Determining Meaningful Changes in Gait Speed After Hip Fracture

Background and Purpose. Older subjects after hip fracture walk more slowly than age-matched peers. The extent to which they walk more slowly is difficult to define because the standard error of the measure (SEM), sensitivity to change, and clinically important change have not been reported for gait speed. The purposes of this study were to quantify the SEM for habitual and fast gait speeds among older subjects after hip fracture, to define the minimal detectable change (MDC), and to estimate the minimal clinically important difference (MCID) for habitual gait speed. Subjects. A sample of 92 subjects after hip fracture was drawn from 3 studies that collected gait speed data. Methods. An estimate of the MDC was determined by use of the SEM. The MCID was determined from expert opinion and from a receiver operating characteristic (ROC) curve. Results. The SEM and the MDC were 0.08 m/s and 0.10 m/s for habitual speed and fast speed, respectively. Both methods of MCID estimation identified 0.10 m/s as a meaningful change in habitual gait speed. Discussion and Conclusion. The estimated MCID for gait speed of 0.10 m/s was supported by clinical expert opinion and the cutoff point of the ROC curve. [Palombaro KM, Craik RL, Mangione KK, Tomlinson JD. Determining meaningful changes in gait speed after hip fracture. Phys Ther. 2006; 86:809–816.]

Key Words: Gait, Hip fracture, Sensitivity, Treatment outcome.

Kerstin M Palombaro, Rebecca L Craik, Kathleen K Mangione, James D Tomlinson
There are currently 350,000 hip fractures per year in the United States, with a predicted increase to over 650,000 per year by 2040. The majority of older people with hip fracture do not return to prefracture functional status 1 year after surgery. The extent of mobility disability, defined as the failure to recover the ability to ambulate independently in one’s surroundings, is reported consistently across studies of residual deficits after hip fracture. Assistive device use remains increased at 6 months after fracture; 42% of patients who report independent ambulation before fracture require at least a cane or a walker. Additionally, 56% report that they cannot walk as well as they did before fracture. At 12 months after hip fracture, approximately 50% of patients are not able to walk across a small room independently. New dependency in functional activities of daily living after fracture persists through 1 year for many patients with hip fractures, with 20% needing help putting on pants, 50% needing assistance to walk, and 90% being dependent in climbing stairs.

Natural recovery of gait speed after hip fracture has been described in the last 10 years. Prior to the late 1990s, gait was described in terms of gross function, such as the ability to walk 3 m (10 ft), the ability to walk outdoors, or a return to the earlier level of function. In studies examining recovery of gait speed at 1 year after hip fracture, subjects demonstrated average gait speeds of 0.47 to 0.68 m/s and 0.71 to 0.99 m/s for habitual speed and fast speed, respectively. A usual gait speed of between 1.2 and 1.5 m/s is the reference standard for adults, with age-adjusted gait speed being reported as 1.0 to 1.2 m/s for older adults who are healthy and similar in age to the population of people with hip fractures. A speed of 1.2 m/s is reported to be necessary to cross the street before the light changes in urban settings. These walking speeds suggest that older people after hip fracture walk more slowly than age-matched peers.

Gait speed also has been used as a global indicator of health and function in the geriatric literature. Geriatricians have compared gait speed with a measure of vital signs—a screening measure that reflects the integration of health, disease, fitness, and emotional state. As for vital signs measurements, reference values have been established; gait speed has been used to describe recovery and to establish thresholds, such as the ability to cross the street or to become a successful community ambulator. Gait speed has been associated with activity levels, changes in the isometric force of lower-extremity muscles, frailty, function, self-rated health, and falls. For elderly people with hip fracture, slower gait speed has been associated with more disability, lower self-efficacy for avoiding falls, and lower Berg Balance Scale scores. Although there are data that describe “normal” ranges of gait speed in elderly people, these gait speed measures have not been accompanied by information concerning error associated with the gait speed measures, the sensitivity of gait speed to change, and clinically important change. A change in walking speed could be useful as an outcome measure for recovery after hip fracture.

