Relationship of Knee Extension Force to Independence in Sit-to-Stand Performance in Patients Receiving Acute Rehabilitation

Background and Purpose. The ability to rise from a chair is important for independence in everyday life. This study was conducted to determine to what extent knee extension force (KEF) could explain independence in sit-to-stand (STS) performance from a standard chair. Subjects and Methods. This was a descriptive and correlational study of patients receiving acute rehabilitation (N=107). Measurements of KEF of both lower extremities were obtained using manual muscle testing (MMT) and hand-held dynamometers (HHDs). The HHD measurements were normalized based on body weight and age- and sex-specific reference values. Measurements of the ability to stand without using the upper extremities (STS [without hands]) and to stand using the upper extremities (STS [with hands]) were correlated with the force measurements. Results. The correlations (r) of the KEF measurements with STS success ranged from .652 to .708 for STS (without hands) and from .545 to .638 for STS (with hands). Body weight added to the explanation of STS (without hands) (R=.662) and STS (with hands) (R=.584) provided by KEF measured by HHD. The receiver operating characteristic curves showed that HHD (weight normalized) was the most sensitive and specific measure for explaining independence in STS. Discussion and Conclusion. Manual and dynamometric measurements of KEF are related to independence in STS. Measurements of KEF quantified with a dynamometer and normalized against body weight provided the most valid, specific, and sensitive cutoff point for explaining STS independence. [Eriksrud O, Bohannon RW. Relationship of knee extension force to independence in sit-to-stand performance in patients receiving acute rehabilitation. Phys Ther. 2003;83:544–551.]

Key Words: Activities of daily living, Dynamometry, Measurement, Muscle, Sit-to-stand.

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The inability to rise from a sitting position is recognized by the World Health Organization (WHO) as a disabling condition.1 Sit-to-stand (STS) performance correlates with walking speed, independent ambulation, and stair climbing.2,3 Difficulty in rising from a sitting position is a predictor of future disability,4 falls,5 nursing home use,6 increased utilization of hospital services,7 and mortality.8 Sit-to-stand performance is one of the activities used in functional indexes and in test batteries of physical functioning.1,9,10

Completion of the STS maneuver is fundamental to transfers and the initiation of gait. Sit-to-stand performance is reduced in many older individuals, particularly women and those who have various pathologies.4,9,11–19 The ability to complete an independent chair rise successfully is highly valued by older individuals.20

Although STS performance has been found to be influenced by lower-extremity range of motion and balance, the physiologic variable shown most consistently to relate to STS performance is lower-extremity muscle force.3,10,17–19,21–23 Wretenberg and Aborelius23 found that the knee extensors contribute 72% of the concentric force at the hip and the knee joint during STS. Bohannon17 estimated that 330 N is needed in bilateral knee extension force (KEF) to successfully stand up once from a chair, but he did not account for body weight. Ploutz-Snyder et al24 indicated that individuals with a force-to-weight ratio of <3.0 N/m/kg are at substantial risk of reduced function in rising from a chair. Other researchers,21 however, have described KEF as a predictor of STS success only when considered in combination with plantar-flexion and hip extension forces. Furthermore, Tinetti and Ginter22 reported that only 44% of people with chair-rise problems had decreased KEF. They, however, used manual muscle testing (MMT), which we consider a subjective measure of force with low sensitivity above the grade 3/5 level.25

Although KEF has an established relationship to STS performance,3,17–19,21,23,24 we believed the measure’s relevance might be enhanced by normalization using other variables. Measurements of KEF have been normalized to body weight, but on a limited basis.3,18,21,26 We consider this noteworthy because muscle force is known to correlate with body weight. In our opinion, therefore, KEF output, when measured with a dynamometer, might better reflect a force-generation impairment when normalized against body weight. Reference values for KEF for male (n=106) and female (n=125) subjects in different age groups have been published.26 Therefore,
it is possible to normalize force measurements with the variables of age and sex.

The relevance of KEF, we believe, also might be enhanced through the establishment of a cutoff point, a value that divides a distribution of scores into 2 classes or categories. A KEF cutoff point, therefore, could serve to formulate goals in therapy or to justify use of an assistive device.

