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THE CONTRACTION OF THE URETER

II. OBSERVATIONS OF THE URETER OF CORD INJURED PATIENTS AND CORD TRANSECTED DOGS

ATSUO KONDO

Department of Urology, School of Medicine, Nagoya University
(Director: Prof. Keizo Shimizu)

Monumental investigations of the etiology and treatment of the neurogenic bladder were made in 1917[1)2)]. Since then, knowledge and understanding of cord injured patients has been extensively developed, because of World Wars I and II. A considerable number of publications on the renal and vesical functions of cord injured patients are found[3)4)5)], but little work has been done upon ureteral movement in these patients[6)7)]. This investigation aims to describe ureteral activity in paraplegics. The effect of direct transection of dog's spinal cords upon ureteral contraction was studied. This was intended to produce a condition analogous to that in a paraplegic's ureter.

MATERIALS AND METHODS

Thirty-three ureters from eighteen male patients (ages twenty-three to sixty-five years) who had sustained traumatic cord injury at various levels were studied. The peristaltic pressure tracing was obtained using an electro-manometer with a strain gauge. The patients had a relatively high urine flow, as water was not restricted, and most were under the continuous medical care because of intermittent high fever and/or diminished renal function. The durations of paraplegia were from two months to fourteen years and one month, and averaged 3 years and one month.

The following classification was made to evaluate the relationship between ureteral contraction and impairment of the kidney and ureter. The pyelograms were classified by the routine excretory urograms:

Grade 1: normal and slight dilated pyelogram.
Grade 2: moderately dilated pyelogram.
Grade 3: markedly dilated and non-visible pyelogram.

The ureterograms were also classified by the average diameter of the systolic

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近 藤 厚 生

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and diastolic phases observed on the abdominal portion of the excretory urogram:

Grade 1: less than 5 mm in width.

Grade 2: less than 10 mm in width.

Grade 3: above 11 mm in width.

Most ureters classified as grade C produced tortous, kinked traces. The results of this classification, correlated with the site of the cord damage in the patients, are tabulated in Table 1 and 2. D_{12} at the vertebral level was classified as a lumbosacral cord lesion because of the existence of the reflex center of the micturition.

Seventeen mongrel dogs, thirteen females and four males, with average weight of 14.4 kg, underwent transection of the spinal cord, which was oriented by correlation of spinal cord segment and vertebral level[8] without tracheal inhalations. In eight dogs the bladder was exposed through suprapubic incision and in nine dogs the bladder exteriorization was performed[9]. Shortly or a few days after this procedure, a dog was secured to a conventional dog surgical table in the prone position. A No. 4 French polyethylene catheter was inserted up to the middle third of the ureter, 8 to 10 cm, and was loosely tied to the adjacent skin to prevent it from slipping out. A 10 cm median incision was made on the back. After the resection of spinous process, the dura mater was opened through a 2 cm longitudinal incision, and the spinal cord was transected. Intravenous anesthesia, infusion and techniques of the pressure recording have been described in a previous report[10].

TABLE 1. Level of Cord Lesion

Level of Cord Lesion	Cases	Average Duration (Months)	Complete Lesion	Incomplete Lesion
Cervical	6	50	2	4
Dorsal	2	12	2	0
Lumbosacral	10	33	6	4
Total	18	37 (Av.)	10	8

TABLE 2. Urinary Tract Involvement

Level of Cord Lesion	Pyelogram			Ureterogram		
	Grade 1	Grade 2	Grade 3	Grade A	Grade B	Grade C
Cervical	3	4	4	2	6	3
Dorsal	3	1	0	2	2	0
Lumbosacral	12	1	4	8	6	3
Total	18	6	8	12	14	6

RESULTS

A. Peristaltic pressure tracings in paraplegics

Amplitude of the ureteral contraction in paraplegics. The peristaltic pressure fell as the grade of hydronephrosis and hydroureter developed (Fig. 1). These observations have been illustrated in comparison with the standard values[10] obtained from twenty-one intact human subjects.

