ELECTRONEUROGRAPHIC (ENG) SIGNALS FROM INTRADURAL S3 DORSAL SACRAL NERVE ROOTS IN A PATIENT WITH A SUPRASACRAL SPINAL CORD INJURY

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Abstract - *The aim of this on going project was to investigate if nerve signals related to bladder pressure and volume can be recorded from sacral roots in patients with detrusor hyper-reflexia. Such signals could then be used in an event driven electrical stimulation neural implant to treat detrusor hyperreflexia. The recordings from this first patient were consistent with recordings made from pelvic nerves in acute animals which showed that both passive filling and bladder contractions were reflected in sacral dorsal root cuff electrode recordings. However, the signal to noise ratio was poor and more studies are being conducted now to improve the reliability and extraction of nerve signals.*

Key words - Detrusor hyperreflexia, S3 dorsal sacral nerve recordings, electrical stimulation

1. Introduction

Detrusor hyperreflexia (DH) is the most common form of bladder dysfunction in spinal cord injury causing failure of the storage function of the lower urinary tract and incontinence. DH is characterized by involuntary detrusor contractions at low bladder volumes which cannot be consciously suppressed. If left untreated this can lead to high bladder pressures, detrusor muscle hypertrophy, and the risk of serious kidney damage.

Treatments for DH have include drugs and surgical interventions such as sacral posterior root rhizotomy but a more acceptable and non-destructive alternative for patients may be the use of electrical stimulation to suppress DH. The principle of this treatment is based on the existence of spinal inhibitory systems which are capable of interrupting a detrusor contraction. These inhibitory systems can be activated by electrical stimulation of appropriate afferent nerve fibres.

Bladder inhibition can be achieved by stimulation of afferent branches of the pudendal nerves at the level of the dorsal penile/clitoris nerve (Wheeler et al., 1994; Shah et al 1999, Dalmose et al. this meeting), or in the sacral nerve roots (Bosch et al., 1998, Craggs et al 2000). Several studies have shown that electrical stimulation of these afferents can have long lasting effects on bladder inhibition in non-neuropathic bladder dysfunction. However, this is not the case in neuropathic bladder dysfunction (Previnair et al., 1998) thus chronic stimulation is needed.

In order to allow event driven stimulation a system is needed that detects the onset of a detrusor contraction. Recent work has shown that afferent nerve signals related to mechanical bladder activity can be recorded using cuff electrodes placed on the pelvic nerves or the (dorsal) sacral nerve roots in acute experiments using both cats and pigs (Jezernik et al., 1999; Jezernik et al., 2000). Using advanced signal processing methods the onset of an contraction could be reliably detected.

The aim of this project was to demonstrate that mechanical bladder activity (changes in pressure/volume) can be monitored by recording the electrical activity from the posterior (dorsal) sacral nerve roots in suitably selected patients. Here we report the results from our first SCI patient studied at the Spinal Injuries Unit of the Royal National Orthopaedic Hospital, UK.

2. Methods

Local ethics committee approval and informed patient consent was given. All experimental measurements were obtained from one male patient with a complete spinal cord lesion (T6, aged 39 years, 1 year post injury). This patient was to be implanted with a standard intra-dural Brindley sacral anterior root stimulator implant (SARSI) for bladder emptying and undergo a complete posterior sacral rhizotomy to treat the hyperreflexic bladder. During the operation under general anaesthesia, the sugical procedure

was interrupted for 45 minutes to allow the ENG recordings from the posterior roots before they were cut.
Pressure measurements from the bladder, rectum and anal canal were recorded by means of catheters inserted before operation. In addition, skin electrodes were placed on the dorsum of the penis to permit stimulation of the dorsal penile nerves.
A normal surgical procedure was used to gain access to the intradural sacral nerve roots [Van Kerrebroeck et al., 1991]. The nerve roots were identified by test stimulation using a hook electrode connected to a handheld stimulator. At this point the surgical procedure was interrupted for the experiment.

