



Original Article

## Anti-gravity treadmill can promote aerobic exercise for lower limb osteoarthritis patients

TOSHIHIRO KAWAE, RPT, MS<sup>1)\*</sup>, YUKIO MIKAMI, MD, PhD<sup>2, 3)</sup>, KOUKI FUKUHARA, RPT<sup>1)</sup>, HIROAKI KIMURA, MD, PhD<sup>3)</sup>, NOBUO ADACHI, MD, PhD<sup>2, 4)</sup>

<sup>1)</sup> Division of Rehabilitation, Department of Clinical Practice and Support, Hiroshima University Hospital: 1-2-3 Kasumi, Minami-ku, Hiroshima 734-8551, Japan

<sup>2)</sup> Sports Medical Center, Hiroshima University Hospital, Japan

<sup>3)</sup> Department of Rehabilitation Medicine, Hiroshima University Hospital, Japan

<sup>4)</sup> Department of Orthopaedic Surgery, Graduate School of Biomedical Science, Hiroshima University, Japan

**Abstract.** [Purpose] The anti-gravity treadmill (Alter-G<sup>®</sup>) allows the load on the lower limbs to be adjusted, which is considered useful for patients with lower limb osteoarthritis. The aim of the present study was to examine the effects of aerobic exercise using an anti-gravity treadmill in patients with lower limb osteoarthritis by using a cardiopulmonary exercise load monitoring system. [Subjects and Methods] The subjects were 20 patients with lower limb osteoarthritis. These subjects walked naturally for 8 minutes and then walked on the Alter-G for 8 minutes at their fastest speed at a load where lower limb pain was alleviated. [Results] Subjective and objective exercise intensity did not differ significantly between level ground walking and Alter-G walking neither before nor after walking. Pain before walking did not differ significantly between level ground walking and Alter-G walking, but pain after walking was significantly greater with level ground walking than with Alter-G walking. [Conclusion] Exercise therapy using an anti-gravity treadmill was useful for patients with lower limb osteoarthritis in terms of cardiopulmonary function, which suggested that this could become a new form of exercise therapy.

**Key words:** Anti-gravity treadmill, Lower limb osteoarthritis, Aerobics exercise

*(This article was submitted Mar. 30, 2017, and was accepted May 29, 2017)*

### INTRODUCTION

The results of the Comprehensive Survey of Living Conditions and Research on Osteoarthritis Against Disability (ROAD) study in Japan showed that locomotive disorder in the form of joint disease reduces senior citizens' quality of life and is a major factor in conferring Need for Long-Term Support and Need for Long-Term Care status<sup>1-3)</sup>. Lower limb osteoarthritis is a joint disease particularly prevalent in senior citizens that decreases physical and daily life functioning and gives rise to various conditions such as depression and metabolic syndrome. Thus, lower limb osteoarthritis contributes to increasing medical and nursing care costs and represents a major social problem.

Obesity is a contributing factor in lower limb osteoarthritis<sup>4, 5)</sup>; therefore, appropriate exercise therapy such as aerobic exercise may be an effective countermeasure<sup>6)</sup>. However, clinical application of such therapy is difficult in patients with advanced lower limb osteoarthritis because loading exacerbates joint pain, preventing intervention.

To overcome these issues, a method of facilitating aerobic exercise using a harness to lift the patient on a treadmill while a counterweight supports some of their body weight has been widely used not only in patients with lower limb osteoarthritis but also those with other conditions such as cerebrovascular disease<sup>7, 8)</sup>. However, many aspects of this approach are problematic,

\*Corresponding author. Toshihiro Kawae (E-mail: toshihiro@hiroshima-u.ac.jp)

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such as the time required to fit the harness and pain caused by localized harness pressure.

The recently developed anti-gravity treadmill (Alter-G<sup>®</sup>; AlterG, Inc., Fremont, CA, USA) uses a pressurized air chamber to adjust the load on the legs and reduces impact on the leg joints, thereby facilitating aerobic exercise<sup>9, 10</sup>. The only preparation required to use the anti-gravity treadmill is dressing in a pair of special shorts; therefore, setup takes little time. Harness-related pain is also eliminated because air pressure is used to lift the entire pelvis. However, while the anti-gravity treadmill should be effective for patients with lower limb osteoarthritis who have pain, reducing the impact on the legs also reportedly reduces exercise intensity<sup>11</sup>. This study aimed to clarify the effects of anti-gravity treadmill walking (AGW) on exercise intensity from the perspective of oxygen uptake and on disease-related pain generated by loading comparison with level-ground walking (LGW) in patients with lower limb osteoarthritis.

