Abstract  The present study examined whether a sit-to-stand score can be related to the force-generating capacity of knee extensor muscles. Fifty-seven subjects (28 men, 63.0±7.8 yrs, and 29 women, 64.2±7.5 yrs, means±SDs) performed a 10-repeated sit-to-stand test as fast as possible, on a steel molded chair. The time taken (Tsit-stand) was measured with a manual stopwatch. The leg length (L), defined as the distance from the great trochanter of the femur to the malleolus lateralis, was measured using a tape. A power index of the test (Psit-stand) was calculated by using the following equation:

\[ P_{\text{sit-stand}} = (L - 0.4) \times \text{body mass} \times g \times 10 / T_{\text{sit-stand}} \]

The cross-sectional area of the quadriceps femoris muscle (CSA KE) and the maximal voluntary isometric knee extension force (F KE) were measured using MRI and a static myometer, respectively. There was no significant correlation between T sit-stand and each of CSA KE and F KE. On the other hand, the P sit-stand was highly correlated with CSA KE and F KE, even after the influence of body mass and L was statistically eliminated. These results indicate that P sit-stand, derived from three variables of body mass, leg length, and time taken for a sit-to-stand test, can be a useful index to assess the force-generating capacity of the knee extensor muscles of elderly individuals.

Keywords: ten-repeated sit-to-stand test, body size, force-generating capacity, knee extensor muscles

Introduction

It is well documented that mass and strength of skeletal muscles decrease with increasing age, notably for knee extensor muscles (Overend et al., 1992; Kubo et al., 2003; Candow et al., 2005; Kubo et al., 2007). For elderly individuals, the reduced force-generation of knee extensors is associated with deterioration of the ability to perform activities of daily life such as walking (Kim et al., 2000) and standing up from a chair (Hughes et al., 1996). Assessment of the ability to perform activities of daily life, especially in the elderly, has been an important topic in the fields of physiological anthropology and exercise sciences. To establish a convenient method for assessing the size and strength of knee extensor muscles is an important issue to develop proper exercise programs for improving physical fitness for the elderly to lead an independent life.

For elderly individuals, the ability to stand up from a sitting position on surfaces of various heights is related to independence (Corrigan and Bohannon, 2001), and the measure of such ability has been considered as an index of thigh muscle strength (Csuka and McCarty, 1985; Bohannon, 1998). In fact, some studies have already reported that sit-to-stand performance, determined as the time required to perform a given number of repetitions or the number of repetitions completed in a given amount of time, is significantly correlated to the strength or power of knee extensor muscles (Schenkman et al., 1996; Ferrucci et al., 1997; Lord et al., 2002). But there are also studies failing to find a correspondence between sit-to-stand performance and knee extensor strength. Csuka and McCarty (1985) found no difference between men and women in 10-repeated sit-to-stand time, although men were stronger than women in knee extension. Ferrucci et al. (1997) observed a departure from linearity in the relationship between the measures of sit-to-stand performance and muscular strength in older women. In their results, time for five chair stands was associated with the knee extensor and hip flexor strength only...
below 98 N and 147 N, respectively. These findings suggest that the measures of sit-to-stand performance in absolute terms (time in second or numbers of repetitions) are not consistently related with knee extension strength.

A sit-to-stand test is commonly performed using the same chair regardless of the body size of the individuals being tested. This leads to individual differences in the distance of the center of gravity in motion during the task. In addition, different body mass can result in inconsistent mechanical work. In other words, for the same time taken for a sit-to-stand test, work (and average power) done by individuals can be substantially different. Muscle size and strength are related to body size (Young et al., 1984; Samson et al., 2000). For reasonable assessment of force-generating capacity of the knee extensors muscles, the score of a sit-to-stand test should be represented by the average power generated during the task rather than the absolute time or number of repetitions. In fact, knee extension strength and leg extension power show good correlations with the average mechanical power in a rising phase, but not with the time (Lindemann et al., 2003).

The advantage of a sit-to-stand test is that anybody can easily perform the task using a chair and a stopwatch. It is technically possible to determine the power developed during standing up from a chair (Lindemann et al., 2003), but it would be more convenient for a larger population if we could estimate mechanical work and power by using easily available apparatus. One can conventionally calculate the average power during sit-to-stand test using the following variables: body mass, leg length, and time taken for the task. The purpose of the present study was how the power index and the time taken for a 10-repeated sit-to-stand test can be related to the size and strength of knee extensor muscles. We hypothesized that the power index reflects more accurately force-generating capacity of knee extensors than the time taken for the test.