Frequency of the ureteral contraction in paraplegics. A decrease in number was noticed with impairment by use of pyelograms and ureterograms

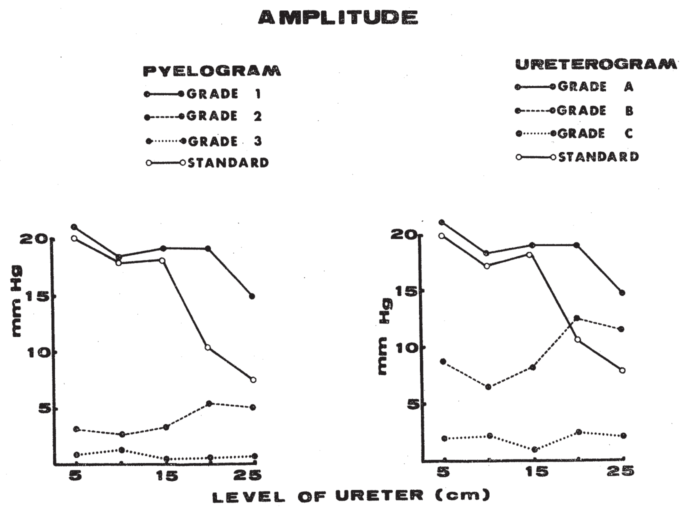

FIG. 1. Relationship of amplitude of ureteral contraction to renal and ureteral involvement in paraplegics. Standard value was obtained from 21 intact human subjects.

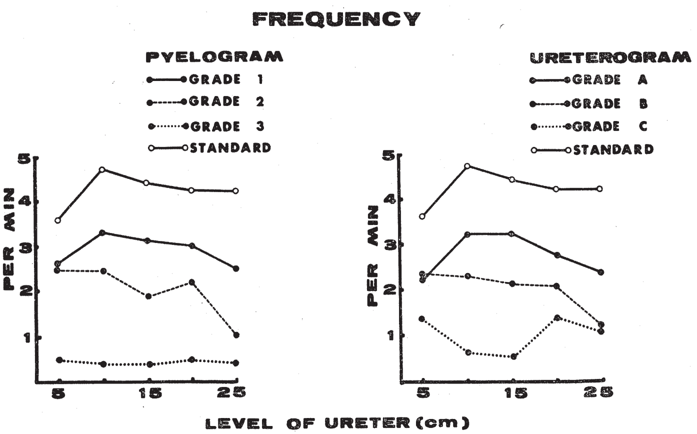

FIG. 2. Relationship of frequency of ureteral contraction to renal and ureteral involvement in paraplegics.

(Fig. 2). In cases of grade 3 and grade C, the frequency resulted in a marked reduction in number.

Resting pressure of the ureteral contraction in paraplegics. The resting pressure rose with advance of the grade; however, it remained at, or a little above, the standard value (Fig. 3).

Two cases of pressure tracings and their excretory urograms are demonstrated in Figs. 4 and 5. One, S. T., a 47 year old male, had sustained the

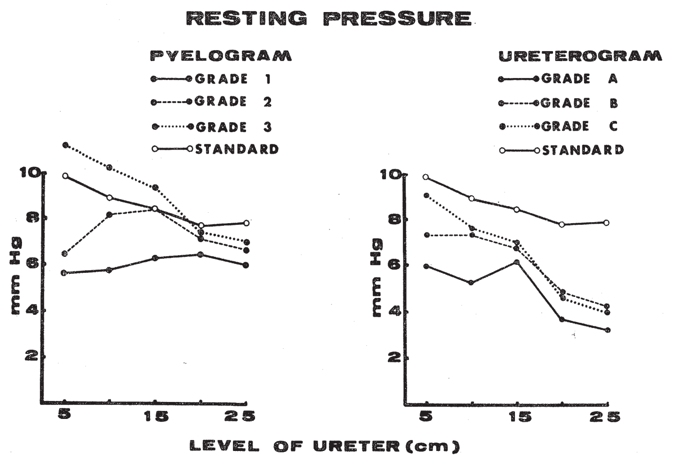

FIG. 3. Relationship of resting pressure of ureteral contraction to renal and ureteral involvement in paraplegics.

