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DYSFUNCTIONAL VOIDING IN MALE AND FEMALE PATIENTS

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The urinary flow rate is the product of area and velocity to the stream. For any given flow rate the larger the stream area, the slower the velocity and vice versa. The narrowest point of the stream is usually the vena contracta, i.e., the stream jet beyond the meatus. An intricate mechanism relates the bladder pressure, outflow resistance, flow rate and stream velocity. Ideally, stream velocity is directly related to the bladder pressure according to the formula

$$gP = 1/2\,\rho v^2 \qquad (1)$$

where g is the gravitational constant, P the bladder pressure, ρ the density of the urine, and v the velocity (cm/s). However, the ideal relationship is never realized in the urethra because of energy losses due to viscosity of the fluid, friction of the fluid with the walls of the urethra etc. Rather, an energy loss term must be introduced and the energy loss will then be proportional to the velocity.

$$\text{Energy Loss (L)} = k\,v^2 \qquad (2)$$

where k = the energy loss constant and therefore

$$gP = 1/2\,\rho(1+k)\,v^2 \qquad (3)$$

is the equation which relates bladder pressure and urinary stream velocity. The energy loss coefficient describes the severity of proximal obstruction and can be calculated if bladder pressure and stream velocity are known. Since the stream velocity will reflect the bladder pressure and energy loss, and severe obstruction or hypotonic bladder will reduce the stream velocity sufficiently in relation to the flow rate, these studies can aid in the diagnosis and assessment of a patient's clinical status without the necessity of instrumenting the patient.

Velocity studies have been used for diagnostic purposes since the work of Schwarz and Brenner[1] in 1921. They related the cast distance of the stream to velocity and then to pathology. A more intricate method involved the measurement of droplet velocity between two beams of light, as the urinary stream broke down into droplets after leaving the meatus[2]. I have used the dynamometer disc most extensively over the last ten years[3]. This disc measures the impact force of the urinary stream voided against it; this impact force equals the flow rate times the velocity, also defined as the stream momentum:

$$F = Qv \qquad (4)$$

where F is the impact force, Q the flow rate and v the velocity. The flow rate is measured electronically with a gravimetric flowmeter. Parallel force and flow curves are generated from which stream velocity and area can be calculated at any point in the stream.

$$v = F/Q \qquad (5)$$

$$A = Q/v = Q^2/F \qquad (6)$$

are the two equations which relate velocity and area of the stream where A is the stream area. Uroflowmetry values for a group of normal women is given in Table 1.

The urinary flow rate in this group is closely related to the volume voided; an observation generally acknowledged in the literature. The stream force also relates to the volume voided as one might expect since the flow rate is the dominant com-

Table 1. Mean values of female parameters

	Normal	Stress Incontinence	Voiding Dysfunction	
			Not Instrumented	Instrumented
No. of woman	36	65	103	38
Volume Voided (ml)	310	263	185	215
Maximum Flow Rate (ml/s)	28	21	14	13
Force (GM) At Max. Flow Rate	6.2	3.7	2.6	2.8
Stream Velocity (cm/s) At Max. Flow Rate	197	184	186	219
Stream Area At Max. Flow (cm^2)	0.149	0.132	0.122	0.073

ponent of the force formulation. In the normal female, flow rate is not related to patient age; it is related to the stream area but not to the stream velocity. In hydrodynamic terms, this relation of stream flow rate to the stream exit area is characteristic of a nozzle controlled flow. By word of explanation, the analogy of the garden hose is applicable. When flow is modified by the nozzle at its end, the flow is considered to be nozzle controlled, in contradistinction to a proximal constriction when for example the spigot is closed. The implication of course, is that urinary flow in females is indeed a nozzle controlled flow characterized by a zone of constriction distally.

More than 100 women with urethral syndrome were studied with flow-velocity measurements and were compared to normals (see Table 1)[4]. In women with urethral syndrome, i.e., symptoms of frequency, uregency and bladder discomfort, about 40% tend to void smaller volumes than their normal cohorts. Moreover, the close relationship between flow rate and volume voided degenerates in women with urethral syndrome. The flow rate is still related to the stream area but the area of the stream is considerably smaller than that in the normal female. Furthermore, the area of the stream tends to increase during the course of voiding so that the area at peak flow is about 30 to 40 percent greater than that at mean flow. This relationship between stream area at mean and peak flow is generally maintained in the presence of voiding dysfunction, though the absolute value of the area is less than normal by a considerable margin. However, if the patient has been instrumented, i.e., her urethra has been repeatedly dilated or some sort of urethral "enlarging" procedure has been done, the urethra seems to lose some of its capability to expand during peak flow. The result is a stream area roughly the same at peak flow as it is at mean flow. This suggests that the urethra has become rigid or lost compliance possibly influenced adversely by the very instrumentation intended to improve it.