Requirements for KEF will vary with use of the upper extremities on armrests,\textsuperscript{19,27} due to chair height,\textsuperscript{18,28,29} and with the technique used to stand.\textsuperscript{18} Chair height has been found to be a determinant of a person’s rising successfully from a chair.\textsuperscript{18,28–31} The knee flexion moment, and therefore the demand on the knee extensors, will increase with a decrease in chair height.\textsuperscript{18,28,29} Similarly, the demand on the knee extensors of taller individuals may be greater than for shorter individuals when rising from a standard-height chair. Upper-extremity assistance at the time of standing, when the knee flexion moment is greatest, will decrease the knee flexion moment and thus the KEF requirement of the task.\textsuperscript{19,27} Some older individuals use a stability-maximizing technique during STS. This technique, in which the center of mass is positioned over the base of support before standing is initiated, requires a greater KEF than a technique that uses momentum.\textsuperscript{28}

The purpose of our study was to determine the role of KEF relative to weight, height, sex, and age in completion of one STS maneuver, whether or not the upper extremities were used for assistance. We also sought to establish sensitive, specific, and valid cutoff points of different KEF measures for predicting independence in rising from a chair.

**Method**

**Subjects**

We conducted a descriptive and correlational study that involved the recording, in a separate database, of information from the medical records of patients who were referred and seen by a physical therapist (RWB) for acute rehabilitation. There were 107 subjects, all of whom were taken from the caseload of the second author. Subjects were included in the study if they were able to follow directions, had no lower-extremity amputations, and had no restrictions on lower-extremity movement or weight bearing ordered by a physician.

The subjects were highly variable in age, size, diagnoses, ambulatory independence, and use of assistive devices. The mean age of the subjects was 62.1 years (SD=16.4, range=24–97). Measurements of weight and height were obtained from their medical records. Their mean weight was 76.7 kg (SD=25.3, range=37.3–198.2), and their mean height was 168.6 cm (SD=11.4, range=147.3–193.0). Fifty-five (51.4%) of the subjects were men, and 52 (48.6%) were women. The subjects were divided into 6 groups based on diagnosis (frequency indicated in parentheses): neuromuscular (n=61), postsurgical (n=7), cardiovascular or pulmonary (n=19), trauma (n=4), cancer (n=7), and other (n=9). For descriptive purposes, ambulatory function was quantified by use of the Functional Independence Measure (FIM). The FIM score was assigned based on the Guide to the Uniform Data Set for Medical Rehabilitation, version 5.0.\textsuperscript{32} The distribution of subjects with an FIM gait score was as follows: FIM 1 (n=27), FIM 2 (n=22), FIM 3 (n=2), FIM 4 (n=22), FIM 5 (n=21), FIM 6 (n=4), FIM 7 (n=9). The use of ambulatory assistive devices was as follows: no device (n=54), cane (n=8), quad cane (n=2), hemiwalker (n=5), rolling platform walker (n=7), rolling walker (n=26), and standard walker (n=5). Of the 54 subjects who were categorized as using no device, 29 were hand assisted by the tester.

**Equipment**

The instrumented measurements of the subjects’ KEFs were obtained using 2 digital hand-held dynamometers (HHDs) and a standard-height chair. The HHDs (Ametek Cadet Gauge and Ametek Accuforce II)\textsuperscript{*} were calibrated periodically over the course of the study and found to be accurate within 1 N. The chairs used were all armless with a slightly padded seat and 44 to 46 cm high. Such chairs are representative of those typically encountered in everyday life.

