Urol Res (1986) 14:53–56

Urological Research

Experimental Electrical Stimulation of the Bladder Using a New Device

T. Petersen[2], P. Christiansen[1], B. Nielsen[1], H. D. Schrøder[2], J. P. Nørgaard[1], B. Klemar[2] and E. Pedersen[2]

[1] Institute of Experimental Clinical Research, University of Aarhus, and
[2] Department of Neurology and Department of Pathology, Aarhus Kommunehospital, Aarhus, Denmark

Accepted: August 30, 1985

Summary. Repeated bladder contractions were evoked during a six month period in three unanaesthetized female minipigs by using unipolar carbon fiber electrodes embedded in the bladder wall adjacent to the ureterovesical junction. In contrast to bipolar and direct bladder muscle stimulation unipolar electrodes at each ureterovesical junction evoked bladder pressure increase similar to those produced in previous investigations in dogs. Sacral nerve stimulation of S_2 evoked bladder contraction at a minimal current. Microscopic examination revealed no cellular reactions to the carbon fibers but a subcutaneous reaction to the receivers was seen and was thought to be due to mechanical irritation. The clinical implication of the findings is discussed.

Key words: Carbon fiber electrodes, Electrical bladder stimulation, Minipigs, Cystometry performed in unanaesthetized minipigs.

Introduction

In patients with bladder emptying disabilities treatment may be unsatisfactory. The value of oral bethanechol bladder contraction stimulation is questionable [21], whereas electrical bladder stimulation in selected patients has proven effective [6, 8, 12]. Yet significant technical problems remain. One of these is breakage of electrode wires, because of the considerable movement accompanying bladder emptying and filling.

Carbon fibers have shown a high degree of tensile strength, combined with flexibility, good electrical conductivity and should be suitable for medical purposes [11, 14, 17]. In addition carbon is inert, without causing electrolytic disturbances [7].

We tested these properties in a pig model and noted the effect of direct electrical bladder stimulation.

Material and Methods

Seven female minipigs (Gøttingen, Ellegaard) were operated under general anaesthesia induced by Ketalar® (Ketamine) and maintained with 1–2% Halothane with spontaneous respiration using a semiclosed circuit. Through a suprapubic midline incision the peritoneal cavity was opened, the bladder exposed and the carbon fibers fixed to the bladder wall with Prolene (4-0) sutures. The bladder wall was plicated over the elctrodes as described by Timm [19]. The receivers were burried in the subcutaneous tissue of the hypogastrium bilaterally.

In the three minipigs laminectomies were performed from L_1, to S_4 and nerve stimulation was effected via a bipolar electrode. Pentrexyl® (Ampicillin) was administered postoperatively for 5 days in all animals.

Electrode Design. Continous filament carbon fibers (Grafil® XAS) were spun and twisted into leads 40–50 cm long and with a diameter of 0.8 mm. The surface was made smooth by an autogen flame. The leads were then embedded in silicone leaving the ends exposed. 8–10 mm of the electrode end and 15 cm of the receiver end was free of silicone. The receiver was shaped as a spiral and glued on a silicone plate with a diameter of 2.16 cm and a maximal thickness of 2 mm.

Stimulation was delivered trancutaneously to the receiver by a monophasic current with a pulse duration of 0.5–1 ms and a frequency of 35 Hz [1]. Two methods were applied to test direct bladder muscle stimulation.

1) Two circles of 4 electrodes with alternating polarity as described by Susset [16].

2) Three electrodes, each with a length of 8–10 cm, embedded in the bladder wall in a zig-zag manner allowing expansion of the bladder, with the central electrode acting as the positive electrode.

Direct pelvic nerve stimulation was performed via two electrodes one cm apart acting as a bipolar system embedded at each ureterovesical junction. These "trigger points" [15] were detected by needle electrodes. A unipolar electrode embedded at each trigger point was also tested, with or without a positive electrode between the trigger points at the anterior part of the bladder, as illustrated in Fig. 1.

