The Estimation of Urine Bolus Volume for Patients with Congenital Hydronephrosis

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Abstract

Harada, T., Noto, H., Etori, K., Kumasaki, T., Kigure, T., Nishizawa, O. and Tsuchida, S. The estimation of urine bolus volume for patients with congenital hydronephrosis. Jap. J. Smooth Muscle Res., 1985, 21 (6), 455-466.— A new examination (bolusmetry) to evaluate the urine transport function of the ureteropelvic system was performed in 7 adult patients with congenital unilateral hydronephrosis. Whistle-tipped Fr. 5 catheters were introduced to each ureter about 5 cm proximal from the ureteral orifice by transurethral endoscopic technique. Bolus volume and frequency, and changes in them caused by furosemide injection, were estimated by using a drop counter which was connected to the terminal end of the ureteral catheter.

Bolusmetry was performed comparing the hydronephrotic side and the healthy side, pre and postoperatively, and these results were then compared with a conventional examination.

We obtained the following results:

1) Bolus volume of the hydronephrotic side was $0.05 \pm 0.02$ (mean $\pm$ S.D.) ml at oliguric state, and it was significantly lower than the value of the healthy side which was $0.19 \pm 0.07$ ml. Injection of diuretics increased the bolus volume of the healthy side ten times or more. On the other hand, the bolus volume of the hydronephrotic side was increased only slightly by the injection of furosemide, it being approximately one-fourth of the value of the healthy side.

2) The value of bolus frequency was similar to peristaltic frequency which was measured by the electromyogram. The tendency of a decrease was noticed in bolus frequency of the hydronephrotic side but it was not significant.

3) Of patients with severe hydronephrosis, the bolus volume of the hydronephrotic side was decreased and the response to the diuretics was not so significant. By bolusmetry, functional or organic obstruction of the ureteropelvic junction was detected.

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4) Of 3 patients who had nephrectomy or nephrostomy, the kidney function had deteriorated severely. The bolus volume was lower than 0.25 ml at the diuretic state.

5) Bolus volume was increased postoperatively in 3 of 4 patients who had received pelvioplasty. One patient did not show the formation of bolus by the injection of diuretics, and the cause of the hydronephrosis was functional obstruction of the pelvioureteric junction.

We concluded that bolusmetry is a valuable method for evaluation of the function of urine transport in the ureteropelvic system. Especially in hydronephrosis, bolusmetry is a useful in the choice of operative procedure, and for postoperative evaluation.

Introduction

The function of the renal pelvis and ureter is to convey urine from the kidney to the urinary bladder. Functional or mechanical disorder of the ureteropelvic system causes infection or back pressure which are the ultimate agents responsible for kidney disease related to hydrodynamic dysfunction. Congenital hydronephrosis is due to primary ureteropelvic junction obstruction, however the exact etiology of ureteropelvic junction obstruction remains an enigma.

When a surgical choice is decided or postoperative evaluation is performed, the following procedures are currently used. Intravenous pyelography visualizes the ureteral obstruction and the degree of pyelocaryceal enlargement (Fryczkowski, 1972). Renal isotope study is used to determine the renal function and the ureteropelvic urine transportation (O'Reilly et al., 1978; Stage and Lewis, 1981). Moreover, the pressure-flow pelvic perfusion test described by Whitaker et al. (1981), ureteral manometry (Kiil, 1978), and electromyogram of the ureter (Tsuchida, 1970; Djurhuus, 1981) are reported. However, there are some shortcomings in these studies respectively, i.e. less objectivity, difficulty in procedure and paucity of information. Whitaker (1975) assumed that the renal pelvis cannot effectively create a bolus of fluid at its junction with the ureter when it is not funnel shaped.

We confirmed that the bolus formation is an important factor in pathogenesis of the congenital hydronephrosis (Tsuchida et al., 1982). Therefore, we measured the urine bolus volume and its frequency to determine urine transport function of the ureteropelvic system in 7 adult patients with congenital unilateral hydronephrosis.

Patients and Methods

There were 7 patients with unilateral congenital hydronephrosis who participated in this investigation (Table 1). Urine bolus volume and its frequency were measured by the following procedures, which we named the urine blousmetry.

Whistle-tipped Fr. 5 catheters were introduced into each ureter about 5 cm proxymal from the ureteral orifice by transurethral endoscopic technique. Bolus volume and its frequency were estimated by using a drop counter (DTC-102 Unique Med.) which was connected to the terminal end of the ureteral catheter. About 10 minutes after the catheter insertion, bolusmetry at oliguric state (the patients having fasted that day) was recorded for 5 minutes. Then,
TABLE 1. Patients and treatments.

