# Intraoperative recording of neurographic signals from cuff electrodes on extradural sacral roots in human

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## Abstract

***The feasibility of conditional stimulation as a treatment option for neurogenic detrusor overactivity in spinal cord injury (SCI) patients depends on a reliable method for chronic monitoring of bladder activity. The purpose of this study was to investigate the possibility of recording afferent nerve activity related to mechanical activity of the bladder and other pelvic organs in human.***

***In 6 SCI-patients, a nerve cuff electrode was temporary placed on the extradural S3 sacral root, and electroneurographic (ENG) signals were recorded during mechanical stimulation of the dermatome (manual tapping and stroking), rectum (balloon distension) and bladder (saline bolus infusion). Increases in ENG were present during stimulation of the dermatome and rectum in all 6 patients, and during bladder filling in 5 out of 6 patients.***

***We therefore conclude that it is possible to record afferent nerve activity from the dermatome, rectum and bladder using cuff electrodes on the extradural sacral root in human. However, the low amplitude of recorded nerve responses indicates the need for improvements in recording quality and signal processing methods to distinguish signals from different afferent sources.***

## 1. INTRODUCTION

The functions of the urinary bladder are storage and periodic elimination of urine. In many patients with a neurological disease or injury to the spinal cord, involuntary detrusor contractions cause a failure of the storage function and incontinence. This so-called neurogenic detrusor overactivity (NDO) is conventionally managed by medication, catheterisation or surgical interventions, such as bladder augmentation or deafferentation. Medication is often unsuccessful or has side effects, and surgery can be destructive and cause loss of sensation. An alternative option is the use of electrical stimulation. Inhibition of the micturition reflex can be achieved by stimulating the appropriate pudendal nerve afferents [1]. Stimulation does not need to be applied continuously, but conditional stimulation is at least as effective [2].

The feasibility of conditional stimulation as a treatment option depends however on a safe and reliable method for chronic monitoring of the intravesical pressure. Long-term implantation of artificial sensors is often troublesome, but recording neural activity from the natural sensors in the human body has become a realistic alternative [3]. Recent acute studies have shown that afferent nerve signals related to mechanical bladder activity can be recorded using cuff electrodes placed on the pelvic nerves or sacral roots in pigs [4], cats [5] and human [6]. A chronic implant study in pigs demonstrated that these signals also can be recorded using implanted cuff electrodes [7].

With the current study we have made the transition from the use of animal models to human subjects. Following our recent report on intraoperative sacral root recordings in two human SCI-patients [8], we have extended the study and in this paper we give an overview of the current status of the project.

## 2. METHODS

Six spinal cord injured patients (4 male, 2 female, age 20-49, 5 complete injury C5-T5, 1 incomplete C6, post injury 2-17 years) who underwent implantation of an extradural FineTech-Brindley Bladder System participated in this study (October 2003 – May 2004). Approval to conduct the study was given by the local ethical committee of the Institut Guttmann and all patients signed an informed consent.

### 1.1. Surgical preparation

Under general anesthesia, the extradural sacral nerve roots were exposed by a dorsal laminectomy (L5-S4), and identified by anatomy and the response of different muscle groups to electrical stimulation with a hook electrode. The sacral root with the best bladder response to electrical stimulation was instrumented with a bipolar cuff electrode (length 10 mm, 1 mm wide platinum foil ring contacts, and reference contact on the outside). After submerging the cuff electrode in saline (body temperature), the electrode impedance was measured (±90 nA sine wave at 1 kHz) and connected to a sterile telemeter [9] as shown in Figure 1. Nerve signals were then recorded for approximately 30-45 minutes, where after the cuff electrode was removed and the normal surgical procedure resumed.

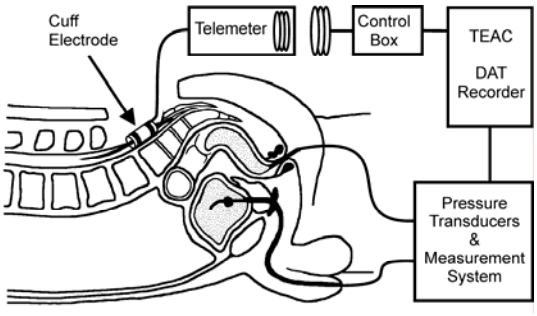


Fig. 1: Schematic overview of experimental set-up.

The intravesical pressure (Pves) was measured using a 5Ch catheter and the rectal pressure (Prect) using a 10Ch balloon catheter, connected to pressure transducers (21C15 manometers, DISA), and together with the recorded ENG signals stored on digital tape (RD-135T, TEAC) for offline analysis.