Methods

Subjects

The present study examined men and women aged 50 or more, because muscle mass and strength begin to decrease from the age of 50 (Lynch et al., 1999). Fifty-seven subjects (28 men and 29 women, 64.2 ± 0.04 m, 50.7 ± 6.0 kg) participated in this study. The means (±SDs) of age, height, and body mass were 63.0 ± 7.8 yrs, 1.67 ± 0.06 m, and 65.8 ± 7.3 kg, respectively, in men, and 64.2 ± 7.5 yrs, 1.54 ± 0.04 m, and 50.7 ± 6.0 kg, respectively, in women. Thirty-three subjects (58%) had regularly performed exercise 30 minutes more than 3 times per week, 18 subjects (32%) 1 or 2 times per week, and 6 subjects (10%) were sedentary individuals. All participants were medically screened before participating in this study. They were free from cardiovascular, metabolic, immunologic disorders, and orthopedic abnormality. This study was approved by the Ethical Committee of the Faculty of Sport Sciences of Waseda University and was consistent with their requirements for human experimentation. Each subject was informed of the purpose and procedures of this study and possible risks of the measurements beforehand. Written informed consent was obtained from each subject.

Measurement of muscle cross-sectional area in knee extensors (CSA_{KE})

A series of cross-sectional images of the right thigh were determined using magnetic resonance imaging with a body coil (Signa 1.5T, GE, USA). Transverse scans were performed with a conventional T1-weighted Spin-echo sequence (repetition time: 500 ms, echo time: 10 ms, slice thickness: 10 mm, interspaced distance: 0 mm, FOV: 24–32 cm, phase FOV: 0.75, matrix: 256×256). The scan time was 104 seconds. A reference marker was placed on the skin at mid-thigh. This portion is where the muscle cross-sectional area of the thigh muscles is maximal (Kanehisa et al., 1994). The subjects lay horizontally to avoid contact between the posterior aspect of the thigh and the bed of the scanner. From the image obtained in which the reference marker was included, CSA_{KE} were determined using image analysis software (SliceOmatic ver4.3, Tomovision, Canada). Only the traced skeletal muscle areas were measured, excluding connective tissue, blood vessels, and fat tissue where visible. The measurement was carried out one time by an experienced analyst. To assess the accuracy of the measurement by the analyst, scanned images were analyzed three times, yielding coefficients of variance of CSA_{KE} of less than 2%.

Measurement of maximum voluntary isometric knee extension force (F_{KE})

The maximal voluntary isometric knee extension torque was measured with a specially designed myometer (VTK-002R/L Vine, Japan). The right side was tested with the subjects seated, keeping a 90-degree angle (full extension: 0°) of hip and knee joints. The axis of the knee joint was aligned with the axis of the lever arm of the myometer. The right inferior shin was firmly secured to the lever arm of the myometer with a strap. Prior to the test, each subject performed adequate warm-up, consisting of 2 to 3 times sub-maximal contractions to become familiar with the test procedure. Each subject performed a 2- to 3-s maximal voluntary isometric contraction two times, with at least 1 minute of rest between trials to avoid any fatigue effects. If the difference between the two values of torque was more than 10% of the higher one, the torque was measured one more time. The torque data during each task were amplified by a strain amplifier (DPM-611A, Kyowa, Japan) and A/D converted (Power Lab/16SP, ADInstruments, Australia) into a personal computer at 100 Hz with a low-pass filter (cutoff frequency: 20 Hz). The highest value out of the 2 or 3 torque measurements was adopted. The maximal voluntary isometric knee extension force (F_{KE}) was calculated by dividing the knee extension torque by the lower leg length, defined as the distance from the lateral condyle of the femur to the lateral malleolus.
Sit-to-stand test

A steel molded chair (0.40 m height and 0.36 m depth) was used for the sit-to-stand test. The subjects were asked to stand up from a sitting position and then to sit down 10 times as fast as possible. The subjects were instructed to stand up fully and to place their buttocks on the chair in a sitting position between repetitions. The time (Tsit-stand) was recorded using a stopwatch to the nearest 10th of a second. The test started when the examiner said “Go” and stopped when the subject fully stood up on the 10th repetition. Prior to the measurements, practice trials with submaximal effort were performed for positioning and learning of the task. The Tsit-stand measurements were performed two times with an interval of 1 min between trials. The fastest time was adopted for the individual data. A power index of the test (Psit-stand) was calculated using the following equation:

\[ P_{\text{sit-stand}} = \frac{(L - 0.4) \times \text{body mass} \times g \times 10}{T_{\text{sit-stand}}} \]

where the 0.4 (m), L (m) and g (m/s²) represent height of the chair, leg length (the distance from the great trochanter of the femur to the malleolus lateralis) and acceleration of gravity (9.8 m/s²), respectively. The leg length was measured using a tape measure.

