Abstract. [Purpose] The purpose of this study was to investigate the measurement method and parameters to simply evaluate the condition of the knee that are necessary for preventing locomotive syndrome as advocated by the Japan Orthopedic Association. [Subjects and Methods] The subjects installed acceleration sensors in lateral condyles of the tibia and measured acceleration and load under the conditions of walking on a flat ground and walking using stairs; the difference between the impulse of impact forces (acceleration × load) of the two knees was defined as a simple evaluation parameter. [Results] Simple evaluation parameters were not correlated with age during walking on a flat ground, but during walking using stairs, it was almost flat up to the age of 20–40 years, and after the age of 49 years, based on the quadratic curve approximation (R²=0.99), a correlation of simple evaluation parameters with age could be confirmed. [Conclusion] The simple evaluation parameter during walking using stairs was highly correlated with age, suggesting a contribution to preventing locomotive syndrome by improving reliability. In the future, we plan to improve reliability by increasing the data, and establish it as a simple evaluation parameter that can be used for preventing locomotive syndrome in elderly people and those with KL classification grades 0–1.

Key words: Impact forces, Acceleration, Impulse

INTRODUCTION

In 2014, the Ministry of Health, Labour and Welfare (MHLW) published a white paper[1] entitled “Towards the Realization of a Healthy and Longevous Society (health/prevention).” According to this paper, the difference between the average lifespan and number of healthy years lived was approximately 9 years for men and 13 years for female. This paper also stated that increasing the number of healthy years of life is critical because increasing healthcare and nursing costs are correlated with the widening of these gaps. In addition, a 2013 MHLW report[2] stated that a quarter of the number of patients require supportive care or nursing services because of musculoskeletal disorders. The report further provided activity guidelines that aimed at improving health and increasing the number of healthy years lived. The Japan Orthopedic Association has proposed the term locomotive syndrome[3] (LS), which describes a state in which the movement function due to a disorder experienced by the exerciser is deteriorated. LS refers to a state characterized by disorders of the bones, joints, cartilage, and muscles, wherein daily movement functions such as walking are deteriorated. Also, early detection in slight gonarthrosis and proper training were recommended for preventing of gonarthrosis on older age groups. Therefore, parameters to evaluate the burden on the knee were examined to support early detection.

One factor that correlated with LS is gonarthrosis. It has been reported[4] that the onset of this disease is caused by the deterioration or hardening of chondrocytes, cartilage matrix, periarticular tendon, ligament, and muscle constituting the joint,
many of which progressively develop with distinct symptoms on the left and right foot. Tachibana\(^9\) reported that “There is no obvious cause in gonarthrosis and it is frequent that chronic mechanical stimulus is added to aging and the frequency of onset is high.” Fukui\(^8\) reported that “prevention of onset has particularly important meaning”. Moreover, reports by Yamada et al.\(^9\) and Kamono\(^7\) state that “Age-related change in gait changes from 50’s,” we recommend that self, prevention for gonarthrosis targeting older age groups after 50’s. We thought that it was necessary to formulate preventive programs including a management program\(^9\). Thus, we reported\(^9\) parameters and measurement methods for the easy evaluation of the condition of the knee required for creation.

In that report, it was presumed that the proportion of the burden carried by the left and right knees at the time of walking was biased because of the daily living environment, walking habit, and deterioration of motor function due to aging\(^10\); this bias was defined as a simple evaluation parameter.

The simple evaluation parameters showed bias in the impulse of the impact force occurring in the right and the left knees. Moreover, these were assumed to be lesser in the young and healthy subjects and were believed to have increased in the elderly with slight gonarthrosis. In this paper, we analyze the simple evaluation parameters of a flat ground and staircase gait and report the possibility that simple evaluation parameters contribute to LS prevention. The impulse of impact force here is the force obtained by integrating the reaction force from HC to TO.

**SUBJECTS AND METHODS**

Eight healthy subjects (mean age: 44.3 years) and one patient with disease (age: 56 years, KL classification grade 2) were enrolled. The nature and purpose of this study were explained to the participants and their families in accordance with the principles of the Declaration of Helsinki. Thereafter, written informed consents were obtained from the participants for the study. This research was approved for human beings by the Research Ethics Review Committee of the Department of Advanced Fibro-Science, Kyoto Institute of Technology (2016–24).

