# A Technique for Reversible Fusimotor Blockade During Chronic Recording from Spindle Afferents in Walking Cats

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## INTRODUCTION

The functional role of the gamma-motoneuron system in the regulation of muscle spindle afferent discharge during the execution of normal movements remains an elusive but very important topic in the field of motor control. The only records from presumed fusimotoneurons have been obtained either in anaesthesized animals (SEARS, 1964 ; APPENTENG et al., 1980), or in decerebrate preparations (SEVERIN, 1970). In recent years, flexible wire electrodes implanted in cat lumbar dorsal roots or ganglia (PROCHAZKA et al., 1976 ; LOEB et al., 1977) have provided records of discharge patterns of spindle afferent endings during unrestrained locomotory movements. Stable recordings from intact alpha-motoneuron axons coursing along ventral roots have also been achieved (HOFFER et al., 1981b). To date, however, implanted wire electrodes have not rendered proven records from gamma-motoneuron axons, which are of finer caliber and consequently generate much smaller extracellular currents.

As an alternative to direct recording, fusimotor firing patterns may be inferred from the normal discharge patterns of spindle afferents, when compared to the "passive" spindle response to similar limb movements in the absence of fusimotor bias. We present here a method for selective blockade of fine-caliber fibers, which has allowed us to monitor the discharge of single spindle Ia fibers in normal cats walking in a treadmill, through periods of progressive functional spindle deefferentation and subsequent reefferentation. The method relies on the well-known differential sensitivity of peripheral nerve fibers of different diameters to sodium-channel blocking anaesthetics. Infusion of a weak solution of procaine has previously been reported to cause conduction blockade in gamma motoneurons with sparing of the much larger Group Ia afferent fibers, in acute cat experiments (MATTHEWS, RUSHWORTH, 1957) as well as in conjunction with microneurography in humans (HAGBARTH et al., 1970).

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We used a cuff electrode, which was installed around the femoral nerve of cats for recording purposes (HOFFER et al., 1981a), to gain access to the perineural space via an implanted catheter. Infusion of a 0.3% solution of sodium xylocaine in small doses over several minutes caused progressive conduction blockade of small myelinated fibers, leading to concomitant changes in the discharge patterns recorded from individual spindle afferents. The progressive functional deefferentation of spindles was gradually reversed after flushing with mammalian saline solution.

## METHODS

### Design and surgical implantation of devices.

Experiments were performed in 17 cats of both sexes, weighing 3.0-5.5 Kg. Prior to surgery, cats were trained to walk on a motorized treadmill at a range of speeds and continuously for periods of up to 30 min. Implantation of devices was performed aseptically under deep pentobarbital anaesthesia. Analgesic drugs were administered if postsurgical pain or discomfort was apparent. The cats were allowed to recover for 3-7 days before recording sessions during locomotion were started, by which time they generally walked with normal load bearing and no visible limping.

Figure 1 shows schematically the "backpack" connector and the pertinent electrodes and devices that were implanted chronically, some of which have been described in detail previously (LOEB et al., 1977 ; 1979 ; 1981 ; HOFFER et al., 1980 ; 1981a ; 1981b). Up to a dozen flexible wire electrodes were implanted in the fifth lumbar dorsal root or dorsal root ganglion (L5 DRG), to record the activity of single Group Ia spindle afferents. The femoral nerve recording cuff was made of silicone elastomer tubing 15-30 mm long, inside diameter 2.5 mm (Extracorporeal 250), slit longitudinally. Three or five Pt-10%Ir (Medwire 10Ir 9/49T) Teflon-coated, stranded-wire recording electrodes, sewn circumferentially along the inside wall, were connected in one or two tripolar arrangements for differential recording (HOFFER et al., 1981a ; 1981b).

