Changes of the Ureteral Movement in Diuretic Condition and after Ureteral Surgery

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KUBO, T., SASAKI, S., NUMASATO, S., TAKAHASHI, S. and AKASAKA, T. Changes of the Ureteral Movement in Diuretic Condition and after Ureteral Surgery. Tohoku J. exp. Med., 1977, 123 (1), 9-22 — An extraluminal ureteral bipolar needle "indwelling" electrode with recording wire was devised to study the ureteral function, and daily recording of the ureteral myogram in human and experimental animal has been successfully carried out. Using this new electrode, ureteral myogram and intraureteral pressure were simultaneously recorded in humans and dogs under various experimental conditions, and the following results were obtained: (1) The average ratio of peristaltic frequency of the renal pelvis to that of the ureter was 3:1 under ordinary diuretic condition. Following Furosemide administration, the peristaltic frequency of the renal pelvis remained unchanged while both the intrapelvic pressure and the peristaltic frequency of the ureter increased, with an average ratio of 1:1. (2) When the middle portion of the ureter was transected and anastomosed with a vinyl ureteral catheter to block the myogenic conduction, an excitation was evoked at the stump of the lower ureter by the stimulation of urinary flow and almost normal peristalsis was observed. There was no relationship in the direction of peristalsis between the lower ureter and the rest of the ureter. (3) Following operation of the ureters in dogs, ureteral myograms were recorded daily. Abnormal discharges were evoked immediately after surgery in the lower part of the ureter below the surgical site. After urinary fistula formation in humans, abnormal discharges were more frequently observed, and at the same time the ureteral peristalsis across the surgical site was decreased. These abnormal discharges disappeared by 7 days after surgery in the group without postoperative fistula formation, but in the humans with urinary fistulation they disappeared only after the fistula was healed. (4) The rate of peristalsis through the surgical site of the canine ureter was greater than 50% in the group without hydronephrosis, but less than 50% in the group with postoperative hydronephrosis. Therefore, it was assumed that postoperative hydronephrosis due to ureteral obstruction would not occur, if the peristaltic rate is maintained greater than 50%. —— ureter; renal pelvis; electromyogram; intraluminal pressure

Following the original macroscopic description of ureteral movement by Engelmann in 1869 and subsequent electrophysiologic measurements by Orbeli and Brücke in 1910, numerous observations of the ureteral function in experimental animals have been reported. Shiratori and his co-workers (1957) reported the nature of the ureteral action potentials and the effect of neostigminae methylsulfatis

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in humans. Tsuchida and Kimura (1964) reported the myographic recording of the human ureter using an intraluminal "U-looped" electrode.

We have recently developed an electrode which is able to measure in situ action potentials of ureters continuously (Kubo et al. 1970). The present report includes observations made in both experimental animals and human patients requiring urologic surgery to assess ureteral activity in normal and abnormal conditions and also to observe postoperative recovery of ureteral function.

**MATERIALS AND METHODS**

**Animal studies**

Adult mongrel dogs weighing 9.5 to 26 kg were used in these studies.

**Experiment I.** Effects of rapid diuresis on renal pelvic and ureteral movements.

After intravenous thiopental-Na administration, one or both of the kidneys and ureters in 18 dogs were exposed, and electrodes were attached to the surface of the renal pelvis and ureter (Akasaka 1976). To record the intraluminal pressure, a 18G needle with a flap was inserted into the lumen of ureter, and a 16G venous-indwelling needle (Top Co. "Venula") was secured in the renal pelvis through the renal medulla. The electromyogram was recorded on a 4-channel pre-amplifier (Nihon Kohden Co. RB-5), and intraluminal pressure recording was made by the use of transducer (Nihon Kohden Co. LPU-0.1) and carrier amplifier (Nihon Kohden Co. RP-5), and recorded on a 4-channel recticorder (Nihon Kohden Co. RJG-3024).

After simultaneous recording of action potentials of the renal pelvis and ureter and their intraluminal pressures under ordinary diuretic condition (abr. ordinary condition), a rapid diuresis was induced by an intravenous administration of Furosemide (10-20 mg), and changes in the pelvic and ureteral action potentials and intraluminal pressures were monitored simultaneously. Studies were performed on 28 pelves and ureters.