In this method, using a system consisting of accelerometers (Unimec; UMJG6) mounted on the lateral condyle of tibia of both feet of a subject and stabilometers (Unimec; UM-BAR II) placed on the stairs and walking path (Fig. 1), we determined the impact force occurring in the knee during walking on a flat ground (Fig. 2) and on stairs (Fig. 3). This force was integrated with respect to the time elapsed from the heel contact (HC) to the toe off (TO) to derive simple evaluation parameters (impulse of impact force)\(^9\). The output voltage of the acceleration sensor (gain was set to 0.98 V/G) and the AMP output voltage of the stabilometer (for 3 channels) were sampled with a single A/D conversion board to allow for precise synchronization of the accelerometers and stabilometers. Thus, the voltage values of 6 channels of the acceleration sensors and 6 channels of the load sensors of the stabilometers were sampled at 1,000 Hz using a single A/D conversion board (Contec: ADA16-32/2 (CB) F, resolution 16 bit, 16 ch, conversion speed 2 µsec/ch) to ensure synchronization. The cutoff frequency of a low-pass filter after A/D conversion is generally set to 8–9 Hz\(^11\); in this study, the cutoff frequency was set to 26 Hz based on the frequency analysis results of the preliminary experiment. For walking on a flat ground, 5 trial measurements were made while the subject stepped on and walked between two stabilometers placed on the floor 4 meters from the starting position, and then at an interval of 40%\(^12\) of the body height. However, for the sake of safety, the subjects were instructed to look at the stabilometers, and step on and pass through the stabilometer that was 4 m ahead, then stop at the point 6 m ahead thereof. For walking on stairs, a staircase with a rise of 1 cm (to add a disturbance) was prepared. The subject walked down the stairs while stepping on the stabilometers placed on the stairs, turned around, and then walked up the stairs. Counting this series of action as one set, 5 trials of measurements were made. During the measurements, the subjects were not informed of the rise, in order to add a disturbance. Instead, they were instructed to watch their feet for safety. The subjects were also instructed to stand still (for approximately 1 second) before the beginning and after completing the action, and when the action was switched (only during the action of walking up and down the stairs) to clarify the start and end of the action during walking on a flat ground and walking using stairs. To eliminate unnecessary vibrations during measurements as much as possible, the acceleration sensor attachment site was depilated, the sensor was attached with a double-sided tape (NITOMS PRO SELF) and then secured with adhesive bandage (PIP: H101), and the signal cable was fixed with surgical tape in such a manner that the cable could not contact the acceleration sensor, to suppress the shakiness of the cable (Fig. 4). We allowed subjects to practice in advance. The reason why the acceleration sensor is attached to the lateral condyle of the tibia is that interference from the skin, and the like, is small based on the result of the preliminary experiment.

The determination of simple evaluation parameters differ between walking on flat ground and walking using stairs; however, impulse (\(S_8\)) obtained by integrating impact force (\(f_k\)) occurring on the left and right knees with respect to the time from the HC to the TO is used for both. The impact force (\(f_k\)) was determined by multiplying the load (\(W=G\)) calculated by the three sensor voltages (\(v_1, v_2, v_3\)) of the stabilometers using the conversion coefficient \((a, b)\)\(^3\) and the vertical acceleration (\(|ak|\)) obtained by converting the sensor voltage of the acceleration meter with 0.98 V/G (Equations 1–4)\(^9\). Here, the load (\(W=mG\)) obtained from the stabilometer is an instantaneous value (1/1,000 second), and this value is altered by the movement of the center of gravity and the muscle force; therefore, \(m\) was regarded as the instantaneous mass on the foot bottom at the instant. The impact force (\(f_k\)) at 1/1,000 second, applied to the knee joint, was defined as the scalar quantity. The absolute value of the vertical acceleration (\(|ak|\)) was used.
\[ W = (v_1 + v_2 + v_3) \times a + b \quad (1) \]

\[ f_k = |a_k| \times \frac{W}{G} \quad (2) \]

Where \( W \) denotes load, \( G \) denotes gravitational acceleration, \( a_k \) denotes vertical acceleration, and \( f_k \) denotes impact force.

\[ \Delta S_{k_i} = \Delta \cdot f_{k_i} - \frac{\Delta (f_{k_i} - f_{k_{i-1}})}{2} \quad i \geq 2 \quad (3) \]

\[ S_k = \sum_{i=1}^{n} S_{k_i} \quad n = \text{number of data} \quad i < n \quad (4) \]