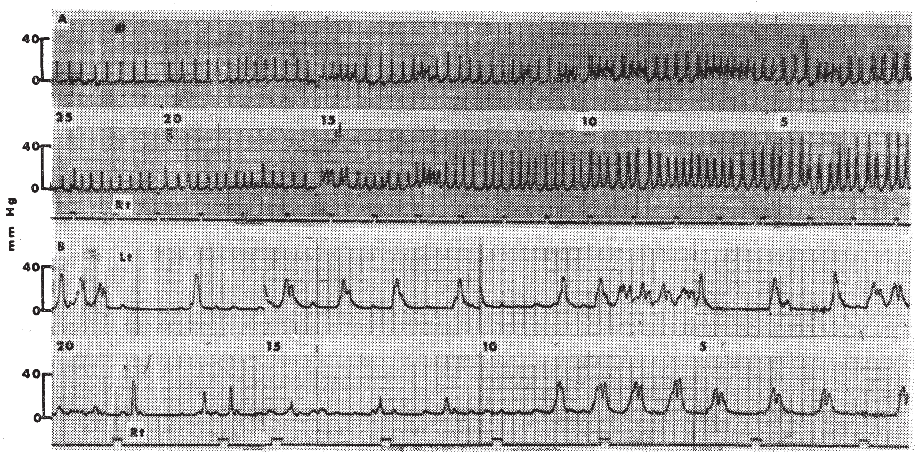

FIG. 4. A. S. N., aged 47 years, complete lesion at L_3, 10 months after injury. Normal contractility was observed in both ureters. B. H. S., aged 42 years, complete lesion at L_1, 4 years and 6 months after injury. Frequency decreased in number, peristaltic waves were irregular in shape and intervals were also irregular. Time signals on the lower edge of figures in minutes.

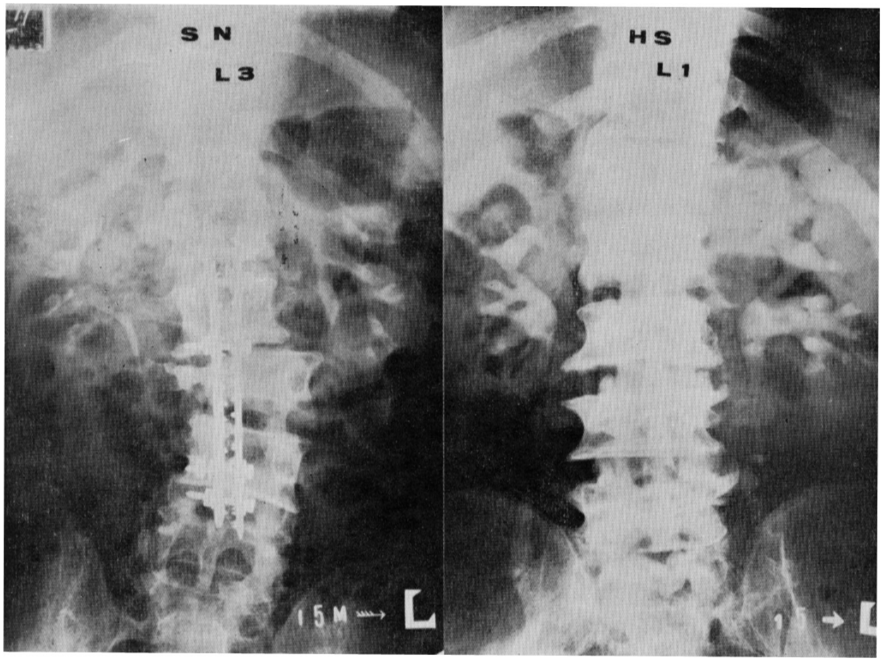

FIG. 5. Excretory urograms of the same cases as those of Fig. 4. Left, S. N., pyelogram and ureterogram were classified as grade 1 and grade A. Right, H. S., grade 2 and grade B.

complete lesion at L_3 of the vertebral column for 10 months. The other, H. S., a 42 year old male, had sustained the complete lesion at L_1 for 4 years and 6 months. The former, classified as grade 1 and grade A (Fig. 5, left), showed almost normal contractility in number and pressure compared with that of intact human subjects (Fig. 4 A). The latter, grade 2 and grade B (Fig. 5, right), demonstrated a decrease in rate, deformed contraction waves and irregular intervals of peristalsis throughout both ureters (Fig. 4 B).

