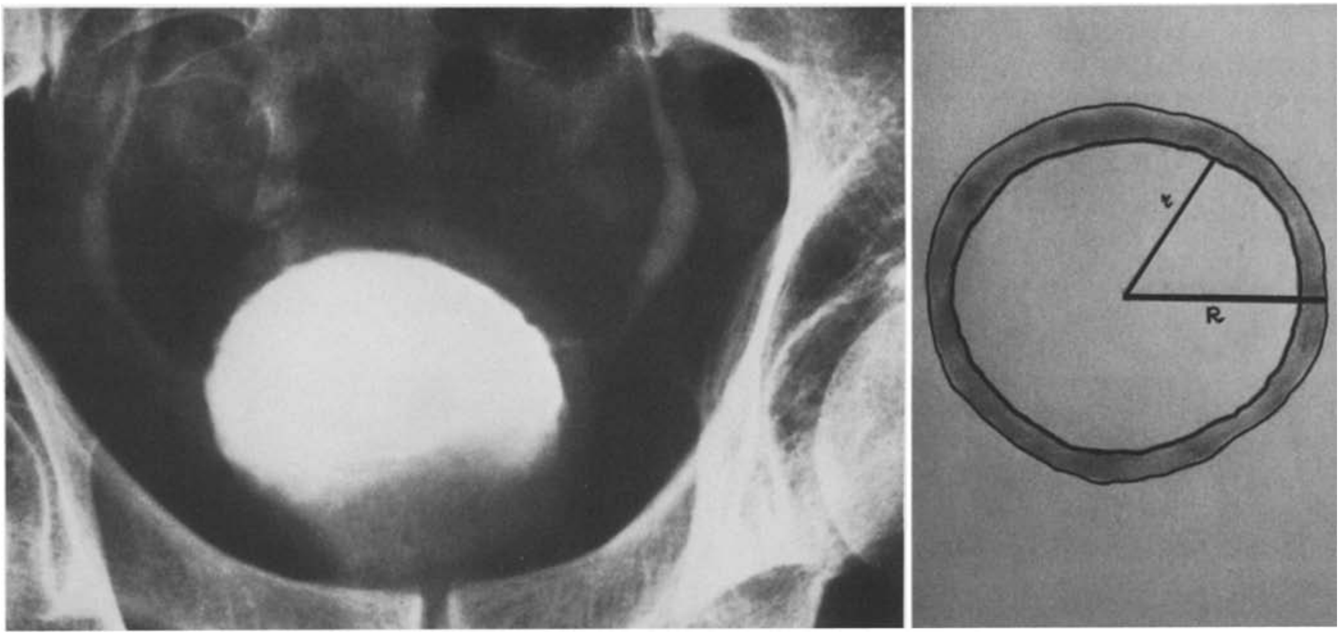

Fig. 2. On the *left* a cystographic IVP film showing the bladder wall's thickness is reported. On the *right* the two concentric spheres with their respective radii (R and r) are schematically represented