For clinicians, an estimate of the error in gait speed measurement and the ability to define a meaningful change in gait speed would assist in the clinical decision-making process.

KM Palombaro, PT, MS, is Research Associate, Department of Physical Therapy, Arcadia University, 450 S Easton Rd, Glenside, PA 19038-3295 (USA) (palombak@arcadia.edu). Address all correspondence to Ms Palombaro.

RL Craik, PT, PhD, FAPTA, is Professor and Chair, Department of Physical Therapy, Arcadia University.

KK Mangione, PT, PhD, GCS, is Associate Professor, Department of Physical Therapy, Arcadia University.

JD Tomlinson, PT, MS, is Assistant Professor, Department of Physical Therapy, Arcadia University.

Dr Mangione provided concept/idea/research design and subjects. All authors provided writing. Dr Craik and Dr Mangione provided data collection and fund procurement. Ms Palombaro provided data analysis. Dr Craik provided project management and facilities/equipment.

The institutional review boards of Arcadia University and Merck Research Laboratories approved the studies that generated the data used for this article.

This study was funded, in part, by a Foundation for Physical Therapy Research Grant, 2000, and by a grant from the National Center for Medical Rehabilitation Research, National Institute of Child Health and Human Development (5 R21 HD043269-02).

This research was presented at the American Physical Therapy Association Annual Conference and Exposition, June 8–11, 2005, Boston, Mass, as part of the balance and falls platform presentations.

This article was received June 29, 2005, and was accepted January 3, 2006.
making process. Without this information, clinicians must speculate about whether a patient actually exhibited an improvement in gait speed after an intervention. The standard error of the measure (SEM) represents the extent to which a variable can vary in the measurement process. Because some error is present in nearly all measurements, it is useful to consider a range of values for a measurement. The measurement of ±1 SEM represents a 68% confidence interval. To be 95% confident about the range for a measurement, one would use \( \pm 1.96 \times \text{SEM} \). The 68% and 95% confidence intervals both have been used to describe the minimal detectable change (MDC) in the literature.\(^32\text{–}35\) The MDC is defined as the amount of change in a measurement necessary to conclude that the difference is not attributable to error; it is the smallest change that falls outside the expected range of error.\(^36\) The minimal clinically important difference (MCID) is the amount of change that is clinically important to patients.\(^37\) Several methods of estimating the MCID have been described in the literature; these include patient self-report,\(^36,38\) clinical expert panel consensus,\(^39,40\) and statistical manipulations, such as calculating the SEM\(^32,33,36,38,39,41\) or receiver operating characteristic (ROC) curves.\(^36,38,42\)

Because the SEM, the MDC, and the MCID for gait speed have not been determined for patients after hip fracture, the purposes of this study were: (1) to quantify the SEM for habitual and fast gait speeds among elderly people after hip fracture and use this estimate to define the MDC for gait speed and (2) to provide an estimate of the MCID by use of both clinical expert opinion and change in subject performance in a subsample of subjects who participated in an exercise trial after hip fracture.

**Method**

**Subjects**

Subjects were recruited from a variety of sources and included community volunteers responding to flyers placed in residential buildings, participants in an exercise trial, and participants in a randomized controlled drug trial. Inclusion criteria for all subjects included having undergone successful fixation (partial or total hip replacement or open reduction-open fixation) of a hip fracture, being older than 64 years, and living at home. Exclusion criteria included a medical history of unstable angina or uncompensated congestive heart failure, treatment with chemotherapy or renal dialysis, history of stroke with residual hemiplegia, Parkinson disease, life expectancy of less than 6 months, Folstein mental status scores of less than 20,\(^43\) and living in a nursing home. All subjects gave written informed consent.

A total of 92 subjects with hip fracture were included in the sample. Their age (mean±SD) was 78.7±7.5 years, and their body mass index was 25.2±4.65. The subjects had an average of 3.6 comorbidities and took an average of 4.9 medications. The subjects were tested at a median of 6 months after hip fracture; the median was used because the sample was not distributed normally. The demographic characteristics for the subjects are shown in Table 1. Table 2 shows a description of the types of assistive devices used by the subjects.

