CARBON DIOXIDE URETHRAL PRESSURE PROFILES IN MALES

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ABSTRACT — Carbon dioxide urethral pressure profiles were obtained in a group of continent and incontinent male patients. Cystometry, needle electromyography of the striated urinary sphincter, and cystourethroscopy were also performed in most patients. A characteristic reproducible urethral pressure profile can be obtained in the continent, obstructed, and incontinent groups. The results also showed that the urethral pressure profile is influenced by the activity of the periurethral striated muscle. The urethral profile when performed with other established urodynamic procedures is a useful test in delineating normal and abnormal urinary sphincter function.

Recently the carbon dioxide (CO_2) urethral pressure profile has been employed in the urodynamic evaluation of individuals with lower urinary dysfunctions.[1,2] In an effort to define further normal and abnormal function of the urinary sphincter, we have performed urethral pressure measurements along with cystometry and electromyography in a group of continent and incontinent male patients. The results and significance of our study will be dicussed.

Material and Methods

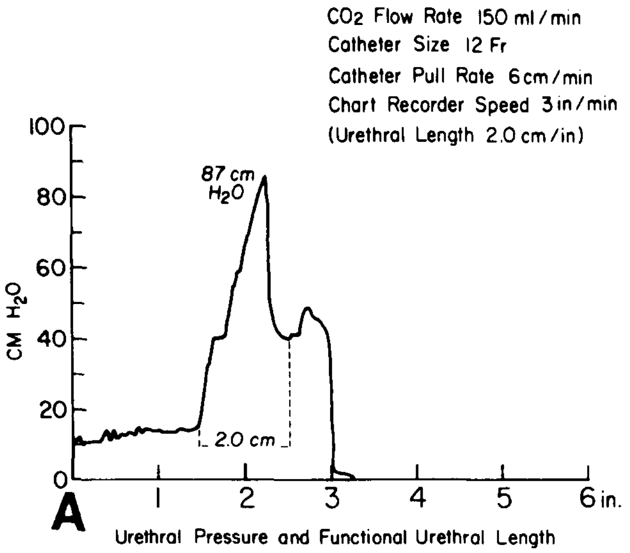
Thirty-nine patients were selected for the study. They were divided into three groups. The first group consisted of 21 continent patients. Eight of the 21 patients were admitted for various urologic complaints but without any obstructive symptoms or history of previous urologic procedures. Five of the 21 patients had transurethral prostatectomy at least six months earlier and at the time of the study had no obstructive symptoms. The remaining eight patients in the group presented with symptoms of prostatism and were found to have enlarged obstructing prostate glands on cystourethroscopy.

The second group consisted of 6 patients with non-neurogenic urinary incontinence. Two of the 6 patients had urinary incontinence after extensive pelvic injury while 4 patients had post-prostatectomy urinary incontinence.

The third group consisted of 12 patients with various types of neurogenic urinary incontinence. In this group 3 patients had an autonomous neurogenic bladder, 2 motor paralytic bladder, 4 mixed upper and lower motor neurone bladder, and 3 with reflex neurogenic bladder.

All patients in Groups II and III and 6 of 8 patients in Subgroup I were also studied with combined cystometry and periurethral striated muscle electromyography. The needle electromyography was also performed in conjunction with the urethral pressure profile whenever electromyography was used with cystometry. All patients had cystourethroscopy.

The technique of the combined cystometry and periurethral striated muscle electromyography has been reported previously.[3] Monopolar or coaxial needle electrodes were used. A TECA TE-4 electromyograph and the Merrill CO_2 cystometer were used for the combined study.