Cystometry was performed repeatedly *without anaesthesia* with a balloon catheter introduced transurethrally. The abdominal pressure was recorded with a thin catheter placed in the rectum. These pressures together with the differences between the pressures were printed on a multipen recorder. Catheters were removed after each session and intermittent catheterisation was performed three times daily as treatment of the bladder denervation.

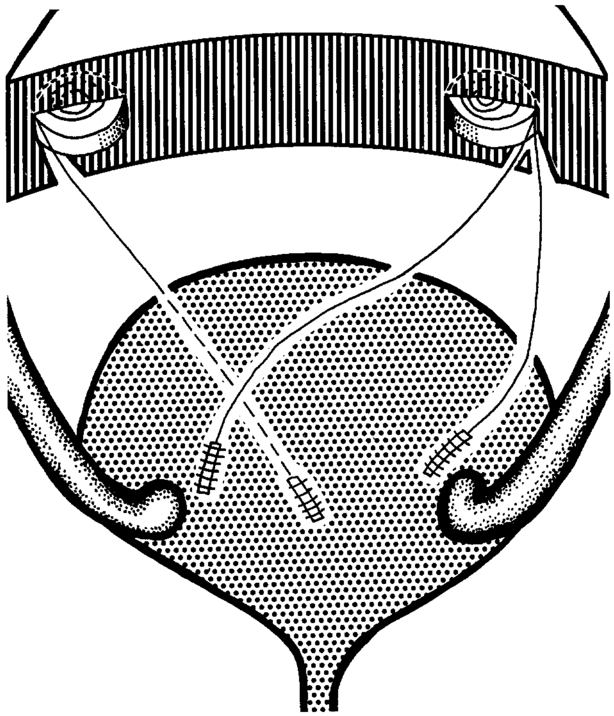

Fig. 1. Unipolar electrodes placed adjacent to the ureterovesical junction and at the anterior part of the bladder. Posterior aspect

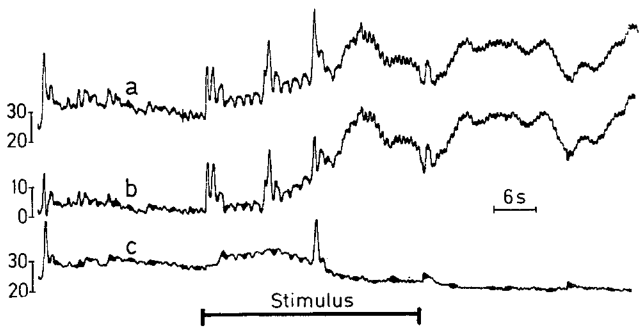

Fig. 2a–c. Immediate bladder response to electrical stimulation. a Intravesical pressure; b detrusor pressure; c abdominal pressure

Pathological Examination. The bladder and the sourrounding tissues of the leads were dissected and fixed in buffered formaline. Blocks of tissue were taken from the sites of stimulation, from tissue surrounding the insulated leads including lymphnodes and from the bladder wall at the implantation sites. The tissue was embedded in paraffin, cut and stained with hematoxylin and eosin, as well as with the van Giesen technique.

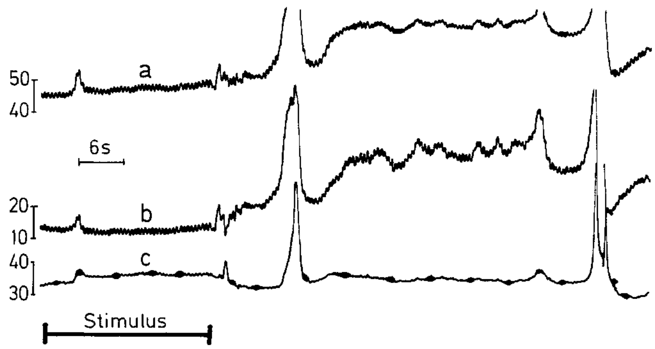

Fig. 3a–c. Delayed bladder response to electrical stimulation. a Intravesical pressure, b detrusor pressure; c abdominal pressure

