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* Present address: University of Chicago, Chicago, Ill.

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Paraplegic Dogs: Urinary Bladder Evacuation with Direct Electric Stimulation

Abstract. *Stimulation of the detrusor muscle by means of two implanted wire electrodes increased intravesical pressure markedly in ten trials in normal dogs and in nine trials following transection of the dog's lumbar spinal cord. The urinary bladder could be completely emptied up to 2 or 3 weeks postoperatively. Later stimulation provoked an equally copious urinary flow but a residue persisted even when progressively higher voltage was applied.*

Although the mortality rate in paraplegic patients with spinal cord injuries has been greatly reduced since World War II, more than half of the deaths in this group still are attributable to complications involving the urinary tract (*1*). These complications include persistence of large amounts of residual urine in the bladder with subsequent infection, vesico-ureteral reflux, and incontinence.

We have found only two reports of attempts to evacuate the neurogenic or cord bladder by electric stimulation in the literature. In the first (*2*), two electrodes were sutured to the parasympathetic pelvic nerves. These nerves are known to predominate in supplying the bladder (*3, 4*). In the second (*5*), an electrode attached to a catheter was placed within the lumen of the bladder.

In our experiments on dogs, one stainless steel wire electrode was implanted in the anterior wall and one in the posterior wall of the detrusor muscle, midway between the trigone and the dome. The muscle was directly stimulated by applying a train of biphasic square waves generated by a Grass stimulator (model S4B). Basic experiments on normal dogs showed that 15 to 35 cy/sec stimuli of 3 to 8 msec duration provoked a good contraction of the entire detrusor, a finding which corresponded closely with that reported by Burghele, Ichim, and Demetresco (*2*). The best response in our experiments was achieved with a 20 cy/sec stimulus of 4 msec duration.

A catheter connected to a Statham strain-gauge (model P23D) was introduced into the bladder through a small cystotomy for measurement of intravesical pressure which was registered on a Sanborn recorder. The minimum voltage required to obtain maximum pressure was determined individually on all dogs before and after spinal cord transection. The limits in the former group were 3.2 and 8 volts and in the latter 1.4 and 10 volts, with a range of 3 to 7 volts in most instances. Voltages above this level did not raise the pressure further. At least 1.5 to 2 volts was usually necessary to provoke a pressure increase to 20 or 25 cm of water, a level at which some urine was eliminated. When the voltage was increased, intravesical pressure in the 10 normal dogs rose to levels between 22 and 81 cm (average 50) and in the 9 paraplegic dogs to between 25 and 180 cm (average 60) 4 to 6 seconds after onset of the stimulus, and 50 to 80 ml of urine flowed in a good stream (Table 1). Maximum pressure determinations exceeded 40 cm in 7 of 10 group I dogs and in 7 of the 9 in group II.

Intravenous injection of neostigmine (1 mg) in addition to the electric stimulus provoked a consistent increase in pressure in all six dogs examined before transection and in two of seven dogs examined after transection.

Three types of contraction were noted with a 5-second stimulus. Maximum contraction was usually achieved within 5 seconds and was not augmented by a longer stimulus. Proof that the bladder can be completely emptied in both normal and acutely paraplegic dogs by this method supports the modern concept of micturition advanced by Lapides (*6*), Muellner (*7*), and Woodburne (*4*). These authors have disproved Elliott's old hypothesis of antagonism between the detrusor and the internal sphincter muscle (*8*) and have demonstrated that the so-called internal sphincter is merely an elongation of the detrusor's bundles and contracts simultaneously with them. According to Woodburne (*4*), micturition is initiated by relaxation of the striated external sphincter muscles, especially the levator ani, and is carried through by concomitant contraction of the detrusor, including the internal sphincter bundles.

Care of the nine paraplegic dogs was difficult. Two died early in the postoperative period. In the other seven, electric stimulation was applied one or several times and was always followed by the evacuation of 100 to 200 ml of urine. Four of the seven died within 20 days from complications related to paraplegia.

Two dogs are alive at 4 months and one at 2½ months postoperatively. These dogs were all examined cystographically with 20 ml Hypaque, administered intravenously. Each electric stimulation provoked a copious flow of urine but progressively higher voltage was required. After 2 or 3 months a stimulus of 20 to 30 volts was necessary to provoke micturition. Cystography in one animal revealed that 10- and 15-volt stimuli were sufficient to empty

Table 1. Resting to maximum intravesical pressures in dogs (in centimeters of water) before and immediately following spinal transection with stimulus alone or with stimulus plus 1.0 mg of neostigmine. A stimulus of 20 cy/sec of 4 msec duration was used.

Animal (No.)	Preoperative				Postoperative			
	Stimulus only		Stimulus plus neostigmine		Stimulus only		Stimulus plus neostigmine	
	Volts	Pressure	Volts	Pressure	Volts	Pressure	Volts	Pressure
198	7.2	5–22						
216	3.8	7–56						
222	8.0	5–41						
225	3.2	11–50						
124	5.4	5–28	5.4	15–41				
235	6.0	3–60	6.0	5–90	4.0	4–56	6.0	7–71
236	4.5	3–33	3.8	6–65	3.2	4–40	4.5	4–35
245	6.8	8–80	6.8	6–93	10.0	2–73	6.8	12–55
260	4.4	20–81	5.6	12–245	4.4	18–180		
270	6.0	7–50	6.0	3–56	6.0	4–29	6.0	4–58
333					3.0	3–45	3.0	4–48
341					6.0	18–44	6.0	14–46
342					5.2	25–44	4.0	16–40
352					1.4	10–25		
Average		7.5–50		7.5–98		10–60		
				7.0–69*		10–43*		8.5–53*