**Experiment II.** Effects of ureteral transection with re-anastomosis on ureteral action potentials and intraluminal pressure.

Under anesthesia, as described in Experiment I, transection of 35 ureters in 24 dogs was performed. Re-anastomosis was established with insertion of a vinyl ureteral catheter to block myogenic conduction. The action potential and the intraluminal pressure were recorded in the lower part of the ureter distal to the transection.

Furthermore, the upper stump of the transected ureter was anastomosed to the ureteral orifice of the same side with insertion of a vinyl ureteral catheter (abr. converse recommunication), and the action potential and intrarureteral pressure were recorded in the lower part of the ureter distal to the transection (Akasaka et al. 1975).

**Experiment III.** Effects of ureteral surgery on ureteral action potentials.

In 24 dogs, the ureter was exposed out of the peritoneum and two electrodes were attached to the surface of the same ureter widely separated. The recording wire was secured and tunneled subcutaneously, with an exit at the neck to make extracorporeal recording possible at will.

After initial recording of the action potential with each electrode a 1 cm longitudinal incision of the ureteral wall was made between the electrodes, and then sutured (12 ureters). In 18 ureters, the ureter was transected between the two electrodes, and reanastomosed end-to-end. The recording of the action potential of the ureters was made immediately after surgery and for 5 to 16 days, thereafter, in an attempt to establish if there is a relationship between the rate of peristalsis through the surgical site and the development of hydronephrosis (18 to 116 days after surgery).

**Clinical studies**

We studied ureteral function in patients with ureteral lithiasis before and after
ureteral lithotomy. The ureter was exposed, and two electrodes were attached to the surface of the ureter proximal and distal to the intraluminal stone, and recording wire was exteriorized to permit recording at will. The recording of the action potential was made just before lithotomy and then daily for 10 to 28 days.

RESULTS

**Effects of rapid diuresis on the peristalsis of the renal pelvis and the ureter (Experiment I) (Akasaka 1976)**

**Discharge frequency.** Under ordinary conditions, the discharge frequency of the renal pelvis was 8.9–42.5/min (average 24.6/min), and small contraction waves with low amplitude and synchronized with the discharges were also observed (Fig. 1). In the ureter, discharge frequency was 1.6–20/min (average 8.7/min) and synchronized contraction waves were also observed. During rapid diuresis the discharge frequency of the renal pelvis remained unchanged 14.3–36.7/min (average 24.1/min), but that of the ureter increased markedly (average 22.7/min), and it became similar to that of the renal pelvis in most cases. Though some individual differences were found in 28 ureters as shown in Fig. 2, the peristalsis ratio between the renal pelvis and the ureter averaged 3:1 under ordinary conditions, but it became 1:1 in 20 ureters and about 1:1 in other 5 ureters under the rapid diuretic condition.

**Electromyogram.** Increased ureteral peristalsis and decreased amplitude of the action potential were observed with rapid diuresis. Generally, the duration and the conduction velocity remained unchanged in both the renal pelvis and the ureter under the conditions of the experiment.

**Intrapelvic and introureteric pressure.** Intraluminal pressure and the action

![Fig. 1. Simultaneous recordings of pelvi-ureteral myograms and pressures. A, pelvic myogram; B, intrapelvic pressure; C, ureteral myogram; D, introureteral pressure.](image-url)
Fig. 2. Peristaltic frequency of pelvis and ureter before and during diuresis.

(A) Control

(B) Transection

(C) After transection

(D) Recommodation

(E) After recommodation

Fig. 3. Complete transection of the ureter and its recommodation using a vinyl ureteral catheter.
potential of the renal pelvis and the ureter were as follows: 11.0 cmH$_2$O (resting) and 11.0 cmH$_2$O (contraction) in the renal pelvis, and 4.4 cmH$_2$O (resting) and 15.9 cmH$_2$O (contraction) in the ureter, under ordinary conditions. With rapid diuresis, it became 21.8 and 24.3 cmH$_2$O in the renal pelvis, and 14.4 and 20.7 cm H$_2$O in the ureter, respectively. Only the increase of the resting intrapelvic pressure was striking.

