

# Application of a New Muscle Exercise Device using Intermittent Sole Pressure Stimulation

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**Abstract.** [Purpose] The aim of this study was to determine the lower-limb muscle activities during muscle exercise using an on-the-bed muscle training device that utilizes the intermittent inflation of an oval rubber balloon placed against the sole. [Subjects and Methods] Ten healthy subjects were asked to adopt a semi-recumbent position with a flat oval chloridized polyvinyl balloon placed against the sole. The subjects were asked to extend both their legs when they felt the inflation of the balloon on their plantar surface. This exercise was defined as leg exercise against intermittent sole pressure stimulation (ExISPS). [Results] The root-mean-square (RMS)-EMG values of the vastus medialis during ExISPS in the semi-recumbent position were similar to those when standing up from 45-degree knee flexion and calf-raising. The RMS-EMG values of the biceps femoris showed no significant difference among these exercises. The RMS-EMG values of gastrocnemius medialis during ExISPS in the semi-recumbent position were higher than those when standing up from 45-degree knee flexion and standing up from a chair. [Conclusion] The findings of this study suggest that the muscle activities during ExISPS mimic or are greater than those required of the leg in daily life.

**Key words:** Muscle training device, Sole pressure stimulation, Compressed air

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## INTRODUCTION

Prolonged bed-rest leads to disuse syndrome<sup>1)</sup>. Disuse syndrome shows local manifestations such as muscle weakness, muscle atrophy, joint contracture, and the loss of bone density, and also shows systemic manifestations such as cardiorespiratory dysfunction, digestive dysfunction, and mental dysfunction.

Muscle atrophy and muscle weakness are representative clinical features of disuse syndrome. It is known that bed rest results in a muscular strength decrease of 1.0–1.5% per day<sup>2)</sup>. Moreover, the muscle weakness of the lower limbs, especially the weakness of antigravity muscles, is known to be more pronounced than upper-limb weakness<sup>3)</sup>.

In clinical situations, straight leg rising (SLR) and resistance exercises using a rubber band have been used to maintain muscle function in bed. Muscle exercise using an oval rubber balloon placed against the sole is also a method used for muscle training in bed<sup>4)</sup>. This device has been found to be effective for some patients who need bed-rest; however, the effectiveness of this device is limited because the leg exercise is a voluntarily performed for which the

patient's motivation is relevant. Voluntary leg exercise may be encouraged nurses or physiotherapists to stimulate patients' motivation to move their feet, we made a device that utilizes an oval rubber balloon which is placed against the sole and intermittently inflated with compressed air.

In this study, we determined, the lower-limb muscle activities during lower-limb exercise using oval balloon device, which was placed against the sole and intermittently inflated with compressed air.

## SUBJECTS AND METHODS

Ten healthy volunteers (mean age 29.4 (25–41) years, 5 male and 5 female) participated in this study. Subjects were included in the study if they were more than 20 years of age and had no musculoskeletal abnormalities that might interfere with the ability to perform the exercise, no significant cardiovascular disease, and no history of cerebral vascular disease. Written, informed consent was obtained from all subjects prior to the exercise tests and ethical approval for the study was granted by the University Ethics Committee (No. 08010).

The subjects were asked to adopt a semi-recumbent position (head of the bed elevated to 30 or 70 degrees) with slight knee flexion in the bed. A flat oval chloridized polyvinyl balloon (30 cm in diameter) was placed against the sole. The center of the balloon was adjusted to give ankle flexion of 0 degree (Fig. 1).

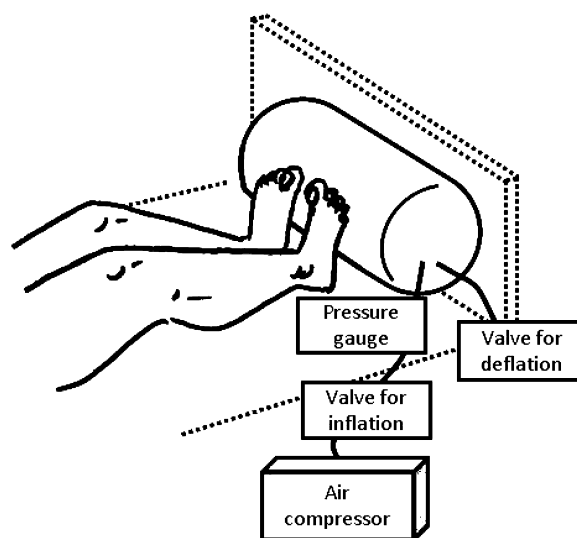
The inner pressure of the balloon was increased using an air compressor (JUN-AIR 3-4, JUN-AIR International A/S, Denmark). The balloon was inflated once every 30 seconds and deflated when the inner pressure of the balloon reached 15 kPa. The subjects were asked to extend both their legs as much as they could when the subjects felt the inflation of the balloon on the plantar surface of their foot. We called this exercise: leg exercise against intermittent sole pressure stimulation (ExISPS).

During each leg exercise, the surface EMG activities of the vastus medialis (VM), long head of the biceps femoris (BF), and gastrocnemius medialis (GM) were recorded using a portable EMG system (ME6000; Mega Electronics Ltd., Finland). After preparation of the skin, pairs of bipolar Ag/AgCl surface electrodes (Blue Sensor, Ambu M-00-S, Ballerup, Denmark) were placed on the VM, BF, and GM (interelectrode distance 30 mm) muscles of the right leg. The placement of bipolar surface electrodes for each muscle was carried out in accordance with Perotto<sup>5)</sup>. The sampling frequency was 1 kHz. The EMG results were analyzed using MegaWin software (ver.2.0, Mega Electronics Ltd., Kuopio, Finland). The root-mean-square (RMS)-EMG values of VM, BF, and GM for one leg extension were calculated during the tenth leg extension of ExISPS in the 70-degree and 30-degree semi-recumbent positions.