As stated above, simple evaluation parameters are determined using the impulse of the impact force, but there are different ways of calculating them, between walking on a flat ground and walking using stairs. For walking on a flat ground, we determined the difference in impulse between the first step and the second step in each trial, and the standard deviation (SD) for all trials was used as a simple evaluation parameter (Table 1). This simple evaluation parameter indicates an imbalance between the left and right sides of the body and was assumed to be less in young and healthy individuals and high in elderly individuals and those at high risk for OA, as stated in the beginning. For stair walking, a value calculated in the following 3 steps was used as a simple evaluation parameter. Step 1: The difference in impulse between the first and the second steps
Table 1. The impulse of impact force by each trial for walking on a flat ground

| Subject information | Trial | Right knee (N·s) | Left knee (N·s) | Difference (left-right) (N·s) |
|---------------------|-------|------------------|-----------------|-------------------------------|
| ID                  | A (healthy) | try1             | 2.50            | 4.74                          | -2.24                        |
| Gender              | Female    | try2             | 3.19            | 3.35                          | -0.16                        |
| Age (years)         | 17       | try3             | 4.33            | 5.72                          | -1.39                        |
| Weight (kg)         | 50       | try4             | 3.34            | 5.87                          | -2.52                        |
| Height (cm)         | 155      | try5             | 2.69            | 5.59                          | -2.90                        |
| BMI (kg/m²)         | 21       | SD               | 0.71            | 1.05                          | -0.33                        |
| ID                  | B (healthy) | try1             | 12.82           | 10.23                         | 2.59                         |
| Gender              | Male     | try2             | 13.51           | 11.62                         | 1.88                         |
| Age (years)         | 28       | try3             | 13.72           | 13.48                         | 0.24                         |
| Weight (kg)         | 75       | try4             | 14.04           | 12.17                         | 1.87                         |
| Height (cm)         | 168      | try5             | 13.32           | 14.21                         | -0.89                        |
| BMI (kg/m²)         | 27       | SD               | 0.86            | 1.29                          | -0.43                        |
| ID                  | C (healthy) | try1             | 16.10           | 16.58                         | -0.48                        |
| Gender              | Male     | try2             | 15.76           | 14.18                         | 1.58                         |
| Age (years)         | 39       | try3             | 16.34           | 13.21                         | 3.14                         |
| Weight (kg)         | 68       | try4             | 17.99           | 13.99                         | 4.00                         |
| Height (cm)         | 168      | try5             | 16.76           | 13.85                         | 2.91                         |
| BMI (kg/m²)         | 24       | SD               | 0.86            | 1.29                          | -0.43                        |
| ID                  | D (healthy) | try1             | 12.41           | 13.08                         | -0.67                        |
| Gender              | Male     | try2             | 13.15           | 15.70                         | -2.55                        |
| Age (years)         | 44       | try3             | 12.43           | 15.58                         | -3.14                        |
| Weight (kg)         | 77       | try4             | 12.52           | 16.23                         | -3.71                        |
| Height (cm)         | 170      | try5             | 11.38           | 15.23                         | -3.84                        |
| BMI (kg/m²)         | 24       | SD               | 0.64            | 1.22                          | -0.58                        |
| ID                  | E (healthy) | try1             | 11.60           | 13.68                         | -2.09                        |
| Gender              | Male     | try2             | 14.06           | 12.40                         | 1.67                         |
| Age (years)         | 49       | try3             | 11.65           | 13.07                         | -1.42                        |
| Weight (kg)         | 72       | try4             | 12.99           | 10.88                         | 2.11                         |
| Height (cm)         | 168      | try5             | 14.41           | 10.10                         | 4.31                         |
| BMI (kg/m²)         | 26       | SD               | 1.31            | 1.50                          | -0.19                        |
| ID                  | F (healthy) | try1             | 10.06           | 10.06                         | 0.00                         |
| Gender              | Female   | try2             | 9.64            | 11.10                         | -1.47                        |
| Age (years)         | 55       | try3             | 9.69            | 9.66                          | 0.03                         |
| Weight (kg)         | 49       | try4             | 10.05           | 9.09                          | 0.96                         |
| Height (cm)         | 155      | try5             | 9.35            | 10.79                         | -1.45                        |
| BMI (kg/m²)         | 20       | SD               | 0.30            | 0.82                          | -0.52                        |
| ID                  | G (healthy) | try1             | 4.88            | 6.67                          | -1.79                        |
| Gender              | Male     | try2             | 3.99            | 9.71                          | -5.72                        |
| Age (years)         | 58       | try3             | 4.98            | 6.25                          | -1.27                        |
| Weight (kg)         | 82       | try4             | 4.67            | 7.33                          | -2.66                        |
| Height (cm)         | 170      | try5             | 6.86            | 7.65                          | -0.79                        |
| BMI (kg/m²)         | 28       | SD               | 1.07            | 1.34                          | -0.27                        |
| ID                  | H (healthy) | try1             | 3.15            | 7.55                          | -4.40                        |
| Gender              | Male     | try2             | 4.17            | 8.33                          | -4.17                        |
| Age (years)         | 64       | try3             | 4.44            | 8.25                          | -3.81                        |
| Weight (kg)         | 72       | try4             | 4.33            | 8.31                          | -3.98                        |
| Height (cm)         | 172      | try5             | 4.11            | 7.16                          | -3.05                        |
| BMI (kg/m²)         | 24       | SD               | 0.52            | 0.54                          | -0.02                        |
was determined for each trial of walking down the stairs, and we then calculated the SD for all trials. Step 2: The difference in impulse between the left and right knees showed negative polarity for all trials. Step 3: The absolute difference between the SDs for walking down (SD.D) and walking up (SD.U) was calculated and used as a simple evaluation parameter (S.E.P) (Table 3). This simple evaluation parameter indicates an imbalance between the left and right sides of the body during walking down and up the stairs and was assumed to be less in young and healthy individuals and high in elderly individuals and a high OA-risk group as stated in the beginning. In addition, variances for walking down (SD.D) and up (SD.U) indicate an imbalance between the left and right sides of the body during walking down and up the stairs, respectively, as for walking on a flat ground. The statistical methods in this paper were the coefficient of determination (The square of the multiple correlation coefficient), single regression analysis and multiple regression analysis, And the regression analysis was set the confidence interval to 95%. The multiple correlation coefficient was used for statistical processing in this paper.

