

Acute and Chronic Effects of Lower Body Positive Pressure Exercise on the Very Elderly: A Pilot Study

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Abstract

Treadmill walking with body weight support can decrease weight bearing on the lower extremities and is a routine treatment used for patients with neurological and musculoskeletal injuries. In particular, lower body positive pressure (LBPP) is effective for decreasing ground reaction forces and provides safe gait training after surgical procedures. However, the effects of LBPP on the very elderly are unknown. We report on the acute and chronic effects of LBPP exercise in very elderly patients without long-term changes in muscle strength or activities of daily living. Thirteen very elderly patients (age 86.3 ± 5.1 years) admitted to a nursing care home were divided into an intervention group ($n=7$) and a control group ($n=6$). The intervention group performed 6 min of LBPP exercises once every week in addition to undergoing a standard rehabilitation program. The control group did not perform LBPP exercises. The outcome measures included quadriceps muscle strength, visual analog scale (VAS)-based pain assessment, grip strength, walking speed (WS), and 6-min walking distance (6MD). Compared with the control group, the LBPP group had significant improvements in quadriceps muscle strength and VAS ($p < 0.05$) just after the first intervention and in WS and 6MD ($p < 0.05$) 1 month after the intervention. LBPP exercise performed by the very elderly was effective for decreasing pain and increasing muscle strength in the short term and for increasing WS and 6MD in the long term. Thus, LBPP exercise is safe gait training alternative in this population.

Keywords: Lower body positive pressure exercise; Latter-stage elderly; Treadmill walking with body weight support; Rehabilitation programs

Introduction

Japan has the most rapidly aging society in the world, and is the first large country with a population declining rapidly because of death due to natural causes [1]. The life expectancy among Japanese is also the highest in the world, with a mean age of 79.4 years for men and 85.9 years for women [2]. Among elderly patients, age-related loss of muscle strength is a main factor causing functional limitations in the activities of daily living (ADL), such as rising from a chair or climbing up and down stairs [3-5].

Rehabilitation is designed to prevent the complications of inactivity, such as muscle atrophy, fibrous contractures, and cardiopulmonary deconditioning. Lower extremity rehabilitation for patients with osteoarticular disorders requires limited weight bearing to protect healing tissues. The use of assistive devices, such as crutches or walkers, for physical therapy can be particularly difficult in patients with osteoarthritis or spinal cord injury. Machine training, aerobics, and other activities are recommended to promote health among the elderly, although there are few programs for strengthening weak lower extremity muscles in inactive elderly people [6]. Thus, treadmill walking with body weight support is commonly used to decrease the load on the lower extremities during rehabilitation.

Recently, a new type of treadmill was introduced (UKI-UKI TRAINER® treadmill; Showa-denki Inc, Osaka, Japan; (Figures 1 and 2)). This device allows for low-load walking using of an emerging technique known as lower body positive pressure (LBPP) technology, which utilizes a waist-high air chamber that can be inflated with positive air pressure to modify body weight during ambulation. During an exercise session, a subject wears a pair of neoprene shorts with a kayak-style skirt that zips into an air chamber, thus creating an airtight seal. When the air chamber is inflated, air pressure increases around the lower body and lifts the subject upward at the hips. This effectively decreases gravitational forces and, consequently, body weight on the lower extremities to a level that can be adjusted with a high degree of

consistency. Positive air pressure then decreases lower extremity weight bearing (i.e., unweighting) in increments ranging from 1% to 80% of the total body weight. LBPP has been found to be superior to other methods of unweighting such as upper body harnesses that partially support body weight and aquatic exercises, because air pressure is applied uniformly over the lower body. This decreases the formation of pressure points, which are common with harness-based systems, while maintaining normal muscle activation and gait patterns, which are altered during aquatic activities.

