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# Mechanical energy efficiency for stepping up and down in persons with medial knee osteoarthritis

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ABSTRACT

Background: Energetic cost contributes to movement impairments observed during stair negotiation in persons with knee osteoarthritis. Specifically, the intersegmental mechanical energy exchange may be diminished in the presence of pathologies.

Research question: The purpose of this study was to evaluate mechanical energy efficiency in persons with knee osteoarthritis during stepping up and down based on mechanical energy analysis.

Methods: Sixteen patients with medial knee osteoarthritis and 16 age-matched controls participated. A three-dimensional motion analysis system and force platforms were used to acquire biomechanical data. The participants were instructed to ascend/descend a 2-step staircase. The mechanical power exhibited during the stance phase at the lower step of the staircase were computed. Mechanical Energy Expenditure (MEE) was calculated as the integral of net joint power at each joint. Mechanical Energy Compensation (MEC) was defined as the proportion of muscle energy compensated by inter-segmental energy transfer. According to energy transfer modes, MEE and MEC were determined separately as three phases: concentric and eccentric transfer phases and no-transfer phase.

Results: While stepping up, the patient group performed the task with less MEC at the ankle joint, which was observed prior to push-off. The patient group displayed less mechanical energy transfer from the shank to the foot segment. The concentric MEC at the hip joint in the late-stance phase of stepping down was lower in the patient group, which meant patients demonstrated less mechanical energy transfer from the pelvis to the thigh segment.

Significance: It was disclosed that persons with knee osteoarthritis demonstrated less mechanical energy transfer while stepping up and down.

## 1. Introduction

Knee osteoarthritis (knee OA) is one of the most common musculoskeletal diseases and afflicts approximately 15% of elderly people [1]. Patients with knee OA experience pain, loss of joint mobility, and muscle weakness, which limit their daily activities [2]. This is especially true for stair negotiation, which requires a larger range of motion and greater muscle strength in the lower extremities than level walking [3,4]. Patients with knee OA take a longer time to ascend and descend stairs than their healthy peers [5]. Investigating the biomechanical changes in stair negotiation could explain these deficits.

Several biomechanical studies on stair negotiation have focused on kinematics. Patients with knee OA ascend stairs with a decreased knee flexion angle and delayed knee and hip flexion movements compared with their healthy counterparts [6]. During descent, patients with knee OA exhibit a smaller knee flexion range of motion in the early stance and a delayed onset of the activity of the quadriceps preceding foot strike [7]. On the other hand, there have been few studies investigating the energetics during stair negotiation in patients with knee OA. During stair ascent and descent, each lower extremity segment interacts to

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increase/absorb the potential energy of the entire body. Thus, it is reasonable and worthwhile to evaluate the energetics of the lower extremity during stair negotiation.

McGibbon et al. evaluated the mechanical energy efficiency during level walking in persons with impaired physical function by quantifying the amount of mechanical energy produced by muscle contraction, i.e., the mechanical energy expenditure (MEE), and the proportion of muscle energy compensated by inter-segmental energy transfer, i.e., the mechanical energy compensation (MEC) [8]. This approach was applied to compare stair negotiation between younger and older adults, and the results indicated age-related differences in the mechanical energy efficiency [9]. Patients with knee OA showed decreased knee joint power while walking, which was compensated by increased hip joint power and mechanical energy transfer from the shank to the thigh segment [10]. Although analyzing the MEE and MEC should be applicable to discriminate biomechanical changes during locomotion in patients with knee OA, there have been no studies investigating the efficiency of stair negotiation and the compensatory mechanics in such patients using this type of methodology.

The purpose of the present study was to quantify the MEE and MEC while persons stepped up and down, which are parts of stair negotiation and are associated with the movement characteristics of stair negotiation in daily living. In the early stance of stepping up, the center of mass (COM) is elevated by the hip and knee power; whereas, the ankle primarily drives the COM forward in the late stance. Considering the history of knee OA, we predicted that an increased power contribution would occur from the hip in the early phase of stepping up and that there would be a deficiency in energy transfer between the shank and foot. During stepping down, when the potential energy must be absorbed by the stance limb, it was hypothesized that patients would place a higher demand on ankle joint power instead of reducing the amount of energy absorbed at the knee.