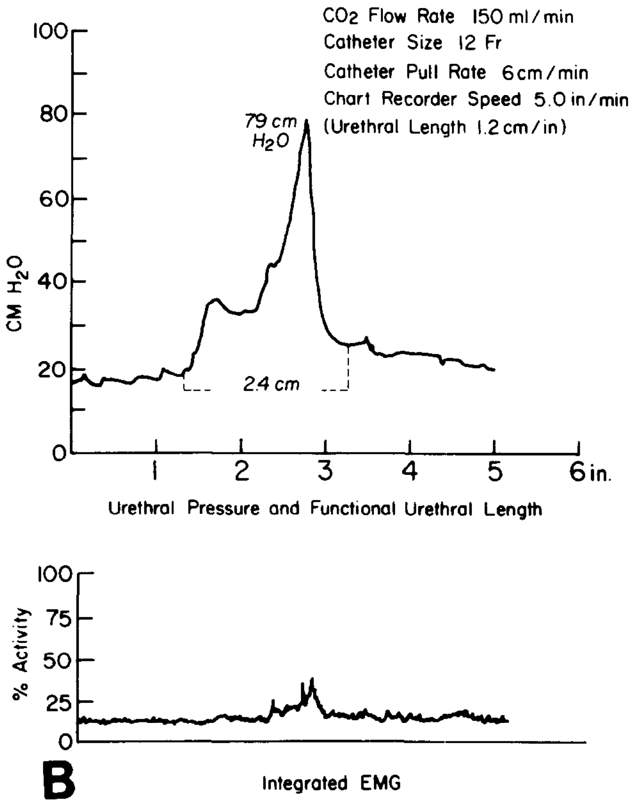


FIGURE 1. *(A) Normal male urethral pressure profile (twenty-three years old). (B) Normal male urethral pressure profile and electromyography (thirty-two years old).*

The urethral pressure profile determination was similar to that of Bradley and Timm's[4] technique. A 10 or 12 F urethral pressure catheter was used. All patients were placed in the dorsolithotomy position, and the bladder was emptied completely prior to the study. They were instructed to "relax" and not to strain, void, or tighten the sphincter. The catheter was automatically pulled at a constant rate of 6 cm./minute while the CO_2 was being infused at a rate of 150 ml./minute. The chart recorder (Merrill CO_2 cystometer) speed varied from 2.5 in. to 5 in./minute with the 2.5 in./minute speed being the one most commonly used.

The urethral pressure profile was analyzed by determining the maximum urethral pressure and the functional urethral length. The maximum urethral pressure is the highest recorded pressure in the region of the posterior urethra. The functional urethral length was arbitrarily defined as the length of the urethra from the point where the intraurethral pressure exceeds the intravesical pressure to the lowest intraurethral pressure immediately after the maximum pressure is achieved (Fig. 1A). In most cases the distal end of the functional urethra is higher than the intravesical pressure.

Results

Group I (Tables I-III)

Normal continent males. The typical urethral pressure profiles seen in this group of patients are depicted in Figure 1A and B. The urethral pressure profile is characterized by a two-step rise in pressure. The first rise in pressure that corresponds to the prostatic urethra is characterized by a moderately sharp rise in pressure ranging from 21 to 40 cm. H_2O where it stabilizes for varying lengths. This is followed by a second sharper rise that corresponds to the membranous urethra. As soon as the maximum urethral pressure is reached, there is a sharp drop in pressure that usually settles above the bladder pressure. This area of the curve corresponds to the bulbous urethra. The pressure then gradually decreases until the catheter reaches the urethral meatus. The maximum urethral pressure in this group ranged from 61 to 98 cm. H_2O with an average of 79 cm. H_2O. The functional urethral length as defined in this study ranged from 2 to 3.6 cm. with a mean of 2.6 cm.

All patients in this subgroup who underwent the combined cystometric and electromyographic evaluation had a normal study. Cystourethroscopy performed in the same group showed no evidence of obstruction.

The electromyographic activity of the periurethral striated muscle (electrode in the striated sphincter) revealed a variable increase of activity as the catheter traverses the urethra. The

TABLE I. *Continent nonobstructed nonoperated male patients**

Case No.	Age	M.U.P. (cm. H_2O)	F.U.L. (cm.)	Prostatic Pressure (cm. H_2O)
1	32	79	2.4	36
2†	22	74	2.0	36
3	32	85	3.6	28
4†	23	87	2.0	40
5	57	83	2.7	33
6	20	61	2.37	21
7	22	65	2.75	34
8	41	98	3.3	21

*Key: M.U.P = maximum urethral pressure; F.U.L. = functional urethral length.
†Cystometry, electromyography, and cystoscopy were not done.

TABLE II. *Continent nonobstructed postprostatectomy patients**

Case No.	Age	M.U.P. (cm. H_2O)	F.U.L. (cm.)
1	77	81	3.0
2	68	72	2.3
3	79	76	2.4
4	81	71	2.37
5	82	75	2.15

*See Table I for key.

changes of electrical activity corresponded to an increase of 10 to 50 per cent of electrical activity as monitored by the EMG integrator (Fig. 1B). The varied response among patients in the maximal urethral pressure (37 cm. H_2O) appeared to be influenced significantly by the activity of the periurethral striated muscle.