**Procedure**

Maximum isometric KEF was tested by one examiner (RWB) who had over 20 years of experience using HHDs and MMT. The reliability of HHD measurements obtained by the examiner has been established previously for both patients and individuals without known impairments or pathology.\textsuperscript{33} The reliability of MMT scores also has been established by Wadsworth et al.\textsuperscript{34} They reported reliability coefficients of .63 to .98 for 11 patients with chronic orthopedic and neuromuscular disorders. Subjects were tested with the HHD while seated upright with the leg vertical and the knee in approximately 90 degrees of flexion to decrease the influence of gravity during testing. They were not allowed to lean back in the chair while being tested. The subjects were asked to take 1 or 2 seconds to come to maximum effort, during which they were to push as hard as possible into the HHD. The counterforce to the KEF was applied by the tester through the HHD, which was perpendicular and just proximal to the malleoli. The

\textsuperscript{*} Ametek Test and Calibration Instruments, 8600 Sommerset Dr, Largo, FL 33773.
subjects were given encouragement and were asked to stop after 4 to 5 seconds. They were given one trial for each lower extremity.35 The peak forces for both lower extremities were recorded in pounds and converted to newtons. Because we were interested in the force that could be used to lift the body’s weight against the pull of gravity, we summed the KEF values of the 2 sides and labeled them “HHD (total force).” The HHD (total force) values were normalized based on body weight and labeled “HHD (weight normalized).” This value was further normalized based on age and sex by dividing HHD (weight normalized) by the expected bilateral KEF output of the appropriate age- and sex-referenced described by Bohannon.26 This category was labeled HHD (norm referenced)” and was limited to subjects (n=106) in the age range to which the reference values applied.26

The MMT of KEF was conducted according to the technique described by Hislop and Montgomery.36 Patients with grades greater than 2 were tested in the chair used for the STS and HHD testing. The numerical grading system (0–5) of the Medical Research Council (MRC) was used.37 Pluses and minuses were designated when required. The scores from one trial of each lower extremity were then converted to a categorical ordinal score (0–12) to facilitate analysis. Consistent with the treatment of HHD values, the ordinal scores assigned to the original MRC grades were as follows: 0=0, 1=1, 1+=2, 2+=3, 2+=4, 2+=5, 3+=6, 3=7, 3+=8, 4+=9, 4+=10, 4+=11, and 5=12. The ordinal scores of both KEF measures were added together (maximum possible score=24) and labeled “MMT (total).”

Following assumption of a forward position on the seat with their feet flat on the floor, the subjects were given 3 opportunities to stand using the upper extremities (STS [without hands]). Subjects were classified as “able” (1) or “unable” (0). If unable to stand without use of the upper extremities, subjects were given 3 opportunities to stand using the upper extremities (STS [with hands]), that is, by pushing down on the chair or their thighs. They were again classified as “able” (1) or “unable” (0).

### Table 1.
Mean (Standard Deviation) for Knee Extension Force Measurements Associated With Differences in Stand-up Performance

<table>
<thead>
<tr>
<th>Stand-up Performance</th>
<th>MMT (Total)</th>
<th>HHD (Total) (N)</th>
<th>HHD (Weight Normalized) (%)</th>
<th>HHD (Norm Referenced) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>STS (without hands): able</td>
<td>22.6 (2.4)</td>
<td>421.5 (153.0)</td>
<td>58.9 (20.6)</td>
<td>58.9 (19.9)</td>
</tr>
<tr>
<td>STS (without hands): unable</td>
<td>16.5 (3.7)</td>
<td>198.8 (106.9)</td>
<td>26.4 (11.4)</td>
<td>28.0 (14.0)</td>
</tr>
<tr>
<td>STS (with hands): able</td>
<td>21.3 (3.3)</td>
<td>366.2 (163.4)</td>
<td>50.7 (21.7)</td>
<td>51.1 (20.8)</td>
</tr>
<tr>
<td>STS (with hands): unable</td>
<td>15.3 (3.6)</td>
<td>166.8 (89.4)</td>
<td>22.0 (10.1)</td>
<td>23.6 (13.7)</td>
</tr>
</tbody>
</table>

*STS=sit-to-stand, MMT (total)=total manual muscle test score for left and right knee extensors, HHD (total)=total hand-held dynamometry force (in newtons) for left and right knee extensors, HHD (weight normalized)=HHD (total)/body weight, HHD (norm referenced)=HHD (total) normalized to age- and sex-specific reference values.

