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MICTURITION AIDED BY ELECTRIC STIMULATION: RELATIONSHIP OF EFFICIENCY TO THE SITE OF STIMULATION*

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Study of micturition by electric stimulation has made a remarkable advance during the past ten years and contributed much informations on this subject[1~3]. Some clinical successes were recently reported by several authors[4,5]. In Japan the research related to this field started in 1965[6] and no successful cases were found in patients yet[7,8].

The fundamental problem regarding this technique is how to achieve the so-called coordinated micturition i.e. a strong contraction of detrusor muscle without increased urethral resistance and undesirable side effects such as pain and spasm of skeletal muscles. This article briefly reports on the relationship found between the efficiency and the site of stimulation.

MATERIALS AND METHODS

A total of 11 mongrel dogs, 8 females and 3 males, weighing 11 to 15 kg, were used for the present acute experiment. The dog was fixed on the table in a supine position and pentobarbital was given intravenously. An episiotomy was made prior to the study in the female dog, and foreskin in the male was kept retracted by a thread and meatotomy at the external urethra was performed. These procedures aimed at easy observation of the urinary stream. Study regarding the stimulating site was carried out as follows.

(1) Pelvic nerve stimulation.

Through a median incision at the lower abdomen, a bundle of peripheral pelvic nerve was found close to uretero-vesical junction bilaterally. This was hookep up and fixed by a stainless steel wire. The wire, 30 strands, was insulated with polyvinyl to the point of fixation. Care was taken not to spread the electric current into adjacent tissue packing dry gauze around it.

(2) Stimulation at uretero-vesical junction (UVJ).

The bladder was exposed through a median incision. Since UVJ has the richest distribution of peripheral pelvic nerve, 3 disc-typed electrodes, 8 mm in diameter shielded with Silastic (Dow Corning Co., Michigan, U.S.A.) in one side, were fixed around a ureteral entrance in the manner of circle (Fig. 1A). The same was done in both sides.

(3) Detrusor muscle stimulation.

The bladder was reached via a median incision and freed from the adherent peritoneum. Detrusor muscle was approximately divided into 3 parts between the apex and the

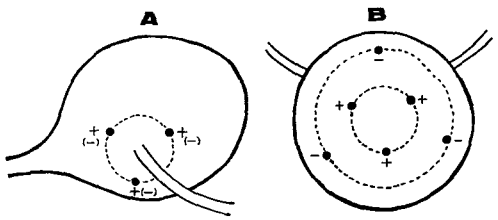

Fig. 1. A solid circle represents an electrode. Three electrodes in each group changes polarity alternately positive and negative. A, a lateral view. B, a vertical view; apex is in the center. (The dotted circle does not represent the electric connection, but only the manner of implantation.)

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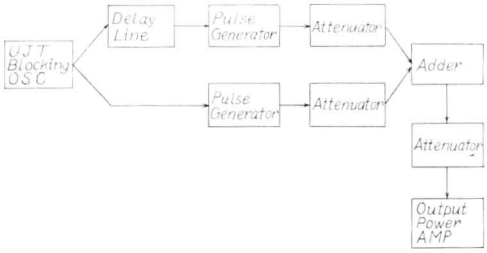

Fig. 2. Block diagram of stimulator.

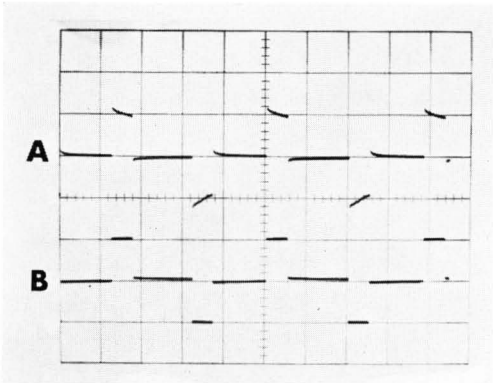

Fig. 3. Electric stimulation at 5 msec duration, 30 cps, 10 volts with biphasic square wave. A, a current flow during stimulation (100 mA/division). B, a pulse form during stimulation. Attenuation of voltage is not observed (10 volts/division). Tissue impedance is found approximately 100 ohms.

level of UVJ ; upper third, middle portion and lower third. Six electrodes, the same as used at UVJ, were implanted in 2 circles; 3 in each circle as reported by Susset and Boctor[4] (Fig. 1B). The electrodes were fixed above serosa with the fine silk after the bladder was inflated with 80 to 100 ml of warm saline.