The involvement of renal and ureteral function was much more likely to develop in patients with cervical lesion, whose average duration was the longest of all, than in those with lesion in other levels (Table 2). The paraplegics of dorsal cord, however, were limited in number (Table 1).

B. Effects of cord transection on ureteral contractility in dogs

Four dogs were transected at the level of the cervical cord, one was at C_5 and three at C_7. All dogs transected at the cervical cord and at a high level of the dorsal cord expired in the acute phase, 30 to 90 minutes after the operation, and their pressure tracings showed gradual decrease in rate of contraction as the respiration and heart beat slowed down, but systolic pressure was well preserved for a reasonably long time. Fig. 6 represents

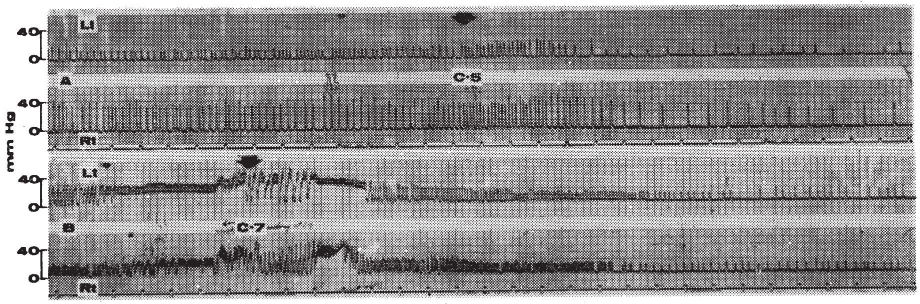

FIG. 6. A. No. 15, transected at C_5. Marked decrease of frequency was obtained without changes in amplitude of contraction in the acute phase. B. No. 28, transected at C_7. Increased frequency and elevated resting pressure occurred during cord transection, which represent movements of respiration and elevated intraabdominal pressure. Time signals on the lower edge of figures in minutes.

the ureteral peristaltic movement before, during, and after the cord transection. Dog No. 15 weighing 12 kg, sustained cord transection at C_5 of vertebral segment which resulted in a marked decrease in peristalsis from 5 per minute to 1 per minute. Peristaltic pressure and resting pressure did not show changes in magnitude. The large black arrow indicates the cord transection and the small arrow the beginning of contact with the spinous process (Fig. 6 A). One of the C_7 dogs, No. 28 weighing 16 kg, showed fast peristaltic waves with elevated resting pressure during the cord transection; however, this pattern was not the true ureteral contraction wave, but the movement of respiration with increased rate and high intraabdominal pressure. A few minutes later the animal turned flaccid again and the true ureteral contraction reappeared, which resulted in a similar way, in a decrease in peristaltic frequency without change of tonus (Fig. 6 B).

The dorsal cord was transected in five dogs at D_1, D_3, D_6, D_9 and D_{10} of vertebral segment respectively. Their ureteral activity kept the constant rate of peristalsis and tonus after cord transection, except for one dog D_1, No. 27, whose contractility weakened in postoperative phase. In two dogs a slight increase and decrease in peristalsis were noted respectively in the acute phase. These did not appear to be significant. Three dogs, D_3, D_6 and D_9, underwent second tracings 48 hours postoperatively. A marked reduction in rate from 4 to 10 per minute to 1 to 4 per minute and slight lowered amplitude with constant resting pressure were observed in the second tracing of dog D_3, No. 37. No significant changes were observed either in acute or 48 hours postoperative phases of the dog D_6, No. 35. A slight elevation in amplitude was obtained in the 48 hours postoperative tracing of dog D_9, No. 32. Dog D_{10}, No. 36 weighing 14 kg, resulted in the unchanged contractility in the left ureter with decreased amplitude in the right ureter (Fig. 7 A).

