

THE CONTRACTION OF THE URETER

I. OBSERVATIONS IN NORMAL HUMAN AND DOG URETERS*

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ABSTRACT

The nature and cause of ureteral contraction has been studied by many authors, using various methods¹⁾²⁾. An electromanometer with a sensitive strain gauge has been extensively used for the past about fifteen years to permit a more precise interpretation of ureteral contraction³⁾⁴⁾⁵⁾. This paper describes the peristaltic activity and dynamic gradients of both human and dog ureters *in vivo*. Previous works are discussed on the excised ureter *in vitro*⁶⁾⁷⁾⁸⁾.

MATERIALS AND METHODS

The physiological studies on the peristalsis of thirty-five ureters from twenty-one patients with apparently normal upper urinary tracts (15 males and 6 females, ranging in age from 20 to 60) were performed at the level from 5 up to 25 cm above the ureteral orifice without water deprivation.

Pressure recordings were made using a No. 5 or No. 4 French catheter connected to a strain gauge transducer. A Nihon Kohden twin multipurpose recorder, RM-20, connected to the transducer, was calibrated before each experiment with 40 and 20 mmHg. Zero level was assumed to be at the symphysis pubis. The ureteral catheter, which was kept completely filled with sterile water to avoid disruption of the existing relationship, was passed into the ureter cystoscopically under urethral anesthesia.

Peristaltic pressure tracings of twenty-seven ureters from nineteen mongrel dogs (3 males and 16 females weighing 9 to 30 kg) were observed, without food restriction, using a No. 4 French polyethylene catheter. The dogs were secured to a conventional dog surgical table in the supine position under intravenous RAVONAL (sodium 5-ethyl-5-(1-methylbutyl)-2-thiobarbiturate) anesthesia (25-30 mg/kg), with physiologic saline slowly fed intravenously.

Catheters were inserted into ureters of four female dogs using a cystoscope. Both ureteral orifices of eleven dogs were exposed through a suprapubic incision,

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and four female dogs underwent bladder exteriorization⁹). Peristaltic pressure tracings were obtained at the lower, middle, and upper third of the ureter, *i.e.*, 4 to 5, 8 to 10, and 12 to 15 cm respectively, depending on the body weight¹⁰).

The relationship between ureteral contraction and rate of urine flow was established graphically by plotting the figures obtained at the middle third versus the flow rate. Intravenous infusion of MANITON S (20 w/v% of N.F.XI. *d*-Mannitol) was given to four dogs to attain the polyuric state, where the flow rate reached 4 cc per minute.

The velocity of peristaltic contraction was measured five times in two dogs using a No. 6 French double catheter⁴). The catheter consist of two tubes, leading to orifices opened at 5 and 10 cm below the tip of the catheter respectively.

RESULTS

A. Amplitude of the ureteral contraction wave

Figure 1 illustrates the relationship of the amplitude to the level of the ureter. The highest value was attained at 5 cm above the orifice in men and at the middle third in dogs, *i.e.*, 19.8 ± 13.49 mmHg and 35.2 ± 16.69 mmHg respectively. At times extremely high systolic pressures were obtained, *e.g.*, 60 mmHg in men and 80 mmHg in dogs.

B. Frequency of the peristaltic wave

The frequency, which varied in the rate from 0.5 to 10 times per minute, reached its peak, 4.7 ± 2.00 times/min, at the level of 10 cm above the orifice in man. In cases of the dog, the peak, 8.0 ± 3.79 times/min, was noticed in

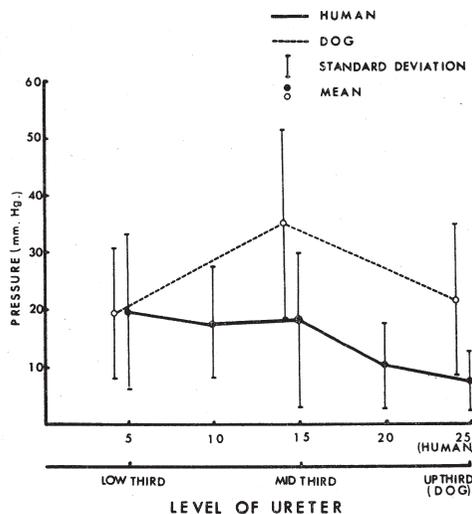


FIG. 1. Relationship of amplitude of contraction to level of ureter.