Statistical analysis

Descriptive data were presented as the mean and standard deviation (SD). Relationships among measurement variables were analyzed using Pearson’s coefficient of correlation (r). After adjustment for body mass and L, a partial coefficient of correlation was used to test association among Tsit-stand, CSAKE, and FKE. In addition, after adjustment for gender (men=0, women=1), body mass, and L, a partial coefficient of correlation was used to test association among Psit-stand, CSAKE, and FKE. The general linear model procedure of SPSS (SPSS12.0J, SPSS Japan, Japan) was used with the statistical significance determined at \( p < 0.05 \).

Results

Relationships between Tsit-stand and measurement variables

The mean value for Tsit-stand in all subjects was 10.3±2.1 s (men: 10.5±1.9 s, women: 10.2±2.2 s). Figure 1 shows the relationships between Tsit-stand and each of CSAKE and FKE. The Tsit-stand was not significantly correlated with each of CSAKE, FKE, body mass, and L (Table 1). When the body mass and L were statistically controlled, however, there were significant negative correlations between Tsit-stand and each of CSAKE (\( r_{\text{Tsit-stand, CSAKE}} = -0.381, p = 0.004 \)) and FKE (\( r_{\text{Tsit-stand, FKE}} = 0.342, p = 0.011 \)).

Relationships between Psit-stand and measurement variables

The correlation coefficients between Psit-stand and measurement variables are shown in Table 1. The Psit-stand was significantly correlated with each of gender (\( r = 0.638, p < 0.001 \)), body mass (\( r = 0.758, p < 0.001 \)), L (\( r = 0.778, p < 0.001 \)), CSAKE (\( r = 0.801, p < 0.001 \), Fig. 2), and FKE (\( r = 0.730, p < 0.001 \), Fig. 2). The CSAKE and FKE were

![Fig. 1](image-url)
significantly related to each of gender, body mass, and L (Table 2). However, the relationships between $P_{\text{sit-stand}}$ and each of CSA$_{KE}$ and $F_{KE}$ were still significant, even when the influences of gender, body mass, and L were controlled statistically (CSA$_{KE}$: $r_{\text{Psit-stand\_CSAKE\_gender,BW,L}} = 0.438$, $p = 0.001$, $F_{KE}$: $r_{\text{Psit-stand\_CSA KE\_gender,BW,L}} = 0.415$, $p = 0.002$).

**Discussion**

The main finding of the present study is that $P_{\text{sit-stand}}$ rather than $T_{\text{sit-stand}}$ was strongly correlated with each of CSA$_{KE}$ and $F_{KE}$. The correlations were still significant, even when the influences of body mass and leg length were controlled statistically. This result agrees with the finding of Lindemann et al. (2003) and supports our hypothesis. In the present study, the $P_{\text{sit-stand}}$ was calculated by three variables, i.e., body mass, leg length, and time taken for a 10-repeated sit-to-stand. On the other hand, Lindemann et al. (2003) obtained the power from body mass, distance of center of gravity from sitting to standing position, and the time taken during a single chair rising. The $P_{\text{sit-stand}}$ obtained in the present study included the phase in standing up from and sitting down onto a chair. The mean value for $P_{\text{sit-stand}}$ (184 W, males: $n=28$, females: $n=29$) is therefore considerably lower than the report of Lindemann et al. (2003) (647 W, males: $n=17$, females: $n=16$). It is possible that the $P_{\text{sit-stand}}$ of the present study could underestimate the power output of knee extensor muscles during the task. However, the present results regarding the correlations with CSA$_{KE}$ and $F_{KE}$ indicate that $P_{\text{sit-stand}}$ rather than $T_{\text{sit-stand}}$ is a useful index to assess the force-generating capacity of knee extensor muscles.