Data from 3 previous studies were combined to increase the sample size for this study. Data were collected over a 4-year period at 2 locations. Site 1 was a university research center, and site 2 was in Nottingham, England.\(^44\) At both sites, the GaitMat II* was used. The

### Table 1.

**Demographic Characteristics of Subjects (N=92)**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex (n)</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>21</td>
</tr>
<tr>
<td>Female</td>
<td>65</td>
</tr>
<tr>
<td>Missing data</td>
<td>6</td>
</tr>
<tr>
<td>Age (y)</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>78.65</td>
</tr>
<tr>
<td>SD</td>
<td>7.50</td>
</tr>
<tr>
<td>Range</td>
<td>64–93</td>
</tr>
<tr>
<td>Missing data</td>
<td>1</td>
</tr>
<tr>
<td>Body mass index</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>25.21</td>
</tr>
<tr>
<td>SD</td>
<td>4.65</td>
</tr>
<tr>
<td>Range</td>
<td>15.79–43.59</td>
</tr>
<tr>
<td>Missing data</td>
<td>14</td>
</tr>
<tr>
<td>Fracture side (n)</td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>40</td>
</tr>
<tr>
<td>Right</td>
<td>44</td>
</tr>
<tr>
<td>Missing data</td>
<td>8</td>
</tr>
<tr>
<td>No. of medications</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>4.88</td>
</tr>
<tr>
<td>SD</td>
<td>3.07</td>
</tr>
<tr>
<td>Range</td>
<td>0–14</td>
</tr>
<tr>
<td>Missing data</td>
<td>33</td>
</tr>
<tr>
<td>No. of comorbidities</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>3.56</td>
</tr>
<tr>
<td>SD</td>
<td>2.06</td>
</tr>
<tr>
<td>Range</td>
<td>0–10</td>
</tr>
<tr>
<td>Missing data</td>
<td>30</td>
</tr>
<tr>
<td>Months after fracture</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>9.24</td>
</tr>
<tr>
<td>SD</td>
<td>16.97</td>
</tr>
<tr>
<td>Range</td>
<td>2–120</td>
</tr>
<tr>
<td>Median</td>
<td>6</td>
</tr>
<tr>
<td>Missing data</td>
<td>3</td>
</tr>
</tbody>
</table>

*Missing data are reported as number of subjects.*

* EQ Inc, Telford, PA 18969.
mat consists of a path 3.87 m long, 0.81 m wide, and 0.03 m thick. The walkway is divided into 40 rows and 256 columns of pressure-sensitive switches that are 15 mm square. The switches and circuitry are covered with black rubber. The switches are open until the foot contacts them as the subject walks across the mat, closing and reopening the switches. Subjects are allowed to use their assistive devices when walking on the GaitMat II. The time required to scan the entire array is 10 milliseconds. The temporal resolution is 10 milliseconds and the spatial resolution is 15 mm in both the longitudinal and transverse directions. Comparison of gait mats showed no significant difference for switch distances across 3 different mats at 3 different locations. An intraclass correlation coefficient (ICC[2,1]) of .99 was reported for validity of comparisons of temporal gait mat values with the Vicon motion analysis system.†,45 Intraclass correlation coefficients (ICC[3,1]) for test-retest reliability of data obtained with the GaitMat II have been reported to range from .90 to .99 for older women walking at a variety of speeds.46

Five physical therapists collected the gait data that were included in this study. Each physical therapist collected repeated measurements for frail elderly subjects who were similar to the subjects with hip fracture to determine that their measurements had adequate reliability before collecting trial data. The intrarater reliability coefficients (ICC[3,k]) for habitual and fast gait speeds ranged from .94 to .99. The same physical therapist performed all of the data analyses.