Cutuk et al. demonstrated that during stance, the heart rate decreased significantly from 83 ± 3 beats/min at ambient pressure to 73 ± 3 beats/min at 50 mmHg LBPP ($P < 0.05$). During ambulation with LBPP exercise at 3 mph (1.34 m/s), the heart rate decreased significantly from 99 ± 4 beats/min at ambient pressure to 84 ± 2 beats/min at 50 mmHg LBPP ($P < 0.009$). Blood pressure, brain oxygenation, blood flow velocity through the middle cerebral artery, and head skin microvascular blood flow did not significantly change with LBPP exercise. As allowed by LBPP, ambulating at 60% and 20% of body weight decreased ground reaction forces ($P < 0.05$), whereas knee and ankle sagittal ranges of motion remained unaffected [7]. Thus, LBPP treadmill technology is gaining popularity as a system that can be used to study weight-supported or low-load exercise in a user-friendly and kinematically correct manner without altering gait dynamics or cardiovascular parameters, such as heart rate and blood pressure [8].

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Received October 31, 2013; **Accepted** December 19, 2013; **Published** December 25, 2013

Citation: Miura M, Kohzaki M, Ito O, Nagasaka M, Kinoshita H, et al. (2013) Acute and Chronic Effects of Lower Body Positive Pressure Exercise on the Very Elderly: A Pilot Study. Int J Phys Med Rehabil 1: 173. doi:10.4172/2329-9096.1000173

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LBPP trials have been reported for patients with several musculoskeletal conditions, including those who had undergone meniscectomy and anterior cruciate ligament reconstruction and those with lower extremity trauma [9-11]. Those studies used LBPP to create a low-load exercise regime that facilitated early and/or pain-free ambulation or allowed patients to walk further and for longer periods than was possible during walking (full weight bearing) before surgery, and without any symptom exacerbation [12]. Their findings suggest that LBPP may be a promising method for providing remediated weight-bearing exercise regimens for patients with progressive knee osteoarthritis (OA) or those at risk for developing or exacerbating knee OA symptoms due to obesity that precludes normal exercise activities.

However, the effects of LBPP exercise on very elderly people are not well understood. Therefore, we studied the acute and chronic effects of LBPP exercise on inactive very elderly patients.

Methods

Subjects and overall design

In this prospective controlled study, we enrolled 13 very elderly patients (5 men and 7 women; mean age: 86.9 ± 4.6 years) who were admitted to an institute or a hospital for nursing care. Although continuous intervention with standard physical therapy was performed, due to chronic inactivity, all subjects had been unable to walk independently for at least 1 month before the start of the study. They

	LBPP group (n = 7)	Control group (n = 6)	P
Age	86.3 ± 5.1	86.0 ± 4.4	0.41
Height (cm)	151.9 ± 5.7	145.5 ± 15.4	0.33
Weight (kg)	49.8 ± 8.9	48.7 ± 11.0	0.41
BMI (kg/m ²)	21.7 ± 4.3	22.9 ± 3.6	0.55
FIM	113.6 ± 8.4	108.8 ± 8.8	0.11
WOMAC	214.8 ± 14.6	214.1 ± 14.1	0.48
Time from onset to start of the study (months)	20.6 ± 11.4	30.6 ± 6.6	0.94

Values are mean \pm SD. No significant differences were found for baseline characteristics.

BMI: body mass index

WOMAC: Western Ontario and McMaster Universities Arthritis Index

FIM: Functional Independence Measure

Table 1: Subjects' Demographic and Clinical Characteristics.