The xylocaine infusion catheter, about 200 mm long, emerged percutaneously just lateral to the spine. It was made of Silastic tubing 1.0 mm inside diameter (ID), 2.1 mm outside diameter (OD ; Dow Corning 602-205). The distal portion of the catheter consisted of finer tubing 0.5 mm ID, 1.0 mm OD (Dow Corning 602-135), which penetrated a hole punched through the nerve cuff wall about half-way along the length of the cuff. The finer tubing also served as

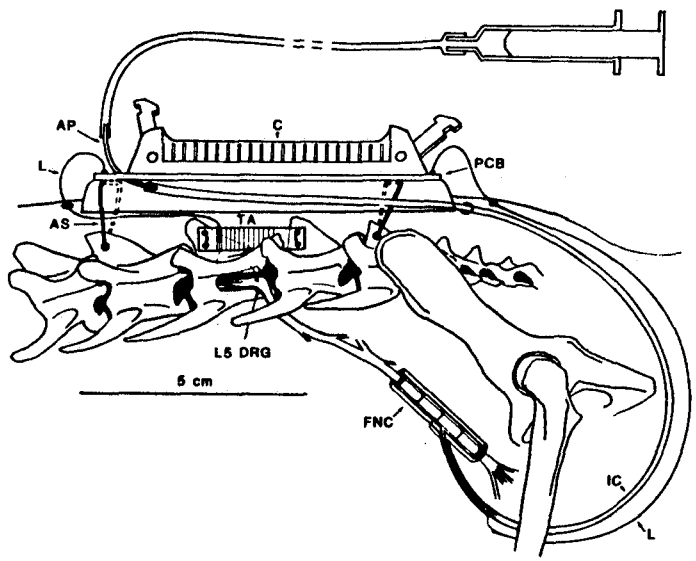


Fig. 1. Schematic diagram of devices implanted in the lumbar region and left hindlimb of cats. Up to a dozen "hatpin" microelectrodes (HOFFER et al., 1981a & b) were implanted in the L5 ganglion (L5 DRG) through a laminotomy. The flexible wire leads (one is shown) were soldered to stranded steel wires inside a Silastic tube array (TA) anchored with sutures to the L5 and L6 spines. The femoral nerve cuff (FNC) contained five electrodes and a flexible catheter which emerged percutaneously and ended in a stainless steel access port (AP) mounted on the "backpack" connector. The backpack was external to the skin, and was anchored to the animal by two sutures (AS; Mersilene size 5) which coursed through holes drilled in the L4 and L7 spines. A total of 40 stranded stainless steel lead wires (L) originating from implanted devices emerged percutaneously in bundles and were soldered to individual pads on a printed circuit board (PCB) on which was mounted a standard 40-pin computer ribbon connector (C; 3M Scotchflex No. 3432). A syringe was connected via a long flexible tube to the catheter access port in order to deliver a solution of xylocaine to the femoral nerve while the cat was walking

a core around which the five fragile Pt-Ir lead wires were wound helically to form a flexible cable. A piece of tubing 1 mm ID, 1.5 mm OD (Sil-Med 40-60) was expanded by immersion in toluene for about 2 min and slipped over the fine tubing and wound wires to provide a protective cover. Silastic Medical Adhesive (Dow Corning 891) was injected between the tubes to insure mechanical strength and impermeability. The Pt-Ir lead wires emerged from the coiled cable portion and were soldered to Teflon-coated stranded stainless steel



wires (Bergen Wire Rope 03.48), which coursed subcutaneously and were soldered to pads on the saddle connector printed circuit board.

The emerging catheter was fitted over a stainless steel hypodermic tube, 1.1 mm outside diameter, bonded with epoxy to the saddle connector (see Fig. 1). The catheter access port was normally capped with tight-fitting Silastic tubing with one end sealed. To prevent plugging, the catheter was flushed every two days with 1.0 ml of a sterile solution of sodium heparin (50 units/ml) in mammalian Ringer's.

Unitary recording and characterization protocol.