## 2. Methods

### 2.1. Participants

Sixteen individuals with mild to moderate medial knee OA (five men and 11 women; age, 72.4 ± 3.5 years; weight, 58.5 ± 9.0 kg; height, 1.57 ± 0.08 m) were recruited for this study. An experienced orthopedic surgeon determined the radiographic severity of each patient using the Kellgren–Lawrence classification. Patients who were diagnosed with any other type of arthritis (e.g., lateral knee OA or rheumatoid arthritis) or had undergone surgery in the lower extremity were excluded. Patients who had a musculoskeletal condition other than knee OA or any other disease that could affect their stair negotiation were also excluded. Sixteen age-matched controls (four men and 12 women; age, 74.0 ± 4.9 years; weight, 55.1 ± 9.4 kg; height, 1.58 ± 0.11 m) also participated in this study. The control subjects exhibited no orthopedic or neurological disorders. All participants could ascend and descend stairs without assistance.

Because most of the patients participating in this study were diagnosed with bilateral knee OA, their more symptomatic side was tested. To determine which side was more symptomatic, for each patient, the pain experienced during daily activities was assessed using a 100-mm Visual Analog Scale (VAS). In addition, the subjective disease-specific symptoms and physical dysfunction of the patients were evaluated using the Japanese Knee Osteoarthritis Measure (JKOM) [11].

All subjects provided written informed consent prior to participation, and this study was approved by the Institutional Review Board of the Graduate School of Medicine at Kyoto University.

### 2.2. Performance measurement

To evaluate the stair ascent and descent ability, a timed stair test was performed [12]. In this test, each subject was instructed to ascend/descend a nine-step staircase as quickly as possible. All patients completed two trials for ascent and two trials for descent. The time taken to ascend or descend a step was calculated by dividing the time taken to complete the trial by the number of stairs; the faster of the two trials was used for analysis.

### 2.3. Motion analysis

A two-step staircase was used for motion analysis of stepping up and down. The individual steps were 20 cm high, 40 cm wide, and 25 cm deep. Patients were instructed to start the stepping up and down with their involved limb; whereas, the participants in the control group started the tasks with a randomly selected limb. The stance phase of the involved side observed at the lower step of the staircase was analyzed. All subjects performed the tasks at cadence of 90 steps/min, which was controlled using a metronome. Three successful trials of each task were recorded for subsequent analysis.

Kinematic and kinetic data were obtained using an eight-camera three-dimensional motion analysis system (Vicon Nexus; Vicon Motion Systems Ltd.; Oxford, England) at a sampling frequency of 200 Hz and force platforms (Kistler Japan Co., Ltd.; Tokyo, Japan) at a sampling frequency of 1000 Hz. The motion analysis system and force platforms were synchronized during the data collection process. Thirty reflective markers were placed on the whole-body landmarks by a single experienced examiner according to a previous study [13].

Before the joint angle and segment position data were obtained, marker trajectories were filtered using a fourth-order bi-directional Butterworth low-pass filter at a cutoff frequency of 6 Hz. The joint centers of both hips, knees, and ankles were defined in accordance with a previous study [13]. The net joint torques at each joint in the lower extremity were calculated according to inverse dynamics. The moments of inertia were determined according to a previous study [14]. The kinetic data were low-pass filtered with a cutoff frequency of 20 Hz and normalized to the body mass of each subject.

### 2.4. Mechanical power analysis

The mechanical power at the distal ends of the proximal segments and at the proximal ends of the distal segments of the involved limb was determined as the product of the joint torque and angular velocity of the segment. The mechanical power exhibited in the stance phase of the involved side was computed. In accordance with a previous study [15], the net joint power (Pj) at each joint was computed by the summation of the mechanical power at the end of the proximal ($P_p$) and distal ($P_d$) segments:

$$P_j = P_p + P_d = M_p\omega_p + M_d\omega_d,$$

where P represents the muscle power (W/kg), M represents the muscle moment (Nm/kg), and ω represents the angular velocity (rad/s). The MEE at each joint was calculated as the integral of the net joint power:

$$\mathrm{MEE} = \int_{t_1}^{t_2} |\mathrm{Pj}|\ dt,$$

where $t_1$ and $t_2$ denote the time periods of each transfer condition described below. The MEC, which represents the proportion of the muscular energy compensated for by the inter-segmental energy flow [8], was calculated as the ratio of the net joint MEE to the amount of absolute mechanical energy at the joint:

$$\mathrm{MEC} = 1 - \frac{\int_{t_1}^{t_2} |\mathrm{Pj}|\ dt}{\int_{t_1}^{t_2} [\,|\mathrm{Pp}| + |\mathrm{Pd}|\,]\ dt}.$$