Continent postprostatectomy patients. This group has a profile similar to the continent nonoperated nonobstructed group (Fig. 2A). A very short and attenuated prostatic urethral pressure can be observed. The maximal urethral pressure ranged from 71 to 81 cm. H_2O (average 75 cm. H_2O) and a functional urethral length of 2.15 to 3 cm. (average 2.44 cm.).

Urethroscopy revealed no evidence of residual obstructing prostatic tissue, intact membranous urethra, and absence of any strictures along the urethra.

Preoperative and immediate postoperative transurethral prostatectomy patients. The profile of the continent obstructive group is similar in configuration to that of the nonobstructive continent group but differs in the functional length which is greater in the obstructive group because of elongation of the

TABLE III. *Continent obstructed preoperative patients**

Case No.	Age	Pre-transurethral Prostatectomy M.U.P. (cm. H_2O)	Pre-transurethral Prostatectomy F.U.L. (cm.)	Postoperative (36–48 hr.) M.U.P.	Postoperative (36–48 hr.) F.U.L.
1	70	74	4.25	33	3.0
2	62	72	3.60	48	1.75
3	77	70	3.00	41	2.0
4	64	79	3.90	66	3.45
5	65	85	6.30	48	3.9
6	69	75	3.25	41	2.1
7	60	75	4.00	Not done	
8	72	87	2.30	Not done	

*See Table I for key.

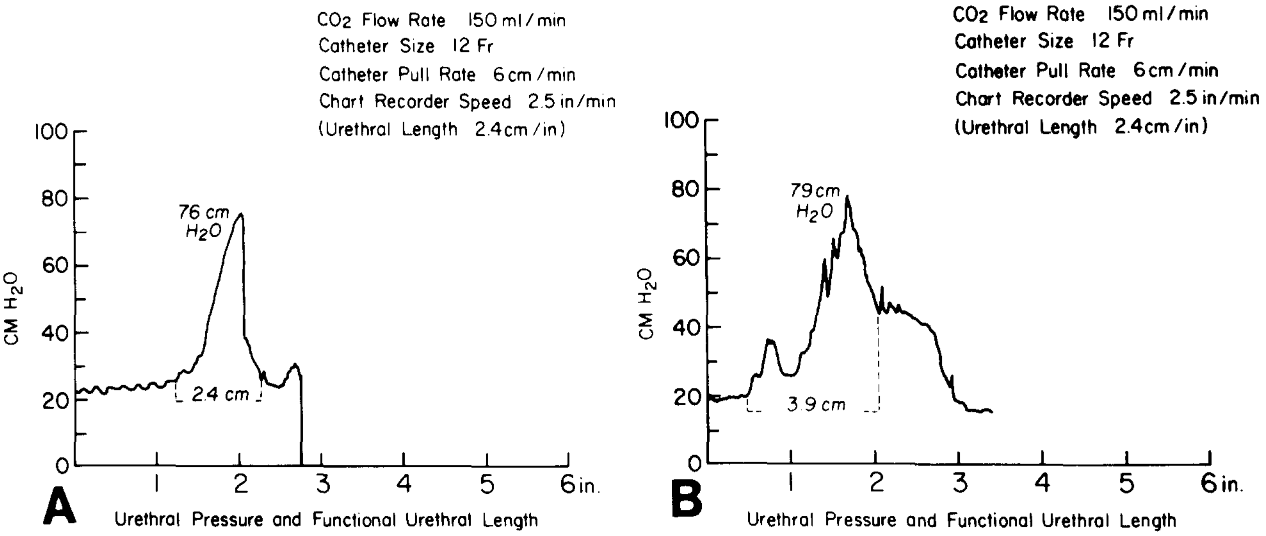


FIGURE 2. *(A) Postprostatectomy (6 mo.) urethral pressure profile. (B) Preprostatectomy urethral pressure profile.*

prostatic urethra. The preoperative maximum urethral pressure ranged from 70 to 87 cm. with a mean of 77.1 cm. H_2O. The preoperative functional urethral length ranged from 2.3 to 6.3 cm. with a mean of 3.85 cm. (Fig. 2B).

The urethral profile obtained thirty-six to forty-eight hours after transurethral prostatectomy differed from the preoperative and the late postoperative urethral profiles (Fig. 3). The prostatic urethral pressure immediately postoperative is either gone or is reduced thereby resulting in a functional urethral length shorter than the preoperative values. The average functional urethral length in the immediate postoperative group was 2.7 cm. with a range of 1.75 to 3.9 cm. The maximum urethral pressures were also dramatically reduced to an average of 46.1 cm. H_2O with a range of 33 to 66 cm. H_2O.