### RESULTS

We first focus on the impulse between the first second steps in each trial. In that case, the impulses of subjects A and G, and H were single digit, whereas that of the subjects B–F was two digits. The differences in the impulses of subjects A, D, G, and H were negative during all trials, indicating that the left foot had larger impulses. Subjects B and C showed positive impulse differences in 4 of 5 trials, whereas the impulse difference was negative and small (less than 1) in one trial. Thus, the right foot generally had larger impulses in these subjects. These results suggest that, while walking on flat ground, the body balance shifted in such a manner that the left foot received more impact force in subjects A, D, G, and H, whereas the right foot received more impact force in subjects B and C. In addition, subjects E and F had both positive and negative polarities during 5 trials. Subject F exhibited small differences in impulse; therefore, this subject is likely to have had a small shift in body balance while walking on flat ground. Focusing on a simple evaluation parameter (SD) for all trials of subjects A–H, no correlation was noted for age, body weight, height, or BMI (Table 1, 2).

### Table 1.

| Subject information | Trial | Right knee (N·s) | Left knee (N·s) | Difference (left-right) (N·s) |
|---------------------|-------|-----------------|----------------|-------------------------------|
| ID P (patient)      | try1  | 12.62           | 13.00          | −0.38                         |
| Gender Male         | try2  | 14.76           | 17.33          | −2.58                         |
| Age (years) 56      | try3  | 12.97           | 15.76          | −2.79                         |
| Weight (kg) 92      | try4  | 13.77           | 16.33          | −2.56                         |
| Height (cm) 162     | try5  | 12.90           | 15.99          | −3.09                         |
| BMI (kg/m²) 35      | SD    | 0.87            | 1.62           | −0.75                         |

The subjects (A, D, G–P) was considered to have a tendency to increase the burden on the left knee because the impulse difference between the left and right knees showed negative polarity for all trials. The subjects (B, C) was considered to have a tendency to increase the burden on the right knee because the impulse difference between the left and right knees shows positive polarity for all trials, except one trial. The subjects (E, F) was considered to have no bias in walking because the impulse difference between the left and right knees showed bipolarity. The bias of walking is recognized through this result for all subjects, except the subjects (B, C).