**Effects of ureteral transection with re-anastomosis and anti-recommunication on ureteral movement (Experiment II) (Takahashi 1974; Akasaka et al. 1975)**

As shown in Fig. 3A, action potential and the contraction wave occurred simultaneously in all cases before surgery. After transection of the ureter, as shown in Figs. 3B, 3C and 4, antiperistaltic discharges were observed in 11 (61%) out of 18 ureters, in which the action potential of the lower ureter could be recorded. After normal recommunication, as shown in Figs. 3D, 3E and 4, only normal peristaltic discharge was recorded in 33 (94%) out of 35 ureters, and at the same time obvious contraction waves were observed.

![Fig. 4. Peristalsis in lower segment of the sectioned and recomunicated ureter.](image)

**Discharge frequency.** In the preoperative state the average discharge frequency was 7.6/min. But in 7 ureters, in which normal peristaltic discharge could be seen immediately after the transection, the discharge frequency was decreased to 0.5-11.3/min, averaging 3.8/min. On the other hand, in 33 ureters in which normal peristaltic discharge was seen after the normal-recommunication, it averaged 5.7/min, and it returned nearly to the normal state.

**Intraureteral pressure.** The intraureteral pressure at preoperative resting state ranged from 0.0 to 10.4 cmH$_2$O and averaged 4.7 cmH$_2$O, while the contraction pressure ranged from 10.0 to 42.0 cmH$_2$O and averaged 11.7 cmH$_2$O in 6 ureters in which intraureteral pressure was recorded immediately after the transection. This was changed to 0.0 to 21.2 cmH$_2$O and averaged 6.6 cmH$_2$O in the resting stage after the normal-recommunication, and the contraction pressure
ranged from 6.1 to 38.9 cmH₂O and averaged 22.1 cmH₂O after the normal-recom-
munication. These values were close to those of the preoperative state. After
the converse-recommunication, as shown in Fig. 5, the excitation was evoked from
the ureteral orifice side, and antiperistaltic discharge was observed in 13 out of
16 ureters.

![Graph showing pressure measurements](image)

**Fig. 5.** Simultaneous recording of ureteral myogram and pressure before and during anti-
recommunication.

![Graph showing myogram recordings](image)

**Fig. 6.** Ureteral myogram after the longitudinal incision and suture. A, control; B,
immediately after suture; C, 1 day after surgery; D, 7 days after surgery.
Postoperative changes of the ureteral function after ureteral surgery (Experiment III) (Sasaki 1973a)

The ureteral myograms recorded from two different points of the ureter in the preoperative state showed that the excitation occurring from the renal side was conducted to the bladder with the discharge ratio of 1:1, as shown in Fig. 6. After the longitudinal incision and suturing the ureteral wall, the discharge frequency of the ureter proximal to the surgical site was increased, and it was diminished in the part of the ureter distal to the surgical site. One day postoperatively, regular discharges were seen proximally, but distally irregular discharges were observed in most cases. After 6 to 7 days, as shown in Fig. 7, normal peristalsis was conducted across the surgical site, and the peristalsis returned to the normal state in most of the cases, without any antiperistaltic discharge. Especially in the cases in which the fistula formation occurred, the peristalsis ratio between the upper and the lower ureter became about 1:1 as the fistula healed, and antiperistaltic discharge disappeared in the lower ureter. In the cases of end-to-end anastomosis of the ureter similar results were obtained, although 14 to 28 days were required for the healing of the fistula.

The passing rate of the ureteral peristalsis at the restored site of the ureter (Sasaki 1973b) was examined. In the cases without postoperative hydronephrosis, the ratio of discharge frequency between the upper and the lower ureter was 1:1, as shown in Fig. 8. But in the 9 cases with the postoperative hydronephrosis, the discharge in the upper ureter was markedly increased, and it was not conducted to the lower ureter. The passing rate calculated from the ratio of peristaltic frequency was greater than 50% in the cases without hydronephrosis and less than 50% in the cases with hydronephrosis as shown in Fig. 9.

Results of clinical cases

The ureteral myography before ureteral lithotomy (Numasato 1975). The results of the ureteral myography from the proximal and distal portions of the ureter before ureteral lithotomy are summarized as follows: (1) The peristalsis

![Fig. 7. Change of peristaltic frequency after surgery.](image-url)
ratio between the upper and the lower ureter was 1:1, (2) the conduction of the action potential of the upper ureter was blocked at the portion of the stone, (3) no action potential was present in the lower ureter, (4) the antiperistaltic discharge spread through the location of the stone from the distal to the proximal ureter, and (5) no discharge occurred in the proximal and the distal ureter.