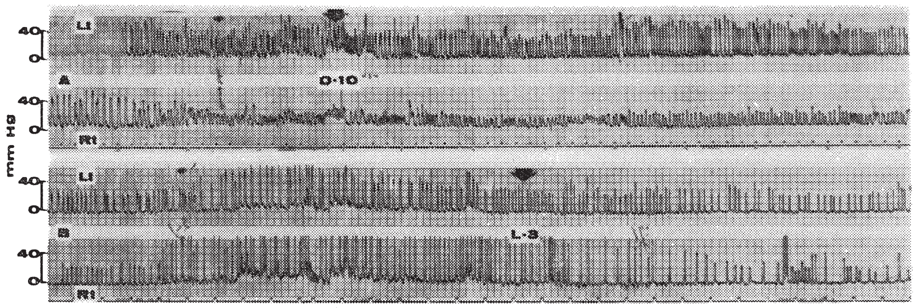

FIG. 7. A. No. 36, transected at D_{10}. The constant peristaltic movement was well preserved in the left ureter. Fall of amplitude of contraction and increase of frequency were observed in the right ureter. B. No. 39, transected at L_3. No essential changes in tonus or frequency were demonstrated.

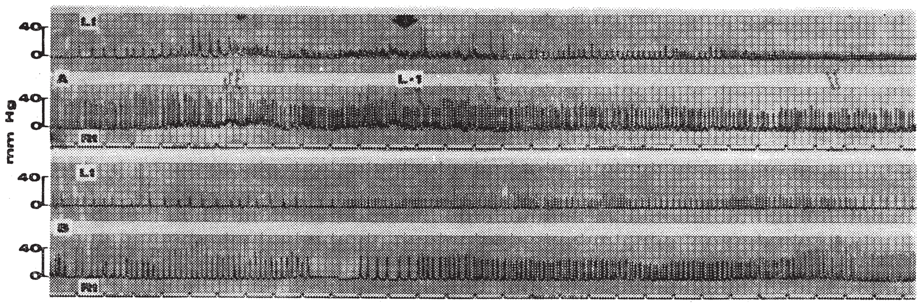

FIG. 8. A. No. 41, transected at L_1. B. 72 hours postoperative tracing. Notable response were not evoked in the peristaltic pressure tracings of A and B.

Lumbar cord was transected in four dogs, two at L_1, one at L_3, which is equivalent to L_3 and L_4 of cord level, and one at L_4 (cord level L_5–L_7) respectively. Notable changes were also not observed in this group. Dog L_1, No. 41 weighing 8.5 kg (Fig. 8 A), underwent the second recording 72 hours later (Fig. 8 B). This showed good preservation of contractility and regular rhythmicity. Another L_1 dog, No. 20 weighing 13.5 kg, was followed up to 122 days postoperatively. Normal tonus and frequency were maintained for 69 days (Fig. 9 A). Reduction in amplitude to one third the previous value occurred during 122 days postoperative tracing with regular peristalsis in the right ureter and with occasional elevated amplitude in the left ureter (Fig. 9 B). The excretory urogram revealed moderate hydroureteronephrosis in the right side and normal appearance in the left. The separate urine culture was positive (E. coli) on both sides. Dog L_3, No. 39 weighing 13.5 kg, is demonstrated in Fig. 7 B. This showed no essential difference in tonus or frequency in the acute phase.