<table>
<thead>
<tr>
<th>Independent Variable</th>
<th>STS (Without Hands)</th>
<th>STS (With Hands)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>r (P)</td>
<td>r²</td>
</tr>
<tr>
<td>MMT (total)</td>
<td>.693 (.001)</td>
<td>.480</td>
</tr>
<tr>
<td>HHD (total)</td>
<td>.652 (.001)</td>
<td>.425</td>
</tr>
<tr>
<td>HHD (weight normalized)</td>
<td>.708 (.001)</td>
<td>.501</td>
</tr>
<tr>
<td>HHD (norm referenced)</td>
<td>.682 (.001)</td>
<td>.465</td>
</tr>
<tr>
<td>Age</td>
<td>- .054 (.583)</td>
<td>.003</td>
</tr>
<tr>
<td>Sex</td>
<td>-.124 (.205)</td>
<td>.015</td>
</tr>
<tr>
<td>Weight</td>
<td>-.072 (.459)</td>
<td>.005</td>
</tr>
<tr>
<td>Height</td>
<td>.079 (.416)</td>
<td>.006</td>
</tr>
</tbody>
</table>

*STS=sit-to-stand, MMT (total)=total manual muscle test score for left and right knee extensors, HHD (total)=total hand-held dynamometry force (in newtons) for left and right knee extensors, HHD (weight normalized)=HHD (total)/body weight, HHD (norm referenced)=HHD (total) normalized to age- and sex-specific reference values.

### Data Analysis
Data analysis was conducted using SYSTAT 10.0 for Windows38 and SPSS 10.0 for Windows.39 Descriptive statistics were calculated first. Zero-order correlations (Pearson r) were calculated among KEF, age, sex, height, weight, and STS performance under 2 conditions (STS [without hands] and STS [with hands]). The correlations were point-biserial correlations because the dependent variable was dichotomous (able versus unable to rise). Hotelling T analyses were used to determine if there was a difference between the KEF measures in their ability to explain STS independence.

Because variables in the study were dichotomous (able versus unable to complete STS), a forward logistic regression analysis was used to determine the effects of multiple independent variables on STS independence. The KEF variables had the highest correlations with STS performance; therefore, these values were introduced first into each prediction model for STS (without hands) and STS (with hands). The subject’s age, sex, weight, and height were then added if not already accounted for through normalization. Weight was not entered into the
model including HHD (weight normalized) because this KEF measure was already normalized to body weight. Weight, age, and sex were not entered into the model including HHD (norm referenced) because that variable was already normalized based on those measures.

Receiver operating characteristic (ROC) curves were generated for the 4 KEF variables (HHD [total force], MMT [total], HHD [weight normalized], and HHD [norm referenced]) against the 2 dependent variables (STS [without hands] and STS [with hands]). These curves were used to determine cutoff points of the different KEF measures with their respective validity, sensitivity, and specificity. The ROC curve has sensitivity values along the y-axis and specificity values along the x-axis. A perfect cutoff point, one with 100% sensitivity and 100% specificity, would be located in the upper left-hand corner of the graph. The point closest to this location was considered the best cutpoint. Sensitivity and specificity values were determined from the x-axis and y-axis of this point, and these values were used in the accompanying data matrix to find the cutoff point value. Validity was described by the proportion of subjects correctly classified as able to succeed at STS, which corresponds to the area under the curve.

### Results

Descriptive statistics of the 4 KEF measures are presented in Table 1, grouped according to the subjects’ ability versus inability to achieve standing (either without use of their hands or with use of their hands). For both categories, the values of the different KEF measures were higher for subjects who were able to complete the STS maneuver than for subjects who were unable to complete the STS maneuver.

