Effects of treadmill speed on the knee angle and stance time of white rats with knee osteoarthritis according to the treadmill speed

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Abstract. [Purpose] The purpose of this study was to identify whether walking on a treadmill at an adjusted speed is suitable for humans by examining the effects of exercise on the joint functions of white rats with induced knee osteoarthritis. [Subjects and Methods] The subjects were 20 Sprague-Dawley white rats, aged eight weeks, weighing 250 to 300 g. The moderate-speed exercise group performed their exercise at a gradient of 0% and a speed of 15 m/min, and the high-speed exercise group performed their exercise at a gradient of 0% and a speed of 26 m/min. [Results] Statistically significant changes were elicited by the moderate-speed and high-speed exercises. [Conclusion] In conclusion, the results of the present study present the importance of walking exercise. In particular, they demonstrate that changes in knee ROM and stance time are elicited by changes in walking speed.

Key words: Osteoarthritis, White rat, Walking speed

INTRODUCTION

Osteoarthritis is a type of joint disease that frequently occurs in elderly people. It is characterized by local degenerative changes in joint cartilage, condrocyte hypertrophy, excessive osteophyte formation in the bones connected with the joint, and joint deformities of the weight-bearing joints, and it causes repetitive pain, joint stiffness, and gradual motor disturbance1). The incidence of osteoarthritis in elderly people aged 65 or above is over 80%, and it is gradually increasing with time. While the precise causes of osteoarthritis are not known, chronic osteoarthritis results from abrasion of the joints due to aging, and later, it occurs due to various biological and mechanical factors that cause cartilage degeneration. The goal of treatment for osteoarthritis is to reduce pain, regenerate cartilage, and recover function by suppressing the factors that cause cartilage degeneration as much as possible2). Osteoarthritis patients experience pain, stiffness, and edema due to inflammation in the joint, as degenerative changes progress around the joint and the lower part of joint cartilage. In addition, loss of joint function occurs due to joint deformation, the exudation of joint fluid, weakening of the muscles around the joint, and reduced muscle strength resulting from the destruction of joint cartilage3). These symptoms exhibit as rubefaction, fever, and edema as inflammatory responses, or pain and functional losses, and they are generally accompanied by physical limitations that differ from those due to external injuries such as contusions or penetrative wounds4). Pain and limitations in the joint range of motion (ROM) occur due to degeneration caused by mechanical stimulation and friction that are continuously experienced by joint cartilage, and changes caused by other articular tissues5). Exercises are selected and performed to prevent ROM limitations resulting from osteoarthritis. Today, the most frequently used exercise for both humans and animals is walking, and
walking on a treadmill or in water is performed most commonly\(^9\). The purpose of treatment for osteoarthritis is to reduce pain and minimize functional losses by maintaining or improving joint function. However, while the current selective therapies for osteoarthritis include exercises and medication, such as the administration of systemic analgesics, detailed exercise methods have not been explained, and medication involves the risk of serious side effects of drugs. Accordingly, the purpose of this study was to identify whether walking on a treadmill at an adjusted speed is suitable for humans by examining the effects of exercise on the joint function of white rats with induced knee osteoarthritis.

### SUBJECTS AND METHODS

The study subjects were twenty Sprague-Dawley white rats, aged eight weeks, weighing 250 to 300 g. During the experiment, the dietary intake of the test animals was not limited, and their breeding room’s environment was maintained under the optimal conditions of 25 ± 3 °C, and 60 ± 5% humidity, and a light/dark cycle of 12 hours (Light cycle: 08:00–20:00, Dark cycle: 20:00–08:00). Osteoarthritis was induced in the test animals after environmental adaptation for two weeks in the breeding room. Then, they were randomly divided into a moderate-speed exercise group (n=10), and a high-speed exercise group (n=10). This experiment complied with the experimental ethics.

Osteoarthritis was induced as follows: The test animals were anesthetized by intraperitoneal injection (2 ml/kg) of a general anesthetic produced by mixing zoletil and rompun (Bayer Korea, Korea) at a ratio of 1:1, one week before performing treadmill exercise. Then, they were injected in the joint cavity of their right knee with monosodium iodoacetate (MIA; Sigma, St Louis, MO, USA) diluted with a 50 µL saline solution using a 26 gauge syringe. After the injection, extension and flexion were repeated for about five minutes to spread MIA into the joint cavity evenly. If a rat exhibited symptoms such as fever, edema or oppressive pain in the knee three weeks after the injection of MIA, the rat was diagnosed as having osteoarthritis\(^7\). This study set the treadmill speed following the protocol of Rodrigues, and the test animals performed walking exercises on a treadmill for small animals (JD-A-09 type, JEUNGDO Bio & Plant Co., Ltd., Korea). The two exercise groups were first trained to adapt to their main treadmill exercise by walking on the treadmill at a gradient of 0% and a speed of 8 m/min for 15 minutes for two days, and they performed the main exercise after a one-day break\(^8\). The moderate-speed exercise group performed their exercise at a gradient of 0% and a speed of 15 m/min, and the high-speed exercise group performed their exercise at a gradient of 0% and a speed of 26 m/min. The exercise was performed at 7:00 pm in the evening when the test animals typically showed a lot of activity. When an animal stopped the given exercise, they were encouraged to continue to exercise by applying an electrical stimulus of 10 volts via a device installed in the lower part of the treadmill’s belt (Table 1). The aim of this study was to examine changes in knee angle and stance time. Kinematic motions at the different walking speeds were evaluated using Dartfish software (ProSuite, Dfkorea, Korea) at one day and 14 days after the animals had been treated.