These patients voided well after the catheter was removed. They had varying degrees of urgency and urinary frequency. All patients were continent.

Group II (Table IV)

Non-neurogenic urinary incontinence. All patients had severe urinary incontinence and required either a penile clamp or an external catheter device for their urinary leakage.

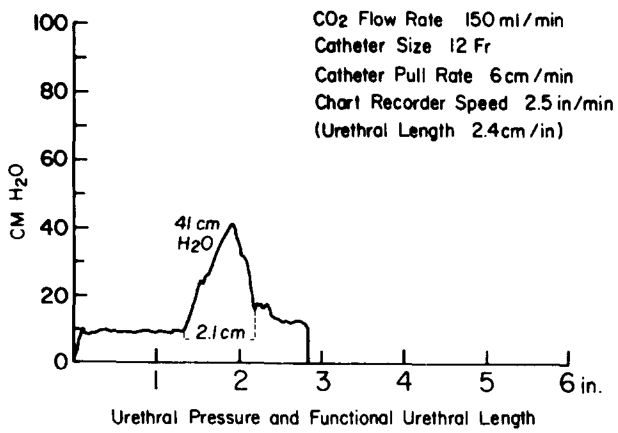


FIGURE 3. *Post-transurethral prostatectomy (thirty-six hr.) urethral pressure profile.*

TABLE IV. *Nonneurogenic incontinence**

Case No.	Age	Diagnosis	M.U.P. (cm. H_2O)	F.U.L. (cm.)
1	45	Postpelvic trauma	25	0.75
2	30	Postpelvic trauma	37	1.20
3	70	Postprostatectomy	38	0.60
4	64	Postprostatectomy	47	0.75
5	72	Postprostatectomy	44	0.60
6	60	Postprostatectomy	30	1.00

*See Table I for key.

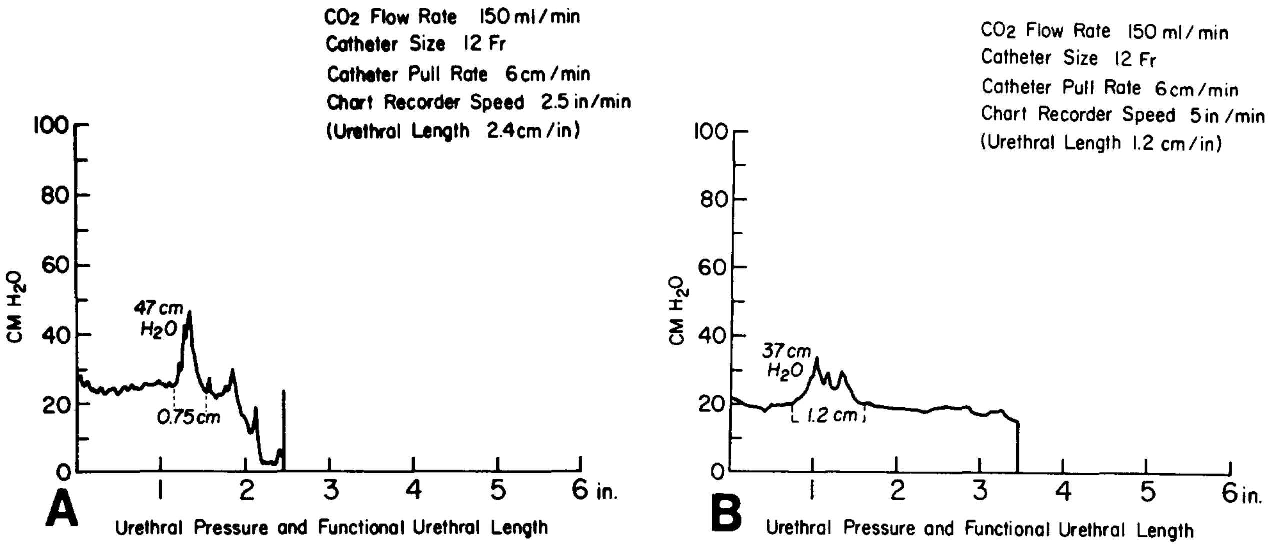


FIGURE 4. *(A) Postprostatectomy incontinence urethral pressure profile. (B) Postpelvic injury incontinence urethral pressure profile.*

Combined cystometry and periurethral striated muscle electromyography was normal for the postprostatectomy incontinence group. There was a noticeable decrease of electrical striated muscle activity in the patients with pelvic injury although the observed motor units were normal.