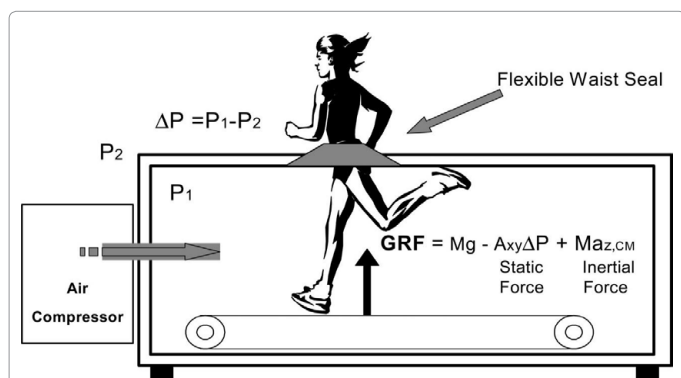


Figure 1: Schematic diagram of the lower body positive pressure (LBPP) treadmill chamber. A buoyant force (F_1) equal to the pressure differential (ΔP) between the pressure inside the chamber (P_1) and outside the chamber (P_2) multiplied by the cross-sectional area of the body and the flexible waist seal (A_{xy}) counteracts the downward gravitational force (Mg), thus decreasing the net vertical ground reaction force (GRF). During ambulation, an inertial force ($M_{a_z,CM}$) equal to the mass of the individual multiplied by the body's acceleration also contributes to net GRF.

had spent the major part of each day in their bedroom. Their OA grades were ≥ 1 based on the radiographic classification of OA and diagnosis of knee OA using American College of Rheumatology (ACR) criteria [13]. Patients were divided into an LBPP group (3 men and 4 women) and a control group (2 men and 3 women) by a physical therapist that was blinded regarding this study (Table 1).

Each subject in the LBPP and control groups completed a rehabilitation program approximately once within 20 min. The LBPP group performed both LBPP exercise and a routine physical/occupational therapy program. The control group underwent the physical/occupational therapy program alone. For the control group, a normal rehabilitation program that did not include treadmill training was conducted during the intervention period. The physical/occupational therapy program was designed according to individual needs and included range of motion (ROM) exercises, muscle-strengthening exercises, ADL exercises, and other similar exercises. All patients underwent a standard physical/occupational therapy program twice per week during the study period. Functional measurements were made before and after the first intervention (acute effects). In addition, inspection measurements were made after the intervention (chronic effects), which included evaluation of quadriceps muscle strength, visual analog scale (VAS)-based pain assessment, grip strength, maximum walking speed (WS), and physical activities (measured using a pedometer).

The room temperature was adjusted to $24-26^\circ\text{C}$ and humidity was maintained at approximately 60%. All patients were instructed to avoid heavy exercise, caffeine, aspirin, and analgesics for at least 24 h prior to experiments. They were also instructed to eat a normal breakfast or lunch 2 h before experiments. All measurements and exercises were performed between 10:00 and 15:00 h in both groups.

The patients were completely informed regarding our protocol, and all provided their informed consent to participate in this study. The Institutional Review Board of Tsukuba University of Technology approved our study protocol. Due consideration was given to the ethical rules for human experimentation as described in the Declaration of Helsinki.

We certify that there were no conflicts of interest with any financial organization regarding the material discussed in this manuscript.

Treadmill walking sessions (LBPP exercise)

The LBPP device consisted of a treadmill in an airtight chamber with an external air compressor (Showa Denki Co., Ltd., Osaka, Japan; (Figures 1 and 2)). Patients wore neoprene shorts with a kayak-style skirt that zipped into the air chamber, thus creating an airtight seal (Figure 1). Patients entered the chamber through a steel ring on top of the chamber. The ring height was adjusted to the level of the patient's anterior superior iliac spine. The waist seal was fastened over a lip of the ring and covered a 60-cm-diameter ring hole. The pressure inside the LBPP chamber was adjustable between 0 and 2.0 kPa above atmospheric pressure by regulating the airflow from the blower. Increased LBPP-induced buoyant forces decreased the ground reaction forces of the patient. Patients could walk on the treadmill with a speed ranging from 0.2 to 3.0 km/h. The decrease in GRF on a patient at 2.0 kPa of LBPP was estimated to be 15.0 ± 0.5 kg [14]. Patients in the intervention group performed LBPP exercise for 6 min once per week for 1 month at the level of an individual's anaerobic threshold [15].

