

APPLICATION OF SENSORY NERVE SIGNALS IN NEURAL PROSTHESIS DEVICES

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ABSTRACT

In this presentation, I will review our experience as to how signals recorded from cutaneous and muscle nerves can be applied to restore foot, hand, and bladder control in subjects with central nervous lesions.

Electric stimulation of the peroneal nerve used for correction of gait is used to enhance dorsiflexion in the swing phase of walking in lower extremities of hemiplegic patients. Instead of an artificial external heel switch, we have tested the use of a nerve cuff electrode picking up information from the sural nerve and calcaneal nerve and feeding this into a one channel FES system (Haugland and Sinkjær, 1995; Upshaw and Sinkjær, 1998; Hansen et al., 1999)

In natural hand control, cutaneous receptors from the fingers play an important role in controlling the muscle activation level. We have implemented an algorithm that makes an FES system able to adjust the stimulation based on the compound information from the mechanoreceptors as recorded by a nerve cuff electrode from a digital nerve (Haugland et al., 1999).

For restoration of bladder function in SCI patients, the sacral root stimulator by Brindley is useful in controlling the emptying of the bladder. At present we are carrying out experiments on animals using cuff electrodes on sacral roots and the pelvic nerve to detect hyperreflexia and to give "warning signals" when the bladder gets full (Jezernik et al., 1999) This information can potentially be used to inhibit unwanted bladder contractions and to trigger the FES system and thereby bladder emptying.

KEYWORDS

Natural sensors, feedback , Neural Prosthesis devices, hand, foot, bladder

INTRODUCTION

New developments in electrode design (Kallesøe et al., 1996; Struijk et al., 1995), implantable amplifiers (Zhou et al., 1998) and signal processing (Jezernik and Sinkjær, 1999) to do long-term and reliable recordings from peripheral nerves emphasise the use of the body's own sensors in Neural Prosthesis devices (Sinkjær et al., 1999). The body's own sensors have been installed and optimised through natural evolution during million of years. Reliable recorded information from these natural sensors can be applied as signals, e.g.:

- i) to control electrical stimulation (ES) that produces a movement
- ii) to detect unwanted (spastic) muscle contractions which can then be inhibited by, e.g. ES
- iii) to communicate with the brain through, e.g. electrocutaneous cognitive feedback systems (Riso, 1999; Matjacic et al., 1999)

in users who have impaired motor and sensory functions because of central nervous lesions.

NATURAL SENSORY INFORMATION USED IN DROP FOOT PROSTHESIS

Electrical stimulation of the peroneal nerve used for correction of gait has proven to be a potentially useful mean for enhancing dorsiflexion in the swing phase of walking in lower extremities of hemiplegic patients. The stimulation is applied during the swing phase of the affected leg and prevents drop foot. This makes the patient walk faster and more securely. The stimulator is often located distally to the knee on the lateral part of the tibia. The stimulator

can be either external or partly implantable. In most commercial systems today the stimulator is triggered by an external heel-switch linked to the stimulator through a wire running from the switch under the heel up to the stimulator, but new implantable devices are being developed (Childs et al., this meeting).

The rationale for implanting a cuff electrode on a cutaneous nerve innervating the foot is to remove the external heel switch used in existing systems for foot drop correction and thereby making it possible to use such systems without footwear and preparing it to be a totally implantable system. During walking, the nerve signal modulates strongly and gives a response at foot contact and a silent period when the foot was in the air through the swing phase of the walking cycle. Reliable detection of afferent nerve signals is essential if such signals are to be of use in artificial sensory-based Functional Electrical Stimulation neural prosthetics. By feeding the processed neural signals to an Adaptive Logic Network (ALN) (Kostov et al., 1996) the ALNs can discriminate precise timing of heel contact as well as heel lift during FES assisted walking, having a detection rate of nearly 100 %.

NATURAL SENSORY INFORMATION USED IN HAND PROSTHESIS

Healthy subjects are able to control the grip force when holding a given object, independent of the weight and surface texture of the object. This is possible because the cutaneous receptors give information about small slips and skin deformation. We have implemented an algorithm that makes an FES system able to mimic this function based on the compound information from the cutaneous receptors in the index finger as recorded by a nerve cuff electrode. The algorithm was initially developed in an animal preparation, and later we have implemented it in two spinal cord injured subjects (Haugland et al., 1999).

Results from a 27-year-old tetraplegic male with a complete C5 spinal cord injury (two years post injury) are presented here. The patient had no voluntary elbow extension, no wrist function, and no finger function. He used a splint for keeping the wrist stiff. He had partial sensation in the thumb, but no sensation in 2nd-5th finger.