### Table 2.

| Element               | R²  |
|-----------------------|-----|
| Age                   | 0.18|
| Weight                | 0.03|
| Height                | 0.19|
| Body mass index       | 0.00|

There was no correlation between SD and elements. For walking on a flat ground, SD was the difference in impulse between the first (SD of right-knee) and the second (SD of left-knee) steps.
The body balance states observed between the first and second steps in walking up and down the stairs were different than those observed while walking on flat ground. For subject A, the impulse difference was negative when climbing the stairs, suggesting a shift to the left foot, similar to walking on flat ground; however, the shift in body balance was minimal when walking down the stairs. The impulse difference between the first step and the second steps was small when walking down the stairs but large when walking up the stairs. Likewise, the body balance states differed between walking up and down the stairs, in all subjects except for subject E. Furthermore, subjects C–F had extremely large impulses when walking down compared to those observed when walking up. Subjects C–F exhibited extremely large impulses when walking up compared to those when walking down the stairs. These results confirm extremely large differences in impact force impulses between walking down- and upstairs, for all subjects. When we analyzed these data by age, the values generated while walking up the stairs were large for the 17-year-old and 28-year-old subjects, and the values generated while walking down the stairs were large for subjects between 39–58 years of age. The oldest (64-year-old) subject, like the 17-year-old and 28-year-old subjects, exhibited a small value while walking down the stairs, and there was no correlation with age. No correlation was also observed with body weight, height, or BMI (Table 3, 4). Nevertheless, the stair walking results were clearly different from those obtained while walking on flat ground. However, the simple evaluation parameter (S.E.P) was almost negligible in healthy subjects aged 20–40 and a quadratic curve approximation for ≥49-year-old subjects had a correlation with age, except for patient P (Fig. 5, R²=0.99).

### Table 3. The impulse of impact force between both knees by each trial for the first and second steps in walking using stairs

| Subject information | Trial | Down the stairs (N·s) | Up the stairs (N·s) | S.E.P (N·s) |
|---------------------|-------|----------------------|---------------------|-------------|
|                     |       | Step 1st | Step 2nd | Difference [2nd−1st] | Step 1st | Step 2nd | Difference [2nd−1st] | Difference [SD.D–SD.U] |
| ID                  |       |          |          |                  |          |          |                  |                          |
| A (healthy)         | try1  | 4.84     | 5.87     | 1.03             | 11.87    | 15.89    | 4.02             |                          |
| Gender Male         |       |          |          |                  |          |          |                  |                          |
| Age (years)         | 17    | try3     | 6.71     | 6.39             | 0.33     | 13.53    | 16.05            | 2.52                     |
| Weight (kg)         | 50    | try4     | 6.16     | 7.30             | 1.14     | 13.53    | 16.05            | 2.52                     |
| Height (cm)         | 155   | try5     | 4.82     | 4.74             | 0.08     | 14.30    | 17.41            | 3.12                     |
| BMI (kg/m²)         | 21    | SD       |          |                  |          |          |                  |                          |
| ID                  |       |          |          |                  |          |          |                  |                          |
| B (healthy)         | try1  | 6.80     | 7.09     | 0.28             | 20.87    | 20.46    | 0.41             |                          |
| Gender Male         |       |          |          |                  |          |          |                  |                          |
| Age (years)         | 28    | try3     | 7.49     | 7.48             | 0.01     | 17.28    | 21.30            | 4.02                     |
| Weight (kg)         | 75    | try4     | 9.28     | 4.90             | 4.38     | 18.99    | 23.36            | 4.37                     |
| Height (cm)         | 168   | try5     | 8.53     | 8.57             | 0.04     | 17.26    | 17.52            | 0.25                     |
| BMI (kg/m²)         | 27    | SD       |          |                  |          |          |                  |                          |
| ID                  |       |          |          |                  |          |          |                  |                          |
| C (healthy)         | try1  | 23.55    | 15.56    | 7.98             | 8.03     | 6.46     | 1.56             |                          |
| Gender Male         |       |          |          |                  |          |          |                  |                          |
| Age (years)         | 39    | try3     | 21.86    | 15.05            | 6.81     | 8.65     | 6.17             | 2.48                     |
| Weight (kg)         | 68    | try4     | 22.64    | 15.66            | 6.98     | 8.19     | 7.61             | 0.57                     |
| Height (cm)         | 168   | try5     | 22.51    | 16.03            | 6.48     | 8.58     | 6.22             | 2.36                     |
| BMI (kg/m²)         | 24    | SD       |          |                  |          |          |                  |                          |
| ID                  |       |          |          |                  |          |          |                  |                          |
| D (healthy)         | try1  | 17.49    | 18.67    | 1.18             | 6.77     | 5.99     | 0.78             |                          |
| Gender Male         |       |          |          |                  |          |          |                  |                          |
| Age (years)         | 44    | try3     | 18.29    | 18.18            | 0.11     | 7.11     | 3.05             | 4.06                     |
| Weight (kg)         | 77    | try4     | 18.16    | 21.17            | 3.01     | 6.43     | 3.57             | 2.86                     |
| Height (cm)         | 170   | try5     | 16.31    | 17.13            | 0.83     | 6.56     | 7.51             | 0.95                     |
| BMI (kg/m²)         | 27    | SD       |          |                  |          |          |                  |                          |
| ID                  |       |          |          |                  |          |          |                  |                          |
| E (healthy)         | try1  | 17.26    | 16.85    | 0.42             | 4.86     | 6.39     | 1.54             |                          |
| Gender Male         |       |          |          |                  |          |          |                  |                          |
| Age (years)         | 49    | try3     | 18.32    | 14.91            | 3.41     | 5.86     | 6.87             | 1.01                     |
| Weight (kg)         | 72    | try4     | 19.43    | 17.95            | 1.48     | 2.68     | 6.67             | 4.00                     |
| Height (cm)         | 168   | try5     | 15.38    | 17.31            | 1.93     | 5.03     | 2.93             | 2.10                     |
| BMI (kg/m²)         | 26    | SD       |          |                  |          |          |                  |                          |
While walking on flat ground, the impact force impulses were of single digit for both feet in subjects A, G, and H and was as large as two digits for subjects B–F (28 to 49 years old). This indicates that subjects A, G, and H had less force when stepping on the floor, compared to other subjects. This may be due to subject A being a 17-year-old female, subjects