The energetics of the stance limb in the first and second halves of the stance phase contribute to different aspects of movement during stepping up and down. Therefore, the stance phase was divided into two sub-phases according to the vertical ground reaction force. Because the

profile of the vertical ground reaction force during both stair ascent and descent exhibited double-peak waveforms, the whole stance phase could be broken down into two sub-phases, which included each peak of the vertical ground reaction force. The MEE and MEC variables were obtained in each sub-phase. Furthermore, as established in previous studies, the joint MEE and MEC variables were reduced to three transfer conditions: concentric transfer, eccentric transfer, and no transfer [8,15]. When adjoining segments rotate in the same direction, mechanical energy is transferred from the segment at which more energy leaves to the segment at which more energy enters. In the concentric transfer phase, mechanical energy is generated at the joint and transferred between segments; whereas, in the eccentric transfer phase, mechanical energy is absorbed at the joint. In the no-transfer phase, when adjoining segments rotate in opposite directions, all of the mechanical energy is generated/absorbed by the muscle contraction (i.e., the MEC is zero at any point in time). All of the energy-transfer conditions are presented in Table 2. The MEE and MEC variables were determined separately for each transfer condition in each sub-phase of the stance.

### 2.5. Statistical analysis

Because the subjects did not exhibit particular energy-transfer modes (e.g., most of the subjects did not display an eccentric transfer mode at the ankle joint in the last half of the stance during stepping up), the ensemble average value could not be obtained for some MEE variables. Therefore, such MEE variables were not used for the group comparison. When the MEE in a phase was zero, MEC in that phase was not calculated. Independent sample *t*-tests were applied for a comparison of the MEE and MEC at each joint and for each sub-phase between groups using the software PASW 18.0 (SPSS, Inc.; Chicago, IL, USA). The times taken for both ascent and descent during the timed stair test were compared between the groups. The criteria for statistical significance was set as $p < 0.05$ for each comparison.

## 3. Results

No significant difference was found in age, height, or weight between the two groups (Table 1).

### 3.1. Timed stair test

There were significant differences between groups with regard to the time taken for both stair ascent ($p = 0.0014$) and descent ($p = 0.0049$) in the timed stair test (Table 1).

### 3.2. Energetics in stepping up

Fig. 1 shows the mean joint and segment power profiles at the hip, knee, and ankle for each group. In the first half of the stance, there were no significant differences in any variable for any of the joints. In the late stance, patients with knee OA exhibited less concentric MEC at the ankle joint ($p = 0.029$, Table 3) than the control group. This indicates that less mechanical energy was transferred from the shank to the foot prior to push-off. No differences were found in any other variables during the late stance.

**Table 1**
Anthropometric variables and subject characteristics and average results of timed stair test for each group (mean ± SD).

| | Knee OA (n = 16) | Control (n = 16) |
|---|---|---|
| Age (years) | 72.4 ± 3.5 | 74.0 ± 4.9 |
| Sex | Males = 5, Females = 11 | Males = 4, Females = 12 |
| Height (m) | 1.57 ± 0.08 | 1.58 ± 0.11 |
| Weight (kg) | 58.5 ± 9.0 | 55.1 ± 9.4 |
| Kellgren-Lawrence Stage | I: 1 II: 10 III: 5 | – |
| JKOM score | 18.3 ± 11.7 | – |
| VAS (mm) | 32.2 ± 21.6 | 0 |
| Timed stair test | | |
| Ascent(sec/step) | 0.45 ± 0.09* | 0.37 ± 0.08 |
| Descent (sec/step) | 0.42 ± 0.10* | 0.33 ± 0.04 |

* A significant difference between groups ($p < 0.05$).

