EFFECTS OF EXERCISE ON REFLEXES IN PARAPLEGIC MONKEYS


Audie L. Murphy VA Hospital and Department of Physical Medicine and Rehabilitation, The University of Texas Health Science Center at San Antonio, San Antonio, Texas 78284, USA
and
Department of Anatomy and Institute of Neurological Sciences
University of Pennsylvania, Philadelphia, Pennsylvania 19104, USA

Abstract. Eight monkeys, after complete spinal cord transection at the midthoracic level, were placed in a supine position and an exercise program was given to one hindlimb but not the other. Within 3 days, the exercised limb showed more muscle tone and more active cutaneous and proprioceptive reflexes. The difference increased progressively throughout the observation period of 11 to 36 days. These results suggest an important role of afferent influence on the recovery of spinal shock. The exercise program probably protects the neuromuscular apparatus from deterioration and thus maximize the recovery.

INTRODUCTION

Spinal cord transection at the midthoracic level in the monkey reduces the hindlimbs almost to an areflexic state (spinal shock). Pinch of the foot yields a slight quiver of the toes. Adductor and knee jerks are feeble. These are the only remnants of reflex activity during the first hour after transection. During the second hour, three other reflexes may appear transiently and then drop out for several days. These are the hamstring jerk, the ankle jerk, and flexion of the hip. This transient activity has been ascribed to antidromic conduction from ephaptic ex-
citation of afferent neurons adjacent to those conducting evoked potentials. About two days after transection, the cremasteric reflex recurs. Thereafter, a number of reflexes return in quick succession. Ipsilateral adduction may be elicited from a point external to the knee at 3 days and as a concomitant of the flexor reflex at 5 days. Toe jerks return at about 5 days. Crossed extension is a late reflex which may be elicited by stroke or pinch of the skin from the external aspect of the thigh at about the 15th day and by passive flexion after 3 weeks. These early changes beyond the ephaptic period are due in part to recovery of ascending neurons from axonal degeneration, recovery of interneurons from loss of mitochondria in their terminals, and release from inhibition from above the transection. During the second month, reflex thresholds continue to fall, and responses grow stronger and irradiate widely. Tapping a flexor muscle yields contraction no longer confined to the muscle tapped but extending to other flexors. This hyperreflexia is a late event which is chiefly due to replacement of degenerated terminals by sprouts from afferent axons and to recurrent facilitation. Hypersensitivity of partially denervated neurons may play a part (1, 2, 4).

Nesmeyanova (5) has studied the long term effects of additional afferent stimulation on the recovery after spinal cord transection. She found that reflex responses in the hindlimbs were better in the chronic T10–T11 spinal cord transected dogs receiving massage, passive exercise and electrocutaneous stimulation than those receiving no such treatments. In this paper, we present our findings demonstrating the significant role of afferent influence on reflex recovery in the monkey during the first 5 weeks following spinal cord transection. Preliminary results were reported (7).

MATERIALS AND METHODS

Eight adult monkeys, Macaca mulatta, were subjected to complete spinal cord transection at the midthoracic level (T5–T8) with aseptic techniques under intravenous Nembutal anesthesia. The animals were then placed in a supine position on a thick foam rubber pad. In each paraplegic monkey, an exercise program was given to one hindlimb but not the other.

The exercise programs consisted of electrical stimulation to induce limb motion and/or passive range of motion exercises. In one monkey, intermittent electrical stimulation was applied to the skin to induce continuous motion of the limb throughout the observation period of 16 days following spinal cord transection. Three monkeys received continuous range of motion exercise, including flexion and extension of
hip, knee and ankle joints utilizing an electrically driven eccentric axle affixed to the foot. This experiment was continued for 11, 18 and 27 days. Two monkeys received manual passive range of motion exercise for 30 min each day and intermittent electrical stimulation during the remainder of the time and observed for 30 and 36 days. The remaining two monkeys, which were kept 17 and 31 days after the surgery, were subjected to range of motion exercises manually for 30 min and by the electrically driven axle for 6 h each day.

All the hindlimbs, exercised or non-exercised, in these paraplegic monkeys were observed for changes in muscle tone, cutaneous (exteroceptive) and proprioceptive reflexes. The findings were documented by electromyography. At the termination of the experiments, spinal cords were removed for anatomical studies. (Anatomical studies have not been completed). Individual major muscles of the hindlimbs were dissected and removed for determination of the bulk and weight.

RESULTS

Although the exercise programs applied to the paraplegic monkey were not the same, the results were relatively comparable.

Muscle tone as determined by the resistance to passive movement of the joint was variable from muscle to muscle and from animal to animal. Recovery of muscle tone could be noted in one to 3 days after spinal cord transection, earlier in the exercised limb. By 8 days postoperatively, muscle tone was clearly more in the exercised limbs than in the non-exercised ones.

Cutaneous reflexes showed varying degrees of difference between exercised and non-exercised limbs. Digital quivering in response to pinching the foot appeared in 1 to 3 days, sooner and stronger in the exercised limb. Clear difference was found as early as the 3rd postoperative day. Ipsilateral hip adduction following pinch of the foot appeared in two to 6 days and became more active in the exercised limb by 3rd to 9th postoperative days. Pinching the foot might also induce hip, knee or ankle flexion, more actively in the exercised limb (Fig. 1). The cremasteric reflex was better in the exercised side in only one monkey and essentially equal on both sides in the other animals. Crossed adductor or extensor responses usually appeared in the exercised limb when the non-exercised limb was stimulated but not the reverse. The threshold of the muscle responding to ipsilateral distant cutaneous electrical stimulation was lower in the exercised limb (Fig. 2).