| Subject information | Trial | Down the stairs (N·s) | Up the stairs (N·s) | S.E.P (N·s) |
|---------------------|-------|-----------------------|---------------------|-------------|
| ID                  | F (healthy) | try1 | 13.44 | 13.31 | 0.13 | 4.68 | 2.09 | 2.58 |
| Gender              | Female | try2 | 13.85 | 14.43 | 0.58 | 4.64 | 2.12 | 2.52 |
| Age (years)         | 55 | try3 | 13.78 | 11.22 | 2.56 | 4.74 | 3.12 | 1.62 |
| Weight (kg)         | 49 | try4 | 14.30 | 13.48 | 0.82 | 4.93 | 2.41 | 2.52 |
| Height (cm)         | 155 | try5 | 13.68 | 12.16 | 1.52 | 5.03 | 2.93 | 2.10 |
| ID                  | G (healthy) | try1 | 18.38 | 15.91 | 2.47 | 8.31 | 5.38 | 2.93 |
| Gender              | Male | try2 | 20.83 | 14.60 | 6.23 | 7.72 | 6.47 | 1.26 |
| Age (years)         | 58 | try3 | 20.49 | 14.25 | 6.24 | 7.60 | 7.06 | 0.54 |
| Weight (kg)         | 82 | try4 | 20.21 | 15.22 | 4.99 | 7.82 | 5.91 | 1.91 |
| Height (cm)         | 170 | try5 | 22.69 | 14.80 | 7.89 | 8.33 | 5.41 | 2.92 |
| ID                  | H (healthy) | try1 | 7.39 | 18.61 | 11.23 | 14.98 | 28.47 | 13.49 |
| Gender              | Male | try2 | 24.47 | 20.87 | 3.60 | 5.25 | 5.98 | 0.73 |
| Age (years)         | 64 | try3 | 6.62 | 9.84 | 3.22 | 14.98 | 28.47 | 13.49 |
| Weight (kg)         | 72 | try4 | 7.16 | 7.91 | 0.75 | 13.54 | 15.02 | 1.48 |
| Height (cm)         | 172 | try5 | 7.15 | 8.38 | 1.22 | 15.03 | 16.23 | 1.20 |
| ID                  | P (patient) | try1 | 25.06 | 19.72 | 5.33 | 5.50 | 6.84 | 1.35 |
| Gender              | Male | try2 | 25.47 | 18.34 | 7.12 | 8.98 | 9.12 | 0.13 |
| Age (years)         | 56 | try3 | 25.47 | 18.34 | 7.12 | 8.98 | 9.12 | 0.13 |
| Weight (kg)         | 92 | try4 | 25.06 | 19.72 | 5.33 | 5.50 | 6.84 | 1.35 |
| Height (cm)         | 162 | try5 | 25.06 | 19.72 | 5.33 | 5.50 | 6.84 | 1.35 |
| BMI (kg/m²)         | 28 | SD | SD.D | SD.U | 0.95 | SD.U | 0.41 |
| ID                  | P (patient) | try1 | 24.47 | 20.87 | 3.60 | 5.25 | 5.98 | 0.73 |
| Gender              | Male | try2 | 24.20 | 23.24 | 0.96 | 6.37 | 3.62 | 2.75 |
| Age (years)         | 56 | try3 | 25.47 | 18.34 | 7.12 | 8.98 | 9.12 | 0.13 |
| Weight (kg)         | 92 | try4 | 25.47 | 18.34 | 7.12 | 8.98 | 9.12 | 0.13 |
| Height (cm)         | 162 | try5 | 25.06 | 19.72 | 5.33 | 5.50 | 6.84 | 1.35 |
| BMI (kg/m²)         | 35 | SD | SD.D | SD.U | 2.61 | SD.U | 0.97 |