The typical preparation was maintained 5-6 weeks. On a typical recording day, the cat was first walked on the treadmill at several speeds. Data from active microelectrodes and ancillary data from peripheral nerve and muscle electrodes, as well as muscle length and force (HOFFER, LOEB, 1980) were recorded on FM tape. The movements were videotaped using two cameras. Spindle afferents were tentatively identified by their response to passive limb manipulations, behavior during voluntary movements, and conduction velocity obtained from spike-triggered averaging (HOFFER et al., 1981a) ; definitive characterization (see LOEB, DUYSENS, 1979) had to await the conclusion of the recording session, when deep pentobarbital anaesthesia was induced via a second implanted catheter leading to an external jugular vein. If any unit was presumed to be a Group Ia spindle afferent, its behavior during a xylocaine blockade run was recorded next. The cat was made to walk at a constant speed, interspersed with brief periods at other speeds or gaits. After a few minutes of control walking, a 0.3% solution of xylocaine in sterile mammalian Ringer's, warmed to 37°C and contained in a 3 ml syringe, was infused via a 30 cm long tube connected to the catheter access port. A total of 2.0-2.5 ml of solution was infused in 0.5 ml increments delivered about once per minute, while the cat continued to walk. The discharge pattern of the presumed spindle afferent was monitored on a loudspeaker and by an oscillographic display of the instantaneous firing rate.

RESULTS

In general, the bursting pattern of a spindle afferent underwent several discrete changes as the fusimotor blockade progressed, which suggests that the several fusimotor fibers innervating the spindle were blocked sequentially. Each incremental infusion caused either no change in spindle activity, or one or two relatively sudden changes in spindle afferent firing, each taking

place only during a particular phase of limb motion. By 5-12 min a final activity pattern was usually reached. Ten to 15 min later, the catheter was infused with a 37°C solution of mammalian Ringer's to wash out the xylocaine and reverse the block. Since the delivery tube and catheter (with combined volume of approximately 0.5 ml) still contained xylocaine, the initial response to infusion of saline was sometimes in the direction of increased blockade. The blockade sometimes extended from gamma- to alpha-range motor fibers, evidenced by a more pronounced yield at the knee joint during the stance phase and by changes in the EMG of knee extensor muscles. In rare occasions the progression of blockade also involved the axon of the recorded IA afferent, which stopped firing abruptly and did not recover until the xylocaine was washed out.

Additional 0.5 ml increments of saline wash solution brought about a progressive restoration to control conditions over the next 10-30 min. The discharge pattern of the Ia afferent typically recovered in discrete steps, suggesting that fusimotor neurons returned to function sequentially, in a roughly symmetric fashion to the sequence of blockade onset (see Discussion).

An example of changes in the discharge pattern of a sartorius pars medialis Group Ia spindle afferent (conduction velocity = 94 $\pm$ 5 m/s) caused by xylocaine infusion is shown in Figure 2. The left half (Part A) shows typical activity during three normal steps, with the cat walking at 0.44 m/s. This ending typically exhibited two periods of activity during each step cycle : a sharp burst late in the swing phase (arrows), which started as the muscle reached minimum length, lasted about 50 ms with a peak rate of about 150 pps, and ended abruptly ; and a smoothly accelerating burst that lasted over most of the stance phase, when the muscle was lengthening, and reached peak values of 100-120 pps. In addition, the afferent fired a few spikes during the flexion phase (in spite of rapid muscle shortening). The amplitude of the sharp burst was not well correlated with velocity of lengthening. The smoothly accelerating burst appeared related primarily to muscle length.

Xylocaine infusion had a dramatic effect on the sharp burst, whereas the second burst was relatively unaffected (Fig. 2B). Ninety seconds after xylocaine infusion, with the cat walking at the same speed on the treadmill, the sharp burst was no longer present at the predicted time in each step cycle (arrows). However, all the recorded kinesiological parameters (muscle length, velocity, force at the patellar ligament, and EMG of the sartorius pars medialis as well as vastus medialis) were virtually unchanged. At this time, the activity of the ending during the extension phase was also not much