<table>
<thead>
<tr>
<th>No.</th>
<th>sex</th>
<th>age</th>
<th>complaint</th>
<th>side of hydronephrosis</th>
<th>treatment</th>
<th>results</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M</td>
<td>32</td>
<td>abdominal mass</td>
<td>right</td>
<td>nephrectomy</td>
<td>—</td>
</tr>
<tr>
<td>2</td>
<td>M</td>
<td>70</td>
<td>fever</td>
<td>left</td>
<td>nephrostomy</td>
<td>fair</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>right renal pelvic ca.</td>
<td>Anderson-Hynes</td>
<td>fair</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>nephrostomy</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>M</td>
<td>49</td>
<td>lumbago</td>
<td>right</td>
<td>Anderson-Hynes</td>
<td>fair</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>nephrostomy</td>
<td></td>
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<tr>
<td>4</td>
<td>F</td>
<td>54</td>
<td>lumbago</td>
<td>right</td>
<td>Fidey-YU plasty</td>
<td>good</td>
</tr>
<tr>
<td>5</td>
<td>F</td>
<td>27</td>
<td>lumbago</td>
<td>left calici</td>
<td>Anderson-Hynes</td>
<td>excellent</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>nephrostomy</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>F</td>
<td>43</td>
<td>abdominal pain</td>
<td>left calici</td>
<td>Anderson-Hynes</td>
<td>excellent</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>removal of scar</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>M</td>
<td>53</td>
<td>abdominal pain</td>
<td>right</td>
<td>—</td>
<td></td>
</tr>
</tbody>
</table>

saline was infused intravenously at a rate of 10 ml per minute and a bolus injection of 10 mg furosemide was added. When an increase of urine secretion was noted in the normal kidney, the bolusmetry at mild diuresis was done. Finally when the urine secretion rate reached the maximum, the bolusmetry at the diuretic state was done.

Three of 7 patients had the examinations both pre and postoperatively, three only preoperatively and the other one only postoperatively. The values of bolus volume and frequency are expressed as mean ± standard deviation for 5 minutes duration respectively.

Moreover we tried to compare the results of urine bolusmetry to pyelogram or radioisotope renogram. The degree of pyelocaryceal enlargement was expressed by the ratio of the collecting system to total nephrographic area in intravenous or retrograde pyelogram. We label this ratio the collecting system index (C.S. index). The area of nephrogram or collecting system was measure by digitizer (Heyward Packard) and microcomputer (ATAC-450, Nihonkoden).

The results of the renogram were estimated in four grades, i.e. non-functioning, obstructive, delayed and normal pattern. Further, in three patients, urometry (pressure measurement in the ureter using by a transducer (P-23Db Statham)), ureteromyogram (read by bipolar surface electrode), and pressure flow study (Whitaker’s test), were performed simultaneously with the bolusmetry and the relevancy in those parameter of ureteropelvic function was discussed.

Prior to the bolusmetry, we measured the capacity of a drop from the catheter end at the various intraluminal flow rates. The bolus volume was calculated by the number of drops multiplied by the constant capacity of a drop. Statiscal analysis was obtained by the method of paired T rest.

Results

Preliminary experiments

The saline perfusion rate was changed periodically from 0.43 ml/min to 10.8 ml/min using an infusion pump (C-2 Truth). The number of drops was constant ranging with a flow rate
between 0.43 and 5.4 ml/min, but it increased gradually as the perfusion rate exceeded 5.4 ml/min (Fig. 1). When calculating bolus volume, the mean value, as 0.029 ml/drop, was used as a constant.

**Urine bolusmetry**

Table 2 and 3 show the results of urine bolus volume and its frequency. The preoperative urine bolusmetry in case 5 is shown in Fig. 2. In the healthy kidney, *i.e.* contralateral kidney to hydronephrosis, the bolus frequency increased temporarily after the administration of furosemide, and then the volume rose for a while. On the other hand in the hydronephrotic side, the increase of bolus frequency due to diuretics was not present and bolus volume was remarkably small both before and after administration of furosemide. The mean volume of
Urine transport in congenital hydronephrosis

OLIGURIC STATE
Healthy side

Hydronephrotic side

1 min

MILD DIURETIC STATE
Healthy side

Hydronephrotic side

1 min

SEVERE DIURETIC STATE
Healthy side

Hydronephrotic side

1 min

Fig. 2. Urine bolusmetry (case 5, preoperative). Upper; during oliguria, middle; immediately after an administration of diuretics, lower; during diuresis. The number of drops from the hydronephrotic kidney is smaller than that from the healthy kidney.

urine bolus in the oliguric state was $0.05 \pm 0.02 \text{ ml}$ in the hydronephrotic kidney and $0.19 \pm 0.07 \text{ ml}$ in the contralateral kidney. There was a significant difference between these two values ($p<0.05$).

