ESTIMATION OF RESIDUAL URINE AND URINE FLOW RATES WITHOUT URETHRAL CATHETERIZATION

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Adequate clinical evaluation of patients with difficulty voiding frequently requires the estimation of voiding pressures, urethral resistance, urine flow rates and residual bladder urine volume. These tests require urethral catheterization. The disadvantages of catheterization have been amply described (*1,2*) and justify the need to develop a method to evaluate the lower urinary tract without recourse to catheterization. Mulrow and associates (*3*) used ^{131}I-labeled diodrast to estimate residual bladder urine volume without catheterization. They administered radiodiodrast intravenously and after 1–3 hr the radioactivity over the urinary bladder was measured before and after voiding. The residual counting rate was taken as a function of the volume of urine remaining in the bladder, and an acceptable correlation was observed between the radiodiodrast estimation of residual urine and the actual volume determined by catheterization. Winter (*4*) has suggested that the evaluation of residual urine should be a final step following the radiorenography and that mean urine flow rates can be obtained during this procedure. However, the use of radionuclides to measure urine flow rates has not been described previously.

The present report concerns the application of radionuclide techniques to the evaluation of residual urine volume and urine flow rates. Radioiodohippurate has been used as suggested by Rosenthal (*5*) in place of diodrast with consequent improvement in the results.

METHOD

Thirty adult male patients were included in the study. Ten subjects had no known urinary tract problems, and the remainder had proven obstructive uropathy. The tests were conducted during midmorning, and the patients were permitted normal activities before examination but were instructed not to urinate after arising. This generally resulted in the bladder being full but not overdistended. An average dose of 25 μCi of ^{131}I-orthoiodohippurate was injected intravenously and a radiorenogram was obtained in each patient. Approximately 30 min after completion of the renogram (45 min after injection) each patient was placed in the standing position with a detector positioned directly over the pubic symphysis. The residual urine test was delayed in patients with reduced renal function until most of the radioactivity had left the renal areas. No patients with severely decreased renal function were used. The patient was asked to void into a graduated container which was shielded from the probe. A 2 $\times$ 2-in. NaI(Tl) crystal with a 5-in. cylindrical collimator was used, and the data were recorded on Scotch Band electromagnetic recording tape and on a Texas Instruments recorder. The digital counting rate was reproduced at 1-sec intervals on a Franklin printout. The initial counting rate over the bladder, the rate of disappearance of the nuclide and the final bladder counting rate were determined after plotting the data on graph paper. In each instance the exact time at which micturition began and ended was obtained from the chart recorder. It was assumed that the normal patients had no significant residual urine on the basis of a negative history of urinary tract disease and the virtually complete disappearance of the isotope from the bladder area. In the remaining subjects, urethral catheterization was performed with a small-gage catheter immediately after voiding. Aliquots of voided urine and of catheterized urine were counted to determine the adequacy of the bladder to serve as a uniform mixing chamber. The validity of the test depends upon the concentration of radioactivity in the bladder being uniform at the time of voiding. The recorded data included initial and final counting rate determinations over the bladder, the voided volume, the time during which micturition occurred, the flow rate in milliliters per second and the actual residual volume determined by catheterization. An estimation of residual urine volume was obtained by dividing

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TABLE 1. ISOTOPIC ESTIMATION OF RESIDUAL URINE

	Measured residual (ml)	Calculated residual (ml)
1	40	34
2	46	57
3	92	68
4	60	64
5	24	27
6	250	190
7	180	196
8	180	187
9	12	18
10	50	50
11	25	22
12	30	27
13	58	65
14	30	22
15	24	16
16	90	83
17	32	25
18	25	27
19	70	62
20	280	290
Mean ± (s.e.)	80 ± 18	77 ± 17

TABLE 2. EFFICIENCY OF BLADDER AS A MIXING CHAMBER

	Counts per min/ml	
Patient	Voided urine	Catheterized urine
1	86,630	86,525
2	42,586	43,893
3	85,585	101,639
4	52,730	53,123
5	177,894	180,752

the voided volume multiplied by residual count by the difference between the initial count and the final count:

$$\text{Residual volume} = \frac{\text{voided volume} \times \text{residual count}}{\text{initial count} - \text{residual count}}.$$

The relationships between voided urine volume and time were used as a measure of urinary flow rate. These values were correlated with initial bladder volumes.

RESULTS

Each of the normal subjects was able to void and completely empty his bladder so that the final counting rates were essentially the same as the background activity in the room. The subjects with obstructive disease all had significant residual counting rates in the post-void period (Table 1). The average residual volume measured by catheter was 80 ± 18 ml (s.e.) and the calculated residual by isotope method was 77 ± 17 ml (s.e.). There is no significant difference between these values by the paired or standard T tests ($0.3 < p < 0.4$). Accurate measurement of the residual urine without catheterization was therefore possible. The aliquots of urine from the voided specimens showed levels of radioactivity comparable with those obtained from the catheterized sample in each subject examined (Table 2), supporting the validity of the method.