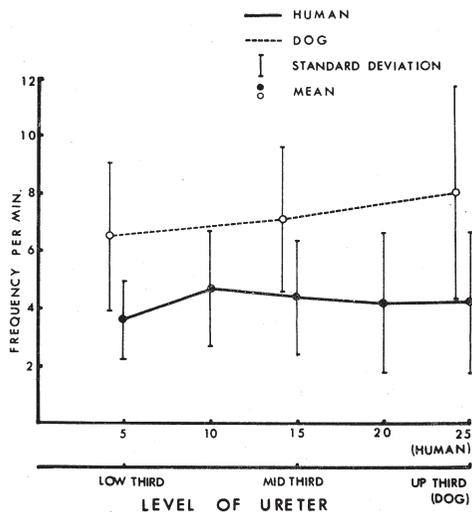


FIG. 2. Relationship of frequency of contraction to level of ureter.

the upper third (Fig. 2).

C. Resting pressure of the ureteral contraction wave

Elevated pressure were obtained at the lower parts of both human and dog ureters. The former showed 9.8 ± 3.85 mmHg and the latter 5.1 ± 3.96 mmHg (Fig. 3).

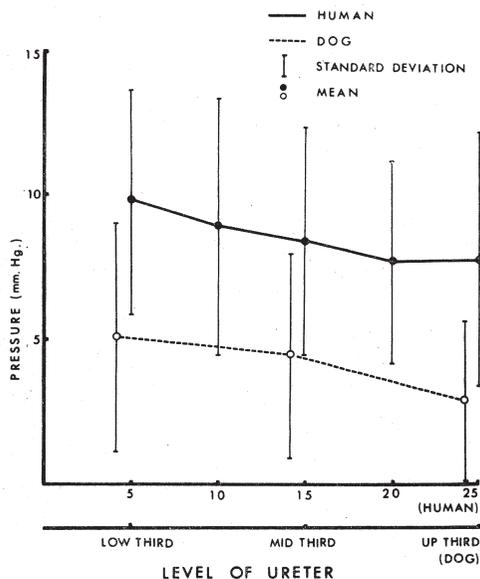


FIG. 3. Relationship of resting pressure to level of ureter.

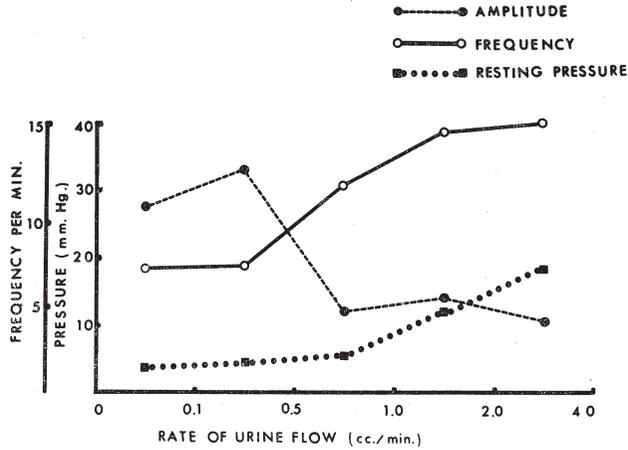


FIG. 4. Response of ureteral contraction to changing rate of urine flow at middle third of dog ureter.

D. Ureteral contraction and rate of urine flow

The interrelationship of the urine flow and ureteral contraction is illustrated in Fig. 4. When the rate of urine flow exceeds 0.5 cc per ureter per minute, the frequency of contraction tends to increase from 7.4 to 15.5 times per minute before rhythmicity is lost, making it difficult to differentiate the small waves from each other. The resting pressure also rose from 3.7 mmHg to 18 mmHg with an increase of urine flow. On the other hand, the amplitude of peristalsis decreased from 32.9 mmHg to 11 mmHg when over 0.5 cc of urine flow took place.

E. Velocity of the ureteral contraction wave

Ureteral contraction, at the portion from 10 to 5 cm above the bladder,

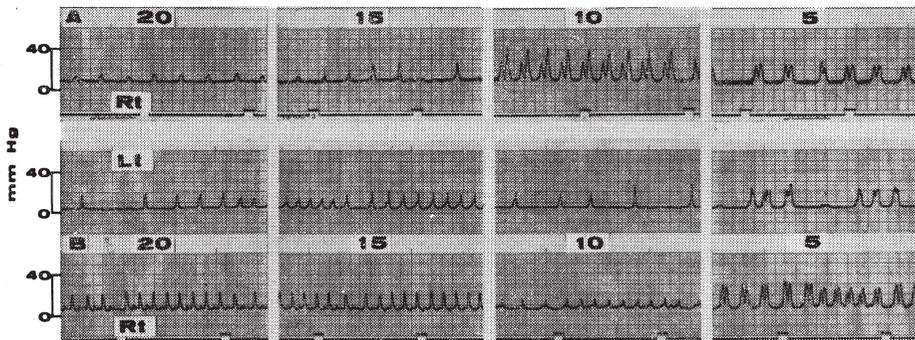


FIG. 5. Biphasic contractions were demonstrated in A 10 and 5 cm of the right ureter of I. T., aged 40 years, and B 5 cm above the right ureteral orifice of F. K., aged 23 years. Time signal on the lower edge of the figure in minutes.