Sacrococcygeal cord was transected in four dogs, two at L_5 (cord level

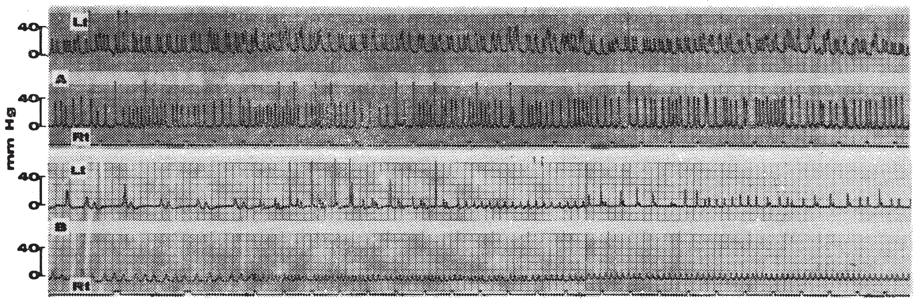

FIG. 9. A. No. 20, transected at L_1. 69 days postoperative tracing was demonstrated, which was almost the same as that of the acute phase. B. 122 days postoperative tracing. Reduction in amplitude occurred with regular peristalsis in the right ureter and with occasional elevated amplitude in the left ureter.

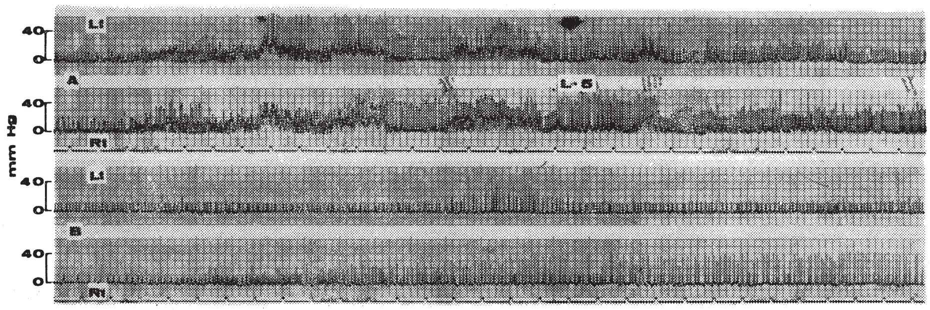

FIG. 10. A. No. 40, transected at L_5. B. 48 hours after transection. No change in tonus or frequency of the ureteral contraction was encountered in either A or B except during cord transection.

L_7–S_3) and two at L_6 (cord level Co_1–Co_5) respectively. No noteworthy changes were noticed in these dogs but one left ureter of dog L_5, No. 29, showed increase of frequency and elevation of resting pressure in the acute phase in spite of unchanged peristaltic waves of the right ureter. Dog L_5, No. 40 weighing 11.5 kg, kept normal contractility in both acute and 48 hours postoperative phases (Fig. 10 A, B). Another dog L_6, No. 3, demonstrated the constant pattern 22 days postoperatively.

DISCUSSION

Many investigators have studied ureteral movement in human subjects and experimental animals, both *in vivo* and *in vitro.* In 1869 Engelmann[11] reported that peristaltic movement occurred by the transmission of impulses from muscle cell to muscle cell because of the existence of ganglion only at both ends. Since then, it has been a permanent subject of debate whether the ureter is myogenic or neurogenic[12)~15)]. The ureter is innervated by autonomic nervous systems; the upper portion of the ureter by the sympathetic, via the splanchnic nerve, and the lower portion by the parasympathetic, via the hypogastric and pelvic nerves[16)~19)]. Intracellular bridge[20)] and unmyelinated nerve fibers[21)] were observed by means of an electron microscope.

Treatment of cord injured patients is still of importance to urologist in spite of the marked reduction of the mortality rate after World War II. Death in paraplegics occurs following the abolishment of renal function, which has an important bearing upon the function of the bladder[22)]. Some workers claim that impairment of renal function, detected by excretory urograms, often developed in patients with lower motor neuron lesions[23)24)], while Irvine[25)] reached the reverse conclusion which was confirmed by the present study of excretory urgorams. From tests of glomerular filtration rate and renal plasma flow, the level of the cord injury had nothing to do with the degree of renal dysfunction[26)]. Pathological changes of the ureter tends to develop with the advance of renal impairment (Table 2). It might be said that "as the kidney goes, so goes the function of the ureter"[22)].

