A Constant Electrical Activity of the Renal Pelvis Correlated to Ureteral Peristalsis

SEIGI TSUCHIDA and OSAMU YAMAGUCHI

Department of Urology, Akita University School of Medicine, Akita

In spite of numerous studies on upper urinary tract, a functional relationship between the renal pelvis and the ureter is not yet completely understood. To explain this relation, a hypothesis of pacemaker of ureteral peristalsis has been suggested by several workers (Bozler 1942; Shiratori and Kinoshita 1961; Kobayashi 1964; Weiss et al. 1967). However, a considerable confusion had surrounded this theory because it was generally difficult to prove a reliable measurement in vivo. Recently, Constantinou (1974) clearly showed that the frequency of pelvic pressure oscillation was constant for various urine flow rates, and ureteral peristaltic rate was directly related with an integral division of this basic pacemaker rate. More recently, Hrynczuk and Schwartz (1975), by the use of a subtraction amplifier with a computer system, analyzed the rhythmic pressure changes of the pelvis concluding the same results.

In this paper, we demonstrate the simultaneous recordings of the pelvic and ureteral EMG and examine a concept of renal pelvic pacemaker as being responsible for the initiation and conduction of ureteral peristalsis.

MATERIALS AND METHODS

Ten mongrel dogs weighing between 18 and 25 kg were used for the experiment. The dogs were anesthetized with an intravenous injection of sodium pentobarbital (Nembutal 25–30 mg/kg). Saline (0.9%) was slowly infused throughout the experiment. The kidney, ureter and bladder were exposed by a midline incision.

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Fig. 1. Experimental arrangement to record simultaneously the electrical activity of both the renal pelvis and ureter together with associated urine flow. The electrodes and their dimensions are shown circled.

The bipolar macroelectrodes shown in the insert of Fig. 1 were used extraluminally throughout the experiment. As shown in the figure, the supporting plate of the electrodes was so thin (1.0 mm) that it was easy to locate the electrodes on the surface of the pelvis. For the measurement of renal pelvic electrical activity, the electrode was fixed in the posterior surface of the pelvis which was carefully separated from the kidney much like the operative procedure of pyelolithotomy. Then, the electrode was inserted into a narrow gap between a wall of the pelvis and the kidney. As the kidney always pressed the electrode toward the surface of the pelvis, no particular effort was needed for stabilizing it. For the measurement of ureteral activity the other electrode was inserted in the midureter and stabilized on the peritoneum with a silk suture.

A 5 Fr. polyethylene catheter was inserted in the ureter 1 cm above the ureterovesical junction, and was connected to micro drop-counter (Tesco, Co.) to record the urine flow rate. The output from the drop-counter was amplified with a DC amplifier and recorded on biophysical polygraph (Nihon-Koden, Co.). The electrical activities of both pelvis and ureter were amplified with AC amplifiers and recorded on the same polygraph. Finally, as shown in Fig. 1, simultaneous recordings of the pelvic EMG, the ureteral EMG and associated urine flow can be made by this experimental arrangement.

Recordings were made continuously at 3 stages of urine flow, i.e., oliguric, increasing and diuretic stages. The experiment started when urine flow rate was low. Subsequently the flow rate was increased by infusing 20 mg Furosemide intravenously to establish a diuretic state following the increasing stage.

On 5 dogs all the interpelvic and interperistaltic intervals were measured for a statistical analysis. In 2 of these 5 dogs, a prolonged observation was made 22 to 40 min after maximum diuresis to examine further the effect of diuresis on both pelvic and ureteral activity.

RESULTS

Seven animals provided reliable recording. As 2 dogs were used to record the potential change near ureteropelvic (UP-) junction, a detailed analysis on 5 dogs was made.

Fig. 2 indicates the typical example of the pelvic extracellular action
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Fig. 2. EMG of the renal pelvis (upper) and the ureter (lower) recorded by the bipolar extraluminal electrodes. N and P, the two components of a bipolar lead, indicate the presence of depolarization at the positive electrode and at the negative electrode, respectively.

potentials recorded approximately at the center of the renal pelvis. Compared with ureteral EMG, the wave has a lower slope of depolarization and is of longer duration. In addition, the amplitude of the potential change, from base line to peak, averaged about 70 μV. This amplitude was significantly lower than that of ureteral EMG (600–800 μV). Although the recorded wave form was not symmetrical, the action potential of both the pelvis and the ureter showed an initial negative deflection followed by a positive deflection (Fig. 2).