Procedure
The same procedure was used at each site to collect the gait data. Each subject was permitted several practice trials of walking across the mat to become familiar with the walking surface. A trial consisted of walking over the mat in 1 direction. The subject completed 3 or 4 trials at 2 different speeds. Habitual speed was tested with 2 trials, in which the subject was instructed to “walk at your normal or comfortable pace.” Fast speed was tested with 2 trials, in which the subject was instructed to “walk as quickly as possible without running.” Some individuals were able to complete only one fast-speed trial or one habitual-speed trial, but the majority of the subjects completed 2 trials at each speed. Individually determined rest periods were given between the trials if needed.

For subjects who were recruited as part of the exercise trial, a battery of measures, including gait and the Timed “Up & Go” Test (TUG), were collected before and after a 12-week exercise program. The exercise program consisted of twice-weekly exercises supervised by a physical therapist. The TUG was administered to all subjects by the same physical therapist as described by Podsiadlo and Richardson:47 the subject is timed while rising from an arm chair, walking 3 m, turning, walking back, and sitting down again.

Data Analysis

Quantifying the SEM. The SEM was calculated to determine the MDC for gait speed in subjects after hip fracture. The SEM was calculated by multiplying the standard deviation of the gait speed measurements by the square root of 1 minus the test-retest reliability coefficient of the GaitMat II.38 The value of 1.96 × SEM represents the 95% confidence interval and defines the possible range of the measurements because of error. A change of greater than 1.96 × SEM represents a change that is unlikely to be the result of error and therefore is an estimate of the MDC.

Estimating the MCID. Two different methods were used to estimate the MCID: a clinical expert panel and statistical calculation of the SEM. Five subjects were identified by publication records as experts in the areas of walking speed of elderly people and hip fracture. The experts all had more than 8 years of publication history and collectively had more than 40 peer-reviewed publications in these 2 areas. Four of the 5 experts were physical therapists who had an average of 24.2 ± 8.43 years of clinical and research experience in working with elderly people. The experts used both instrumented techniques for measuring gait speed and stopwatches. The experts were asked to quantify the amount of change in habitual gait speed considered to be a clinically meaningful change. The experts were not provided with the results of our SEM analysis. The expert assessments of meaningful gait speed change were compared with the MDC.

Table 2.
Types of Assistive Devices Used by Subjects (N=92)

<table>
<thead>
<tr>
<th>Device</th>
<th>No. of Subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>32</td>
</tr>
<tr>
<td>Single-point cane</td>
<td>23</td>
</tr>
<tr>
<td>Narrow-base quad cane</td>
<td>3</td>
</tr>
<tr>
<td>Wide-base quad cane</td>
<td>1</td>
</tr>
<tr>
<td>Lofstrand crutches</td>
<td>1</td>
</tr>
<tr>
<td>Rolling walker</td>
<td>16</td>
</tr>
<tr>
<td>Standard walker</td>
<td>3</td>
</tr>
<tr>
<td>One Lofstrand crutch</td>
<td>1</td>
</tr>
<tr>
<td>Two single-point canes</td>
<td>3</td>
</tr>
<tr>
<td>One axillary crutch</td>
<td>1</td>
</tr>
<tr>
<td>Missing data</td>
<td>8</td>
</tr>
</tbody>
</table>

† ViconPeak, 9 Spectrum Pointe Dr, Lake Forest, CA 92630.
In the second approach for estimating the MCID, we compared the change in gait speed and the change in TUG performance. One of the 3 studies mentioned above included 29 participants who had preintervention and postintervention gait speed and TUG assessments related to a 12-week exercise intervention. The TUG was chosen as the measure to determine whether a functional change had occurred. The TUG was chosen for several reasons. This test is commonly used to examine functional mobility in frail, community-dwelling older adults, who are similar to people after hip fracture. The time that it takes for a person to complete the test is correlated strongly with the level of functional mobility. The TUG has been shown to have predictive validity for falling and test-retest reliability. It contains walking speed as one of its components but also contains other elements, such as a sit-to-stand transfer. The correlation of TUG times and gait speed upon hospital discharge after hip fracture repair has been reported to be .728. The TUG also has been shown to predict walking ability 1 year after hip fracture. Therefore, we believe with 95% confidence that a change in the TUG time beyond the error of measurement represents a meaningful change in function.