Peristaltic amplitude and frequency decreased in magnitude and in number with development of renal and ureteral dysfunction in patients with cord lesion at various levels. On the other hand, resting pressure rose to the normal value with advance of the grade of the pyelogram and ureterogram; however, there was no significant variation amongst these figures. In other words, impairment of renal and ureteral function accompanied the lack of contraction force and decrease of peristalsis, while the intraluminal diastolic pressure remained almost constant. The abnormal action potential was observed in paraplegic's ureter with deterioration of renal function[6)]. Factors such as elevated resting pressure, urinary tract infection[27)], past history of urinary tract infection and experimental ureteritis[28)] will play an important role in abolishing ureteral contraction. Inflammations of the kidney, ureter and bladder were caused by transection of the pudendal and sacral nerves[29)]. Amongst the present paraplegics, persistent positive urinary cultures were obtained in 13 cases, intermittent positive cultures in 3 and negative cultures in 2. The resting pressure also had a slight tendency to rise as the grade advanced.

The first report of ureteral activity in paraplegics was made by Bors and Blinn[30)] in 1955. Ureteral kymographic examinations were performed using their special catheter for intraluminal pressure together with electromyography, but they did not mention any specific clinical findings for paraplegics.

Shalit and Morales[7)] investigated the ureteral activity in patients with upper and lower motor neuron lesions, although the degree of deterioration of renal and ureteral functions was not mentioned. They suggested the probable nerve influences on the ureteral fuction. These were based upon the decrease of the peristaltic amplitude and fall of the resting pressure in patients with upper motor neuron lesions by low spinal anesthesia and was based upon the rise of contraction and resting pressure in the lower ureter after injection of urecholine.

In contrast, the direct influence was not immediately encountered in the ureteral activity of the dog after complete transection of the spinal cord, except in dogs who sustained it at the cervical and upper dorsal cord. Autonomic nervous systems supplied to the ureter start below the 11th of the dorsal cord; therefore, it seems likely that the immediate decrease of peristalsis, without change in tonus, manifested in those dogs at the cervical and upper dorsal cord was caused, not by the direct nerve effect subsequent to cord transection but, by the acute general physiologic changes of the body, that is, by a shock condition. On the other hand, Gould *et al.*[31] suggested that the ureteral tonus could be influenced by both branches of the autonomic nervous systems and that ureteral peristalsis was not affected by nerve control. No significant chages in peristaltic contraction were obtained even after the trasections at lower dorsal, lumbar and sacrococcygeal cords, and, moreover the ureteral activity of dog L_1 was preserved reasonably well 69 days postoperatively. This peristaltic amplitude fell 122 days later with positive urine culture and moderate hydroureteronephrosis on the right side (Fig. 9 A, B).

It is clear from these observations that ureteral peristaltic movement is not directly affected by transection at any levels of the spinal cord. The main cause of destruction of ureteral activity is thought to be, not the impairment of the spinal cord but, secondary to such factors as urinary tract infection, calculus, reflux and hydronephrosis[22][32]. However, a discrepancy between the results obtained here and evidence of innervation of the autonomic nervous systems still exists. The author is of the opinion that the abolishment of the ureteral contraction does not occur following the cord damage or cord transection in both humans and dogs, because the ureter is the autonomous organ *per se* and that the autonomic nervous systems which innervate the ureter have their sources in many roots.

SUMMARY

The ureteral peristaltic movement was studied with reference to development of hydronephrosis and hydroureter in 18 patients with spinal cord damage. A tracing of ureteral peristalsis, in 17 dogs, was made, before, during, and after the spinal cord transection at various levels.

In cord injured patients the peristaltic pressure fell in amplitude and the frequency of contraction decreased, with the development of hydronephrosis and hydroureter. The resting pressure rose with advancement of urinary tract involvement. Peristaltic pressure tracings from dogs transected at various levels did not show the remarkable change after the cord transection.

Thus, it is likely that the ureters in paraplegic patients and dogs are autonomous organs which are not directly affected by complete transection of the spinal cord. The impairment of renal and ureteral functions is more affected by various factors subsequent to the cord damage than by the direct injury to the spinal cord.

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