The processed signals from the receptors in the index finger are used to control the "Freehand" system (NeuroControl Inc. Ohio, USA) and it is today developed to an extent where the subject can use it during functional tasks (Inmann et al., this meeting). During an eating session, where the subject has a fork in his instrumented hand (grasped between the thumb and index finger), the control system is designed to decrease the stimulation of the finger muscles until the feedback signal from the skin sensors detects a slip between the index finger and the fork. When a slip is detected, the stimulation to the thumb increases automatically proportional to the strength of the sensory feedback, and if no further slips are detected, the controller again start to decrease the stimulation. A typical eating session will last 20-30 min. A large fraction of this time is dedicated to "non-eating" activities. During such times, the stimulation is at a minimum (keeping the fork in the hand with a loose grasp) and thereby preventing the hand muscles to be fatigued. When the feedback is taken away, the subject will typically leave the stimulation on at a high stimulation intensity for the full eating session. This will fatigue the stimulated muscles, and the subject will try to eat his dinner faster, or he will rest his muscles at intervals by manually decreasing the stimulation. An effort that requires more attention from the subject than the automatic adjustment of the stimulation intensity.

NATURAL SENSORY INFORMATION USED IN CONTROL OF NEUROGENIC BLADDER

In the case of neurogenic bladder, the elevated intravesicular pressure can force urine to travel back up to the kidneys and produce upper urinary tract infection. Equally common are

infections of the lower urinary tract caused by insufficient voiding which leaves a persistent high volume of residual urine. In addition to these problems, overfilling of the bladder can lead to a condition of autonomic dysreflexia, which can also be life threatening.

These problems could be reduced if it would be possible to provide spinal injured individuals with information about the state of fullness of the bladder. This requires that there will be some sensors which can monitor the bladder volume and bladder pressure.

Recently, it has been demonstrated that a nerve cuff applied around the sacral roots or the pelvic nerve innervating the bladder in anaesthetised pigs can record activity that correlates with the status of fullness of the bladder (Jezernik et al., 1999). Further more, in an anaesthetised “hyperreflexive bladder” cat model rhythmic contractions can be reliably detected by the cuff electrode recordings and the bladder contraction inhibited by e.g. electrical stimulation of the sacral roots (Jezernik et al., this meeting). This demonstrate that patients with a hyperreflexive bladder (SCI, some incontinence patients) could, when needed, get a closed loop controlled FES implant that uses this recorded sensory input. Present solutions for such patients are suppression of reflex contractions by drugs and bladder emptying by catheterisation. In some cases, drugs do not work - then surgical intervention is needed, where the detrusor is deafferented by cutting the dorsal sacral roots to prevent reflex contractions, and the bladder can be emptied by use of a sacral root stimulator that has electrodes on the sacral ventral roots. Dorsal rhizotomy increases the bladder capacity, but reflex erection in male patients is lost. To prevent cutting dorsal sacral roots, one could detect fast pressure rises and detrusor activation with nerve cuff recordings from bladder nerves, and the controller could then take appropriate actions as, e.g. inhibit detrusor contractions by stimulating pudendal or penile nerves, or block efferent or afferent pelvic nerve transmission to prevent reflex detrusor contractions (Jezernik et al., 1999; Rijkhoff et al., 1998). In this way continence could be re-established, low pressure voiding achieved, bladder functional capacity increased, and beside medical status improvement, patients would become more independent as well and could socialise more easily.

DISCUSSION

The use of cuff electrodes to record the activity of cutaneous and bladder afferents in peripheral nerves was described with emphasis on making functional use of natural sensors in FES systems. An important area not being dealt with in this paper is the multitude of different electrode designs which have been used and are being developed for recording (and stimulation) of peripheral nerves (Naples et al., 1988; Struijk et al., 1995). Future developments of cuff electrodes will probably focus on fabrication methods, such as the use of thin film electrodes, addition of electronics on the cuff, improvement of signal to noise ratio, cuffs for fascicle selective recordings (Struijk et al., 1997; 1999), and signal processing (Upshaw and Sinkjær, 1998; Sinkjær et al., 1998, Jezernik et al. this meeting). In this respect, it is important to evaluate the long-term implant of such electrodes (Slot et al., 1997; Larsen et al., 1998). Application of the cuff in FES can also be used for sensing of proprioceptive information from, for example, muscle afferents (Jensen et al.; Micera et al – this meeting) to control joint positions and in cognitive feedback systems (Riso, 1999). Cuff electrodes may thus be a valuable part to provide sensory feedback information in fully implantable FES systems. For a detailed description on applying cuff electrodes for long-term implants in humans, see Sinkjær et al. (1999).

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