Outcome measures

Quadriceps muscle strength: The maximal isometric voluntary contraction of the hip knee extensors was tested with a hand-held



Figure 2: Treadmill walking sessions: lower body positive pressure (LBPP) exercise. A patient wore neoprene shorts with a kayak-type skirt attached at the waist. Then, he/she stepped into the lower body positive pressure (LBPP) chamber and the compliance properties of the skirt were such that a subject was able to walk comfortably on an electronically controlled treadmill without leaning on the seal for support. Seal height was adjusted to the level at each subject's iliac crest, so that the seal itself exerted little or no vertical force when at ambient pressure.

	LBPP group (n = 7)			Control group (n = 6)		
	before	after	P	before	after	P
Muscle strength (N)	97.7 ± 12.1	112.3 ± 12.7 *†	.013	61.3 ± 3.0	60.5 ± 4.4	0.74
VAS	1.3 ± 0.8	0.0 ± 0.0 *†	.029	2.1 ± 2.3	2.3 ± 2.6	0.77
Grip (kg)	19.1 ± 6.2	17.0 ± 5.4	.64	17.2 ± 4.8	16.1 ± 4.1	0.60

Values are mean ± SD.

*p<0.05, significant difference from the beginning of the study

†p <0.05, significant difference between groups

Muscle strength: quadriceps muscle strength

VAS: visual analog scale (VAS for acute knee pain)

Table 2: Acute effects of lower body positive pressure (LBPP) exercise.

dynamometer (MODEL GT-300; OG-Giken Inc., Okayama, Japan). A subject was positioned in a high sitting position, with the hip and knee in 90° flexion. The dynamometer was placed on the anterior aspect of the tibia 5 cm proximal from the inferior tip of the medial malleoli. The mean value of 3 trials was used for data analysis. A 2-min rest period was allowed between trials to prevent muscle fatigue [16]. Then, quadriceps muscle strength was assessed before the intervention, immediately after the first 6-min intervention, and 1 month after the intervention.

Visual analog scale (VAS) for assessing acute knee pain: VAS scores for acute knee pain were recorded for all subjects. Average pain severity over the previous week was rated using a 100-mm VAS before the intervention, immediately after the first 6-min intervention, and 1 month after the intervention [17].

Grip strength: A digital hand dynamometer (MODEL T.K.K.5401; Takei Kogyo, Inc., Tokyo) was used for grip strength measurements by a trained physical or occupational therapist. The higher of 2 measures in the dominant hand was used for analysis [18]. Grip strength was measured before the intervention, immediately after the first 6-min intervention, and 1 month after the intervention.

Walking speed (WS) for a 10-m distance with maximum effort: A patient began to walk as quickly as possible from 3 m before the starting line, and timing commenced by a physical therapist when the patient's swing leg crossed the starting line and ended when the patient's swing leg crossed the finish line. Two trials were performed successively; the fastest time was used for calculations [19]. WS was then recorded for all subjects before and 1 month after the intervention.

Six-min walking distance (6MD): We measured 6MD according to American Thoracic Society guidelines [20]. The 6MD test was conducted on a 30-m long, hard, flat indoor corridor marked with orange traffic cones every 3 m. 6MD results are highly correlated with maximum oxygen uptake [21] and indicate the distance (m) that a person can cover in 6 min while walking quickly on a flat surface. This test imposes a decreased burden on a subject and easily evaluates ADL [22]. 6MD was recorded for all patients before and 1 month after the intervention.

Assessment of physical activity (measured using a pedometer): A patient's activities were measured using a pedometer (LIFECORDER; Suzuken Inc., Nagoya, Japan) over 2 weeks before the start of intervention and for 2 weeks after the completion of intervention. Physical activity levels were calculated as the product of the duration and frequency of each activity (in hours per day), and summed for all activities performed [23]. Activities were recorded for all patients before and 1 month after the intervention.

Statistical analysis: We performed statistical analysis using SPSS version 16.0 (SPSS Inc., Chicago, Illinois). Results are given as means ± standard deviations. Wilcoxon signed-rank tests were used to compare within-group results before and after the interventions. Mann-Whitney U tests were used to compare the results of unpaired data. A p-value of <0.05 was considered significant.