Cystourethroscopy in the postprostatectomy group revealed a wide open, well-resected prostatic urethra with defects and cicatrization of varying degree in the wall of the membranous urethra. The pelvic injury group showed an extensive scarification and distortion of the prostatic and membranous urethra.

In all patients the urethral pressure profile was significantly different from the continent group (Fig. 4A, B). There was marked shortening of the functional urethra and reduction of the maximum urethral pressure. The functional urethral length ranged from 0.6 to 1.2 cm. (average 0.81 cm.) while the maximum urethral pressure ranged from 25 to 47 cm. H_2O (average 36.8 cm. H_2O).

In 1 patient a stricture that calibrated at 14 F was encountered at the junction of the membranous and bulbous segments of the urethra. A urethral pressure profile revealed a 1.75-cm. functional urethral length and a maximum urethral pressure of 82 cm. H_2O (Fig. 5). After dilatation of the stricture, a repeat profile revealed a marked reduction in maximal pressure and length of functional urethra.

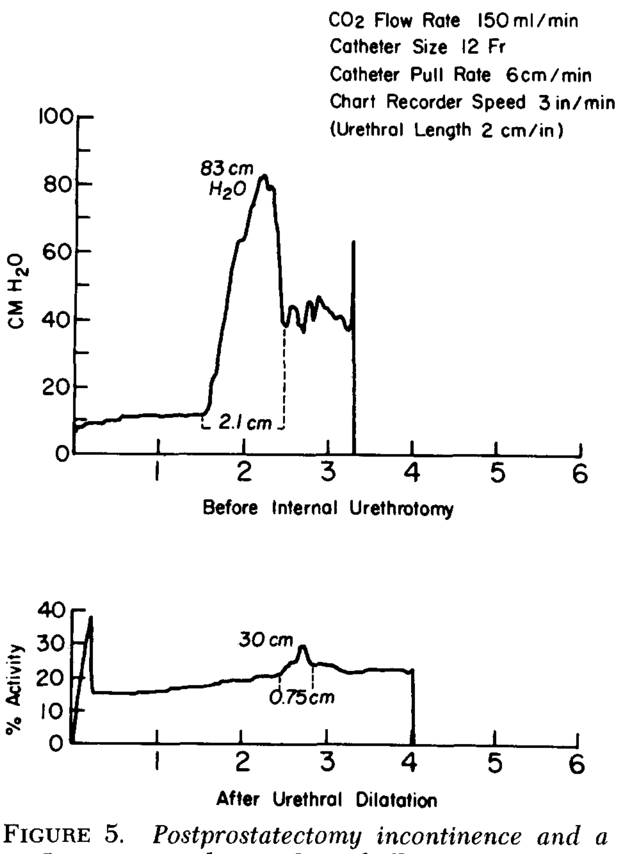


FIGURE 5. *Postprostatectomy incontinence and a 14 F stricture at the membranobulbous urethra.*

Group III (Table V)

Neurogenic incontinence–autonomous neurogenic bladder. These patients had suffered severe injury to the sacral spinal cord. They had no perineal or bladder perception, absent bulbocavernosus reflex, and an areflexic bladder. Striated muscle electromyography revealed complete denervation in 1 patient and near complete in 2 others. All had severe urinary stress incontinence. Cystourethroscopy revealed a normal bladder and urethra.