At the maximum diuretic state, the bolus volume in hydronephrotic kidneys increased slightly but it was $0.53 \pm 0.43 \text{ ml}$ which was smaller than the value ($i.e. 2.04 \pm 0.68 \text{ ml}$) in the contralateral kidney ($p<0.05$). There was no difference in ratio of increase of bolus volume between the hydronephrotic and contralateral kidneys (Table 2).

Additionally, it was noticed that accurate bolus volume was not always measured in healthy kidneys at maximal diuresis, because urine flowed over the catheter to the bladder through a space between the ureter and catheter. This phenomenon was observed when the bolus volume exceeded $1.5 \text{ ml}$. The frequency of urine bolus in the healthy kidney increased in accordance with urine secretion. A significant difference was noticed between the oliguric and diuretic states in the normal kidneys, but there was no significant difference between these in hydronephrotic kidneys (Table 3).
The relationship between C.S. index or renogram, and bolusmetry

The data of C.S. index preoperatively is shown in table 4. C.S. index in hydronephrosis ranged from 36.5% to 80.6%, with a mean of 53.9±16.0%. The mean value in healthy kidneys was 17.0±6.0%, and remarkably lower than in hydronephrosis (p<0.05).

Of 4 cases who were evaluated C.S. index pre and post pyeloplasty operation, the value was decreased slightly from 45.2±8.1% to 38.0±9.8%, but there was no significant difference. On 3 of these 4 patients, the bolusmetry was done pre and postoperatively. In these cases the postoperative bolus volume increased significantly comparing to the preoperative value (p<0.01).
OLIGURIC STATE

Fig. 3. Urine bolusmetry combined with Whitaker's test (case 4). Bolusmetry (upper), pelvic pressure (middle) and ureteral pressure were recorded immediately after the onset of perfusion.

DIURETIC STATE

Fig. 4. Urine bolusmetry combined with Whitaker's test (case 4). Bolusmetry (upper), pelvic pressure (middle) and ureteral pressure were recorded 5 minutes after the onset of perfusion. Pelvic and ureteral pressure increase, and bolus formation diminishes.
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UROMETRY (OLIGURIC STATE)

Fig. 5. Urometry (case 3). Because measuring catheter works obstructively on the ureter of healthy side during diuresis, urine stasis in the ureter and the static pressure increases.

The pattern of renogram in each of the patients was shown in table 4. Of 4 cases who had pyeloplasty surgery, the improvement in renogram test was noticed in 2 patients post-operatively and there was no change in the other 2 patients with renogram tests.

The relation bolusmetry to pressure flow study, ureteromanometry and electroureterogram

The pressure flow study in accordance with Whitaker's test was done on case 4. The renal pelvis was perfused with saline at a rate of 10 ml per minute, and simultaneously the pelvic pressure measurement and urine bolusmetry were done. Initially, pelvic pressure registered 5 cm water high (Fig 3). Five minutes later, it increased to 37 cm water high, and the patients complained of abdominal pain. The bolus volume was 0.09 ml and the bolus frequency was 2.1/min before perfusion. Three minutes after the onset of perfusion, urine flowed smoothly without formation of urine bolus as shown in Fig. 4.

Case 3 and 5 had the uromanometry. In the oliguric state, static pressure of the ureter was from 5 to 8 cm H₂O, and the peristaltic pressure was from 10 to 18 cm H₂O in healthy kidneys (Fig. 5). At mild diuresis, the peristaltic pressure increased to 26-38 cm H₂O. During extreme urine secretion, the static and peristaltic pressure were not measured because the catheter worked obstructively (Fig. 5). On the other hand, in the hydronephrotic kidney, the peristaltic
pressure was 8 cm H$_2$O at oliguria, and 13 cm H$_2$O at diuresis. This was lower than the values for the healthy kidney.

Electroureterograms were done on cases 4 and 5. The peristaltic frequency was similar to the value calculated from blousmetry (Fig. 6). There was no significant difference between hydronephrotic and healthy sides.