NP-intervals measured in one case at the oliguric steady state averaged 0.52±0.01 sec in pelvic EMG and 0.33±0.02 sec in ureteral EMG. Mean conduction velocity calculated from these values was 1.32±0.03 cm/sec in the renal pelvis and 2.12±0.09 cm/sec in the ureter, respectively, indicating that action potentials were conducted more slowly in the renal pelvis than those of the ureter.

From the simultaneous recording of pelvic and ureteral EMG, it was established that the rate of the renal pelvis was generally constant throughout the observed period. In addition there was a definite relation between incidence of pelvic discharge and ureteral peristalsis. As all of 5 dogs used in this recording showed similarly characteristic responses to the changes in urine flow rate, the tracings obtained from 1 dog (No. 5) will be shown and described in further detail. Thus Fig. 3A is a part of tracings recorded when the urine flow rate was approximately 0.07 ml/min/ureter. At this low urine flow rate, interpelvic interval between two pelvic EMG complexes was 2.45 sec and the interperistaltic interval in the ureter showed three different values (7.41 sec, 9.76 sec, and 17.20 sec). Thus, the interperistaltic interval of the ureter was found to be a multiple of the basic interval of renal pelvis which varied 3×, 4× and 7× in this case. With increasing in urine flow rate, the interperistaltic interval decreased maintaining the relationship of multiples of pelvic rate. Fig. 3B indicates the effect of acute diuresis on both pelvic and ureteral EMG. In this recording, the discharge interval in the renal pelvis averaged 2.48 sec. The correlation between pelvic and ureteral EMG were gradually changed from 4:1 to 2:1 and finally a 1:1 correspondence was observed. During the increasing phase of diuresis the shape of pelvic action potential was distorted until maximum diuresis was established. At high urine flow rate following this recording, the frequency of pelvic EMG was identical with
A.

Pelvic EMG
200 µV

Ureteral EMG
1 mV

Urine flow rate

B.

Pelvic EMG
200 µV

Ureteral EMG
1 mV

Urine flow rate

C.

Pelvic EMG
200 µV

Ureteral EMG
1 mV

Urine flow rate

Fig. 3A, B, and C. The effect of an increasing urine flow on electrical activity of both the renal pelvis and the ureter. A represents the recording at low flow rate as control. B is the segment recording 1 min after intravenous administration of 20 mg Furosemide. C represents the recording at high flow rate. Note the constant rate of pelvic discharge throughout these segment recordings.

that of ureteral EMG. In Fig. 3C, the mean flow rate was approximately 1.40 ml/min/ureter, and the length of discharge interval in both pelvis and ureter showed the same value of 2.51 sec. Thus all of the action potentials probably generated in the renal pelvis were conducted to the ureter at high flow rate. The time plot of these segmental recordings is shown in Fig. 4.

It may be seen from Fig. 4 that discharge interval of the renal pelvis is constant throughout the observation period. This regularity was clearly shown for each dog from the measurements of all the intervals of the pelvic discharge. These are shown in Table 1 which clearly indicates that the standard deviation was extremely small despite a change in urine flow rate.

A more detailed analysis on the discharge intervals of both pelvic and ureteral EMG was performed with relation to an alteration in urine flow rate. For
practical reasons, a state of urine flow over the observation period was grouped into 3; a stage of low flow rate, increasing flow rate and high flow rate. These results are cumulatively summarized in Table 1. Some variability of pelvic rate was observed during each stage. Thus, comparing with the mean values at different flow rates, the interval of pelvic discharge was slightly increased in 3 dogs (dog Nos. 2, 4, 5) and also slightly decreased in 2 dogs (dog Nos. 1, 3) during the stage of increasing flow rate. At high flow rate, a little prolongation was observed for each dog. However, this deviation was within only 10% of initial mean value identified during the control period of low flow rate. The regularity of pelvic rate was also shown by this analysis (Table 1). Typically the ratios of discharge interval between pelvis and ureter were in the order of 4:1, 6:1, 8:1, etc., at low flow rates. With increasing flow rates, this ratio decreased to smaller multiple of pelvic rate until finally a 1:1 correspondence was observed between them (see Table 1).

With regard to the variability of discharge intervals which may occur after acute diuresis, a prolonged observation was performed on 2 of the 5 dogs. A lengthening of pelvic interval gradually became evident at the period of decreasing flow rate following high diuresis. In Table 2, 2 dogs showed a significant prolongation in pelvic rate from 22 to 44 min after maximum diuresis. However, ureteral rate was still maintained as an integral times of pelvic rate.