The absolute difference in impulse between the first step and the second step was determined for each trial of walking down the stairs, and the standard deviation for all trials (SD.D) was calculated. Calculate similarly and find SD.U. The absolute difference between the standard deviation for walking down (SD.D) and the standard deviation for walking up (SD.U) was calculated and used as a simple evaluation parameter (S.E.P).

As a result, these subjects (A, B, H) tend to have a larger burden volume when walking up the stairs than walking down the stairs, and other subjects (C–G, P) tends to have a larger burden volume when walking down the stairs than walking up the stairs.

A quadratic curve approximation for ≥49-year-old subjects except for patient P confirmed a correlation with age ($R^2=0.99$).

Table 4. The correlation coefficient between SD of walking using stairs and elements by linear approximation

| Item | $R^2$ of SD.D | $R^2$ of SD.U |
|------|--------------|--------------|
| Age  | 0.35         | 0.21         |
| Weight | 0.19         | 0.19         |
| Height | 0.31         | 0.27         |
| BMI  | 0.08         | 0.02         |

There was no correlation between SD and element.
For walking on a flat ground, SD was the difference in impulse between the SD.D (SD of down the stairs) and the SD.U (SD of up the stairs).

DISCUSSION

While walking on flat ground, the impact force impulses were of single digit for both feet in subjects A, G, and H and was as large as two digits for subjects B–F (28 to 49 years old). This indicates that subjects A, G, and H had less force when stepping on the floor, compared to other subjects. This may be due to subject A being a 17-year-old female, subjects
G and H being middle-aged 58 and 64 year old male (Table 1). However, exercise performance does not appear to indicate muscle weakness or abnormal gait. Even when we focused on the simple evaluation parameter (SD) for the denote balance of the body, no correlations were found with regard to age, body weight, height, or BMI (Table 2). Therefore, impact force impulses and the simple evaluation parameter (SD) values of the left and right feet show the gait for walking on flat ground in individual subjects, but are unsuitable for prevention of knee OA in those older than 50 years of age.