Stream velocities in the female, as might be expected are not of great clinical interest being similar in both the normal subjects and patients with voiding dysfunction. In fact, separation of patients according to their urethral procedure (including dilation, meatotomy, urethrotomy, and urethroplasty) shows no great difference among them, except for a small group of patients (about 20%) who have benefitted from urethrotomy and have flow rates in the normal range. All instrumented patients seem to void at lower flow rates and stream areas than either normals or uninstrumented patients. Indeed, much research into the mechanism of voiding dysfunction tends to support physiological and not a mechanical impediment to voiding in urethral syndrome. Medical treatments ranging from musculotropic agents, anti-cholinergics, prostaglandin inhibitors and even striated muscle relaxants have been tried with varying degrees of success.

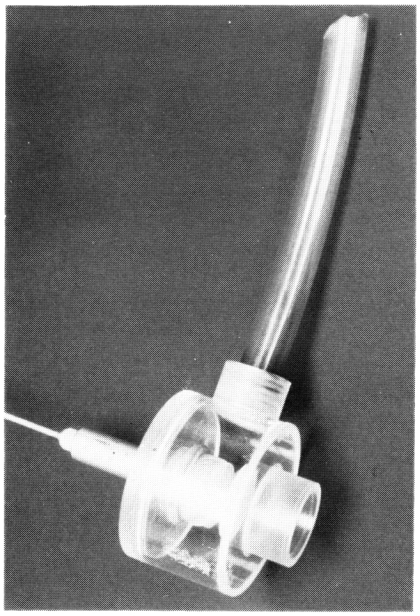

Fig. 1. The urinary stream is directed against the voiding dynamometer disc which measures impact force. The urine is directed downwards into a gravimetric uroflowmeter. From the measured stream force and flow rate, stream velocity and stream area can be calculated

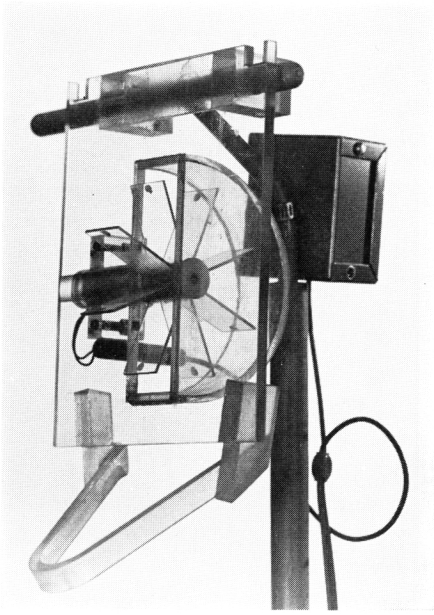

Fig. 2. A simple velocity meter was constructed from a light plastic paddlewheel against which the patient voided. The rotation of the paddlewheel turned a small electric motor which generated an electric current. The voltage generated was proportional to the stream velocity and was easily measured with a small voltmeter

Women with stress incontinence have an interesting voiding pattern[5]. They tend to void smaller amounts than their normal cohorts. More likely this represents a habit pattern, born of the tendency to leak more freely as the bladder fills. However, the relationship of flow rate to volume voided is retained in these women, and they tend to void lower flow rates than normal, the mean value for peak flow lying in the region of 21 ml/s (compared to about 28 ml/s for normals). The data is skewed however, and about 30% void with supernormal values. The stream area closely follows the flow rate and is decreased for the majority of the population of stress incontinent women but may be increased to higher than normal values in the few with supernormal flow.

An interesting relationship of the four variables: bladder pressure, stream velocity, stream area and flow rate, is found in the small group of women with stress incontinence who have high flow rates. From engineering theory of pumps it is known that a pump with a specific power output can convert its energy into a high fluid flow at low pressure, or low fluid flow at high pressure. To pump a high flow at high pressure would require an increase in the power output. The bladder is the pump of the lower urinary tract and given a limit to its power output by its intrinsic biochemical mechanisms, any outflow constriction which slows flow will raise pressure. Similarly, removal of outflow resistance will increase the flow rate and reduce the bladder pressure. With reference to the present patient population, a small number of women with stress incontinence have a stream area larger than normal, probably a result of a patulous urethra occurring as part of their disease. The flow rate is correspondingly higher than normal and according to pump theory, the bladder pressure would be expected to fall to subnormal levels.

The stream velocity which, as explained before, relates back to the bladder pressure, falls in parallel with the falling bladder pressure. Thus, there seems to be a paradox: very high flow rate in the absence of a bladder contraction, (or more precisely, in the absence of significant bladder pressure). This finding defined as the "trapdoor urethra" occurred in about 10% of our group and presented with high flow rate and low stream velocity. The recognition of such patients could be determined from study of the stream alone without the necessity for instrumentation.