After disinfecting each rat’s hind leg with alcohol and shaving the relevant region, the lateral epicondyle of the knee, lateral malleolus of the ankle, and metatarsophalangeal joint of the fifth toe were marked with black dots, and the rats were filmed in the sagittal plane; the average of three repeated values was adopted for use\(^9\). This study confirmed the significance of group differences using the independent sample t-test. SPSS Win. 18.0 for Windows was used to compare kinematic changes between the treadmill speeds. The statistical significance level was chosen as α=0.05.

### RESULTS

Statistically significant changes were elicited by the moderate-speed and high-speed exercises. For the moderate-speed exercise, the knee angle changed from 104.5 ± 0.6° to 92.5 ± 2.4°, and the stance time changed from 327.1 ± 64.6 ms to 288.6 ± 49.1 ms. For the high-speed exercise, the knee angle changed from 104.5 ± 0.5° to 96.7 ± 1.0° and the stance time changed from 295.1 ± 33.7 ms to 377.4 ± 63.0 ms (Table 2).

### DISCUSSION

This study examined the effects of different treadmill walking speeds on the knee angle and stance time in the initial contact stage of white rats with induced knee osteoarthritis. The aim was to suggest a more effective exercise by determining the appropriate speed at which osteoarthritis patients should perform walking exercises. This study filmed the rats with a video camera and analyzed their moving images with the Dartfish software to learn about the changes in the functional walking of white rats with knee osteoarthritis elicited by different speeds of change treadmill exercise. Individuals with knee osteoarthritis generally exhibit a reduced ability of lower-extremity joints in functional walking, and when osteoarthritis occurs, reduction in the knee angle and range of motion of the knee, and atrophy in the muscles around the affected region may occur\(^9\). Another complaint of osteoarthritis patients is that they experience limitations in daily activities such as walking, walking up stairs, and housework. In general, these patients additionally experience obesity-related disorders such as heart diseases, high blood pressure, and diabetes, and depression or sleep disturbance which all reduce the subjects’ quality of life and satisfaction with life\(^11\). These problems can be improved through proper exercise, and osteoarthritis patients can improve their gait ability and experience positive effects on their daily lives and occupational environments by performing...
specific exercises\textsuperscript{(12)}. Walking is a type of locomotion specific to humans, which is essential in daily life. In recent years, it has been widely performed as an exercise for health, and is the most natural motion for humans\textsuperscript{(13)}. A study reported that lower-extremity muscle strengthening exercises and treadmill walking exercises had positive effects on balance ability and skeletal muscle strength\textsuperscript{(14)}. In addition, walking exercises have positive effects on cardiorespiratory functional capacity\textsuperscript{(15)}, and when stroke patients’ walking outside and walking on the treadmill were compared at low and high speeds, statistically significant changes were observed in endurance, walking speed, and balance ability\textsuperscript{(16)}. Another study instructed hemiplegic patients to walk at a speed of 1 km/h for 30 seconds, have a break, and then walk again at a speed of 2 km/h for 30 seconds after adapting to this main walking exercise by initially walking at comfortable speeds. These changes in walking speed influenced foot rotation, weightbearing responses, and joint movements in the mid-stance and swing phases\textsuperscript{(17)}. A study was conducted to analyze dynamic changes in the knee and gait characteristics of patients with knee osteoarthritis walking at a high speed. This study also noted that an increase in walking speed is correlated with an increase in the range of the joint movement\textsuperscript{(18)}. Moreover, another study provided a normal individual and a patient with knee osteoarthritis with different variables for walking conditions. When the subjects selectively adjusted their walking speed themselves or performed fast walking, they exhibited functional changes in the joints\textsuperscript{(19)}. The above research results suggest that changes in walking speed during walking exercise may be associated with the effects of the exercise. While the cited studies mostly examined neurological patients performing walking exercises, future studies should examine musculoskeletal patients. In conclusion, the results of the present study demonstrate the importance of walking exercise. In particular, they demonstrate that changes in knee ROM and stance time were generated as the walking speed changed. The knee joint’s angle during the early-stance phase showed changes in both the moderate-speed and high-speed exercise groups, and the high-speed walking group exhibited statistically significant changes in knee angle. This shows that the degree of joint stiffness, a characteristic of progressive knee osteoarthritis, gradually increased. Moreover, changes in early stance time were also statistically significant in the high-speed walking group. This suggests that pain was at a moderate level despite weight-bearing during the stance phase.

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\begin{table}
\centering
\caption{Protocol of treadmill exercise}
\begin{tabular}{|c|c|c|c|c|}
\hline
Group & N & Duration (weeks) & Frequency (days/week) & Speed (m/min) & Exercise time (min) \\
\hline
MSEG & 10 & 2 & 5 & 16 & 30 \\
HSEG & 10 & 2 & 5 & 25 & 30 \\
\hline
\end{tabular}
\end{table}

\begin{table}
\centering
\caption{Comparison of changes in the moderate speed and high speed exercise groups}
\begin{tabular}{|c|c|c|c|c|}
\hline
 & MSEG & & HSEG & \\
\hline
 & pre & post & pre & post & \\
ICAK (°) & 104.5 ± 0.6 & 92.5 ± 2.4 & 104.5 ± 0.5 & 96.7 ± 1.0* \\
ICSPT (ms) & 327.1 ± 64.6 & 288.6 ± 49.1 & 295.1 ± 33.7 & 377.4 ± 63.0* \\
\hline
\end{tabular}
\end{table}

MSEG: moderate speed exercise group; HSEG: high speed exercise group

ICAK: initial contact angle knee; ICSPT: initial contact stance phase time; MSEG: moderate speed exercise group; HSEG: high speed exercise group; *p<0.05
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