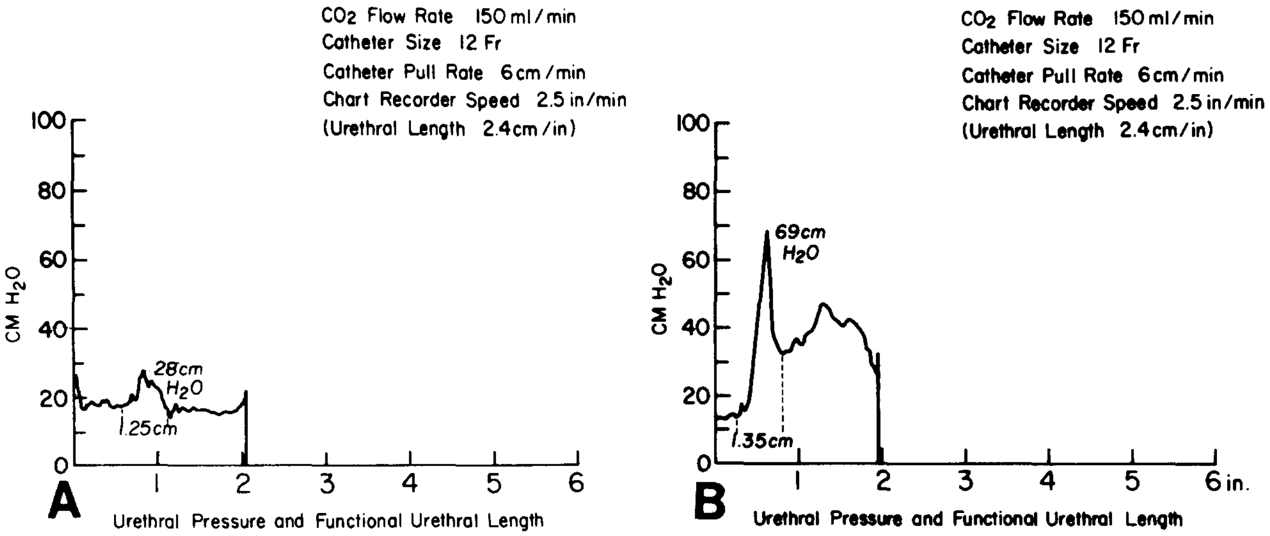


FIGURE 6. *(A) Autonomous neurogenic bladder with severe sphincter denervation. (B) Motor paralytic bladder and incomplete sphincter denervation.*

The urethral pressure profile was strikingly similar to that of the non-neurogenic incontinent group (Fig. 6A). The maximal urethral pressure ranged from 28 to 41 cm. H_2O while the functional urethral length ranged from 0.3 to 1.8 cm.

Motor paralytic bladder. Two patients had low thoracic vertebral injury with sensory sparing. They were on intermittent self-catheterization and manifested stress incontinence prior to catheterization if the bladder was allowed to overdistend.

Cystometry and sphincter electromyography confirmed the areflexic bladder with preserved bladder sensation. The electromyography revealed denervation potentials interspersed with

TABLE V. *Neurogenic incontinence**

Case No.	Age	Cystometry	Electromyography	M.U.P. (cm. H_2O)	F.U.L. (cm.)
1	33	Autonomous neurogenic bladder	Severe denervation	28	1.25
2	64	Autonomous neurogenic bladder	Complete denervation	40	0.3
3	35	Autonomous neurogenic bladder	Severe denervation	41	1.8
4	18	Motor paralytic bladder	Incomplete denervation	69	1.39
5	18	Motor paralytic bladder	Incomplete denervation	96	1.2
6	28	Mixed upper and lower bladder	Incomplete denervation	66	1.9
7	7	Mixed upper and lower bladder	Incomplete denervation	58	1.35
8	8	Mixed upper and lower bladder	Incomplete denervation	40	1.5
9	2	Mixed upper and lower bladder	Incomplete denervation	71	1.35
10	19	Reflex neurogenic bladder	Uncoordinated sphincter	145	4.2
11	26	Reflex neurogenic bladder	Uncoordinated sphincter	130	3.6
12	30	Reflex neurogenic bladder	Uncoordinated sphincter	130	3.45

*See Table I for key.