Addressing this challenge was the objective of this study. During stair walking with 2-cm rises to simulate an unconventional situation in daily life (hereafter referred to as stair walking with altering feet14), we observed an imbalanced impact force impulse, either when walking down- or upstairs in all subjects; however, the difference in the impact force impulse between the first step (right foot) and the second step (left foot) when walking down- or upstairs was not correlated with age, body weight, body height, or BMI, as was the case for walking on flat ground (Table 4). This was attributable to intersubject variability, which likely depends on the position of the center of gravity (whether the load during walking up- and downstairs is placed anteriorly or left posteriorly), adjustment of walking up/down speed by muscle force15, 16), the habitual actions of each subject during stair walking with altering feet, and visibility, sense of insecurity, etc., as reported by Verghese et al17). However, when focusing on the simple evaluation parameter (S.E.P), it was near flat among subjects in the 20s–40s, and correlation with age can be confirmed for subjects of 49 years old and older, with respect to quadratic curve approximation (Fig. 5, $R^2=0.99$). These data are consistent with reports by Yamada et al.6) and Kamono7) showing that the gait starts to change at the beginning of the fifth decade of life. In contrast, patient (P) deviated from the quadratic curve approximation. Presumably, KL grade 2 and above are considered elderly and, as a group, older than their actual age in terms of the simple evaluation parameter (S.E.P). However, we cannot be certain in these observations, as we had only one patient. While there are undefined factors such as habit and a sense of insecurity as mentioned above, the simple evaluation parameter (S.E.P) is a product of the load and acceleration (knee shakiness) while climbing or descending the stairs and the time factor from HC to TO. Therefore, the phenomenon in which the polarity of the difference in the impact force impulse randomly changes, as seen in Table 1–3, is caused by intersubject differences in force and timing of stepping. This is likely attributable to age-associated deterioration of muscle strength, range of joint motion18), sense of balance, etc.19) and indicates that impacts to the left and right feet can no longer be equalized with aging, thus suggesting deterioration of locomotory apparatuses. In this regard, possible effects may include loosening of ligaments, changes to cartilage thickness, damage to the meniscus, and reduced muscle strength thereby functional deterioration of a specific apparatus does not indicate. However, Tokuda et al.20) state that one factor in the lateral thrust (Phenomenon that the knee shakes sharply in the outward direction in the early stance phase) occurring in gonarthrosis is a mechanical stress which is mainly caused by pressure and shearing force due to repeated posture and motion every day. Therefore, these effects (living environment and habit of walking, etc.) are estimated as compression or shearing force of the entire knee.

In addition, Tanaka et al.21) evaluated the state of the knee with a highly sensitive small acceleration meter mounted on the joint surface for early detection and prevention of knee OA, and reported that more mechanical vibrations occur as the severity of the symptom increases. This suggests that early-stage OA may be detected using acceleration. Thus, the high correlation between the age and the simple evaluation parameter (S.E.P) allows for motor function evaluation of the whole knee in elderly and high-risk individuals by improving the reliability of the quadratic curve coefficient and contributing to exercise guidelines for preventing locomotive syndrome.

These findings are in line with recommendations for prevention of locomotive syndrome by the Japan Orthopedic As-
sociation and a report by Fukui\(^8\) that states “prevention of the onset is particularly of significance for OA.” In this study, we reported a simple evaluation parameter (SD) for walking on flat ground and a simple evaluation parameter (S.E.P) for stair walking with altering feet. The simple evaluation parameter (SD) for walking on flat ground is an accurate measure of gait during this activity, but was considered unsuitable as a simple evaluation parameter for prevention. Meanwhile, the simplified evaluation parameter (S.E.P) for stair walking with altering feet was highly correlated with age during quadratic curve approximation. Thus, this may serve as a parameter for simple evaluation of whole-knee function, once the reliability can be improved. Although an increased amount of data are necessary to improve the reliability of quadratic curve approximation, this parameter focuses on variability during trials of stair walking with altering feet accompanied by disturbance, rather than determining statistically significant differences between randomly sampled healthy individuals and patients as in conventional approaches. Further, this method does not involve averaging of trial data. Therefore, it is possible that the reliability of this parameter can be improved by measuring a large number of trials while taking care not to generate data with coarse/dense in age ranges over the 10s–60s age groups, rather than simply increasing the volume of sampled data. It may be used as a simple method of evaluating the locomotive syndrome by guaranteeing reliability.

As Fukui says, early detection using MRI at medical examinations or the like is thought to be beneficial for prevention of knee OA, but the medical burden of MRI is large, and almost no use is made for KL grade 0 and 1. Under this circumstance, parameter can be utilized, that establishing parameter focusing on non-invasiveness, convenience, is considered useful for evaluating risk for slight knee OA. In the future, we intend to create a database and establish an indirect but useful parameter for simple knee evaluation in the elderly and those at high risk for OA to prevent locomotive syndrome.

Conflict of interest
None.

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