Postoperative changes after the ureteral lithotomy (Numasato 1975). Postoperative changes in the ureteral myogram of the cases with fistula formation were marked differences between the discharge frequencies of the upper and the lower ureters 6 to 12 days after lithotomy, when the fistulization had been completed.
Fig. 10. Ureteral myogram after ureterolithotomy. A, immediately after surgery; B, 1 day after surgery; C, 10 days after surgery; D, 17 days after surgery.

Fig. 11. Postoperative change of the peristaltic frequency in the upper and the lower ureter of the operated site.

But, after the fistulization had been restored on the 15th day of the operation, frequency rates became similar, as shown in Figs. 10 and 11. The passing rate of peristalsis also decreased, and high incidence of antiperistalsis in the lower ureter was seen until the 14th day following surgery. But, these changes were hardly seen beyond the 15th day with the restoration of the fistula, as shown
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Fig. 12. Postoperative change of the peristaltic passing rate through the surgical site and the rate of antiperistalsis in the lower segment of the ureter.

in Fig. 12. Thus, there appears to exist a relationship between the formation of urinary fistula and the passing rate of peristalsis at the surgical site or the occurrence of antiperistalsis in the lower ureter. Therefore, several comparisons could be made between the groups with or without fistula formation: (1) preoperative state and the stage when fistula formation was completed, in the fistula group, or stage of 1 to 7 days after the surgery in the non-fistula group; (2) the stage when fistula was restored or the stage of 8 to 15 days after the surgery. The appearance rate of antiperistalsis in cases with fistula formation was 0% in the upper ureter and 27.3% in the lower ureter, while it was 15.4% in the upper ureter and 0% in the lower ureter in cases without fistula formation. The passing rate was 25.5% in the former, and 17.5% in the latter.

The frequency of antiperistalsis at the time of fistula formation was 4.8% in the upper ureter, and 33.3% in the lower ureter. In cases without fistula formation, it was 0% in the upper and 21.4% in the lower. The passing rate was 41% in cases with fistula and 63% in cases without fistula. The frequency of antiperistalsis at the time of fistula restoration was 0% in the upper ureter and 37.5% in the lower ureter, and in cases without fistulization, it was 0% in the upper and 12.5% in the lower. Furthermore, the passing rate was 60% in cases with fistula restoration and 73% in cases without fistulization.

These results show a direct relationship between the postoperative fistula formation and the passing rate of peristalsis at the surgical site, the frequency of antiperistalsis in the lower ureter.

These cases were also grouped, according to the presence or absence of hydronephrosis in the postoperative IVP. As shown in Fig. 13, the passing rate at the surgical site of the ureter was 15 to 100% in 15 cases of hydronephrosis, averaging 58%, and it was 20 to 100%, averaging 67% in cases of non-hydronephrosis. So, cases of the passing rate over 50% was observed in
hydronephrosis and that under 50% in non-hydronephrosis. The antiperistalsis was observed only in the lower ureter in both groups, and its frequency was 22% in the former and 20% in the latter. There was no significant difference in the occurrence of antiperistalsis between these two groups.

**DISCUSSION**

The ureter does not respond to neural blocking agents. In the extirpated ureter, stimulation at one point results in conduction of peristalsis and antiperistalsis with equal velocities. Thus, the conduction of the excitation has been regarded as myogenic but not neurogenic.

The localization of a pace-maker for ureteral peristalsis is thought to be in the calyceal pelvis. The pace-maker, which is widespread in the calyceal pelvis, creates automatically a constant rhythm of action potentials in the renal pelvis, a part of which is conducted by muscle fibers to the ureters and the bladder.

Tsuchida (1969) reported that the action potential evoked at the renal pelvis was conducted to the ureter without being blocked at the pelvicoureteral junction if no abnormal stimulus was given at the renal pelvis. However, he also reported that when the renal pelvis was excited or a rapid diuresis occurred, blocking effect at the pelvicoureteral junction occurred. Others have reported similar findings.