Results

In three *"acute"* experiments direct muscle stimulation yielded a minimal bladder pressure response (ranging from 0–5 x 10^2Pa) and often a nonuniform bladder contraction. When the electrodes were embedded like a nerve throughout a large area of the bladder, there was a mechanical impediment to bladder contraction. An intermediate bladder response was evoked by bipolar electrodes at the trigger points and maximal responses were evoked by unipolar electrodes at the same points with pressure amplitudes ranging from 5–10 x 10^2Pa, as shown in Table 1. Even using the latter method the bladder contractility was variable and fast fatigueing.

In three *"chronic"* experiments the unipolar method was used and bladder contraction with a pressure rise ranging from 25–55 x 10^2Pa was evoked two weeks after implantation in the unanaesthetized animals, as shown in Table 1. The response appeared to be either immediate (Fig. 2) or delayed (Fig. 3). Simultaneous abdominal muscle contraction was observed, but this was not significant as revealed from the substracted bladder pressure and direct abdominal muscle stimulation. Micturition was provoked when the bladder volume was approximately 3/4 of its capacity. During a six month period bladder stimulation was repeated at least 40 times. An increase of 10 mA in threshold for bladder contraction was observed.

In two of the "chronic" experiments where sacral neurectomy of S_2 was performed electrical bladder stimulation was performed electrical bladder stimulation was continued for continued for 5 days and gave rise to bladder contraction in one animal. The third neurectomized animal was sacrified because of bladder wall inflammation and hypertrophy.

Table 1. Bladder pressure increase provoked by electrical stimulation of the pelvic and S_2 nerves in three minipigs

	Anaesthetized animals	Unanaesthetized animals	S_2 stimulation
Baldder pressure increase	5–10 x 10^2Pa	25–55 x 10^2Pa	5–15 x 10^2Pa
Threshold stimulation	22–24 mA	28–30 mA	1.2–1.8 mA