## SUBJECTS AND METHODS

The subjects were 20 patients with lower limb osteoarthritis (8 men, 12 women, mean age: 62.8 ± 10.8 years) who visited the Department of Rehabilitation Medicine at Hiroshima University Hospital from April 2014 through to March 2016. Inclusion criteria were patients with advanced deformation of the joints of the lower limbs on plain X-ray findings and scheduled for surgery. Exclusion criteria were patients with lower limb pain resulting from a condition other than lower limb osteoarthritis, patients with dementia or mental illness, and patients who did not give their consent to participate. The subjects included 14 patients with osteoarthritis of the hip, 5 patients with osteoarthritis of the knee, and 1 patient with osteoarthritis of the ankle.

Subjects performed walking under two conditions: level ground walking (LGW) and anti-gravity treadmill walking (AGW). Subjects first performed LGW and then AGW after taking a sufficient break. The measurement protocol was 1 minute of rest before both LGW and AGW, followed by 8 minutes of walking and another 1 minute of rest after completion of walking. LGW was done as natural walking at normal everyday walking speed. Any subjects who usually used a cane were permitted to do so during the exercise. In AGW, the load was adjusted to a level that alleviated lower limb pain, and this load was recorded. Walking speed was the fastest speed possible without exacerbating pain.

Endpoints were subjective exercise intensity, pain, walking speed, heart rate, oxygen uptake, and calorie consumption. Subjective exercise intensity was evaluated by interview before and after walking using the modified Borg scale breath (hereinafter “m-BS (B)”) for breathing difficulty and the modified Borg scale leg (hereinafter “m-BS (L)”) for the lower limbs fatigue<sup>12</sup>. A rating of 0 indicated no intensity, while a rating of 10 indicated the maximum intensity. Pain was evaluated by interview before and after walking using a Numerical Rating Scale (NRS), which rates pain on an 11-point scale from 0 to 10. A rating of 0 indicates no pain, while a rating of 10 indicates the strongest pain. Changes in NRS and subjective exercise intensity after exercise were calculated as  $\Delta$ NRS and  $\Delta$ m-BS (B) and  $\Delta$ m-BS (L), respectively. Walking speed was calculated for LGW from the distance walked in 8 minutes, while in AGW, the set speed of the anti-gravity treadmill was recorded. Heart rate was recorded during walking by an electrocardiogram monitor (PVM-2703; Nihon Kohden Corp., Tokyo, Japan). To evaluate oxygen uptake, oxygen uptake during LGW and AGW was measured using a portable cardiopulmonary exercise load monitoring system (Mobile Aeromonitor AE-100i; Minato Medical Science Co., Ltd., Osaka, Japan). Calorie consumption were measured from oxygen uptake in each subject during the 8 minutes of exercise. This measurement described by previous study<sup>13</sup>.

For all endpoints, the mean value was calculated from the measured values of each subject. The trends in mean values for heart rate and oxygen uptake are shown over time. Paired t-tests were used for the statistical analysis, with the level of significance set at less than 5%. In addition, two-way analysis of variance was performed for LGW and AGW as a statistical analysis of heart rate and oxygen uptake, with the level of significance also set at less than 5%.

The present study was reviewed and approved by the ethics committee of Hiroshima University, and the subjects gave their written informed consent to participate after receiving a sufficient explanation of the purpose of the study.

## RESULTS

There were no falls, and stable walking was possible for all subjects during AGW. There were no significant differences between LGW and AGW were observed in subjective exercise intensity before and after walking (Table 1). No significant difference in NRS of pain was observed before walking. However, NRS was significantly lower after AGW than after LGW. There was also significantly less change in NRS ( $\Delta$ NRS) after AGW than after LGW (Table 2). Walking speed was significantly faster during AGW than during LGW (Table 3). Changes in oxygen uptake during walking are shown in Table 4. Oxygen uptake was significantly increased during exercise compared with rest of LGW and AGW. There was no change between LGW and AGW in oxygen uptake. Furthermore, no interaction was observed in oxygen uptake for LGW or AGW. Calorie consumption during the 8-min walking period was significantly higher for AGW than for LGW (Table 5).