**Table 2**
Summary of the energy transfer conditions.

| Energy transfer condition | Power | Description | Arrow direction | Bar color |
|---|---|---|---|---|
| Concentric transfer | $P_p > 0$, $P_d < 0$, $P_j > 0$ | Power is generated and transferred from the distal to the proximal. | Up | Dark gray |
| | $P_p < 0$, $P_d > 0$, $P_j > 0$ | Power is generated and transferred from the proximal to the distal. | Down | |
| Eccentric transfer | $P_p > 0$, $P_d < 0$, $P_j < 0$ | Power is absorbed and transferred from the distal to the proximal. | Up | Light gray |
| | $P_p < 0$, $P_d > 0$, $P_j < 0$ | Power is absorbed and transferred from the proximal to the distal. | Down | |
| No transfer | $P_p > 0$, $P_d > 0$, $P_j > 0$ | All power is generated by the muscles. No transfer occurs. | Outward double | Black |
| | $P_p < 0$, $P_d < 0$, $P_j < 0$ | All power is absorbed by the muscles. No transfer occurs. | Inward double | |

P, power; j, joint; p, proximal segment; and d, distal segment.
The arrow direction and the bar color denote what the arrows and bar colors in Figs. 1 and 2 represent.

### 3.3. Energetics in stepping down

The mean joint and segment power profiles at each joint for each group are shown in Fig. 2. No significant differences at the knee or ankle joints were observed throughout the stance. However, in the first half of the stance, less concentric MEE at the hip was observed in the patient group ($p = 0.0029$, Table 4). On the other hand, in the late stance, the patients displayed less concentric MEC at the hip joint ($p = 0.029$, Table 4), meaning that they transferred less mechanical energy from the pelvis to the thigh while lowering their body.

## 4. Discussion

In stepping up, the patient group exhibited less MEC at the ankle joint, whereas the concentric MEC at the hip joint in the late-stance phase of stepping down was lower in the patient group. In contrast, no significant differences between the groups were observed at the knee joint for either stepping up or stepping down. According to a comparison of the performance in the timed stair test, the participants in this study demonstrated a limited ability for both stair ascent and descent compared with their healthy counterparts, as reported in previous studies [5,16]. Therefore, we primarily hypothesized that patients with knee OA performed stepping up and down with a deficit in the knee joint power, which was supposed to be compensated by the power of the other joints or by the energy transferred between the segments. The patients participating in this study were physically independent, and although their performance was inferior to that of the control group, their stair-negotiation ability appeared to be better than that of patients involved in previous research [12]. Hence, no difference was observed in the energetics at the knee between the groups. Although the present study did not support the hypothesis, an exploration of the energetics during stepping up and down revealed lower energy efficiency in the patient group.