In our in vivo experiments on the canine ureter during a rapid diuresis, the action potentials and the intraureteral pressures were simultaneously recorded. Since a physiological state of the system was maintained throughout the study, the results obtained should be reliable. We found that the peristaltic ratio of the renal pelvis to the ureter under ordinary condition was 3:1, indicating rather low...
rate in the ureter. During a rapid diuresis, however, the resting intrapelvic pressure was elevated, with a concomitant activation of the ureteral peristalsis, and the peristaltic ratio became 1:1. This increased ureteral peristalsis appears to be a physiological phenomenon which prevents the renal pelvis from rapid elevation of its intraluminal pressure due to the increase of urinary output. To paraphrase this, the peristalsis of renal pelvis has a constant rhythm without any relation to the amount of urinary output. The amount of urine which passes through the pelvioureteral junction has rather a closer relation to the increase of intrapelvic pressure than to the passing rate of the action potential from the renal pelvis to the ureter. Furthermore, the ureter increases its peristalsis as the amount of urine passing the pelvioureteral junction increases, and thus makes the transportation of urine more effective. When the amount of urine passing through the pelvioureteral junction increases suddenly, peristalsis of the ureter responds most rapidly until the peristaltic frequency of the ureter becomes equal to that of the renal pelvis, and thus it may prevent an increase of intrapelvic pressure due to diuresis.

The transport of intraureteric urine continues by the myogenic conduction of peristaltic excitation to the urinary bladder. When the conduction of the ureteric excitation is blocked, urine transport should be impaired. In our experiments described above, normal peristalsis was observed in the ureters which were recommunicated across a vinyl ureteral catheter after complete transection. When recommunication was made in the reversed direction, the direction of peristalsis had also to be reversed, and the urine had to be transported by the antiperistalsis. From the above results, we assumed that in the ureter in which the myogenic conduction was blocked, a new excitation was evoked by the passage of the urine through that portion, and the urine was transported dependently on the direction of the ureteral peristalsis.

Up to the present, it was difficult to observe the ureteral myogram continuously in vivo for several weeks, but we have succeeded in making this possible with the use of a newly-developed extraluminal ureteral bipolar needle "indwelling" electrode with recording wire (Kubo et al. 1970).

The myographic recording of the ureter after ureteral surgery in dogs as well as in human clinical cases revealed an increase of peristaltic frequency in the upper ureter as well as a decrease of it in the lower ureter with the occurrence of antiperistaltic discharge. These phenomena are thought to reveal that the conduction of the excitation is blocked at the surgical site of the ureter. From the results of experiments in which the myogenic conduction was blocked by the complete transection of the ureter, it was thought that if the conduction of the excitation is blocked, but passes through the portion, there is a new generation of excitation of the ureter.

Furthermore, the main origin of such an abnormal peristaltic discharge would be the passage obstruction of urine due to inflammation or edema of the surgical site of the ureter, resulting in some stenosis of that portion. This assumption
appears to be correct, since the rate of abnormal discharge in the lower ureter decreases with the lapse of time after the surgery, and the peristaltic frequency of the lower ureter becomes close to that of the upper ureter. If the restoring process of operated wound of the ureter is poor, it causes some suture insufficiency and a urinary fistula develops. This assumption is based on the fact that the occurrence of abnormal discharge in the lower ureter is rather frequent in cases of fistula formation, and it is improved after the repairing of the fistula. Furthermore, these results may show that pseudo-anuria develops after surgery of the ureter when unilateral nephrectomy in the opposite side is done.

There appears to be some organic change in the operated ureter. The occurrence of postoperative hydronephrosis would depend upon the degree of such organic change of the ureter. From the passing rate of action potentials at the surgical site, it was found that in the canine no hydronephrosis developed in the cases with the passing rate over 50%. In the clinical cases, however, one month after the ureteral surgery, better passing rate was observed in the case without hydronephrosis, but no clear border line could be drawn at 50%. In the case of hydronephrosis, some cases showed the passing rate over 50%. But, in most of such cases the hydronephrosis was improved. The restoration of the renal calyces and the renal pelvis in such cases was rather slow as compared with the recovery of renal function. These results suggest that the increment of intrapelvic pressure should be avoided if the passing rate is over 50%.

References