## DISCUSSION

Patients with lower limb osteoarthritis become unable to perform simple activities of daily living (ADL), such as going

**Table 1.** Differences in subjective exercise intensity for level-ground walking and anti-gravity treadmill walking

	LGW	AGW
Pre-mbs (B)	0.1 ± 0.4	0.6 ± 1.8
Post-mbs (B)	2.4 ± 1.5	2.5 ± 2.0
Δmbs (B)	2.3 ± 1.4	1.8 ± 2.2
Pre-mbs (L)	0.3 ± 0.7	0.5 ± 1.3
Post-mbs (L)	2.4 ± 1.7	2.3 ± 1.9
Δmbs (L)	2.2 ± 1.7	1.8 ± 1.7

Values are mean ± SD.

mbs (B): Modified Borg scale breath for breathing difficulty;  
mbs (L): Modified Borg scale leg for the lower limbs fatigue

**Table 2.** Differences in numerical rating scale scores for level-ground walking and anti-gravity treadmill walking

	LGW	AGW
Pre-NRS	1.3 ± 0.3	2.1 ± 0.4
Post-NRS	4.3 ± 2.3	2.2 ± 1.9*
ΔNRS	2.9 ± 2.2	0.2 ± 1.2*

Values are mean ± SD. NRS: Numerical Rating Scale of pain  
\*p<0.05: significantly different between LGW and AGW

**Table 3.** Differences in walking speed during level-ground walking and anti-gravity treadmill walking

	LGW	AGW
Speed (km/h)	2.8 ± 0.6	3.7 ± 0.8*
Distance (m)	370.1 ± 82.1	510.0 ± 102.3*
PWB (%)	-	72.4 ± 11.2

Values are mean ± SD. PWB: partial weight bearing  
\*p<0.05: significantly different between LGW and AGW

**Table 4.** Changes over time in oxygen uptake during level-ground walking (LGW) and anti-gravity treadmill walking (AGW)

	Rest	1 min	2 min	3 min	4 min	5 min	6 min	7 min	8 min	Recovery
LGW	4.66 ± 1.77	7.88 ± 3.57*	10.26 ± 2.88*	11.08 ± 3.0*	11.08 ± 3.19*	11.15 ± 3.15*	11.13 ± 2.97*	10.95 ± 3.33*	9.95 ± 3.3*	5.00 ± 1.56
AGW	5.58 ± 2.0	10.30 ± 4.94*	12.89 ± 4.54*	13.33 ± 4.36*	13.40 ± 4.55*	13.24 ± 4.46*	13.25 ± 4.35*	12.75 ± 4.6*	11.51 ± 4.27*	6.09 ± 2.18

Values are mean ± SD. \*p<0.05: significantly different between Rest.

Oxygen uptake was significantly increased during exercise compared with rest of LGW and AGW. There was no change between LGW and AGW in oxygen uptake. No interaction was observed in oxygen uptake for LGW or AGW.

**Table 5.** Differences in calorie consumption for level-ground walking and anti-gravity treadmill walking

	LGW	AGW
Calorie consumption (cal)	25.1 ± 10.0	30.5 ± 16.6*

Values are mean ± SD. \*p<0.05: significantly different between LGW and AGW

outside, walking, and jogging, due to pain. Their resulting social withdrawal can cause various problems, such as depression and metabolic syndrome. Thus, while a suitable form of exercise therapy is recommended for patients with lower limb osteoarthritis, patients who cannot perform effective aerobic exercise due to lower limb pain are frequently encountered.

The anti-gravity treadmill allows the load on the lower limbs to be adjusted by 1% at a time within a range of 20% to 100% by suspending the body in a pneumatic chamber. Moreover, patients are secured to the body of the apparatus by means of dedicated shorts, which reduces the risk of falls to almost zero. Because walking with a load burden on the lower limbs is possible with the anti-gravity treadmill, this therapy is considered useful as aerobic exercise for patients with lower limb osteoarthritis who have pain.

In fact, Patil et al.<sup>14)</sup> reported that the force applied to the knees decreased in accordance with the reduction of load on the lower limbs during anti-gravity treadmill walking in patients who had undergone total knee replacement. Furthermore, Gojanovic et al.<sup>11)</sup> described while the exercise intensity is reduced as a result of the alleviation of load by the anti-gravity treadmill, this reduction can be compensated for by increasing the walking speed.

We are even introducing the anti-gravity treadmill as aerobic exercise for patients with lower limb osteoarthritis at our hospital. Patients have been very receptive to this therapy because walking is possible with reduced pain.