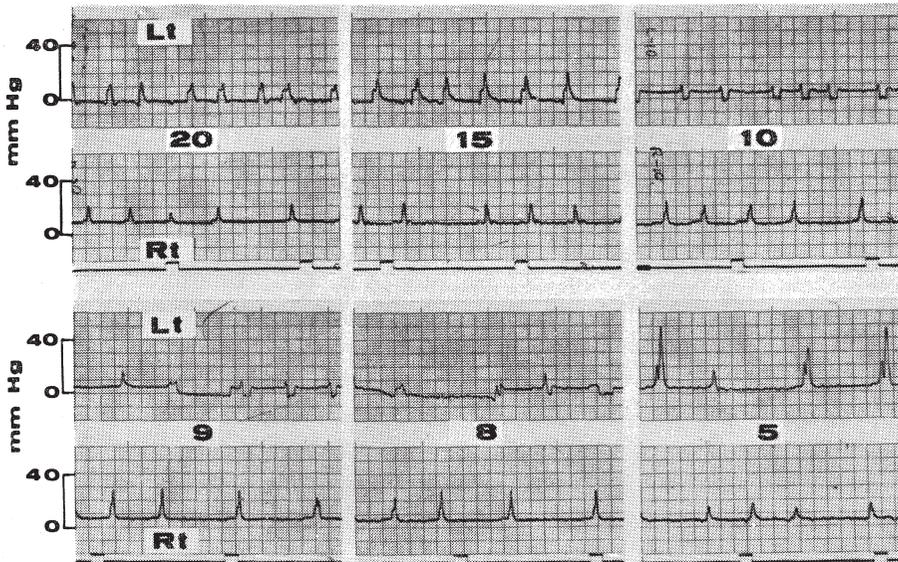


FIG. 6. M. M., aged 42 years. Appearance of negative systolic pressure immediately after the slight positive contraction, which occurred at 10, 9, and 8 cm above the left ureteral orifice in intact man. The contraction of right ureter was normal. Time intervals in minutes.

was transmitted at speeds of 2.5 to 5.5 cm per second, (average 3.8 cm per sec), with urine flow rates below 0.2 cc per ureter per minute.

F. Rhythmicity

Biphasic waves were obtained especially in the lower segment of human ureters. Only two of the thirty-five ureters (6%) recorded them at the 10 cm level, whereas five ureters (14%) showed them at the 5 cm level (Fig. 5). The negative pressure immediately following the positive peristaltic contraction was recorded in two of three ureters placed in two men (Fig. 6). One of them belongs to another group of observations (spinal cord injury).

DISCUSSION

The results obtained here share general similarities with those reported previously for man⁴⁾¹¹⁾¹²⁾ and for dog¹³⁾¹⁴⁾¹⁵⁾. The standardization of ureteral peristalsis and ureteral tonus has been made by Weinberg and Maletta⁵⁾ for man and Ensor *et al.*¹⁶⁾ for dog.

The amplitude of contraction in man had a tendency to rise with descent of the recording level in the ureter. This agrees with the reports of Kiil⁴⁾, Rattner *et al.*¹¹⁾ and Weinberg and Maletta⁵⁾ but is different from that of Ross *et al.*¹⁷⁾ who reported the greatest value at the upper third. Trattner¹⁸⁾

obtained the greatest amplitude just above the intramural position. *In vitro* findings could not be applicable to the human ureter because of the nonphysiological experimental condition¹⁹⁾.

In dogs the peristaltic pressure had its peak at the middle third which exactly confirmed the finding of Ensor *et al.*¹⁶⁾. The same conclusion was obtained in excised ureters of dogs²⁰⁾ and pigs⁶⁾; but in contrast, Wu⁸⁾ observed the peak at the pelvic third. In the present study, the highest pressure of dog was approximately one and a half times that of man.

The rate of contraction in intact man was 0.5 to 10 times per minute, but large rate disparities were not observed throughout the ureter. Previous values⁴⁾⁵⁾¹⁷⁾ were substantiated by these observations.