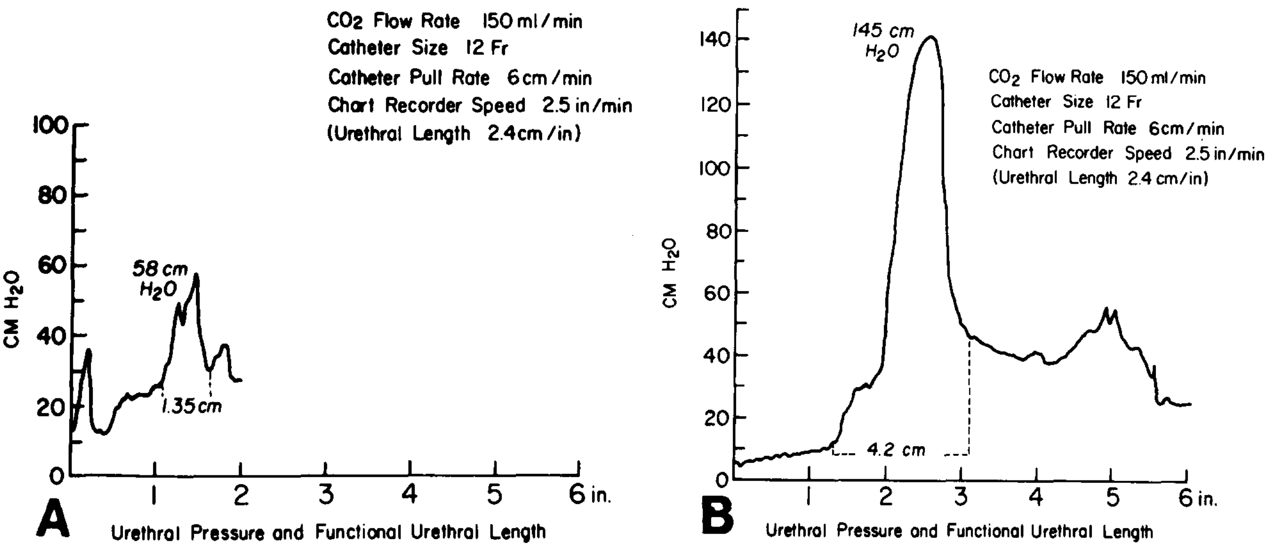


FIGURE 7. *(A) Mixed upper and lower motor bladder with partial sphincter denervation. (B) Reflex neurogenic bladder with uncoordinated sphincter.*

normal motor units. Cystourethroscopy revealed no significant bladder or urethral abnormalities.

The urethral pressure profile showed a shortened functional urethral length (1.2 cm. and 1.39 cm.) and normal maximum urethral pressure (69 and 96 cm.) (Fig. 6B).

Mixed upper and lower motor neuron bladder. These patients demonstrated lumbosacral lesions associated with myelomeningoceles. All were incontinent and wearing diapers when seen for the first time. Cystometry and sphincter electromyography revealed the presence of incomplete denervation.

The urethral pressure profile was characterized by generally low maximum urethral pressures (40 to 66 cm. H_2O) (Fig. 7A). The functional urethral length was also shorter and ranged from 1.35 to 1.90 cm. The maximum urethral pressure correlated very well with the incompleteness of the denervation of the periurethral striated muscle.

Reflex neurogenic bladder. These patients had transverse myelitis in the thoracic and cervical areas. Two patients were incontinent between intermittent catheterization while 1 patient was voiding by reflex with elevated residual urine. The studies performed prior to the urethral pressure measurement revealed absent sensory perception in the bladder, strong reflex detrusor contractions, and an uncoordinated hyperactive periurethral striated muscle.

The urethral pressure profile was characterized by a longer functional urethral length and a significantly increased maximum urethral pressure (Fig. 7B). With the stationary electrode in the periurethral striated muscle, there is definite increase of the electromyographic activity associated with the maximum urethral pressure.

Comment

The posterior urethra is composed of the vesical outlet and the prostatic and membranous portions of the urethra.[5] The periurethral striated muscle surrounding the membranous urethra acts as the external urinary sphincter. The posterior urethra and the periurethral striated muscle together constitute the continence mechanism in the male which prevents urine from flowing through the urethra under stress conditions.

Stress urinary incontinence can result from injury or dysfunction of the posterior urethra or the periurethral striated muscle or both. Exertional incontinence results when intravesical pressure exceeds the intraurethral pressure. The degree of incontinence will depend on the extent of posterior urethral dysfunction or injury and intravesical pressure.

Urgency or reflex urinary incontinence is the result of the uncontrolled detrusor contraction overcoming the urethral resistance. The increase in pressure is generated purely by the detrusor contraction without the aid of the intra-abdominal pressure.

The urethral pressure generated in the profile is the result of the interaction between the infusing agent and the tonicity of the urethral wall. Because of the numerous variables that can affect the urethral pressure profile, it is necessary to standardize gas flow rate, catheter pull rate, and the catheter size. Our results are in agreement with others that the use of carbon dioxide is safe and reliable.[1,2,4]

One of the initial difficulties we encountered in the male was the determination of functional urethral length. It became obvious from our results that the bulbous urethral pressure was higher than the bladder pressure. If we use the definition proposed by the urodynamic society,[6] the functional urethral length will be extremely long and will include the bulbous and even part of the proximal penile urethra. Knowing that the maximum urethral pressure corresponds with the membranous urethra, the functional urethral length was arbitrarily chosen as that segment of the urethral pressure from the time the pressure rises above the intravesical pressure to the lowest pressure reached immediately after the maximum urethral pressure is obtained. Using these criteria, we can exclude the bulbous urethral pressure which does not contribute to the continence mechanism even though its pressure is higher than the intravesical pressure. This is believed to be due to the increased resistance produced by the length of the urethra that the gas must traverse. It may also be related to the bulbocavernosus muscle located in this region.