* Average not including dog No. 260.

the bladder on the 24th day, while on the 78th day there was residual urine after 15- and 19-volt stimuli. In the other two dogs examined cystographically, one on the 15th and one on the 35th day, small amounts of urine remained after stimulation with 24 and 12 volts, respectively. The dog whose cystogram showed residual urine 15 days after transection was reoperated on the 23rd day, at which time marked hypertrophy of the bladder wall was found. When the cystometry was repeated the pressure rose to 93 cm-H_2O with a 34-volt stimulus, and to 115 cm with a 29-volt stimulus plus 1.0 mg of neostigmine. This finding suggests that failure of the chronic cord bladder to empty is not due to insufficient intravesical pressure during stimulation, but rather to increased intraurethral resistance because of high spasticity of the striated external sphincter muscles. Spasticity, probably associated with a mass reflex phenomenon, occurs with upper motor neuron lesions in which bladder hypertrophy is characteristic. This phenomenon was noted in two dogs that underwent relaparotomy. Bors (*9*) reported highly elevated sphincterometric values (70 to 197 cm-H_2O) in patients with lesions of the upper motor neuron. Following pudendal neurectomy the values dropped to between 27 and 54 cm.

Long-term results will have to be improved before direct electric stimulation of the detrusor can be applied clinically; however, the method is considered promising (*10*).

ADRIAN KANTROWITZ
MARTIN SCHAMAUN
Surgical Research Laboratory, Maimonides Hospital, Brooklyn, New York

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Distress Call of the Bottlenose Dolphin: Stimuli and Evoked Behavioral Responses

Abstract. *Analysis of the many different vocal productions of pairs of bottlenose dolphins* (Tursiops truncatus *Montagu*) *and the related behavior patterns shows that one pair of specific short (0.2 to 0.6 second) whistles was consistently stimulated by physical distress. This call stimulated nearby animals to push the head of the distressed animal to the surface to breathe. After the animal breathed, a vocal exchange preceded other forms of aid.*

The bottlenose dolphin (*Turisops truncatus* Montagu) emits specific sounds under well-defined conditions (*1–3*). A special pair of whistles and the behavior associated with these whistles was first observed in 1955 and briefly described in 1958 (*3*). This account presents further evidence that this pair of whistles is a "distress call" (*2–4*). This call is one of many unique short whistle patterns (*1, 2, 4*) and is not to be confused with general "alarm whistling" (*5–7*); the latter is apparently the same as some of the more prolonged "vocal exchanges" between dolphins (*2, 5*) and similar to the secondary exchanges which occur as consequences of rescue actions.

Distress calls of animals other than the dolphin have been described in the literature (*8*). In the case of the dolphin, the responses of nearby animals of the same species may resemble, in general effects, those described in the literature for some terrestrial mammals but they differ from those described for some birds and some fish.

Behavior was visually and sonically recorded with motion pictures and tape recordings (*1, 2*). The underwater whistles were recorded by means of a hydrophone and the whistles in air by means of an air microphone (*1, 2*). The observations were made from 1955 into 1962 under a variety of environmental situations on 23 different animals captured from three regions of the shoal waters of Florida (the St. Augustine inlet to Jupiter inlet, the middle Florida Keys near Marathon, and at Naples on the west coast of Florida).

The call itself is similar to other whistles in the "vocal exchange" group of sounds (*2*). It is repeated many times until an appropriate response is elicited either from the other dolphins in the neighborhood or from a human. The call consists of a group of two whistles (Fig. 1). The first whistle starts at a relatively low fundamental frequency (3 to 5 kcy/sec) and rises to a relatively high fundamental frequency (8 to 20 kcy/sec). The second whistle of the pair starts at a relatively high fundamental frequency (8 to 20 kcy/sec) and falls to a relatively low fundamental frequency (3 to 5 kcy/sec). This pair is emitted repeatedly with a delay of only a few tenths of a second between pairs for several seconds or several hours and stops when appropriate relief is obtained.

The call is emitted underwater or in air depending on the circumstances. The intensity (measured at the dolphin's head) of the underwater call can be as low as the noise level of the electronic apparatus or up to 100 decibels higher. In the usual cases during underwater emissions the blowhole slit can either emit air or not emit air (*6*). Young, small (5 to 6 feet long) dolphins usually emit air; older ones may or may not.

In air the call was heard faintly, accompanied by bubbles, at the outer lips of the blowhole or heard loudly at the open blowhole from structures deeper in the airways. The sounds in air can be of such low intensity that they can be barely audible even near the head (closed or open blowhole) or they can be piercingly loud a few feet away from the head (open blowhole); the range from the lowest to the highest intensity is about 80 decibels. The animals vary individually in their abilities to whistle a distress call in air with high intensity. However, each animal was able to make quite loud whistles under water. While a dolphin was whistling under water we manually felt, over the skull, the vestibular sacs participating in the vocal process as these sacs filled and emptied during whistling.

There were individual differences in the voices of the animals (*2, 5*); trained human listeners could distinguish emissions from individual dolphins. Such differences did not affect the rescue responses of animals meeting for the first time. For example, the calls of an injured large female (8 feet 3 inches), newly captured from the Gulf of Mexico near Naples, Florida, elicited a rescue response at first meeting by a