In animals the rate of peristalsis was identical with rates obtained by previous workers¹⁴⁾¹⁶⁾²¹⁾. Peristalsis had a slight tendency to decrease in rate as the contraction wave approached the bladder, which confirmed the study of Satani⁶⁾ and Gruver⁷⁾ who worked with excised pig ureters. The present study showed that the frequency of dog was approximately twice that of man.

The resting pressure gradient in man rose as one descends the ureteral catheter. This finding agrees with that of Weinberg and Maletta⁵⁾, but differs from that of Rattner *et al.*¹¹⁾ who found the reverse gradient. The resting pressure is "similar in magnitude to intra-abdominal pressure"¹⁷⁾. The highest pressure was obtained in the lower third of both man's and dog's ureters. The resting pressure of the dog was reported to be 2 to 5 mmHg¹⁴⁾ and 2 to 5 cm water²¹⁾, but Boyarsky and Martinez¹⁵⁾ observed 0 mmHg at the oliguric stage in a dog ureter. In this study the level of resting pressure of man was approximately twice that of dog.

No uniform ureteral response to increase in urine flow was admitted in man⁴⁾¹¹⁾, but in results obtained here for experimental dogs, the change in peristalsis was quite similar to that observed by Boyarsky and Martinez¹⁵⁾ and in part by other workers¹³⁾²²⁾. Lapidés¹⁹⁾ has emphasized that studies of ureteral functions must be accompanied by observation of the volume of urine excreted because "peristaltic activity of the ureter could be altered by changes in urine volume output, within certain limits". Boyarsky and Martinez¹⁵⁾ noted diminished peristaltic amplitude, elevated baseline pressure and "small regular fluctuations of 120 to 180 per minute frequency" in the diuretic phase, with a urine flow rate of 2 to 12 cc per minute per ureter. They considered that these diuretic patterns were similar to those of an obstructed ureter. Tracings obtained here suggest that the ureter becomes like a conduit of elevated intraluminal pressure. Many contraction waves of low amplitude occur and continuous urine flow takes place, with weak expellant contraction. Morales *et al.*²²⁾ considered that the ureter behaved "as simple dilated tubes" and poured out a continuous urine stream with vigorous contraction and diminished frequency.

The velocity of antegrade peristalsis in excised pig ureters was found to be 10.6 mm per second and retrograde peristalsis 11.2 mm per second²³⁾. Bors and Blinn³⁾ obtained 2 to 3 cm per second in cord injured patients, using their new kymographic technique, and Kiil⁴⁾ found 1 to 6 cm per second in man. These values are confirmed by the present work.

A biphasic contraction wave was obtained in the lower portion of the ureter. This has already been reported by some investigators⁵⁾¹²⁾¹⁷⁾. The highest resting pressure is encountered in the lower segment of the ureter, and the pressure at the lower portion is higher than the intravesical pressure when the bladder is distended by water²⁴⁾. The first wave is the pressure wave transmitted from above, and the second one is due to the true ureteral contraction¹⁷⁾. The present tracing in this study was performed with about 100 cc of water in the bladder to avoid irritating the bladder mucosa. The author is of the opinion that, when the ureteral contraction approaches the bladder it delays proceeding downwards and divides into two parts, because the intraluminal pressure gradually rises, the intramural ureter becomes more oblique and longer and the muscle bundles of Waldeyer's sheath contract as the bladder is filled with water²⁵⁾. Another multiphasic wave hardly occurred, and it is thought that this is an artifact caused by the probable existence of an air bubble somewhere in the watertight system, or a foreign body in the ureteral catheter.

Trattner¹⁸⁾ observed a negative pressure, without urine output, between peristaltic contractions. In this work the negative systolic contraction took place, following a slight positive contraction, at 10, 9 and 8 cm above the orifice in a normal man, and 25, 20 and 15 cm above the orifice in a cord injured patient, despite normal peristalsis in the other level of the ureter. The exact cause could not be determined, but dysfunction of the ureteral wall or disturbance of the urine flow, at that level, by unknown causes are strongly suspected.

SUMMARY

Ureteral peristaltic contractions were studied in twenty one normal human subjects and nineteen normal dogs. Amplitude of contraction, frequency of peristalsis, and resting pressure of contraction were recorded at various levels of both human and dog ureters. The response of ureteral contraction to the changing rate of urine flow was studied in dogs. The velocity of peristaltic contraction was determined using a double catheter. Biphasic contraction waves were mostly observed in the lower third of man's ureter. The negative pressure immediately after the positive systolic contraction was recorded in human subjects. The findings allowed the dynamic gradient of ureteral physiology to be discussed.

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