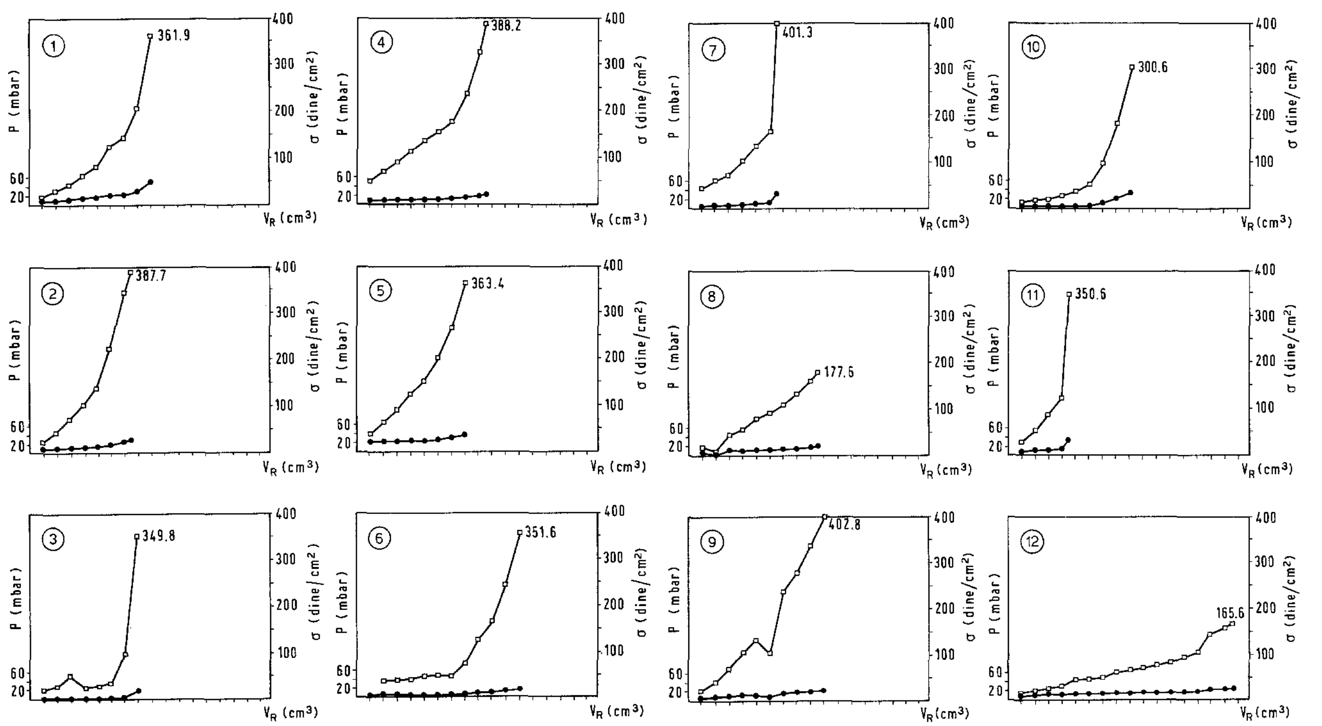

Fig. 3. The 12 σ(V) curves (-□-□-), obtained in the examined patients are reported and compared with P(V) curves (-●-●-). Every detection on the curve corresponds to a one minute interval

Table 1. The values of V_M, V_R, P and σ in the 12 examined patients are reported. Note that the refered data were obtained at one minute intervals, starting from the first pressure value detectable on CMG

1 B. C.	sex M. (BPH) age 73		2. Z. M.	sex M. (BPH) age 63		3. G. B.	sex M. (varico) age 27 (cele)		4. C. F.	sex F. (kidner) age 42 (stones)		5. B. A.	sex M. (BPM) age 62		6. V. P.	sex M. (varico) age 18 (cele)	
$V_m = 120.3\ cm^3$			$V_m = 44.1\ cm^3$			$V_m = 36.3\ cm^3$			$V_m = 51.6\ cm^3$			$V_m = 80.1\ cm^3$			$V_m = 39.2\ cm^3$		
V_R cm^3	P mbar	σ $dine/cm^2$	V_R cm^3	P mbar	σ $dine/cm^2$	V_R cm^3	P mbar	σ $dine/cm^2$	V_R cm^3	P mbar	σ $dine/cm^2$	V_R cm^3	P mbar	σ $dine/cm^2$	V_R cm^3	P mbar	σ $dine/cm^2$
119	9	19.4	57	9	23.6	109	4	20.8	200	7.5	49.0	63	21	38.6	46	2	4.9
173	11	31.3	114	10	45.9	169	4	30.8	258	8.5	69.9	125	21	63.7	94	8	34.4
226	13	45.7	171	11	71.9	239	5	53.0	316	9	89.2	188	21	88.8	141	6	36.7
276	15.5	64.3	228	12	101.8	295	2	25.8	366	10	113.7	250	23	124.2	188	5	39.6
370	23.5	125.3	342	18	222.6	419	2	36.1	458	11	154.5	375	26	201.5	282	4	46.1
420	24	143.0	400	24	344.2	464	5	99.5	480	12	176.3	438	30	268.0	329	3.5	46.6
460	32	206.7	425	25.5	387.4	480	17	349.8	538	14.5	237.5	500	36	363.4	367	5	73.9
500	52	361.9							596	18	325.1				414	7.5	124.3
									626	20.5	388.2				461	9	165.4
															508	12	242.1
															555	16	351.6

7. R. C.	sex M. (BPH) age 73		8. S. D.	sex M. (MPH) age 52		9. S. L.	sex M. (kidney) age 47 (stones)		10. Z. M.	sex M. (BPM) age 74		11. M. E.	sex M. (kidney) age 42 (stones)		12. B. V.	sex M. (BPM) age 64	
$V_m = 51.6\ cm^3$			$V_m = 66.4\ cm^3$			$V_m = 39.2\ cm^3$			$V_m = 88.6\ cm^3$			$V_m = 50.1\ cm^3$			$V_m = 102.0\ cm^3$		
V_R cm^3	P mbar	σ $dine/cm^2$	V_R cm^3	P mbar	σ $dine/cm^2$	V_R cm^3	P mbar	σ $dine/cm^2$	V_R cm^3	P mbar	σ $dine/cm^2$	V_R cm^3	P mbar	σ $dine/cm^2$	V_R cm^3	P mbar	σ $dine/cm^2$
196	7	44.9	61	8	16.3	62	7	21.4	132	4	11.7	100	8	29.5	33	12	13.0
238	8	61.1	113	2	6.5	114	8	40.6	190	4	15.6	156	10	53.8	63	13	20.4
283	8	71.6	163	10	43.9	166	10	70.7	243	4	19.3	204	13	88.8	88	14	27.4
325	10	101.8	213	10	55.3	218	12	108.8	283	5	27.5	252	15	124.1	113	14	32.7
360	12	134.4	260	12	79.1	268	12	131.8	333	6	38.1	320	34	350.6	137	15	40.5
410	13	164.4	297	12	89.2	320	8	103.8	381	7	50.2				161	15	45.9
420	31	401.3	335	13	107.8	366	16	235.9	427	12	95.4				184	15	51.1
			380	14	130.4	409	17	278.6	469	21	182.0				208	16	60.2
			410	16	159.9	442	19	335.4	495	33	300.6				231	16	55.7
			430	17	177.6	482	21	402.8							254	16	71.1
															277	16	76.6
															300	16.5	84.6
															326	17	93.7
															352	18	106.1
															376	23	143.8
															400	23.5	115.2
															420	24	165.6