The output stimulator was made by one of us (K.M.). This works at frequency of 7 to 50 cycles per second (cps), pulse duration of 1 to 15 milliseconds (msec), and generates 0 to 30 volts. The pulse shape can be selected either mono- and biphasic square wave, or rectangular wave. The block diagram is shown in Fig. 2. Since electric current is correlated with the tissue impedance, an oscilloscope (SS-5157 ; Iwasaki Tsushinki Co.) was always used in order to watch the voltage given, pulse shape and resultant electric current, which in turn gave the tissue impedance (Fig. 3). The attenuation of voltage was prevented with setting the impedance of stimulator as low as 10 ohms. Three electrodes or a wire in each group changes polarity alternately positive and negative.

A known volume of warm saline, usually 40 to 60 ml, was slowly introduced to the bladder and experiment started after the pressure stabilized. The interval of 5 min was allowed between each stimulation[9,10]. The pressure change was transmitted through a small plastic cutdown tube (I.D. = 0.6 mm, O.D. = 1.0 mm), placed either in a urethra (female) or in a ureter (male and female), into a pressure strain gauge transducer, then to a 2-channel heat-writing electronic recorder (RM-20, Nihon Kohden Co.).

RESULTS

Preliminary experiment revealed that the best response of bladder contraction was yielded with the frequency of 30 to 50 cps, pulse duration of 3 to 5 msec and biphasic wave.

Table 1 summarizes the results obtained. Pelvic nerve stimulation at as low as 2 volts resulted in an excellent micturition in a female dog. The same trial with 3 volts in a male was not quite satisfactory with 30 % of residual rate (residue/capacity) because of an extremely high intravesical pressure as well as the tonic spasm of the lower extremities. It is of interest to note that the micturition was interrupted coincidentally with the second peak of pressure curve (Fig. 4A). The bilateral severance of pelvic nerve at proximal site did not improve the residual rate in spite of the disappearance of tonic spasm. The second peak still climbed up as high as 51 mmHg (Fig. 4B).

Stimulation at UVJ was only effective in the female dog, though the tonic spasm of the lower extremities and pelvic floor encountered in both sexes. An extremely high pressure completely prevented a male dog from voiding (Fig. 4C).

The variable results were obtained with stimulation at detrusor, depending upon the level of electrodes implanted. In general stimulation at middle portion and the upper third yielded the better result than that at the lower third in respect of residual rate

Table 1. Results of micturition study in an acute experiment.

Stimulation Site		Dog & Sex	Parameters*	Pressure Change (mmHg)	Micturition	Residual Rate	Tonic Spasm	Remarks
Pelvic Nerve		# 7, M	3 v 3 v	6→48→83 10→38→52	good good	30% 30%	(+) (−)	Double-peaked curve.
		# 6, F	2 v	16→30	excellent	0%	(−)	Proximal end is severed. Double-peaked curve.
UVJ		# 8, M	5 v 7.5 v	10→57 9→88	none none	100% 100%	(+) (+++)	
		# 4, F	3 v**	4→22→24	excellent	0%	(+)	Double-peaked curve.
Detrusor Muscle	Lower third	# 9, M	2.5 v	8→43→83	good	10%	(+)	Double-peaked curve.
		#11, F	3 v	1→35	excellent	0%	(±)	
	Middle portion	# 3, F	5 v** 10 v** 15 v**	2→35 2→32 2→35	poor good excellent	60% 50% 0%	(−) (−) (−)	
	Upper third	#10, F	2.5 v 7.5 v 15 v	7→20 8→50 15→74	none good excellent	100% 30% 0%	(−) (+) (+++)	
		# 9, M§	2.5 v 7.5 v 15 v	4→ 8 6→46 6→48	none good excellent	100% 40% 0%	(−) (−) (+)	

* Frequency of 30 cps and pulse duration of 5 msec, otherwise specified.
** Frequency of 50 cps and pulse duration of 3 msec.
§ The same dog as used 5 weeks before at the lower third.