As another reason for the discrepancy mentioned above, the lower mean value for $P_{\text{sit-stand}}$ in the present study compared with the report of Lindemann et al. (2003) might be the result of differences in subjects’ body size. The mean values for height and body weight of the subjects examined in the present study were $1.54 \pm 0.04$ m and $50.7 \pm 6.0$ kg, respectively. On the other hand, the corresponding values in the study by Lindemann et al. (2003) were $1.67 \pm 0.09$ m and $74.9 \pm 11.2$ kg. These differences could have affected the power values since both studies are based on body size, i.e., body mass and/or leg length.

The $F_{KE}$ and CSA$_{KE}$ were not significantly correlated with $T_{\text{sit-stand}}$ in the present study. However, the corresponding correlations were significant after controlling body mass and leg length. This result implies that body size has a substantial influence on the relationship between the time taken for a 10-repeated sit-to-stand and the force-generating capacity of knee extensors.

Buchner et al. (1996) reported that the relationship between walking speed and leg strength was nonlinear. They further indicated that there was a “threshold” of leg strength above which the leg strength did not affect walking speed. These findings suggest that there is no clear relationship between walking speed and leg strength in a group of subjects with relatively greater leg strength. From the findings of Ferrucci et al. (1997), the relationship between 5-repeated sit-to-stand time and knee extension force was nonlinear, but, below 98 N, the corresponding relationship became linear. Most of the subjects in the present study were moderately to highly active. The mean value for $F_{KE}$ was $298.5 \pm 103.1$ N (Men: $380.7 \pm 85.3$ N, Women: $219.1 \pm 31.3$ N). There was no subject with her/his knee extension force below 98 N. They did not have difficulty in performing the repeated sit-to-stand task. Knee extension strength in active elderly individuals is higher than those in sedentary elderly individuals (Klitgaard et al., 1990; Loard et al., 1993). Therefore, there is a possibility that the time scores for the subjects examined here might be assumed to be ranked in the “plateau region” of the relationship between $T_{\text{sit-stand}}$ and $F_{KE}$, as indicated in prior studies (Buchner et al., 1996; Ferrucci et al., 1997).

In the present study, the $P_{\text{sit-stand}}$ was significantly correlated with each of CSA$_{KE}$ and $F_{KE}$. The findings that body mass and
leg length were significantly related to CSAKE and FKE are similar to previous reports (Young et al., 1984; Samson et al., 2000). At the same time, this result implies that the relationships between Psit-stand and each of CSAKE and FKE are affected by body size. However, the corresponding correlations were still significant, even when the variables of body mass and lower leg length were statistically eliminated. Hence we may say that Psit-stand, unlike a conventional method (time or number of repetitions of sit-to-stand), can be a useful assessment of the force-generating capacity of knee extensors, regardless of the difference in body size.

In conclusion, the present results indicate that the power index derived from the three variables of body mass, leg length, and time taken for a sit-to-stand test, but not the time only, can conveniently assess the force-generating capacity of knee extensors in middle-aged and elderly individuals.

Acknowledgements This research was supported by a Research Grant for Comprehensive Research on Cardiovascular and Life-Style Related Diseases from the Ministry of Health, Labour and Welfare, Japan (19160101). The author would like to thank all the members of the laboratory who assisted with data collection.

References


Table 2 Correlation coefficients among variables except for Tsit-stand and Psit-stand

<table>
<thead>
<tr>
<th></th>
<th>Age</th>
<th>Sex</th>
<th>BW</th>
<th>L</th>
<th>CSAKE</th>
<th>FKE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td></td>
<td>−0.075</td>
<td>−0.086</td>
<td>−0.123</td>
<td>−0.326*</td>
<td>−0.328*</td>
</tr>
<tr>
<td>Sex</td>
<td>0.755***</td>
<td></td>
<td>0.652***</td>
<td>0.791***</td>
<td>−0.790***</td>
<td></td>
</tr>
<tr>
<td>BW</td>
<td>0.730***</td>
<td></td>
<td>0.777***</td>
<td>0.716***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CSAKE</td>
<td></td>
<td></td>
<td></td>
<td>0.727***</td>
<td>0.609***</td>
<td></td>
</tr>
<tr>
<td>FKE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.851***</td>
<td></td>
</tr>
</tbody>
</table>


*** Significant at $p<0.001$.
* Significant at $p<0.05$.

Received: November 17, 2008
Accepted: February 25, 2009
Correspondence to: Yohei Takai, Graduate School of Sport Sciences, Waseda University, 2–579–15 Mikajima, Tokorozawa, Saitama 359–1192, Japan
Phone: +81–04–2947–6783
Fax: +81–04–2947–7483
e-mail: pacific-t1981@akane.waseda.jp