In the late-stance phase of stepping up, mechanical energy must be

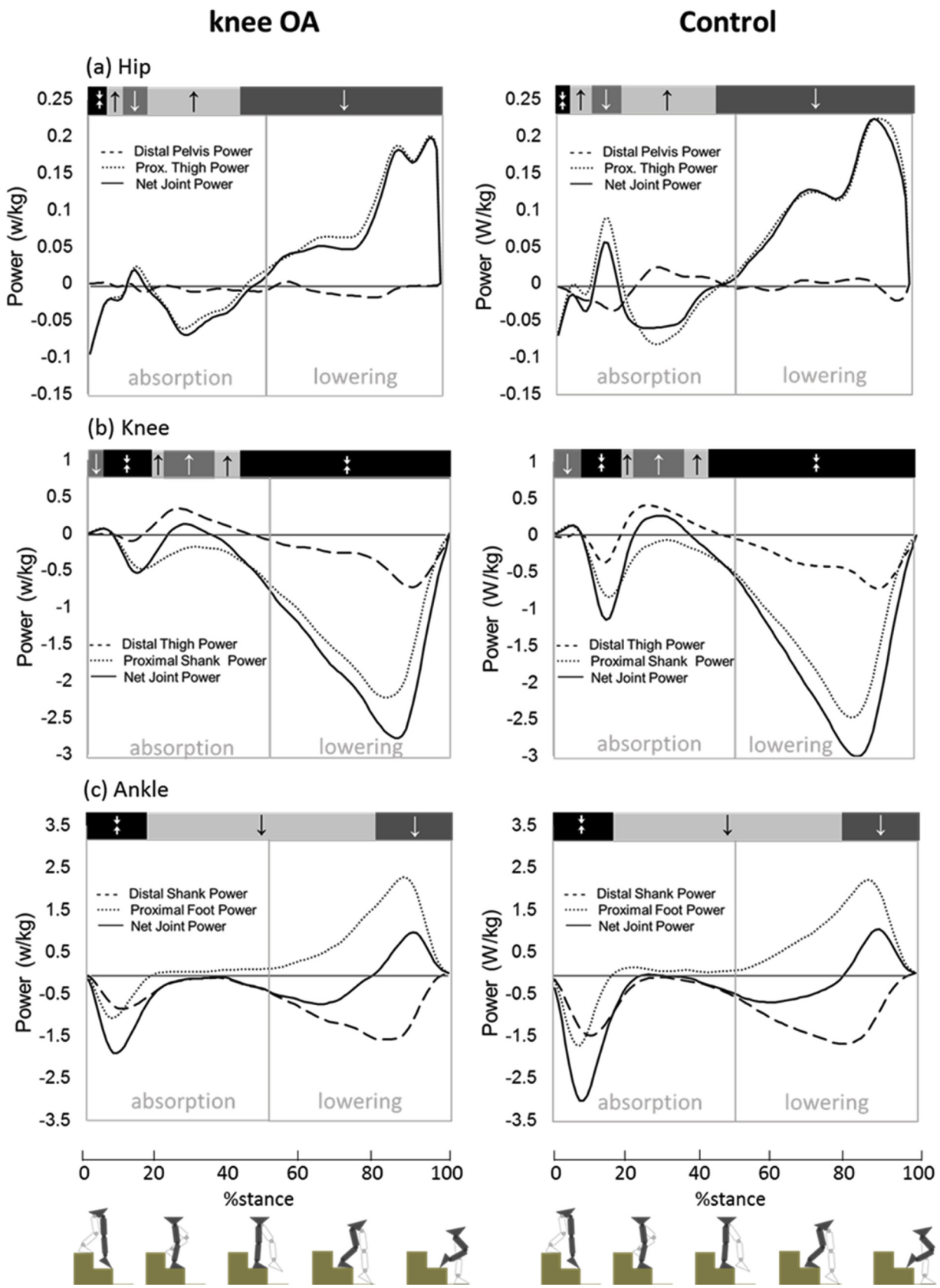


**Fig. 1.** Mean power profile at the (a) hip, (b) knee, and (c) ankle joint during the stance phase of stepping up for patients with knee osteoarthritis (left) and their healthy counterparts (right). Shaded bars represent the energy transfer condition; dark gray = concentric transfer, light gray = eccentric transfer, black = no transfer. Arrows indicate the direction of energy transfer; up arrow = toward the proximal segment, down arrow = toward the distal segment, outward double arrow = concentric (no transfer), inward double arrow = eccentric (no transfer).

**Table 3**
Mechanical energy expenditure and compensation at the hip, knee, and ankle joint for each energy transfer mode (no-transfer, concentric, and eccentric transfer) in each half of the stance during stepping up (mean ± SD). Variables very close to 0 J/kg (≈0) were not used for the group comparison. When the mechanical energy expenditure in a phase was zero, the MEC in that phase was not calculated.

| | Elevation (1st half of the stance phase) | | Propulsion (2nd half of the stance phase) | |
|---|---|---|---|---|
| | Knee OA | Control | Knee OA | Control |
| Hip MEE (J/kg) | | | | |
| Concentric | 28.65 ± 6.78 | 28.63 ± 10.71 | 2.66 ± 1.91 | 3.06 ± 3.05 |
| Eccentric | ≈ 0 | ≈ 0 | ≈ 0 | ≈ 0 |
| No Transfer | 54.91 ± 16.94 | 55.66 ± 18.85 | 1.26 ± 8.17 | –0.54 ± 8.03 |
| Knee MEE (J/kg) | | | | |
| Concentric | 13.68 ± 7.58 | 14.33 ± 7.67 | 2.93 ± 2.20 | 2.37 ± 1.87 |
| Eccentric | –0.20 ± 0.22 | –0.43 ± 0.51 | –1.63 ± 2.03 | –2.74 ± 2.69 |
| No Transfer | 68.04 ± 18.64 | 72.80 ± 16.66 | 2.64 ± 7.02 | 3.24 ± 5.87 |
| Ankle MEE (J/kg) | | | | |
| Concentric | 1.65 ± 0.99 | 1.15 ± 0.72 | 48.20 ± 14.79 | 43.57 ± 15.67 |
| Eccentric | –2.48 ± 1.47 | –3.51 ± 2.48 | ≈ 0 | ≈ 0 |
| No Transfer | –3.24 ± 3.26 | –6.35 ± 7.82 | 33.28 ± 19.61 | 44.13 ± 24.96 |
| Hip MEC | | | | |
| Concentric | 0.32 ± 0.06 | 0.28 ± 0.09 | 0.46 ± 0.18 | 0.47 ± 0.15 |
| Eccentric | – | – | – | – |
| Knee MEC | | | | |
| Concentric | 0.30 ± 0.07 | 0.35 ± 0.07 | 0.58 ± 0.10 | 0.57 ± 0.11 |
| Eccentric | 0.78 ± 0.16 | 0.76 ± 0.15 | 0.66 ± 0.18 | 0.59 ± 0.14 |
| Ankle MEC | | | | |
| Concentric | 0.47 ± 0.14 | 0.47 ± 0.12 | 0.30 ± 0.09 * | 0.41 ± 0.17 |
| Eccentric | 0.42 ± 0.13 | 0.39 ± 0.10 | – | – |