The data of the preceding experiment were obtained with pelvic electrode located at the center of renal pelvis. When the electrode was located close to UP-junction within the renal pelvis, the results were somewhat different from the preceding observations. In the region near UP-junction, pelvic action potentials became similar to those of ureteral EMG and the discharge interval varied with increasing urine flow. These results were observed on 2 dogs used in this experiment. In Figs. 5A and 5B, the discharge interval of the pelvic EMG averaged $4.33 \pm 0.11$ sec at low flow rate, but at high flow rate the interval diminished to
a half length (2.17±0.12 sec) and never decreased below this value. Thus, at the region near UP-junction, electrical activity of renal pelvis was still in modal manner much like ureteral activity.

**DISCUSSION**

It is apparent that pelvic EMG in vivo can be recorded by the method

**Table 1. Statistical characteristics of data obtained from 5 dogs studied**

<table>
<thead>
<tr>
<th>Dog No.</th>
<th>Low flow rate</th>
<th>Increasing flow rate</th>
<th>High flow rate</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Urine flow rate</td>
<td></td>
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</tr>
<tr>
<td>1</td>
<td>0.12–0.16 ml/min/ureter</td>
<td>0.18–2.94 ml/min/ureter</td>
<td>2.88–2.50 ml/min/ureter</td>
</tr>
<tr>
<td></td>
<td>Observation period 0–6'00&quot;</td>
<td>6'00&quot;–8'20&quot;</td>
<td>8'25&quot;–12'00&quot;</td>
</tr>
<tr>
<td></td>
<td>Pelvic interval 2.16±0.05 sec (n=103)</td>
<td>2.07±0.09 sec (n=72)</td>
<td>2.20±0.12 sec (n=103)</td>
</tr>
<tr>
<td>2</td>
<td>3.54±0.08 sec (n=125)</td>
<td>3.58±0.07 sec (n=32)</td>
<td>3.62±0.05 sec (n=48)</td>
</tr>
<tr>
<td></td>
<td>Ureretal interval 14.18±0.35 sec (n=20) 4:1</td>
<td>3.51±0.09 sec (n=18) 1:1</td>
<td>3.63±0.06 sec (n=48) 1:1</td>
</tr>
<tr>
<td></td>
<td>Pelvic interval 2.84±0.05 sec (n=14) 7:1</td>
<td>2.81±0.07 sec (n=40) 1:1</td>
<td>2.90±0.07 sec (n=52) 1:1</td>
</tr>
<tr>
<td></td>
<td>Pelvic interval 19.80±0.09 sec (n=5) 7:1</td>
<td>5.62±0.09 sec (n=2) 2:1</td>
<td>8.50±0.10 sec (n=3) 3:1</td>
</tr>
<tr>
<td></td>
<td>Pelvic interval 2.85±0.05 sec</td>
<td></td>
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<tr>
<td>3</td>
<td>0.07–0.08 ml/min/ureter</td>
<td>0.09–2.20 ml/min/ureter</td>
<td>2.15–1.92 ml/min/ureter</td>
</tr>
<tr>
<td></td>
<td>Observation period 0–7'23&quot;</td>
<td>7'32&quot;–10'29&quot;</td>
<td>10'40&quot;–13'20&quot;</td>
</tr>
<tr>
<td></td>
<td>Pelvic interval 2.84±0.05 sec (n=154)</td>
<td>2.83±0.06 sec (n=62)</td>
<td>2.92±0.04 sec (n=52)</td>
</tr>
<tr>
<td>4</td>
<td>2.12±0.06 sec (n=190)</td>
<td>2.17±0.08 sec (n=48)</td>
<td>2.21±0.03 sec (n=86)</td>
</tr>
<tr>
<td></td>
<td>Ureteral interval 8.49±0.21 sec (n=8) 4:1</td>
<td>2.16±0.06 sec (n=33) 1:1</td>
<td>2.20±0.05 sec (n=86) 1:1</td>
</tr>
<tr>
<td></td>
<td>Pelvic interval 16.83±0.19 sec (n=5) 8:1</td>
<td>8.72±0.10 sec (n=3) 4:1</td>
<td></td>
</tr>
</tbody>
</table>