However, to date, few reports have evaluated the effects of the anti-gravity treadmill on lower limb osteoarthritis, and the effects of aerobic exercise in particular do not appear to have been the focus in such studies<sup>15)</sup>. This report is therefore the first to evaluate the effects of aerobic exercise using an anti-gravity treadmill on lower limb osteoarthritis.

As mentioned earlier, the differences in exercise intensity as a result of the reduced load and walking speed of the anti-

gravity treadmill have already been reported<sup>11, 14, 16</sup>). The present study therefore placed emphasis on comparing the effects of exercise using the anti-gravity treadmill as an aerobic exercise apparatus with the effects of exercise by normal walking or strolling in patients with lower limb osteoarthritis, instead of conducting a study where set values were simply changed on an anti-gravity treadmill.

Accordingly, in this study, patients were permitted to use a cane during LGW if necessary and set the walking speed of the anti-gravity treadmill to the maximum possible within the range of bearable pain. Moreover, while it is typical to do 6 minutes of walking for evaluation of gait and endurance, we decided to perform evaluations over a longer walking time than is usually feasible in the present study. However, patients with lower limb osteoarthritis find walking for long periods of time difficult, so we evaluated walking for just 8 minutes.

In the present study, pain was exacerbated and walking speed did not increase during LGW in patients with lower limb osteoarthritis. In contrast, AGW allowed walking load to be reduced and walking speed to be increased.

As a result, it was possible to raise the subjective exercise intensity of the anti-gravity treadmill to the same level as that of LGW, both in terms of breathing difficulty and lower limbs fatigue. Moreover, the trends in heart rate and oxygen uptake during 8 minutes of walking were the same in both LGW and AGW; however, the mean values for heart rate and oxygen uptake during AGW slightly surpassed those during LGW.

Exercise intensity and calorie consumption during 8 minutes of walking were significantly higher in AGW than in LGW. Also, this result shows the significantly lower NRS score on completion of AGW as compared with LGW. While most subjects did not wish to prolong the walking time due to pain after LGW, many expressed the desire to extend the walking time after AGW because pain was mild. Exercise motivation on completion of exercise was not evaluated in the present study, but we anticipate that exercise intensity and calorie consumption would increase, and that the effects of this treadmill as an aerobic exercise apparatus would be further enhanced if the exercise time on the anti-gravity treadmill could be extended by alleviating pain.

Other exercise therapies such as pool walking are also performed for patients with lower limb osteoarthritis. In the pool, walking with a reduced load on the lower limbs is possible due to the buoyancy of the water. Moreover, the resistive force of the water also allows patients to perform muscle strength training. However, when walking speed is increased, the resistive force of the water has been found to increase the load on the lower limbs and cause problems with pool space, water management, cost, and other factors<sup>14</sup>). The anti-gravity treadmill is therefore superior to the pool in terms of space and management, which makes it more convenient. However, Mercer et al.<sup>17</sup>) reported a reduction in lower limb muscle activity along with the reduction of load on the anti-gravity treadmill in measurements of lower limb muscle activity using a surface electromyogram<sup>18</sup>). They also reported that pool walking has superior muscle strengthening effects over anti-gravity treadmill walking. This indicates that the anti-gravity treadmill is an apparatus that is essentially intended more for aerobic exercises than gait training and muscle strength training.

The limitations of the present study were the varied target diseases and the small number of subjects per disease. Furthermore, the chosen pain threshold setting was ambiguous, and the effects of the anti-gravity treadmill could not be evaluated by disease differences and degrees, or by the intensity of pain. To address these issues, we intend to repeat this study with a larger subject sample and additional evaluations of exercise motivation and self-efficacy on completion of exercise. Another problem with this study was that both AGW and LGW were done on the same day. However, subjects were able to rest sufficiently after LGW, which allowed heart rate and subjective exercise intensity before AGW to recover to the same levels as those before LGW. The long-term effects of aerobic exercise using an anti-gravity treadmill in patients with lower limb osteoarthritis are also unclear from this study; this would be an extremely interesting topic of study for the future. Furthermore, all of the patients in the present study were scheduled for surgery directly after the study finished, so that it was difficult to evaluate the long-term effects. We intend to evaluate the long-term outcomes of the anti-gravity treadmill, including its direct effects and its effects on patient ADL, instrumental ADL, and social inclusion, as a conservative therapy apparatus for lower limb osteoarthritis. Moreover, we believe that clinical studies at other facilities, including studies of the improvement effects on depression and metabolic syndrome, will also be needed.

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