Another difficulty that may be encountered during recording of the urethral pressure profile is the occurrence of an uncontrolled detrusor contraction which would alter not only the catheter pull rate and the eventual urethral length measurement but also the actual pressure recording. This can be avoided by starting the profile close to the urethrovesical junction to minimize gas infusion into the bladder. It is also important to avoid bladder and urethral irritation by starting with the urethral pressure measurements prior to other urodynamic procedures or instrumentation.

Urethral strictures in the posterior urethra or the bulbous urethra can produce a misleading observation. An apparently normal urethral pressure profile in a patient with severe stress urinary incontinence should make one suspect the possibility of a urethral stricture. This can easily be identified at the time of urethral calibration or urethroscopy. A repeat profile can be performed after the eradication of the stricture.

The urethral pressure profiles obtained in the continent nonobstructed nonoperated patients were very similar to the continent previously prostatectomized men. The functional urethral length and the maximum urethral pressure were comparable.

Our urethral pressures are in accord with the profiles obtained by others in the obstructed nonoperated group.[1,7] The functional urethral length is longer because of the increase of the prostatic urethral length. The maximum urethral pressure is similar to the other continent nonobstructed group.

A significantly different profile was obtained in patients shortly after transurethral prostatectomy. The profile showed obliteration or shortening of the prostatic urethra and marked reduction of the maximum urethral pressure when compared with the preoperative profile. The functional urethral length, on the other hand, was an average of 2.7 cm. which is consistent with the continent nonobstructed group. The low maximal urethral pressure can be attributed to urethral dilatation by the use of the resectoscope and the 24 F Foley catheter left indwelling for thirty-six to forty-eight hours. This hypothesis is supported by the fact that the maximum urethral pressure in the late prostatectomy group was similar to the continent nonoperated group or to the preprostatectomy patients. The finding of the lowered maximum urethral pressure and a relatively shorter functional urethral length when compared with the preoperative level may explain the transient stress incontinence that may be observed during the immediate postoperative period.

The urethral pressure profiles among the severely incontinent males after prostatectomy and pelvic injury were striking. The maximum urethral pressure and functional urethral length were markedly reduced. These observations were consistent in this group except for the patient with the small caliber posterior urethral stricture.

Electromyography of the periurethral striated muscle in the non-neurogenic incontinent group did not show any evidence of denervation. The normally active periurethral striated muscle in the postprostatectomy group suggested that the abnormal profile and the incontinence are due to the defective membranous urethra as confirmed by cystourethroscopy. It is also evident in the 2 patients with pelvic injury that there is partial impairment of the periurethral striated muscle which undoubtedly contributes to the severity of the incontinence.

The urethral pressure profile in the neurogenic incontinence group correlated well with the extent of the periurethral striated muscle denervation. The profile of patients with autonomous neurogenic bladder and severe sphincter denervation is characterized by shortened functional urethral length and reduced maximum urethral pressure. In patients with the motor paralytic bladder but with the periurethral striated muscle partially spared (partial denervation), the functional urethral length is relatively longer and the maximum urethral pressure in the normal range. Similar findings are noted in the mixed neurogenic group of bladders (upper and lower motor). All patients tested in the motor paralytic and mixed neurogenic bladder group showed significant preservation of the striated muscle on electromyography, and this was reflected in the minimal shortening of the functional urethra and slightly low to normal level of maximum urethral pressure.

In the reflex neurogenic bladder with an uncoordinated sphincter in which the incontinence is entirely on the basis of uncontrolled detrusor contraction, the functional urethral length and the maximum urethral pressure are significantly lengthened and elevated, respectively, when compared with the normal group.

Electromyographic study of the periurethral striated muscle in conjunction with urethral pressure measurements has been extremely helpful in analyzing the urethral pressure reading. It appears from our study that the periurethral striated muscle influences the functional urethral length and the maximum urethral pressure. Hyperactivity of the periurethral striated muscle will be associated with higher urethral pressure values while severe paralysis will lead to decreased urethral pressure values.

In the final analysis, it is clearly important that a thorough urologic evaluation of the entire urinary tract is necessary in evaluating a patient with lower urinary tract dysfunction. Carbon dioxide urethral pressure profile in the male patient appears to be a useful test when performed in conjunction with other established urodynamic procedures.

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