### 1.2. Experimental protocol

The protocol used to evoke a neural response from mechanoreceptors in different pelvic organs included:

*Dermatome:* ENG was recorded when tapping and stroking the relevant dermatome;
*Rectum:* ENG was recorded during consecutive 50 ml saline bolus infusions into a rectal balloon (condom on a single lumen catheter);
*Bladder:* ENG was recorded during consecutive 50 ml saline bolus infusions into the bladder until the intravesical pressure (Pves) exceeded 100 $cmH_2O$ or a volume of 400 ml was reached.

### 1.3. Signal processing and data analysis

After resampling from tape (fs = 20 kHz), the ENG signal was band-pass filtered (300-3000 Hz), and its variance (proportional to number of active nerve fibers [10]) and the average of the pressure signals were calculated per time bin (Tbin = 40 ms for skin, and 100 ms for bladder and rectal ENG). The SNR of ENG responses was quantified as the corrected ratio of variances of peak ENG and background noise (0.5 s averages for bladder and rectal ENG).

## 3. RESULTS

Cuff electrodes were placed on the left (n = 4) or right (n = 2) S3 sacral root and had an inner diameter of 2.6 – 3.8 mm to fit snugly around the nerve. The impedance of the contacts inside the cuff electrode ranged from 700 - 2100 Ω.

### 3.1. Cutaneous nerve responses

In all six patients, clear ENG responses were recorded when tapping and stroking the S3 dermatome. The amplitude of responses in the raw signal was often just above the noise level, but became much more distinct after calculating the variance per time bin. The largest ENG responses were recorded during tapping and varied between patients from SNR = 1.43±0.41 to SNR = 5.25±1.65 (n = 20 per patient).

### 3.2. Nerve responses from the rectum

Because the size of the distension balloon was initially too large and the 3-4 boluses infused were not sufficient to increase Prect above 27 $cmH_2O$ in the first three patients, the recorded ENG responses were very small. After decreasing the size of the balloon by half and infusing up to 6-8 boluses in the last three patients, peak pressures reached 68-104 $cmH_2O$ but ENG responses remained small and mainly phasic in nature. It was only during the repetitive withdrawal and fast re-infusion of 50 ml from the full balloon that large increases in Prect ranging from 18 to 67 $cmH_2O$ were created and ENG responses with SNR = 0.06 to 0.30 were recorded.

### 3.3. Nerve responses from the bladder

ENG responses during bladder filling were present in 5 out of 6 patients. Because of technical problems, Pves did not increase during filling in one patient and was not recorded in one another patient.

Figure 2 shows a recording during a bladder filling. Pves hardly increased during the 1st infusion, but increased more with subsequent infusions. An ENG response was absent during the 1st infusion, but mainly phasic responses with increasing amplitude for increasing peak pressure were recorded for the 2nd - 5th infusion.

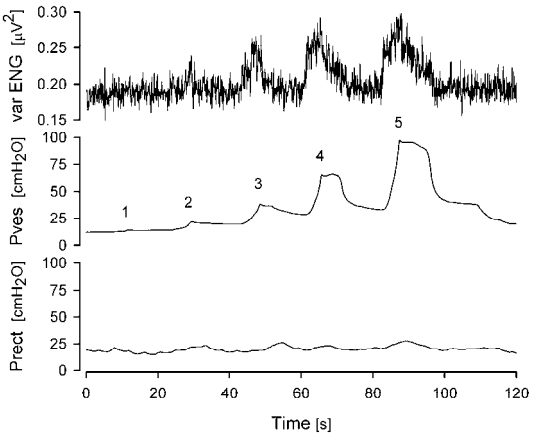


Fig. 2: Variance (var) of ENG signal and pressure responses recorded during five consecutive saline bolus infusions in the bladder of patient 5.

An ENG response during the 1st infusion was present in only 2 out of 5 patients. For the total group the first response was recorded during the 3rd infusion with a Pves of 32±8 $cmH_2O$ (n=4). The largest ENG responses with an SNR ranging 0.25 - 0.53 were recorded during the 2nd to 11th infusing where the peak intravesical pressures reached 80 - 140 $cmH_2O$.

## 4. DISCUSSION AND CONCLUSIONS

The results demonstrate that an increase in extradural sacral root nerve activity can be recorded during mechanical stimulation of different pelvic organs in human. Although assumed mostly afferent, of a possible efferent contribution cannot be excluded. The amplitude of ENG signals could be improved by recording intradurally using smaller diameter cuff electrode. Furthermore, because various afferent sources contribute to the sacral roots, greater selectivity towards organ specific afferent fibers is needed for clinical application. Advanced signal processing methods can improve selectivity and SNR of ENG responses to single source afferent stimulation [11], and recent developments in electrode design predict improved velocity-selective recording [12], but their effectiveness on the compound nerve signal remains unknown.

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