The relation to operations

Case 1: C.S. index was 73.6% in the right kidney. Renogram proved non-functioning. Bolus volume was low which was 0.14 ml even after administration of diuretics. Therefore a right nephrectomy was done.

Case 2: The patient had right renal pelvic cancer and left hydronephrosis for which the C.S. index was 80.6%. A delayed pattern was shown by renogram. The bolus volume was 0.03 ml at oliguria and 0.25 ml at diuresis. Thereafter, the right kidney was removed and a nephrostomy operation was done on the left kidney. Although, 3 months after the operation, he died because of lung metastasis of the cancer.

Case 3: The patient had pyeloplasty at the age of 4 years. At 42.4%, the C.S. index was not so bad. Bolusmetry detected fair response to diuretics administration. Anderson–Hynes procedure was done. But 2 weeks after the operation, the kidney was removed because of severe infection.

Three cases previously described proved the poor response to diuretics administration on bolusmetry.

Case 4: She had already had pyeloplasty with nephrostomy. She was examined to determine if the removal of the nephrostomy catheter was possible at the time. Renogram showed an obstructive pattern, bolusmetry proved that the bolus volume was 0.09 ml at oliguria and urine bolus was not formed at diuresis (Fig. 4). That is to say the ureter transported urine as a simple duct without a bolus formation after diuretic administration. At this time, the
renal pelvic pressure elevated to 20–30 cm H₂O and abdominal pain was noticed. Because of the above reasons, it was concluded that the removal of the nephrostomy tube was probably impossible.

Case 5, 6 and 7: Pyeloplasty was performed on case 5 and 6, and removal of the scar at pyelo-ureteral junction was done on case 7. Each case had a good postoperative course. The bolus volume of these hydronephrotic kidneys before the operation were 0.07 ml at oliguria and 0.88 ml at diuresis, and they were lower than the value of healthy kidney. However, a good response to diuretics was noticed on bolusmetry as compared with case 1, 2 and 3 (Fig. 7).

**Discussion**

Primary obstruction of the ureteropelvic junction causes congenital hydronephrosis. In the event of pre- and postoperative examination, there are two important factors to discuss. One is the function of renal urine secretion and the other is the urine transport of the ureteropelvic system. The urine bolusmetry described in this study is a trial to evaluate directly the urine transport function. There have been some reports concerning urine bolus formation. Constatinou et al. (1974) measured urine bolus volume on dogs by a method similar to the urine bolusmetry in this study. Lutzeyer and Melichior (1969) reported urorheography based on the heat conduction method, and Tscholl et al. (1974) measured he velocity and the rate of ureteral contraction by videodensitometry. We measured the urine bolus volume of hydronephrotic kidneys, and determined that the value for hydronephrotic kidneys was lower than the value of healthy kidneys at either the oliguric or diuretic state.

The schema of the ureteropelvic junction is shown in Fig. 8. A normal ureteropelvic junction shown in Fig. 8-A presents funnel shape and there is a satisfactory mechanism for the formation of a urine bolus for normal ureteral peristaltic transport. However, in hydronephrosis, shown in Fig. 8-B, the ureteropelvic junction is lacking a funnel, and there is, therefore, a less efficient mechanism. The results in this study certified that the insufficiency of the bolus formation is one of the factors in the pathogenesis of congenital hydronephrosis.
Urine transport in congenital hydronephrosis

There was a negative correlation between the C.S. index and urine bolus volume. This fact indicates that the urine transport function of the pelvis and ureter affects directly renal function, and enlargement of the renal calyx and pelvis.

There was not significant correlation between renogram pattern and the results of urine bolusmetry. Whitaker and Flower (1981) stated that standard isotope renography suggested some delayed emptying in some cases. This was assumed to be due to gradual mixing of the isotope within the large volume of the kidney and not due to obstruction. Diuresis renography is recommended in the evaluation of patients with equivocal urinary tract obstruction.

In case 4, a functional obstruction was detected by bolusmetry, since the ureter had an inadequate caliber, though the mechanical obstruction of ureteropelvic junction had been removed and repaired by pyeloplasty to form a funnel. It is difficult to differentiate a functional obstruction from mechanical obstruction by pressure flow study or isotope renography.

Uromanometry is a useful procedure to evaluate the ureteral function. But it is difficult to measure accurate ureteral pressure during diuresis, because of urine stasis in the ureter owing to the obstructive working of the measuring catheter.

Concerning the urine transport function of the ureteropelvic system, bolusmetry is a valuable method especially in hydronephrosis when determining operative procedure and for the evaluation of the postoperative course.

References