In contrast to women, men have a quite different hydrodynamics of flow related to their urethral anatomy. Whereas women exhibit "nozzle controlled flow", i.e., the control region of the urethra lies distally, in the male, the constrictive region whether it lies at the bladder neck, prostate or membranous urethra, lies in the proximal urethra. The mechanism limiting flow rate in the male is based on energy losses imposed on the stream by fluid viscosity, turbulence due to local areas of constriction and expansion of the stream, wall friction and other factors. The stream velocity, which measures the energy content of the stream is exhausted by these impedimenta to flow. The result is a flow rate that is closely correlated, not with stream area as in the female, but with stream velocity. In fact, the stream area in most males tends to be constant.

We studied a group of about 650 males including 120 normals and others with benign prostatic hypertrophy, stricture and other obstructive conditions. We used a very simple device, a light paddle wheel (Fig. 2) which the patients voided against to measure the velocity. The speed of rotation of the paddle wheel was proportional to the velocity of the stream and turned a small electric toy motor which generated a voltage proportional to the stream velocity. The peak flow rate was measured with a Peakometer, a commercially available disposable flowmeter. Patients voiding volumes less than 125 ml/s were eliminated from the study.

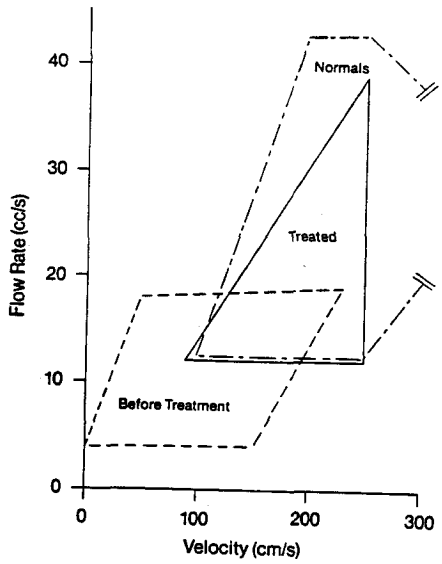

Fig. 3. A plot of individual patient flow-velocity date points obtained at maximum flow rate tended to cluster into groups. Normal subjects could be separated from obstructed patients more easily using the two discriminants together than they could using each alone

The relation of flow rate to volume voided and age is already well known[6]. On the other hand, stream velocity is responsive to volume voided only at low volumes, less than 200 ml. At volumes beyond that the stream velocity is volume insensitive. The stream velocity is directly and linearly related to the flow rate. Stream velocity decreases with advancing age in a linear fashion up to age 55, after which it seems to level off. Obstructive disease modifies these relationships. The velocity is decreased by obstructive prostatism, for instance, and never reaches normal levels despite the degree of bladder filling. The relationship of velocity to flow rate in both normal and diseased states, is best seen in two dimensional data plots. If flow rate is plotted against velocity (Fig. 3), the patient data points will cluster separating normal subjects from obstructed patients[7]. Flow and velocity together provide much greater discrimination in separation of patient populations than either parameter alone. The

clinical value of these studies lies in the assessment of patient disease and progress without the necessity of instrumentation. Similarly, urethral strictures, bladder neck contraction and prostatitis work their effect on flow and velocity and can be followed in this way.

There is much information buried in the urinary stream, which if studied carefully, will reveal much about the nature of urethral and bladder function. Simultaneous flow/velocity measurement is one such example. For the clinical urologist, studying the patient without invasive techniques is a clear imperative. We should certainly make every effort to extract as much information as possible from the uninstrumented stream.

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和文抄録

男子および女子の排尿障害

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尿線は尿流率，尿流速度，尿流断面積の3つのパラメーターにより評価できる．3パラメーターは相関するが必ずしもお互いに平行するものではない．男子では尿流率は速度と相関するが，尿流断面積とは相関しない．いっぽう，女子では尿流率は断面積と相関するものの，速度とは相関しない．これは男女の排尿エネルギーの研究にあたり，きわめて重要な基礎となる．男子の排尿は尿道でのエネルギー損失と膀胱収縮間の調和に支配される．すなわち，膀胱内圧が高いほど，尿流速度は速やかに，尿流率は高くなるのに対し，女子ではエネルギー損失により排尿が障害されるものではなく，有効なノズルにより調節されているかのように振舞う．膀胱内圧は女子では男子よりかなり低く，しかも尿道の調節下にあると思われる．尿流断面積が大きいほど尿流率は高く，膀胱内圧は低く速度も遅い．

女子では機械的閉塞はほとんど見られないので，尿道を拡張したり伸展させる手術は，おそらく不適切な前提にもとづくものと思われ，他覚的改善を示すことはほとんどなく，かりに有効であった場合は別の理由によるものであろう．反対に，男子では尿道の機械的閉塞を除けば改善されるが、機械的閉塞と閉塞にもとづく症状とを区別すべきであり，この目的には尿流動態検査が有用である．排尿筋が障害を受ける以前に尿道の器質的変化を早期に発見できれば，手術を決定する時大きく寄与することができる．