Zero-order correlation coefficients between the independent variables (KEF measures, age, sex, height, and weight) and the 2 STS variables are presented in Table 2. The coefficients of the different KEF measures correlated with STS performance were all significant ($P < .001$). They ranged from .652 to .708 for STS (without hands) and from .545 to .638 for STS (with hands). Although varying in magnitude, the coefficients between the KEF measures and STS performance were not found to differ by the Hotelling $T$ analyses. None of

### Table 3.

<table>
<thead>
<tr>
<th>Predictors</th>
<th>Coefficient ($\beta$)</th>
<th>Standard Error</th>
<th>Wald</th>
<th>$P$</th>
<th>Odds Ratio</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without Hands</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HHD (total)</td>
<td>0.085</td>
<td>0.016</td>
<td>27.813</td>
<td>.000</td>
<td>1.088</td>
<td>1.055–1.123</td>
</tr>
<tr>
<td>Weight</td>
<td>-0.024</td>
<td>0.007</td>
<td>11.220</td>
<td>.001</td>
<td>0.976</td>
<td>0.963–0.990</td>
</tr>
<tr>
<td>Constant</td>
<td>-1.676</td>
<td>0.975</td>
<td>2.963</td>
<td>.085</td>
<td>0.187</td>
<td></td>
</tr>
<tr>
<td>With Hands</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HHD (total)</td>
<td>0.084</td>
<td>0.018</td>
<td>21.277</td>
<td>.000</td>
<td>1.088</td>
<td>1.049–1.127</td>
</tr>
<tr>
<td>Weight</td>
<td>-0.023</td>
<td>0.007</td>
<td>9.552</td>
<td>.002</td>
<td>0.978</td>
<td>0.964–0.992</td>
</tr>
</tbody>
</table>

*STS=sit-to-stand, HHD (total)=total hand-held dynamometry force for left and right knee extensors, CI=confidence interval.

### Table 4.

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Force Measure</th>
<th>Cutoff Point</th>
<th>Area Under Curve</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>STS (without hands)</td>
<td>MMT (total)</td>
<td>20.5</td>
<td>0.907</td>
<td>88.0</td>
<td>82.5</td>
</tr>
<tr>
<td>STS (without hands)</td>
<td>HHD (total) [N]</td>
<td>300.3</td>
<td>0.888</td>
<td>82.0</td>
<td>84.2</td>
</tr>
<tr>
<td>STS (without hands)</td>
<td>HHD (weight normalized) [%]</td>
<td>40.0</td>
<td>0.928</td>
<td>86.0</td>
<td>91.2</td>
</tr>
<tr>
<td>STS (without hands)</td>
<td>HHD (norm referenced) [%]</td>
<td>39.7</td>
<td>0.898</td>
<td>81.6</td>
<td>82.5</td>
</tr>
<tr>
<td>STS (with hands)</td>
<td>MMT (total)</td>
<td>18.5</td>
<td>0.878</td>
<td>75.3</td>
<td>79.4</td>
</tr>
<tr>
<td>STS (with hands)</td>
<td>HHD (total) [N]</td>
<td>223.7</td>
<td>0.868</td>
<td>76.7</td>
<td>76.5</td>
</tr>
<tr>
<td>STS (with hands)</td>
<td>HHD (weight normalized) [%]</td>
<td>31.1</td>
<td>0.899</td>
<td>78.1</td>
<td>82.4</td>
</tr>
<tr>
<td>STS (with hands)</td>
<td>HHD (norm referenced) [%]</td>
<td>31.6</td>
<td>0.870</td>
<td>76.4</td>
<td>76.5</td>
</tr>
</tbody>
</table>

*STS=sit-to-stand, MMT (total)=total manual muscle test score for left and right knee extensors, HHD (total)=total hand-held dynamometry force (in newtons) for left and right knee extensors, HD (weight normalized)=HHD (total)/body weight, HHD (norm referenced)=HHD (total) normalized to age- and sex-specific reference values.
the other measures (age, sex, height, or weight) were found to correlate with STS performance. With one exception, with use of multiple logistic regression (Tab. 3), we did not find any measure to add to the explanation of STS performance provided by the KEF measures. That exception was the additional contribution offered by weight to the explanation of STS (without hands) and STS (with hands) by HHD (total force). After accounting for weight, the correlation ($R$) of HHD (total force) with STS (without hands) was .662 and the correlation of HHD (total force) with STS (with hands) was .584.