The SEM for the TUG time was calculated with data from the exercise trial sample. The test-retest reliability coefficient (ICC) was .99, and the standard deviation was 13 seconds for the exercise trial; therefore, the SEM was 1.3 seconds. With the MDC, or 1.96 SEM, participants were categorized as showing improvement if the TUG time decreased by 2.5 seconds or more. Participants with TUG change scores of less than 2.5 seconds were categorized as not showing improvement. The next step was to find the threshold for the change in gait speed that best discriminated between participants categorized as showing improvement and those categorized as not showing improvement. A range of gait speed change values was used to categorize the participants as having increased gait speed or not having increased gait speed. The smallest change value used was 0.01 m/s, because this is the slowest speed that can be detected by the GaitMat II. Incrementally larger gait speed change values of up to 0.20 m/s were used to classify subjects as having increased gait speed. The upper limit of 0.20 m/s was chosen because this value represents twice the MCID reported by clinical expert opinion.

The sensitivity and specificity of the classifications at each gait speed change threshold were calculated. The ROC curve is a graph that compares the rate at which the threshold correctly identified participants showing improvement (sensitivity on the y-axis) to the rate at which participants were identified as showing improvement in gait speed but not in TUG (1-specificity on the x-axis). The optimal threshold was the gait speed change that resulted in the largest area under the ROC curve (the point closest to the upper left-hand corner of the graph shown in the Figure).

**Results**

The habitual gait speed (mean±SD) for the entire sample was 0.66±0.28 m/s; habitual gait speed ranged from 0.14 to 1.33 m/s. The fast gait speed (mean ± SD) was 0.92±0.35 m/s; fast gait speed ranged from 0.20 to 1.64 m/s. Four subjects were unable to perform fast gait speed testing.

The SEM values were 0.04 m/s for habitual speed and 0.05 m/s for fast speed. To create a 95% confidence interval for the measurement, 1.96 × SEM, or 0.08 m/s for habitual speed and 0.10 m/s for fast gait speed, was used. These values also represent the MDC.

The median of experts’ estimation of clinically meaningful change in habitual gait speed was 0.10 m/s (range of 0.08 to 0.16 m/s). The median of experts’ estimation was used because the distribution was skewed; 1 expert worked with subjects who walked considerably faster than the other 4 experts. The MCID identified by the ROC curve was 0.10 m/s and had a sensitivity of 0.63 and a specificity of 0.77 for the TUG (Figure).

**Discussion**

The SEM for gait speed in subjects after hip fracture was 0.04 m/s. The MDC values, or 1.96 × SEM, were 0.08 m/s.

![Figure](image_url)
for usual speed and 0.10 m/s for fast speed. The MCID, determined by expert opinion and ROC analysis, was 0.10 m/s. The MDC and the MCID can be used by clinicians to assist in determining whether a patient has experienced a real and meaningful change. Gait speeds are compared before and after an intervention. If a person’s gait speed changes less than 0.08 m/s, then the gait speed is within measurement error, and it can be concluded that there has been no change. However, if a person’s gait speed increases 0.08 m/s or more, gait speed is considered to be improved, and the question that follows is whether that change is meaningful. The MCID provides a threshold for clinical meaningfulness with which to compare a gait speed change that is greater than measurement error. On the basis of our analysis, we believe that people who have a hip fracture and who improve their gait speed by at least 0.10 m/s have experienced an important change. Converting the change from meters per second to meters per minute suggests that the subject will travel 6 m or more in 1 minute.