Results

The demographic and clinical characteristics of the patients at the beginning of this study are summarized in Table 1. There were no differences between the 2 groups for any of these variables.

Acute effects of LBPP

The measured results for the 2 groups at each time point are shown in Table 2. There were no significant differences between the 2 groups in any of the functional variables at the beginning of the study. In the LBPP group, quadriceps muscle strength significantly increased from 97.7 ± 12.1 to 112.3 ± 12.7 N (p<0.05), whereas VAS scores significantly decreased from 1.3 ± 0.8 to 0.0 ± 0.0 (p<0.05). However, extremity muscle strength in the LBPP group did not increase. No significant changes were observed in the control group.

Chronic effects of LBPP

The measured results for the 2 groups at each time point are summarized in Table 3. There were no significant differences between the 2 groups in any of the functional variables at the beginning of the study.

In the LBPP group, WS significantly improved from 11.0 ± 3.3 to 18.5 ± 3.2 m/min (p<0.05), and 6MD significantly improved from 58.7 ± 10.8 to 108.5 ± 20.5 m (p<0.05). However, quadriceps muscle strength and VAS did not improve 1 month after the intervention. Immediately after the first intervention in the LBPP group, activity increased from 824.3 ± 443.1 to 1098.5 ± 544.2 steps (p<0.05), whereas upper extremity muscle strength remained unchanged. No significant changes were observed in the control group.

Discussion

In this study we examined the acute and chronic effects of LBPP exercise on the very elderly. We evaluated the effects on selected functional variables and found that LBPP exercise may facilitate a change from inactivity to activity in these very elderly patients.

It should be noted that VAS scores, WS, 6MD, and activities

	LBPP group (n = 7)			Ctrl group (n = 6)		
	Before	After 4W	P	Before	After 4W	P
Muscle strength (N)	97.7 ± 12.1	112.5 ± 9.7	.72	61.3 ± 3.0	63.1 ± 18.4	0.74
VAS	1.3 ± 0.8	1.0 ± 1.0	.28	2.1 ± 2.3	2.2 ± 1.9	0.77
Grip strength (kg)	19.1 ± 6.2	18.7 ± 6.0	.64	17.2 ± 4.8	16.8 ± .4	0.10
WS (m/min)	11.0 ± 3.3	18.5 ± 3.2*†	.02	9.8 ± 6.4	10.0 ± 6.5	0.35
6MD	58.7 ± 10.8	108.5 ± 20.5 *†	.04	48.0 ± 33.5	43.1 ± 27.4	0.10
Activities	824.3 ± 443.1	1098.5 ± 544.2 *	.02	1296.0 ± 251.5	1363.7 ± 259.8	0.23

Values are means ±SD's.

*p< 0.05, significant difference from the beginning of the study

†p< 0.05, significant difference between groups

Muscle strength: quadriceps muscle strength

WS: walking speed

VAS: visual analog scale (VAS for acute knee pain)

6MD: 6-minute walking distance

Activities (measured by pedometer) per day

Table 3: Chronic effects of lower body positive pressure (LBPP) exercise.

improved in the LBPP group but not in the control group. Even after the first 6-min intervention, we found significant changes in motor function variables related to the lower extremities (i.e., VAS scores and quadriceps muscle strength). Furthermore, there were significant changes in motor function variables related to exercise tolerance (i.e., WS, 6MD, and activities). Although the mechanisms underlying these functional changes may be complex, both acute and chronic changes were evident with LBPP exercise.

First, the acute changes seen in the LBPP group may provide pain relief and increase quadriceps muscle strength. These results showed that both quadriceps muscle strength and VAS scores improved significantly ($p < 0.05$) just after the first 6-min intervention. However, grip strength did not improve in either group at any time point after the intervention. This is consistent with the expectation that the effect of LBPP exercise is limited to the lower body and not the entire body [7]. However, the increase in muscle strength and improvements in VAS scores did not last over the first month. Indeed, it is unlikely that persistent effects would result from short-term therapy.