*A significant difference between groups ($p < 0.05$).
≈ 0 A variable that was very close to zero and was not used for group comparison.
– Eccentric MEC at the hip joint during stepping up and the ankle joint in 2nd half of the stance phase were not calculated because MEE values in those phases were zero.

produced at the ankle joint for forward progression. Previous research indicated that older adults perform stair ascent with less concentric mechanical energy transfer at the ankle joint compared with younger adults [9]. In that study, no significant difference in the ankle MEC was observed when the cadence was considered as a covariate. In the present study, where all of the participants performed the tasks at the same cadence, altered movement strategies in patients were found to be independent of a reduction in the gait speed. As a previous study found that patients with knee OA exhibited less MEC than healthy subjects at the ankle joint in the late stance of paced gait [10], it can be concluded that less energy transfer also occurs in stepping up. Prior to push-off, the kinematic energy at the foot segment should be significantly increased, and the mechanical energy transferred from the shank to the foot segment could compensate some parts of the work produced by the ankle plantar flexor muscles. The patients in this study performed stepping up with the same MEE but less MEC at the ankle joint compared with the control group, indicating that the patients were unable to supply much mechanical energy without muscle contractions.

For stepping down, there was a statistically significant difference in the concentric MEE at the hip joint in the early stance. However, the net joint work at the hip joint in the early stance of stepping down was approximately one-fifth the amount of the concentric hip MEE in the late stance. Therefore, although the statistical difference appeared to be significant, the meaningfulness of the difference in the hip MEE in the early stance is questionable. Although the amount of mechanical energy absorbed at the hip joint is smaller than the joint negative work at the knee and ankle joints, the hip muscles contribute to pelvis and trunk control while the body is lowered. In the late stance, the patients exhibited less MEC at the hip joint than healthy subjects, indicating that the patients with knee OA limited their energy transfer from the pelvis to the thigh to maintain mechanical energy at the pelvis and to stabilize their pelvis and trunk. According to previous studies that indicated the relationships between the fear of falling and the trunk instability during gait in older adults [17,18], this seemed to be a strategic alteration in patients, who supposedly were at a greater risk for falls owing to their symptoms and physical dysfunction. Patients, who had limited ability for stair descent, displayed such a strategy from the beginning of the stair negotiation or even while descending only a single step because of their greater risk of falls due to their pathology.

This study has limitations. First, because inverse dynamics was used for the mechanical energy analysis, we could not evaluate the true muscle power. Future studies using forward dynamics to evaluate the muscle power may provide further pathology interpretation. In addition, although the participants in this study were asked to perform the tasks at the same pace to eliminate the effect of the gait speed on the mechanical work, which is defined as the time-integrated power at each joint/segment, there is a possibility that different results can still be obtained if the participants perform the tasks at a preferred pace in their daily lives. Furthermore, the single steps up and down used as testing tasks in present study differ from true stair negotiation in the biomechanical features of movement. Although some changes were found in the single steps up and down, which might be related to the disability of the patients regarding stair negotiation, further differences should be found if we evaluate the energetics in true stair negotiation, which will elucidate the disability of the patients.