**mean pelvic interval 2.15±0.06 sec**
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Table 1 (continued)

<table>
<thead>
<tr>
<th>Dog No.</th>
<th>Low flow rate</th>
<th>Increasing flow rate</th>
<th>High flow rate</th>
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</thead>
<tbody>
<tr>
<td></td>
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<tr>
<td></td>
<td></td>
<td>0.10–1.50 ml/min/ureter</td>
<td>1.48–1.32 ml/min/ureter</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8'05&quot;–11'10&quot;</td>
<td>11'12&quot;–13'00&quot;</td>
</tr>
<tr>
<td></td>
<td>Pelvic interval</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.45±0.06 sec (n=190)</td>
<td>2.48±0.06 sec (n=71)</td>
<td>2.53±0.04 sec (n=44)</td>
</tr>
<tr>
<td></td>
<td>7.41±0.22 sec (n=15) 3:1</td>
<td>2.48±0.08 sec (n=54) 1:1</td>
<td>2.54±0.05 sec (n=44) 1:1</td>
</tr>
<tr>
<td></td>
<td>9.76±0.18 sec (n=28) 4:1</td>
<td>4.83±0.08 sec (n=4) 2:1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>12.03±0.03 sec (n=2) 5:1</td>
<td>9.74±0.08 sec (n=2) 4:1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>14.70 sec (n=1) 6:1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>17.20 sec (n=1) 7:1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>mean pelvic interval 2.46±0.05 sec</td>
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</tbody>
</table>

Pelvic interval means the discharge interval of pelvic EMG, and ureteral interval also means the interperistaltic interval. These values are indicated as mean±s.d.

Table 2. Prolonged observation following maximum diuresis

<table>
<thead>
<tr>
<th>Dog No.</th>
<th>Time from maximum diuresis</th>
<th>Pelvic interval</th>
<th>Ureteral interval</th>
<th>Urine flow rate ml/min/ureter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>22 min</td>
<td>2.53±0.05 sec (n=60)</td>
<td>5.23±0.08 (n=2) 2:1</td>
<td>0.42</td>
</tr>
<tr>
<td></td>
<td>(22'00&quot;–24'40&quot;)</td>
<td>initial interval</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>40 min</td>
<td>2.73±0.08 (n=42)</td>
<td>5.61±0.1 (n=5) 2:1</td>
<td>0.50</td>
</tr>
<tr>
<td></td>
<td>(40'00&quot;–42'00&quot;)</td>
<td>initial interval</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Initial interval is the mean value of pelvic interval observed during the state of low flow at the start of the experiment (see Table 1).

described in this study. As for the characteristics of the pelvic EMG, our results show that the recorded pelvic potential is the propagared action potential and its amplitude is lower and its conduction speed is slower than that of the ureter. In the isolated pelviureteral preparation, Kobayashi (1964) observed that the specific potential change was initiated at the border of the pelvis and calyces and it was conducted to the pelvis and ureter where the propagated action potential was recorded. He also measured these potential changes and their conduction speed, and obtained results similar to those in our observation in vivo. Thus, it seems probable that the pelvic EMG reflects a pacemaker activity generated somewhere in the renal pelvis.

Regularity of the pelvic activity in dogs has been demonstrated mainly by the pressure studies (Constantinou 1974; Hrynczuk and Schwartz 1975). Our results also show the analogous regularity of the electrical activity of the renal pelvis. This is substantiated from the results of simultaneous recording of both EMG and urine flow that the interval of pelvic discharge was observed to be constant although urine flow changed from oliguric state to high flow state.
Simultaneous recording of the pelvic EMG, ureteral EMG and urine flow
when the pelvic electrode was located close to UP-junction in the renal pelvis. A is
the recording at the urine flow rate of 0.13 ml/min/ureter. B is the same recording at
high flow rate (2.60 ml/min/ureter). Note a difference of pelvic interval between A
and B.

Furthermore, statistically a small s.d. for each length of interval also indicates the
narrow spectrum of pacemaker contractions.

In relation to ureteral peristaltic activity, it is possible to say that interperi-
staltic interval is a multiple of a constant length of pelvic interval at low flow rates.
With increasing flow rate, ureteral peristaltic rate reaches that of the renal pelvis.
This relationship between the renal pelvis and the ureter was electromyographically
demonstrated in this study (Fig. 4 and Table 1).

On the other hand, some variability of the pelvic interval is observed
immediately after peak flow stage, and this trend of lengthening will become more
evident at prolonged observation following maximum diuresis. One of the
reasons to explain this phenomenon is that the experiment was performed under
the condition of increasing urine flow. Therefore, rapid distention of the renal
pelvis occurs and this may modify the excitability of smooth muscle in the pelvis by
decreasing the threshold of depolarizations. Constantinou et al. (1974) examined
a basic interval of ureteral peristalsis defined as the most minimal interval of
ureteral EMG, and found such a lengthening of the basic interval particularly at
high urine flow. However, they demonstrated no direct correlation to the pelvic
activity. This study shows that the lengthening of the pelvic interval also
prolongs the interperistaltic interval, and maintains the relation of multiples of
pelvic rate. It can therefore be concluded that any changes in the rate of ureteral
peristalsis are strictly correlated to the pelvic rate and consequently to that of the pacemaker.

References