Several reports showed that LBPP exercise was safe and effective for simulating weight loss in a symptom-specific manner. Kurz et al. reported that LBPP treadmill training could be used to improve walking performance, balance, and strength [24]. Patil et al. demonstrated that LBPP allowed for significant unweighting of patients and could potentially enhance recovery after lower extremity surgery [8]. Raffalt et al. demonstrated that LBPP was a suitable training device and provided for training with high aerobic stimuli with the benefit of low weight bearing and a near-normal movement pattern [21]. In addition, LBPP supports the body weight to prevent exacerbations and manage acute knee pain during prolonged treadmill walking exercise [25].

During LBPP exercise, electromyographic activities in the quadriceps, biceps femoris, tibialis anterior, and gastrocnemius muscles are different from those under full weight bearing conditions [12]. In the present study, the acute effects of LBPP exercise included significant improvements in VAS scores and increases in muscle strength after intervention only in the LBPP group, which indicated that this LBPP unweighting technology may be safe and effective for this type of therapy.

Second, the chronic changes seen in the LBPP group may represent

an increase in exercise tolerance. In the present study, exercise tolerance was demonstrated in that both daily activities and 6MD were significantly increased 1 month after the LBPP intervention. This suggests that very elderly people became more active in their daily lives after LBPP exercise. It is possible that patients had limited their mobility prior to LBPP because of a loss of confidence caused by pain or previous falls. However, because they could walk pain free during LBPP, their confidence may have improved and allowed for their activities to increase. Thus, the LBPP treadmill may be an effective tool for the rehabilitation of patients with diseases of the lower extremities.

Our findings for grip strength suggest that changes in function did not occur over the whole of the body. Thus, the effects of LBPP were limited to those local functions executed by the lower extremity muscles. However, lower extremity muscles play an important role in whole body motor function and contribute to blood circulation [7]. Although, the strength of these muscles declines rapidly with aging.

The control group in this study did not show any changes in the measured variables. The effective rehabilitation programs used for inactive very elderly people with limited mobility who spend most of their time in bed are limited to exercises that involve low loads or stretching; thus, positive effects on muscle strength are highly unlikely with these strategies.

Several investigators [8,11,26,27] found increased pain relief, increased skeletal muscle strength, decreased atrophy, and improved muscle contraction in patients who performed LBPP exercise after knee surgery [12]. In a study that compared the effects of LBPP exercise and suspended treadmill walking among healthy adults, heart rates were lower and comfort was greater during unloaded LBPP ambulation than during suspended harness walking [28]. Another study reported that ambulating with LBPP had no adverse effects on variables in the systemic and cerebral circulations, while it produced significant unweighting and minimal alterations in gait kinematics [7]. These findings indicate that LBPP can prevent and improve disuse through immobilization and can facilitate early mobilization.

Our present results suggest that treadmill walking in an LBPP chamber is useful for safe, comfortable rehabilitation of patients with weight-bearing restrictions, muscle atrophy, or knee osteoarthritis without exacerbating their pain. Thus, LBPP exercise shows a good potential for improving the motor function of inactive elderly people through body weight unloading. LBPP-specific problems for the elderly include the possibility of causing autonomic dysreflexia and problems associated with use for patients with healing wounds [24]. However, we could not confirm this in our study.

Our study had some limitations. First, our study involved a relatively small cohort. Second, the study period was too short to reveal the actual long-term effects of LBPP. Third, we did not include a control group in which gait training was performed on a standard treadmill. Future studies with larger cohorts observed over longer periods will be necessary to determine the long-term effects of LBPP.

To the best of our knowledge, this study is the first to demonstrate the effectiveness of LBPP in very elderly people. Several functional improvements were observed in our LBPP group, which indicated that LBPP should be considered as an effective rehabilitation program for the inactive elderly.

Acknowledgment

A part of this work was carried out in collaboration with Showa Denki Co., Ltd.

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