Cutoff points and the proportion of subjects who were correctly classified, as well as sensitivity and specificity, for the 4 KEF measures are presented in Table 4. Of the KEF measures, HHD (weight normalized) could be used to classify the highest proportion of subjects (.928 for STS [without hands] and .899 for STS [with hands]). The HHD (weight normalized) cutoff point for STS (without hands) was determined from the ROC curve (Fig. 1) to be 40.0% of body weight, with a sensitivity of 86.0% and a specificity of 91.2%. With the use of the upper extremities (STS [with hands]), the cutoff point decreased to 31.1% of body weight (Fig. 2), with a sensitivity of 78.1% and a specificity of 82.4%.

Discussion

All of the KEF measures in our study were found to have moderate correlations with STS independence, which is in agreement with previously published data.3,10,17–19,21–24 Because we found no significant difference between the various KEF measures in their ability to predict STS independence, we believe none can be advocated (as a measure) over another on the basis of correlations. On the basis of ROC curve analysis, however, HHD (weight normalized) appears to have a slight advantage. Forward logistic multiple regression analysis demonstrated that use of body weight added to the correlation of STS (without hands) and STS (with hands) provided by HHD (total force) (Tab. 3). This relationship persisted with STS (with hands) as the dependent variable, we believe because this variable involves the use of the upper extremities, which can decrease the demand that body weight places on the knee extensor muscles during STS performance. This finding shows the importance of taking body weight into consideration, and thus the possible advantage of the HHD (weight normalized) when interpreting performance of the knee extensor muscles. Our findings do not support taking the time to normalize KEF measurements with age- and sex-specific force measurements if prediction of STS performance is desired.

For measures that are designed to predict function, cutoff points, in theory, can be used to identify problems
and guide goal setting. There are, however, few functionally relevant cutoff points reported in the literature. Ikezoe et al. determined that a KEF cutoff point of 45.5% of body weight was needed for independent ambulation. Ploutz-Snyder et al. reported a torque value of 3.0 N·m/kg of body weight to be important for performance of several activities, including the STS maneuver. However, no cutoff points involving an absolute force measurement normalized to body weight (HHD [weight normalized]) have been published relative to the ability to do the STS maneuver. Bohannon estimated an HHD (total force) cutoff point of 330 N and an MMT (total) cutoff point of 22 for independence in the STS maneuver without the use of the upper extremities. In our study, which involved more subjects in a different setting, we found cutoff points of 300 N for HHD (total force) and 20.5 for MMT (total). However, the HHD (weight normalized) cutoff points were consistently found to have the highest sensitivity, specificity, and correct classification proportions for both STS (without hands) and STS (with hands). The usefulness of the cutoff points can be illustrated with an example. If a patient is observed to be unable to stand from a standard armless chair (even when using the upper extremities) and the patient is known to have an HHD (weight normalized) value of 20.0%, we believe it is reasonable to say that the patient has a KEF impairment that might be responsible for the failure to do the STS maneuver because the cutoff point for STS (with hands) is 31.1%. We contend it is also reasonable to set a goal of 31.1% for HHD (weight normalized) if independence in STS is a goal.

There are many variables that were not analyzed in our study that can have an effect on the ability to rise from a sitting position. Balance and technique have been described as influencing STS capabilities. Balance, which we did not quantify, in our view tends to correlate with muscle force, which was measured in our study. Sensation and dizziness are other variables found to correlate with balance, which we did not quantify in our study. Subjects were not restricted or instructed in a specific chair-rise technique. Other factors such as vision, available range of motion, joint pain, and a history of falls can affect the ability of patients to rise from a sitting position. We believe the most important factor contributing to the increased success of rising from a sitting position in STS (with hands) as compared with STS (without hands) is upper-extremity muscle force, which we also did not measure. Researchers, we contend, should take this variable into consideration in future research, especially when the upper extremities are used. Our data suggest that upper-extremity muscle force and training of the upper extremities might affect a person’s success in rising from a chair.

**Conclusion**

Multiple measures of KEF are valuable for explaining STS performance. In our study, HHD measurements normalized to body weight were found to be the best predictor of STS independence. However, the generalization of these measures may be limited by the restriction of measurements to hospitalized adult patients. The KEF required of patients in other settings may vary slightly.

**References**