Of the proprioceptive reflexes, some, such as adductor and knee jerks, persisted after spinal cord transection and became more active in the
Fig. 1. Responses of Rectus femoris (RF), Semitendinosus (ST) and Tibialis anterior (TA) to pinch of skin in a monkey 9 days after spinal cord transection at the midthoracic level. Top tracing: time scale in seconds; 2nd tracing (E): EMG of muscles in the exercised limb; 3rd tracing (N): EMG of muscles in the non-exercised limb; the bottom tracing: horizontal bars indicate the duration of pinch. The 5th toe was pinched in the exercised limb at A, C, E and in the non-exercised limb at B, D, F. Note the more active muscle responses in the exercised limb.

Fig. 2. Responses of Rectus femoris (RF), Semitendinosus (ST) and Tibialis anterior (TA) to distant electrical stimulation of skin in a monkey 9 days after spinal cord transection at the midthoracic level. Top tracing: time scale in seconds; 2nd tracing (E): EMG of muscles in the exercised limb; 3rd tracing (N): EMG of muscles in the non-exercised limb; the bottom tracing: arrows indicate onset of stimulation. The dorsal skin between the 1st and 2nd toe was stimulated in the exercised limb at A, C, E. and in the non-exercised limb at B, D, F. (4 mA, 5 ms and 30 volleys were applied). Note the active response in the exercised limb but no or minimal response in the non-exercised limb.

exercised limb than in the non-exercised limb by 2 to 6 days (Fig. 3). Ankle jerk returned in 3 to 6 days in exercised limbs and in 4 to 8 days in non-exercised limbs and was more active in the exercised sides thereafter. Hamstring jerk returned by 6 days in the exercised limb but was absent for 9 or more days in the non-exercised limb. There was then always a weaker hamstring jerk in the non-exercised limb (Fig. 3). Toe jerks returned in 4 to 6 days and did not show a clear difference
Fig. 3. Responses of Adductor (AD), Semitendinosus (ST) and Quadriceps (QC) to tapping of the tendon in a monkey 16 days after spinal cord transection at the midthoracic level. Top tracing: time scale in seconds; 2nd tracing (E): EMG of muscles in the exercised limb; 3rd tracing (N): EMG of muscles in the non-exercised limb; bottom tracing: vertical bars indicate tapping of the tendon. Exercised limb was tested at A, C, F, and non-exercised limb at B, D, E. Note that these deep tendon reflexes are more active in the exercised limb. Note also the cross Adductor response in the exercised limb when the adductor jerk was tested in the non-exercised limb.

Fig. 4. Responses of Rectus femoris (RF), Semitendinosus (ST) and Tibialis anterior (TA) to stretch by passively moving the joint in a monkey 9 days after spinal cord transection at midthoracic level. Top tracing: time scale in seconds; 2nd tracing (E): EMG of muscles in the exercised limb; 3rd tracing (N): EMG of muscles in non-exercised limb; bottom tracing: horizontal bars indicate the duration of stretch. The muscle was stretched in the exercised limb at A, C, E and in the non-exercised limb at B, D, F. Note the marked difference between exercised and non-exercised limbs. Note also the crossed response in the RF of the exercised limb when the muscle of the non-exercised limb was stretched.

between exercised and non-exercised limbs in five animals but were more active in the exercised limb in the other three animals. Muscle responses to manual passive stretch were more active in the exercised limbs. Crossed responses were noted in the muscles of the exercised
limbs when the non-exercised muscles were stretched but not the reverse (Fig. 4).

The difference between exercised and non-exercised limbs increased progressively throughout the observation period. When individual major muscles of the hindlimbs were dissected and removed, the bulk and weight of these muscles were found to be greater in the exercised limb.

DISCUSSION

The results suggest an important role of afferent influence on the recovery of spinal shock. The reflex responses in the exercised limbs, though much more active than those in the non-exercised limbs, were similar to those reported earlier. Thus, the exercise programs seemed to maintain the neuromuscular apparatus in a healthy state and maximize the spontaneous recovery. The marked differences in reflex responses between exercised and non-exercised limbs are probably due to the deterioration of neuromuscular condition in the non-exercised limbs.

In this study, some animals were subjected to exercise and/or electrical stimulation continuously and some received exercise for about 6 h per day. In the earlier studies (2, 4), the attempt to keep paraplegic monkeys healthy consisted only of range of motion exercises for 5 to 10 min per day. However, the recovery pattern of reflex responses in the exercised limbs of the monkeys in this study and in both hindlimbs of the monkeys used in the earlier studies was similar. These findings suggest that the exercise programs maximize the effects of spontaneous recovery but do not facilitate the rate of the recovery. Maximal spontaneous recovery can be expected as long as the neuromuscular systems are kept healthy. The more intensive training program does not necessarily shorten the time required to reach the plateau of spontaneous recovery.

Our studies on functional recovery with training after central nervous system lesions have shown that training can improve function beyond that due to spontaneous recovery (6). The trained behavior is difficult to transfer to an unconditioned or another conditioned behavior. Thus, direct training is usually essential. In this study with paraplegic monkeys, the reflexes, even in the exercised limbs, did not seem to improve beyond that seen with spontaneous recovery. This is probably because the exercise and/or electrical stimulation applied to these monkeys were not specifically designed to improve the reflexes under investigation. If a direct training program were given, the effects might be different. For example, scratch reflex could be elicited in cats following spinal cord transection at T6. Frequent testing of this reflex gradually decreased
the threshold and increased the response and even induced tonic-clonic seizures following it. With passage of time, seizure threshold was reduced and the trigger zone expanded (3).

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REFERENCES


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