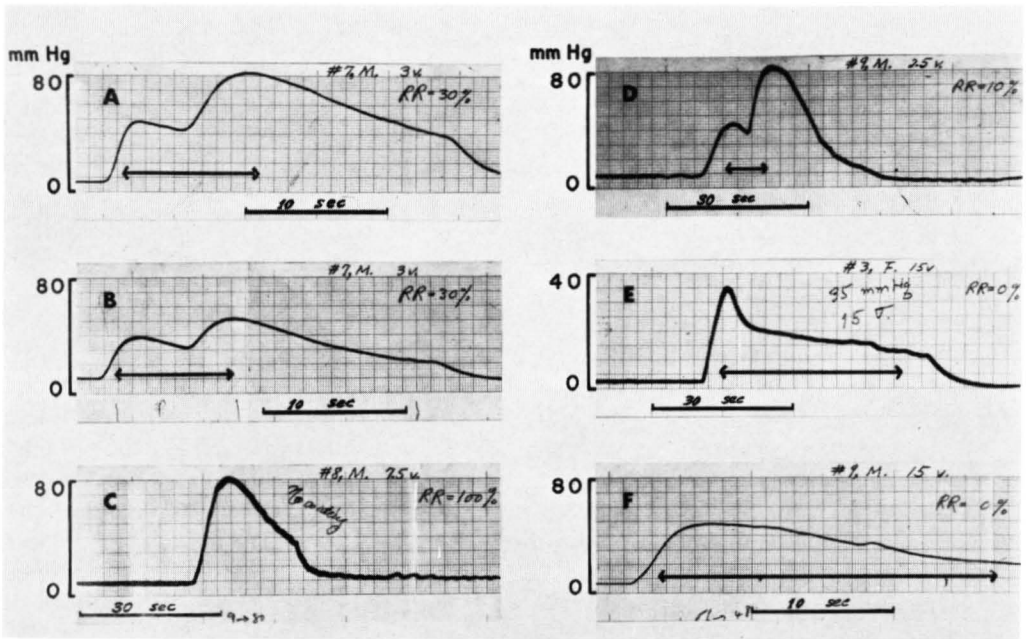

Fig. 4. Intravesical pressure during electrical stimulation. A solid bar represents the period of voiding. R.R.: Residual Rate. A, a double-peaked curve with pelvic nerve stimulation, 3 volts (Dog #7, M). B, the same dog as A with severance of pelvic nerve at proximal site. C, no voiding stimulated at UVJ, 7.5 volts (#8, M). D, a double-peaked curve stimulated at the lower third of detrusor, 2.5 volts (#9, M). E, a complete voiding with stimulation at the middle portion of detrusor, 15 volts (#3, F). F, no residue with stimulation at the upper third of detrusor, 15 volts (#9, M, the same dog as 4D used 5 weeks before).

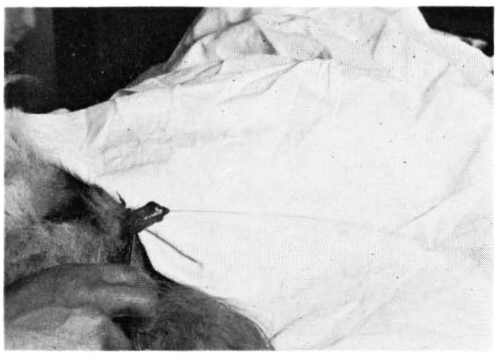

Fig. 5. A good urinary stream is seen with stimulation at the upper third of detrusor, 15 volts (#9, M).

and occurrence of skeletal muscle contraction. The lower voltage less than 5 volts were sufficient in the lower third to induce a so-called balanced micturition[11] (Fig. 4D). The further the electrodes were from UVJ, the more electric current were required (Fig. 4E & F). A good stream is shown in Fig. 5 with stimulation at the upper third of detrusor (Male dog, #9).

DISCUSSION

The urinary bladder is composed of approximately 70 % of smooth muscle and 30 % of collagenous tissue[12,13]. An intercellular connection bears an important role to propagate the depolarization from cell to cell[14]. Bladder muscle resembles the muscle of heart. They are smooth muscle organ, governed by autonomic innervation and able to perform a powerful contraction as their prime function. However, there is an essential difference between them regarding the onset of contraction. The nerve impulse via a sacral reflex arc is mandatory for the former, while the latter does not require the extrinsic nerve stimulation since it has own pacemaker cells.

It is found that the best electronic parameters are frequency of 30 to 50 cps, pulse duration of 3 to 5 msec and biphasic square wave, which consequently gives 60 to 100 stimuli per second. These are in good accord with the averaged value reported by many investigators[15]. The tissue impedance was found between 100 and 200 ohms. The voltage required was dependent upon the site of stimulation. When the stimulation was given at either pelvic nerve or UVJ, less than 5 volts were found sufficient to void completely in the famale. When the stimulation site shifted to the middle portion and to the upper third of detrusor, the threshold of effective electric current elevated, i. e. more than 10 volts were needed (Table 1).