A cuff electrode was temporarily placed on dorsal sacral nerve root S3. The electrode was connected to a battery powered amplifier/transmitter (Donaldson et al, this meeting). The amplified nerve signals were sent to an external receiver, sampled and stored together with bladder and anal sphincter pressures on a digital tape recorder. The following experimental protocol was used:
- To check the quality of the recorded ENG signal, the dorsal penile nerve was stimulated at a pulse rate of 3 pulses/s. The evoked action potentials were recorded with the cuff electrode.
- To measure the relation between ENG signals and mechanical bladder activity, a bladder contraction was induced by stimulating the ventral root S3 by the hook electrode. In addition ENG was recorded during consecutive rapid infusions of 50 ml warm saline.
After the experiment the impedances of the electrode contact with respect to ground were measured. The cuff electrode was then removed by cutting the dorsal root distal and proximal to the cuff. From this point the normal surgical procedure was resumed by cutting the remaining dorsal sacral nerve roots (S2-S4/5).
The cuff electrodes were made of silicone (medical grade) and biocompatible stainless steel contacts. Similar types of electrode are used chronically in human implants to control hand grasp (Haugland et al, 1999) and restore dropfoot (Haugland and Sinkjær, 1995).

3. Results

The nerve-cuff interface
The exposed S3 nerve root was approximately 1 mm in diameter. A cuff (#267) with an inner diameter of 2.6 mm and a length of 18 mm was installed. The inside of the cuff and the surrounding areas were filled with room temperature sterile saline. Cuff electrode impedances as measured with respect to ground at 1 kHz was 662 ohm at proximal electrode, 880 ohm at central. electrode, and 730 ohm at distal electrode.

Compound nerve action potential (CAP) responses
To verify the viability of the S3 afferent nerve within the cuff the dorsal penile nerve was stimulated through a bipolar surface electrode. The stimulus (3 pulses per second, pulse duration 200 μs) were delivered at an amplitude equal to twice the pudendo-anal threshold (sufficient to inhibit a reflex mediated bladder contraction in an awake patient (Shah et al, 1998). Figure 1 shows the averaged response of the CAP responses to 10 single penile stimuli.

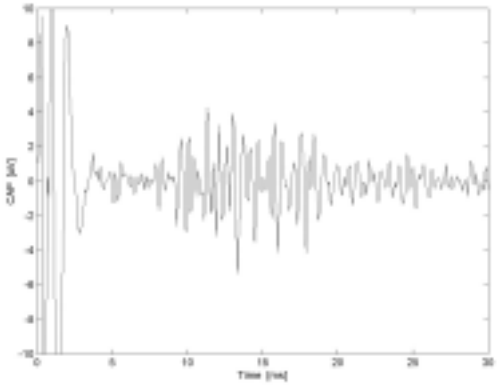

Fig. 1: Averaged CAP from cuff electrode on the sacral dorsal S3 root to single penile stimuli. The stimulus was delivered at time t=0. Stimuli artefact is present in the ENG signal from 0-4 ms.

The average onset latency of the CAP to penile stimulation was 9 ms, with two smaller responses at 5 and 7 ms (observed in 3 of the 10 averaged stimuli evoked responses). The polyphasic response reflects that nerve fibers with different conduction velocities and/or receptors at a different distance to the recording cuff electrode were activated. The maximal CAP was 9 μV_{pp}. The distance from the stimuli location to the recording electrode was estimated to 0.2 m suggesting a conduction velocity (CV) of 22 m/s. The CV and the amplitude of the CAP were lower than expected. E.g. in the sural nerve just distal to the ankle joint the fast conducting cutaneous nerve have a conduction velocity above 50 m/s and an amplitude above 50μV (Haugland and Sinkjær 1995). The rather large inside diameter of the chosen cuff (2.6 mm) as compared to the size of the S3 dorsal root (1 mm) and the room temperature saline attenuated the amplitude and decreased the nerve conduction velocity of the recorded signal. With a smaller diameter cuff electrode and with saline at body temperature we expect the signal to be at

least at least a factor of 5 times higher. It is very likely that the ENG signal shown in the following during passive bladder fillings (Fig. 2) and active bladder contraction (Fig. 3) are similarly smaller because of these factors.