The urinary flow rate as a function of bladder volume was uniformly reduced in the patients with obstructive disease (Fig. 1). The average urine flow rate was 5.9 ml/sec ± 3.3 (s.d.) in the abnormal subjects and in the control subjects it was 16.1 ml/sec ± 8.3 (s.d.). There is a highly significant difference between these values ($p < 0.01$). It was also noted that in both the normal and the obstructed subjects the urinary flow rates increase as the initial bladder volume becomes larger.

The correlation coefficient between bladder volume and urine flow rate in the normal subjects was 0.91 and is highly significant. In the abnormals the correlation coefficient was only 0.38, demonstrating a

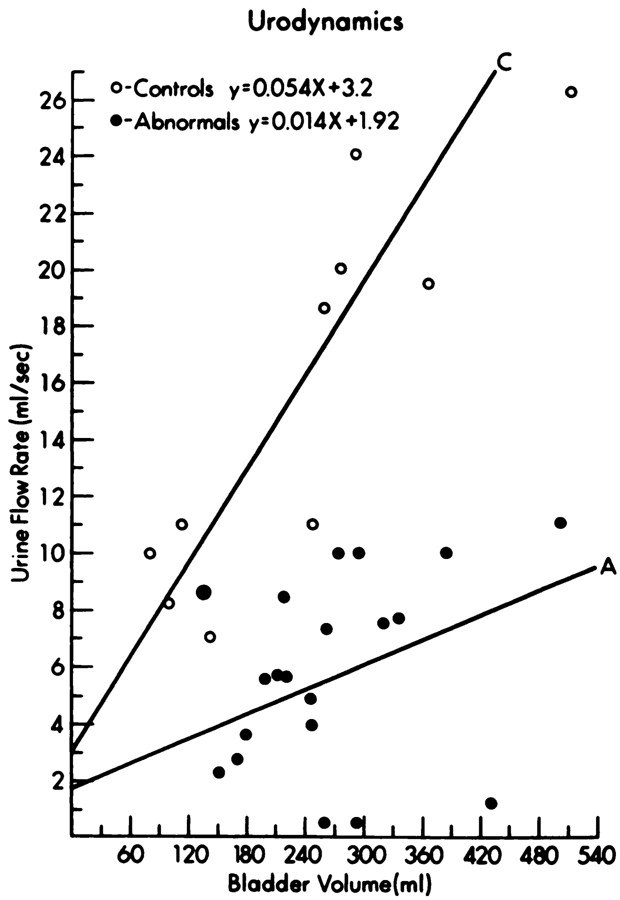

FIG. 1. Controls are indicated by open circles and abnormal subjects by closed circles. Urinary flow rates are correlated with initial bladder volumes demonstrating clear separation between two groups. Individual represented by closed circle in circle was treated for 4 months with hormonal therapy and had 12 ml residual urine when that value was obtained.

loss of the normal linear relationship between volume and flow. One abnormal patient was treated for benign prostatic disease with hormonal therapy. When restudied his residual urine had been reduced from 180 ml to 12 ml, and his urine flow rate was normal.

DISCUSSION

The problem of measuring instantaneous urine flow in the past has been approached with a variety of devices which record the amount of urine voided per unit time. The method presented here provides a record of the exact time at which flow begins and ends (Fig. 2). This permits accurate calculation of the midpoint maximal flow rate.

These maximal flow rates readily separate the normal subjects from the abnormal subjects. This separation is shown best when the initial bladder volume exceeds 200 ml (Fig. 1). This does not take into account the etiology of the obstructive process, nor does it permit evaluation of the relationship between the degree of obstruction and concomitant vesical hypertrophy. When performed simultaneously with isotopic residual urine measurements, two parameters of vesical function are obtained to aid in therapeutic decisions.

The study shows the highly significant linear relationship between urine volume and urine flow rate in normal individuals. Not only is urine flow rate reduced in lower urinary tract obstruction, but the statistically significant correlation between flow and volume is lost as demonstrated by the low correlation coefficient.

It is particularly significant that with adequate therapy in one individual who was restudied, not only was residual urine virtually eliminated, but also the urine flow rate fell within the normal range. The untreated patients with benign prostatic hypertrophy and low residual urine volumes had significantly abnormal flow rates. There was no correlation between the urine flow rate and the amount of residual urine, reflecting varying degrees of compensation.