A previous study revealed that muscle strength influences the energetics during ambulation even in populations diagnosed with the same musculoskeletal disease [15]. Thus, further studies are needed to explore the relationship between physical function and mechanical energy efficiency in such patients. In the present study, the patient group and their healthy counterparts exhibited comparable mechanical power profiles at the knee joint. However, this remains inconclusive because patients, who have diverse symptoms and physical functions, might perform stair negotiation with a variety of movement strategies. A future study may also focus on the relationship between the energetics at the knee joint and the energetics at other joints for a larger

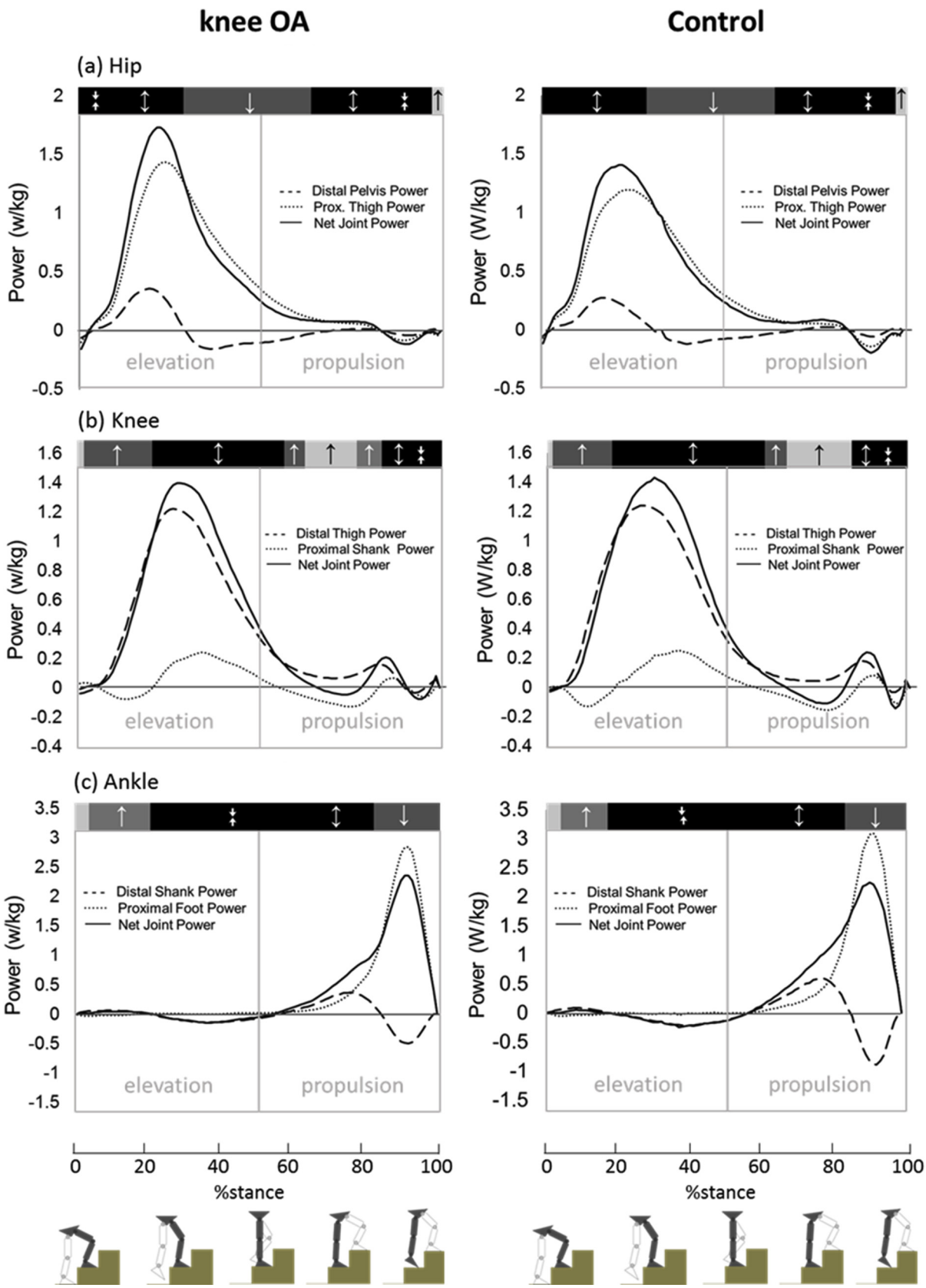


**Fig. 2.** The mean power profile at the (a) hip, (b) knee, and (c) ankle joint during the stance phase of stepping down for patients with knee osteoarthritis (left) and their healthy counterparts (right). Shaded bars represent the energy transfer condition; dark gray = concentric transfer, light gray = eccentric transfer, black = no transfer. Arrows indicate the direction of energy transfer; up arrow = toward the proximal segment, down arrow = toward the distal segment, outward double arrow = concentric (no transfer), inward double arrow = eccentric (no transfer).