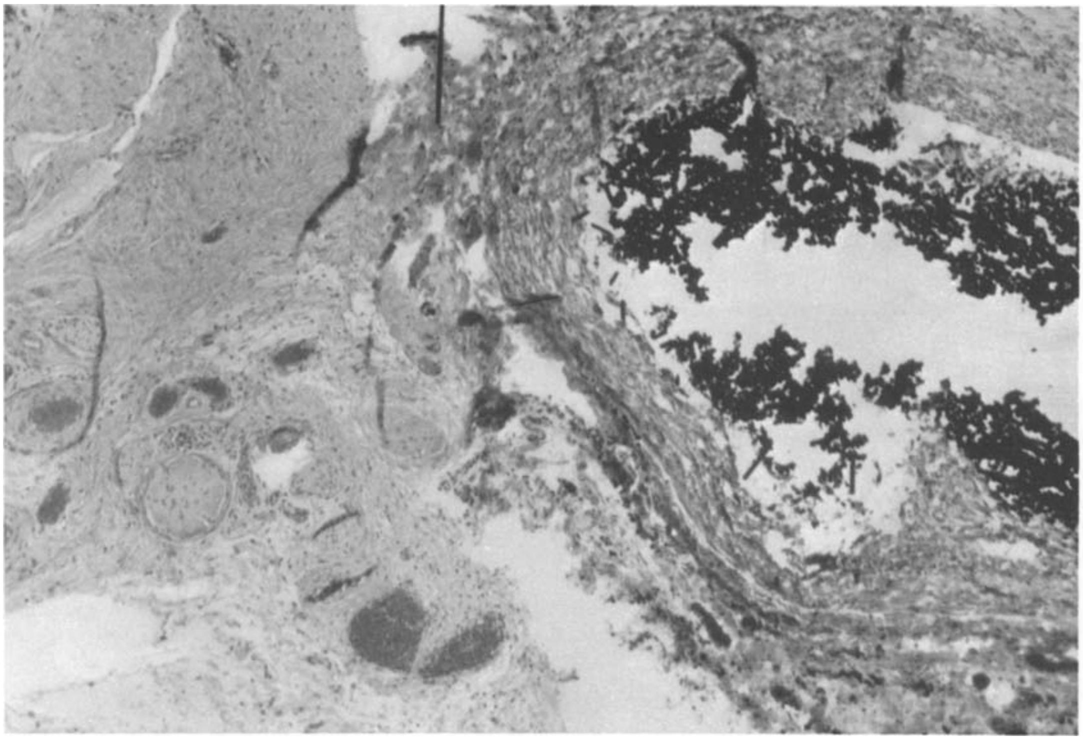

Fig. 4. Carbon fiber electrode surrounded by a connective tissue reaction adjacent to nerve bundles

Electrical stimulation of S_2 in the anaesthetized animals elicited bladder contraction even at a current from 1.5 to 1.8 mA, as shown in Table 1. Stimulation of S_1 and S_3 elicited bladder contraction only when S_2 was intact.

Complications. During this 6 months period two receivers eroded through the skin. One was caused by incorrect position, which was too superficial. In the second case, pathological examination showed acute and chronic inflammation in the subcutaneous tissue, but no reactive changes in the epidermis. An analogous pathological situation was found around two other receivers after 40 stimulations. No reaction was seen in the remaining skin preparations.

Gross pathological examination of the bladder and the surrounding tissues after 40 stimulations showed unchanged position of the electrodes and wires.

Microscopical examination revealed a connective tissue reaction but no signs of inflammatory changes due to the carbon fibers. However the prolene suture material gave rise to a foreign body giant cell reaction. As seen from Fig. 4 nerve bundles were present next to the implantation site. No carbon fragments were seen in the lymphatic tissue adjacent to the bladder.

Discussion

The carbon fiber electrodes were well tolerated, unlike metal electrodes [10]. Such biocompatibility has been described previously when carbon fibers were used as pacemaker electrodes [14]. Biocompatibility reduced the power requirement compared to metal pacemaker electrodes. Similarly we assume that power requirements are reduced when carbon fibers are used for bladder stimulation. It may be the case that the number of patients, who have had to stop bladder stimulation because of intolerable stimulus induced pain [13] might be reduced.

We found that the bladder pressure increase was highest when stimulating the base of the bladder, between the ureterovesical junctions, where the pelvic nerves enter the detrusor. In the anaesthetized animals pressure increase was low and variable, as stated before [2], especially when a bipolar electrode was used. A bipolar electrode has been recommended in order to reduce spread of current to the external sphincter [6]. Only a minor degree of current spread occurs by direct muscle spread [4], and since a more marked bladder contraction was elicited by a unipolar electrode, unipolar electrodes were chosen for the "chronic" experiments. Bladder contraction evoked by this method in the unanaesthetized minipigs was comparable to previous findings in dogs [10] and humans [5].

Erosion of the receivers through the skin has been described earlier [8] and was also seen in this study although the receiver used was smaller and more flexible than other receivers. In all previous investigations radiolinked electrical transmission was used and this current causes no dermal reaction. This is in contrast to low frequency electrical stimulation used in this experiment which causes epidermal reaction at high currents [18]. However, no epidermal reaction was seen in the present study; the erosion of the receivers was probably due to mechanical irritiation. This mechanical irritation might be enhanced by poor fixation and difficulties in localizing the receivers. A new receiver has been developed to reduce this complication.

Sacral nerve stimulation only required a small current to elicite bladder contraction. Unfortunately a concommittant high degree of sphincter contraction is present and the net effective voiding pressure has been shown to be lower by sacral stimulation [9]. A more selective sacral anterior motor nerve stimulation has shown encouraging results, but a parallel activation of the urethral sphincter during the detrusor stimulation still occurred [3]. According to Merrill [12], who reported on 150 patients with implanted bladder stimulators, the primary indication for stimulator implantation is in patients with vesical hypotonia of unknown etiology and in patients with lower motor neurone lesions secondary to spinal cord injury or multiple sclerosis. Bladder stimulation in patients with myelomeningocele is questionable benefit [20]. Clean intermittent self-catheterisation has been successful in many of the above mentioned patients, but some are not compliant with the treatment. A bladder stimulator device as described might therefore be a future alternative.