The error associated with measurement in gait speed has not been reported in the literature describing patients with hip fracture. We can use our estimates as a way to compare the results reported in the literature even though the data were collected with different measurement technologies. For example, Ingemarsson et al\textsuperscript{11} reported a change in stopwatch-timed habitual gait speed of 0.21 m/s in their cohort study examining subjects from hospital discharge to 1 year after hip fracture. In a study examining the effects of intervention, Mendelsohn et al\textsuperscript{52} reported an average change of 0.15 m/s in stopwatch-timed habitual gait speed for subjects who had hip fracture and who participated in an average of 28 days of inpatient rehabilitation, and Binder et al\textsuperscript{14} reported an average change of 0.32 m/s in stopwatch-timed fast gait speed for subjects who had hip fracture and who participated in 6 months of outpatient rehabilitation. Hauer et al\textsuperscript{53} reported an average change in stopwatch-timed habitual gait speed of 0.18 m/s for a sample of subjects who participated in 2 months of training, and Freter and Fruchter\textsuperscript{50} reported an average change in stopwatch-timed habitual gait speed of 0.23 m/s in a sample of subjects who engaged in an average of 109 days of inpatient orthopedic rehabilitation. Therefore, we believe that the subjects in these studies made clinically meaningful improvements in gait speed. However, Sherrington and Lord\textsuperscript{54} reported a statistically significant average change of 0.05 m/s in stopwatch-timed habitual gait speed. Our calculation of the MDC as 0.08 m/s suggests that most of the participants in the study of Sherrington and Lord did not experience a change in gait speed that exceeded measurement error. Therefore, we cannot be 95% confident

that the changes reported by Sherrington and Lord were meaningful according to the threshold that we established in the present study.

The literature suggests that the SEM, the MDC, and the MCID may vary depending on baseline scores or initial abilities of subjects.\textsuperscript{55} Our expert opinion ratings support this notion. The expert who provided the lowest estimate for an important change worked with subjects who were homebound after the fracture and had the lowest average gait speed and the smallest standard deviation. In contrast, the experts who provided the highest estimates for an important change worked with high-functioning subjects who were in an outpatient exercise setting and had the highest average gait speed and the largest standard deviation. It would be a reasonable assumption that a change of 0.08 m/s may be more meaningful to subjects who walk at 0.40 m/s (20% change) than to subjects who walk at 1.0 m/s (8% change). Further work is needed to determine whether the MCID is gait speed dependent.

There are several limitations of the present study. Gait speed was measured over the distance of the mat (~3.9 m). We believe that although this distance is short in comparison with what is needed to be independent in the community, there are data to support the notion that gait speed during a 4-m walk is highly related \((R=.93)\) to gait speed during a 400-m walk.\textsuperscript{56} Measurement of gait speed for a short distance is used both clinically and in large epidemiologic studies, such as established populations for epidemiologic studies of older subjects (2.4 m [8 ft]) and aging and body composition studies. The use of the GaitMat II system limits the generalizability of the findings. The ICC(3,1) values for reliability of the GaitMat II data range from .90 to .99.\textsuperscript{46} These reliability coefficients are higher than those of stopwatch-timed gait speed (ICC=.83–.89).\textsuperscript{57} However, the validity of data for the GaitMat II has been established with the Vicon motion analysis system.\textsuperscript{45} Thus, our estimation of error using the SEM in gait speed may be more similar to those obtained with instrumented measures. Estimates of the SEM are needed for gait speeds obtained with a stopwatch.

Another limitation is the diversity of the sample with respect to time after fracture. The mean time after fracture was 9 months (range=2–120), but the distribution was positively skewed because of the upper limit of 120 months after fracture. However, the sample may not be as diverse as the range of time after fracture implies. The median and the mode were both 6 months; thus, the majority of our measures were obtained for subjects at or near the end of the natural recovery curve.\textsuperscript{5}
Conclusion
The SEM values of gait speed after hip fracture were 0.04 m/s for habitual speed and 0.05 m/s for fast gait speed. The MDC values were 0.08 m/s for habitual gait speed and 0.10 m/s for fast gait speed. The MCID for habitual gait speed after hip fracture was determined to be 0.10 m/s by clinical expert opinion and through calculation of an ROC curve.

References