The most important application of the radionuclide method is the estimation of residual urine volume and urine flow rate without urethral catheterization. The value of quantitating residual urine as a measure of bladder efficiency has long been a mainstay of urologic investigation. Attempts have been made by Beer (*6*) to determine residual urine volume without catheterization using radiographic criteria. Cotran and Kass (*7*) have reported determination of residual urine with phenosulphthalein. Both these methods require adequate renal function to obtain accurate results. The method reported here can be used if renal function is poor. This would

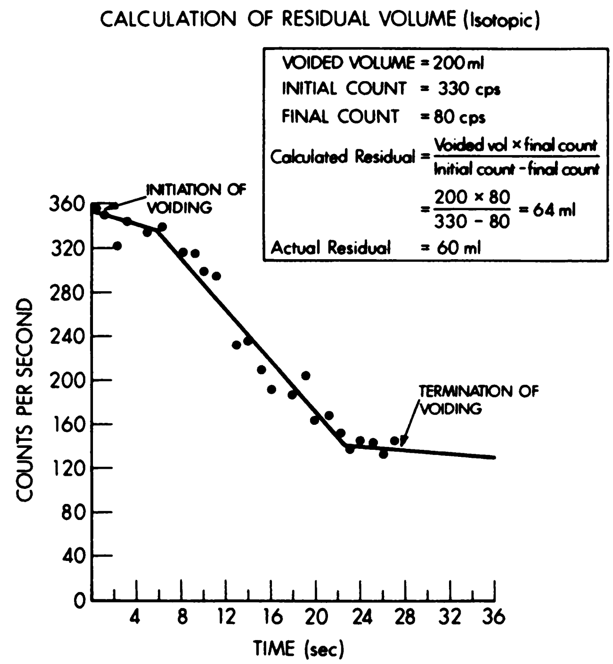

FIG. 2. Representative curve of dynamics of urinary stream demonstrating characteristics of flow, flow rate and manner in which residual urine volume is determined. There is good correlation between actual and calculated residual urine.

be discerned immediately from the renogram, and under these circumstances correction for background activity should be made as reported by Rosenthal (*5*). Mulrow was the first to report the use of radioisotope techniques to estimate residual urine. His method did not take into account the dynamics of bladder function. Winter suggested the combination of radioisotope renography with residual urine determinations but did not pursue the method. Rosenthal proceeded further by comparing isotopic methods of estimating residual urine with roentgenographic methods. He introduced the use of Hippuran and found the isotopic method to be quite accurate. However, other workers have not adopted his methodology, and he did not report on the urodynamics. In the present study, a reliable and statistically significant estimation of residual urine has been obtained along with the above mentioned data relevant to the dynamics of the lower urinary tract. The use of orthoiodohippurate has been found to be practical and simple. The test is best performed in patients with normal or moderately decreased renal function where no correction for blood background is necessary if an adequate time is used between the injection and the bladder count. Collimation presents no problem unless the bladder is allowed to become grossly overdistended. A 3 × 5-in. cylindrical collimator placed over the pubic symphysis views the bladder in most instances. Shand *et al* (*8*) have reported recently the use of orthoiodohippurate in the estimation of residual urine. However, they only studied five normal subjects and presented no data on patients with obstruction or residual urine. The possibility of performing the estimation of residual urine before most of the nuclide is in the bladder, thereby obtaining a falsely high estimate, is obviated by permitting the renogram to be carried out until most of the nuclide is in the bladder. This lets one detect patients with decreased renal function in whom the test should be performed at a longer time interval after injection. The dose of radiation per examination is the same as that for radiorenography, and undesirable side effects have not been noted.

It is concluded from these studies that radioisotope methodology permits the accurate and useful measurement of residual urine and an assessment of urodynamics in patients with obstructive uropathy. Catheterization of the bladder may be completely avoided with no significant loss of accuracy and with equal ease of performance.

SUMMARY

Thirty patients (20 with obstructive uropathy and 10 normal) have been studied to evaluate the use of radionuclides for the estimation of residual urine and urine flow rates without urethral catheterization. The residual urine was estimated from the radioactivity detected in the bladder area 45 min or longer after the intravenous injection of ^{131}I-orthoiodohippurate. The mean residual volume determined in 20 patients with obstructive uropathy by the isotopic method was 77 ± 17 ml (s.e.). Catheterization performed immediately after the isotope study revealed a residual of 80 ± 18 ml (s.e.). This difference is not significant ($0.3 < p < 0.4$). None of the 10 normal subjects had a significant residual by the isotopic method; they were not catheterized. The mean urine flow rate in the normal subjects was 16.1 ml/sec ± 8.3 (s.d.) and 5.9 ml/sec ± 3.3 (s.d.) in the abnormal patients ($p < 0.01$). The method described is accurate and reliable and should be used in preference to urethral catheterization to determine residual urine volume and urine flow rates in patients with lower urinary tract obstruction.

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