Acknowledgement. This study was supported by a grant from the Danish Multiple Sclerosis Society.

References

1. Boyce Wh, Lathem JE, Hunt LD (1964) Research related to the development of an artificial electrical stimulator for the paralyzed bladder. J Urol 91:41–51
2. Bradley WE (1977) Experience with electronic stimulation of the micturition reflex function. In: Hambrecht FT, Reswick JB (eds) Functional electrical stimulation: Applications in neural protheses. Marcel Dekker, New York, pp 119–140
3. Brindley GS, Polkey CE, Rushton DN (1982) Sacral anterior root stimulators for bladder control in paraplegia. Paraplegia 20:365–381
4. Carstensen HE, Freed PS, Molony DA, Kantrowith A (1970) External sphincter fatigue as an adjunct to electrical detrusor stimulation. Invest Urol 7:387–397
5. Hald T, Meier W, Khalili A, Agrawal G, Benton JG, Kantrowitz A (1967) Clinical experience with a radiolinked bladder stimulator. J Urol 97:73–78
6. Halverstadt DB, Parry WL (1975) Electronic stimulation of the human bladder: 9 years later. J Urol 113:341–344
7. Hench LL, Ethridge EL (1982) Biomaterial – An interfacial approach. Academic Press, New York London, pp 126–130
8. Jonas U, Hohenfellner R (1978) Late results of bladder stimulation in 11 patients: Followup to 4 years. J Urol 120:565–568
9. Jonas U, Jones LW, Tanagho EA (1975) Spinal cord stimulation versus detrusor stimulation. Invest Urol 13:171–174
10. Jones LW, Jonas U, Tanagho EA, Heine JP (1976) Urodynamic evaluation of a chronically implanted bladder pacemaker. Invest Urol 13:375–379
11. Katahira K (1979) A new type of force-sensitive device using carbon fiber and its biomedical application. Fukushima J Med Sci 26:121–132
12. Merrill DC (1979) Electrical vesical stimulation. Acta Urol Belg 47:110–114
13. Merrill DC (1975) Clinical experience with the Mentor bladder stimulator. III. Patients with urinary vesical hypotonia. J Urol 113:335–337
14. Minns RJ (1983) Carbon as an implant material. Meeting report. J Med Eng Technol 7:200–201
15. Scott FB, Quesada EM, Cardus D, Laskowski T (1965) Electronic bladder stimulation: Dog and human experiments. Invest Urol 3:231–243
16. Susset JG, Boctor ZN (1968) Implantable electrical vesical stimulator: Clinical experience. J Urol 98:673–678
17. Tayton K, Philips G, Ráliš Z (1982) Long-term effects of carbon fibre on soft tissues. J Bone Joint Surg 64;B:112–114
18. Thomsen HK, Danielsen L, Nielsen O et al (1983) Epidermal changes in heat and electrically injured pig skin. Acta Pathol Microbiol Immunol Scand 91:297–306
19. Timm GW, Bradley WE (1971) Electromechanical restoration of the micturition reflex. IEEE Trans Biomed Eng BME-18: 274–280
20. Wheatley JK, Woodard JR, Parrott TS (1982) Electronic bladder stimulation in the management of children with myelomeningocele. J Urol 127:283–285
21. Wein AJ, Hanno PM, Dixon DO, Raezer DM, Benson GS (1978) The effect of oral bethanechol chloride on the cystometrogram of the normal male adult. J Urol 120:330–331

Dr. T. Petersen
Neurological Laboratory
Department of Neurology
Aarhus Kommunehospital
DK-8000 Aarhus C
Denmark