**Table 4**
Mechanical energy expenditure and compensation at the hip, knee, and ankle joint for each energy transfer mode (no-transfer, concentric, and eccentric transfer) in each half of the stance during stepping down (mean ± SD). Variables very close to 0 J/kg (≈0) were not used for the group comparison. When the mechanical energy expenditure in a phase was zero, the MEC in that phase was not calculated.

| | Absorption (1st half of the stance phase) | | Lowering (2nd half of the stance phase) | |
|---|---|---|---|---|
| | Knee OA | Control | Knee OA | Control |
| Hip MEE (J/kg) | | | | |
| Concentric | 0.32 ± 0.21 * | 1.15 ± 0.99 | 5.48 ± 3.61 | 4.30 ± 3.66 |
| Eccentric | –1.23 ± 0.85 | –2.03 ± 1.99 | –0.82 ± 1.60 | –2.51 ± 4.12 |
| No Transfer | –1.27 ± 2.17 | –0.85 ± 2.24 | 6.81 ± 5.74 | 7.23 ± 8.21 |
| Knee MEE (J/kg) | | | | |
| Concentric | 4.11 ± 2.92 | 5.38 ± 3.67 | ≈ 0 | ≈ 0 |
| Eccentric | –7.28 ± 6.95 | –4.70 ± 2.81 | –17.55 ± 23.35 | –9.80 ± 17.89 |
| No Transfer | –11.82 ± 8.08 | –13.14 ± 9.76 | –149.76 ± 45.32 | −151.20 ± 34.56 |
| Ankle MEE (J/kg) | | | | |
| Concentric | 1.15 ± 1.24 | 0.88 ± 1.29 | 26.66 ± 6.91 | 22.94 ± 6.18 |
| Eccentric | –8.77 ± 6.72 | –9.05 ± 3.58 | –30.08 ± 10.58 | –27.99 ± 13.01 |
| No Transfer | –42.84 ± 17.30 | –55.59 ± 23.45 | –11.81 ± 6.90 | –11.81 ± 11.11 |
| Hip MEC | | | | |
| Concentric | 0.58 ± 0.14 | 0.48 ± 0.16 | 0.28 ± 0.08 * | 0.37 ± 0.14 |
| Eccentric | 0.46 ± 0.11 | 0.45 ± 0.13 | 0.60 ± 0.16 | 0.55 ± 0.21 |
| Knee MEC | | | | |
| Concentric | 0.58 ± 0.16 | 0.51 ± 0.09 | – | – |
| Eccentric | 0.51 ± 0.07 | 0.56 ± 0.06 | 0.21 ± 0.12 | 0.28 ± 0.19 |
| Ankle MEC | | | | |
| Concentric | 0.57 ± 0.18 | 0.65 ± 0.17 | 0.75 ± 0.04 | 0.76 ± 0.05 |
| Eccentric | 0.37 ± 0.13 | 0.41 ± 0.12 | 0.61 ± 0.08 | 0.62 ± 0.14 |

* A significant difference between groups ($p < 0.05$).
≈ 0 A variable that was very close to zero and was not used for group comparison.
– Concentric MEC at the knee joint during stepping down in 1st half of stance the phase was not calculated because MEE values in those phases were zero.

number of cohort patients with knee OA to obtain further information regarding the compensatory mechanics in the patients.

## 5. Conclusions

The mechanical energy efficiency during stepping up and down was evaluated in patients with knee OA using mechanical energy analysis. The results indicate that the patients with knee OA performed stepping up with less energy transfer between the shank and foot segment in the late stance compared with healthy subjects, which indicates a lower efficiency at the ankle joint prior to push-off. On the other hand, in stepping down, the patients exhibited less distal energy transfer from the pelvis segment. These differences were assumed to be associated with the limited stair-negotiation performance of patients with knee OA.

## Conflict of interest

None of the authors have any conflicts of interest associated with this study.

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