In addition to ExISPS, we measured the muscle activities when standing up from a chair (40 cm), standing up from 45-degree knee flexion, and calf-raising of three times. The RMS-EMG values were calculated during the second performance each activity. The RMS-EMG values of ExISPS in the 70-degree and 30-degree semi-recumbent positions were compared with the RMS-EMG values of standing up from a chair (40 cm), standing up from 45-degree knee flexion, and calf-raising.

Systolic blood pressure (SBP) and heart rates (HR) were measured at rest and before and after each exercise.

All statistical analyses were conducted using a statistical analysis software program (SPSS ver. 17.0; SPSS, Japan, Tokyo, Japan). Statistical significance was tested using the paired t-test or Wilcoxon's signed rank sum test, and the statistical significance of all statistical analyses was accepted if the p value was below 0.05.



**Fig. 1.** A device for intermittent sole pressure stimulation

## RESULTS

Table 1 listed the average RMS-EMG values of VM, BF, and GM in each exercise. The RMS-EMG values of VM during ExISPS in both semi-recumbent position were similar to those when standing up from 45-degree knee flexion and calf-raising, whereas that of standing up from a chair (40 cm) was significantly higher than those of the other exercises. The RMS-EMG values of BF showed no significant differences among the exercises. The RMS-EMG values of GM during ExISPS in the 70-degree and 30-degree semi-recumbent positions were higher than those when standing up from 45-degree knee flexion and standing up from a chair (40 cm). On the other hand, the RMS-EMG value of GM during calf-raising were significantly higher than those of the other exercises.

Heart rate and blood pressure showed no anomalous variation during each exercise.

## DISCUSSION

In this study, we determined the lower-limb muscle activities during lower-limb exercise using an oval balloon which was placed against the sole and intermittently inflated with compressed air. The sole surface senses the pressure stimulation when the balloon set up against the plantar area is inflated. This pressure stimulation becomes a clear

**Table 1.** Average root-mean-square (RMS)-EMG values of vastus medialis, biceps femoris, and gastrocnemius medialis for each exercise

	Vastus medialis ( $\mu$ Vs)	Biceps femoris ( $\mu$ Vs)	Gastrocnemius medialis ( $\mu$ Vs)
ExISPS in 30-degree semi-recumbent	242.9 $\pm$ 38.7	217.2 $\pm$ 38.4	476.8 $\pm$ 126.1
ExISPS in 70-degree semi-recumbent	269.8 $\pm$ 45.7	177.8 $\pm$ 21.8	520.2 $\pm$ 146.3
Standing up from a chair (40 cm)	591.0 $\pm$ 57.1*	180.5 $\pm$ 59.3	154.6 $\pm$ 24.1*
Standing up from 45-degree knee flexion	231.9 $\pm$ 34.0	157.6 $\pm$ 29.6	145.5 $\pm$ 27.3*
Calf-raising	228.1 $\pm$ 65.3	154.0 $\pm$ 48.9	895.0 $\pm$ 146.7*

Values are mean  $\pm$  SEM. \*p<0.05 vs. ExISPS. ExISPS: leg exercise against intermittent sole pressure stimulation (ExISPS).

afferent sensory stimulation as the balloon expands. This pressure stimulation is a trigger, and the patient starts to stretch his/her by pushing legs against the balloon. We thought that this trigger is an appropriate stimulus for starting leg exercise for patients in bed.

The possibility of muscle training in bed with this device was demonstrated, as muscle activities of VM, BF, and GM during ExISPS in both the 70-degree and 30-degree semi-recumbent positions were similar to those when standing up from 45-degree knee flexion, standing up from a chair, and calf-raising.

Ichihashi et al. reported that SLR exercise 5 times with maximum contraction did not prevent muscle atrophy at the normal side of the lower limbs of patients who were in bed for 30 days after an operation<sup>6)</sup>. Moreover, Ichihashi et al. reported that the amounts of muscle activities during SLR and patella setting, which are often performed while in bed, were overwhelmingly insufficient to prevent disused muscle atrophy of the quadriceps muscle<sup>7)</sup>. From the viewpoint of muscle activity, they suggested that it would be necessary to do many repetitions to prevent disused muscle atrophy of the quadriceps muscle. That is, it is necessary to carry out muscle exercise equal to that performed in daily living activities to prevent disuse muscle atrophy. Since our balloon device elicited the same degree of muscle activity as used in ADL and provides a trigger for automatic muscle contraction, the clinical application of this device can be expected.

A feature of the muscle activity in the total leg extension performed in the present study is that it was not just movement of pushing against a balloon that was inflated beforehand. The muscle activity of total leg extension pushing against the oval balloon, which was placed against the sole and intermittently inflated, simulated standing up training. It is said that muscle training should be performed as much as possible along with the “principle of specificity”<sup>8)</sup>. This type of exercise is also called a closed kinetic chain exercise<sup>9)</sup>. Closed kinetic chain exercises are already being used in physical therapy practice for muscle training (coordinated neuromuscular training) with afferent stimulation<sup>9)</sup>.

The leg muscle activities during ExISPS in the 70-degree

semi-recumbent position were similar to those when standing up from 45-degree knee flexion and calf-raising. This result suggests the possibility of lower-limb training using this device in bed. The practical utility of the device is expected.

In this research, we did not determine whether muscle atrophy could be prevented since this study examined only muscle activity and cardiovascular responses, together with a comparison of the muscle activities with those of other ADL task. Therefore, further investigation, including a larger controlled study, is needed to confirm the device’s clinical application.

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