Female subjects were apparently easier to have the micturition complete compared to the male, because they are not provided with an external urethral sphincter, and have a short urethra. An increased urethral resistance, one of the major problems, prevents a smooth urinary flow resulting in a higher intravesical pressure (Fig. 4C). A double-peaked curve is characteristic of micturition which terminates in a sudden arrest (Fig. 4A, B & D). It has been assumed that the urethral occlusion is caused by the excitation of pudendal nerve through an afferent fiber of pelvic nerve[3,7]. That the severance of pelvic nerve did not improve the residual rate (Dog, #7) indicates the persistence of spread of current to the adjacent skeletal muscles via another root. In order to eliminate the occlusion of bladder outlet and to lower the urethral resistance, several methods have been examined; Y-V plasty in bladder neck[16], curarization[17], pudendal neurectomy[7], insulation of electrodes[4], fatigue current to proximal urethra[18], and so on.

The pelvic nerve is the motor nerve of the bladder. The stimulation at pelvic nerve or more proximally at sacral nerve would theoretically be preferable, since it simulates the normal spread pattern of excitation. However, the development of fibrosis would be inevitable in a chronic observation, and the erection of penis and contraction of skeletal muscle would happen in a case of sacral stimulation[19]. Susset and Kondo[20] have stimulated the canine bladder by means of a so-called sequential stimulating technique. Their theoretical ground based upon the finding of Conway and Bradley[21]. They reported that the spread of excitation in a normal reflex micturition initiates "in the dorsal urethrovesical junction proceeding superiorly to the fundus and then ventrally, laterally and inferiorily to the urethrovesical junction" in several seconds. More experi-

ments are necessary regarding the sequential stimulating technique to simulate the normal micturition.

As far as the results obtained in an acute study can tell, the first choice of stimulation site seems to be the detrusor muscle close to the apex, though a fairly large electric current is required. Consequently the statement of Halverstadt[5] is confirmed. The second choice would be the pelvic nerve. These two portions are superior to the UVJ in respect of the residual rate and the degree of skeletal muscle contraction. Further study seems to be necessary in a chronic experiment to confirm the effectiveness of these stimulating sites and to develop an implantable stimulation, which is the subject of forthcoming publication.

SUMMARY

Electric stimulation of the canine bladder was studied in relation to efficiency and the site of stimulation.

(1) The best parameters for stimulation were found to be frequency of 30 to 50 cycles per second, pulse duration of 3 to 5 milliseconds, biphasic square wave and amplitude of 2 to 15 volts.

(2) The most preferable site for stimulation was the detrusor muscle in the middle portion and the upper third between the bladder apex and the level of uretero-vesical junction, where a fairly large electric current is required. The next choice was the pelvic nerve. The stimulation at these two resulted in a less residual rate (residue/capacity) and a lesser grade of skeletal muscle spasm compared to that at uretero-vesical junction. Further laboratory investigations are indicated in a chronic experiment.

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電気刺激による排尿：刺激位置と有効性との関係について

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膀胱の電気刺激位置と有効性との関係を雑種犬を用いて検索した．刺激位置としてはつぎの3点を選んだ．(1) 骨盤神経，(2) 尿管膀胱移行部，(3) 膀胱利尿筋である．さらに (3) については頂部と尿管膀胱移行部との間を3つに区分した．(1) には2本のステンレス線を用い，(2) と (3) には6個の円板状電極を用いた．観察事項は排尿状態，残尿率，骨格筋の痙攣，排尿時膀胱内圧などであった．

膀胱を最もよく収縮させた電気刺激条件はつぎのごとくであった．すなわち，2相性直角波，30～50サイクル/秒，3～5ミリセカンドのパルス幅，電圧は2～15ボルトであった．膀胱の組織抵抗は100～200オームであった．

10ボルト以上の高電圧を必要とするものの最も有効な場所は，膀胱利尿筋とくに頂部に近い部位であり，ついで骨盤神経であった．尿管膀胱移行部は骨格筋の緊張性痙攣を伴い刺激部位としては好ましくなかった一般的にメスイヌのほうが残尿率が低く，効率の高い排尿活動が認められた．