Nerve recordings during passive bladder filling.
Figure 2 top show the rectified and bin integrated S3 ENG recordings, bladder pressure and anal pressure during three consecutive bladder fillings where 50 ml saline is injected at approximately 15-20 s, 32-40 s and again from 50-55 s (reflected as an increase in the bladder pressure in the middle trace of Fig. 2). The bladder was emptied just prior to this experiment. For unknown reasons the ENG signal decreased until the first injection at 15 s, where after it increased (Fig. 2 top) as the bladder pressure increased at each of the three injections from about 25 to 40 cmH_2O (Fig. 2 middle) with no related changes in the anal pressure (fig. 2 bottom). No distinct phasic ENG responses are detected at the time of the injections as earlier observed in the acute animal experiments (Jezernik et al., 1999,2000).

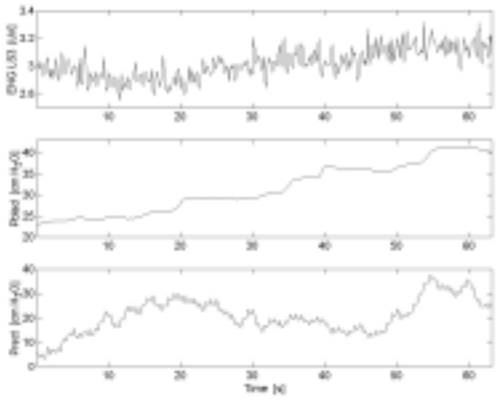

Fig. 2: Rectified and bin integrated sacral S3 root cuff electrode recordings (top), bladder (middle) and anal (bottom) pressures during passive fillings of prior emptied bladder.

Nerve recordings during detrusor contraction
Active bladder contractions where induced by stimulating the ventral sacral S3 root at 20 Hz (200 µs pulse width) in bursts of 5-10 s. The stimulation resulted in fast and distinct anal pressure changes due to the direct activation of the striated external anal sphincter (Fig. 3 bottom).
The first stimulus train (mark 1) made the detrusor contract from 20 to about 70cm H_2O (Fig. 3 middle). The second stimuli made the bladder pressure increase sligthly more whereas the remaining two stimuli trains kept the pressure high (>60cm H_2O) for an extended period. The increase in bladder pressure was reflected in the rectified and bin integrated ENG signal (Fig. 3 top) throughout the recordings. An interesting observation was that the increase in the ENG signal preceded the increase in the bladder pressure.

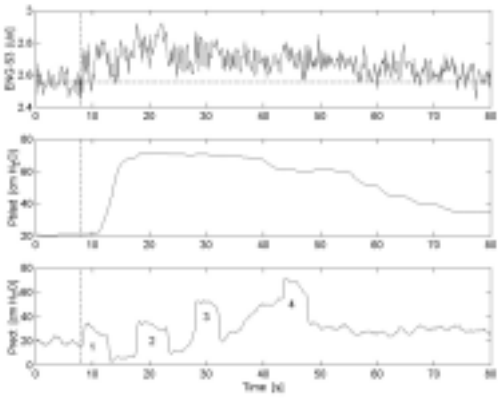

Fig. 3: Correlation between rectified and bin integrated sacral S3 root cuff electrode recordings (top), bladder (middle) and anal (bottom) pressures during an active bladder contraction. The bladder was made to contract by stimulating the sacral S3 ventral root at 20 Hz for 5-10 s at the marked periods 1-4. Stimuli artefacts were removed from the ENG signal before it was rectified and bin integrated.

4. Discussion.

The recordings from this first patient is in accordance with cuff electrode recordings on pelvic nerves in acute pigs (Jezernik et al., 2000) and sacral roots in acute cats (Jezernik et al., 1999). Future studies will show if the recorded nerve signal can be used to detect the onset of a detrusor contraction in patients and in turn could be used to trigger a stimulator which will stop the ongoing bladder contraction by activating an inhibitory spinal reflex.

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