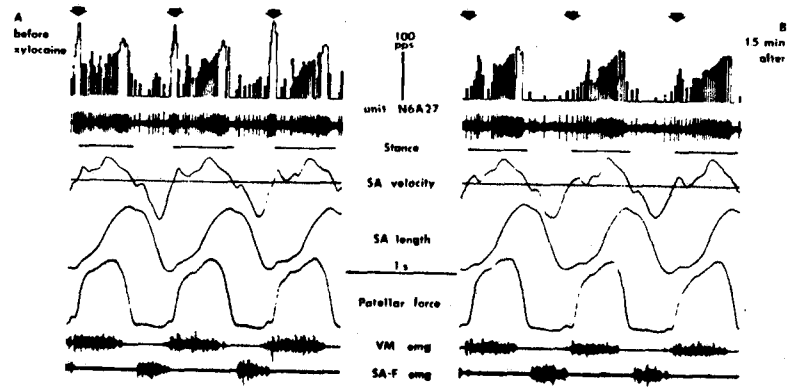


Fig. 2.

A : Activity recorded from a Ia afferent supplying a spindle in the proximal part of sartorius pars medialis, during three consecutive steps. Traces show : instantaneous frequencygram and raw microelectrode record from afferent unit ; bars indicating stance phase of gait ; electronically derived velocity of sartorius ; length of sartorius, obtained from an implanted length gauge (HOFFER, LOEB, 1980) ; force generated at the patellar ligament, obtained from an implanted transducer (HOFFER, LOEB, 1980) ; and electromyograms from indwelling bipolar electrodes sampling vastus medialis (VM) and the medial portion of sartorius (SA-F). Arrows above indicate the times of occurrence of a sharp burst in each step cycle.

B : Activity recorded from the same Ia fiber ninety seconds after xylocaine infusion via the femoral nerve catheter. Note the disappearance of the sharp bursts at the end of the swing phase, unaccompanied by any major changes in the kinesiological parameters monitored. Figure reproduced from HOFFER, LOEB, 1981. Further description in text

affected. A few minutes later the block progressed further, causing a reduction in the amplitude of the smoothly accelerating burst, to 60-80 pps. Activity of this fiber returned to normal some 20 min after the xylocaine was flushed out with saline. We interpret these observations to indicate that this spindle ending was normally under the influence of strong static gamma bias during the swing phase. Dynamic fusimotor activity appeared to have only a moderate role in influencing the stretch sensitivity during the stance phase.

## DISCUSSION

The method of progressive nerve fiber blockade with xylocaine infusion has demonstrated directly that fusimotor neurons can have marked effects on the discharge patterns of individual Group Ia spindle afferents during normal locomotion. The discrete changes observed after xylocaine infusion are consistent with the sequential blockade of several fusimotor fibers influencing a spindle ending. The order in which different fusimotor axons cease to conduct presumably depends on the inherent sensitivity of each fiber to the anaesthetic, which is related to the inverse of the fiber diameter. In the case of a large peripheral nerve like the cat femoral (about 2 mm in diameter), the diffusion rate of the drug through the tissue must also be taken into account. Superficial fibers can be expected to block earlier than fibers of similar diameter that lie deeper in the nerve. Some blockade of the smallest alpha-motoneurons may occur, particularly if fusimotor blockade must include the intermediate-sized beta-motoneurons. Interestingly, this loss appears to be fully compensated, since limb trajectory is preserved despite a significant alteration in cutaneous as well as proprioceptive feedback.

Detailed observation of the changes in firing patterns of seven Group Ia endings from sartorius have suggested to us that, in general, the functional removal of one fusimotor fiber affects either the activity burst during flexion or the activity burst during extension, but not both simultaneously. Thus, fusimotor neurons innervating sartorius appear to be organized into at least two distinct functional pools (HOFFER, LOEB, 1982 ; see also LOEB, 1981 and LOEB, HOFFER, 1981). This type of analysis of the discharge patterns of spindle endings in the presence and in the absence of fusimotor blockade is expected to reveal further details about the functional organization of fusimotor neurons and about their patterns of activation during normal movements.

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