"science of constructions", we have proposed the introduction of a new quantity for the analysis of bladder dynamics: strain (σ). It represents the relation between tension and thickness of the wall on which tension is exerted. We have derived the following formula for the calculation of strain:

$$\sigma = \frac{P(\sqrt[3]{V_R} + \sqrt[3]{V_R + V_M})}{4(\sqrt[3]{V_R + V_M} - \sqrt[3]{V_R})}$$

where P = intravesical pressure; V_R = filling volume; V_M = bladder volume.

Following experiments in live rabbits, isolated bladders and rubber balloons, this work reports the preliminary results obtained by applying the strain analysis to the human bladder.

Materials and Methods

Clinical investigations were performed at the Department of Surgical Anatomy of the University of Milan, Institute for Biomedical Sciences S. Raffaele.

Twelve subjects entered the study; exclusion criteria for the study were drug therapy and previous surgical operations on the bladder. Age ranged from 18 to 74 years (mean age 53); eleven subjects were male, one was female.

Seven patients were affected by benign prostatic hypertrophy (BPH). The other five did not show clinical, laboratory or cystoscopic evidence of any cervico-urethral or vesical disease.

Subjects underwent CMG evaluations in supine position by cystouroflowmeter Wolf mod. 2018.12. Saline solution was infused by gravity, with an average initial flow-rate of about 50 ml/min, the absence of a constant infusion device avoided interference with the mechanism of vesical adaptation during filling.

A 12 Ch catheter, mod. Wolf 2018.90, with a pressure transducer at 1 cm from the tip was employed. The data obtained by the CMG P(V) curve were used to apply the above reported formula for the calculation of σ and then to extrapolate the σ(V) curve. Three categories of data were necessary: P (pressure), V_R (filling volume) and V_M (bladder wall volume). Parameters were surveyed and elaborated at regular one minute intervals, up to the onset of the "urge" sensation.

The values of P, expressed in mbar, were reported from single points of the P(V) curve.

The values of V_R, expressed in cm^3, were calculated by recording the time intervals necessary for every 50 ml filling, then obtaining mathematically the flow-rate for every minute. The values of V_M, expressed in cm^3, were constant for each subject and were determined by an original geometrical process.

Observing the cystographic phase of an IVP and assuming the bladder to be a sphere, the radius was calculated by adding the two orthogonal diameters then dividing the sum by 4. The IV cystogram which gave the best evidence of the thickness of the bladder wall was selected.

The mean thickness of the bladder wall could be measured by considering two concentric spheres. One represented by the inner vesical space and the other delineated by the external bladder surface. The radius of inner sphere *I* was called *r*; by adding to its value the bladder wall thickness, the radius *R* of the external sphere *E* was obtained. The volumes of two spheres V_E and V_I were calculated and the value of V_M was extrapolated from the difference of the two volumes by the following formula:

$$V_M = V_E - V_I = \left(\frac{4}{3}\pi R^3\right) - \left(\frac{4}{3}\pi r^3\right)$$

as outlined in Fig. 2.

Other methods for determination of V_M, both as computerized tomography (CAT) and ultrasonography, have not been useful in other experiments.

Having obtained the values of the three categories of data, the σ(V) curves, were traced and the σ characteristic were expressed in $dine/cm^2$. Results are reported in Table 1 and Fig. 3.

Discussion

First examination of the obtained curves would seem to confirm the hypothesis expressed by Tang and Ruch, stating that the bladder during its filling phase is regulated not by pressure, but by tension.

Moreover, it appears from our data that the σ(V) characteristic is more significant than the T(V) characteristic proposed by Tang and Ruch. The P(V) characteristic is of little significance in its quantitative variations during vesical storage. In fact, it appears that for slight or absent pressure variations, considerable variations in σ values occur and the slope in the σ(V) curves is constantly much more marked than in the P(V) curves. It is also interesting to observe that the "urge" condition, which arises at widely variable values of pressure and filling volume, in 9 cases out of 12 appeared for values of σ ranging from about 350 to 400 $dine/cm^2$.

On the basis of this last consideration, we express the hypothesis that the mean values of σ comprised in a similar range could represent the threshold for the stimulation of bladder wall's tension receptors.

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Dr. F. Ronchi
Department of Surgical Anatomy
Institute for Biomedical Sciences S. Raffaele
I-20132 Milan
Italy