The Assessment of Walking Capacity Using the Walking Index for Spinal Cord Injury: Self-Selected Versus Maximal Levels

Myeong Ok Kim, MD, Anthony S. Burns, MD, John F. Ditunno Jr, MD, Ralph J. Marino, MD


Objectives: To assess (1) the frequency and magnitude of differences between self-selected and maximal walking capacity following spinal cord injury (SCI) by using the Walking Index for Spinal Cord Injury (WISCI) and (2) how these levels differ in efficiency and velocity.

Design: Prospective cohort.

Setting: Academic medical center.

Participants: Fifty people with chronic incomplete SCI.

Interventions: Not applicable.

Main Outcome Measures: Subjects ambulated at the level used in the community (self-selected WISCI) and the highest level possible (maximal WISCI). Velocity (in m/s), Physiological Cost Index (PCI), and Total Heart Beat Index (THBI) were calculated. Differences were compared using the paired t test (parametric) or Wilcoxon signed-rank test (nonparametric).

Results: For 36 subjects, maximal WISCI was higher than self-selected WISCI; 21 subjects showed an increase of 3 levels or more. Ambulatory velocity was higher for self-selected WISCI compared with maximal WISCI (.68 m/s vs .56 m/s, P<.001). PCI and THBI at self-selected WISCI were lower than at maximal WISCI (PCI, 0.99 beats/m vs 1.48 beats/m, P<.001; THBI, 3.39 beats/m vs 4.75 beats/m, P<.001).

Conclusions: Many people with chronic SCI are capable of ambulating at multiple levels. For these people, ambulation at self-selected WISCI was more efficient as evidenced by greater velocity and decreased PCI and THBI. The findings have implications for assessing walking capacity within the context of clinical trials.

Key Words: Outcome assessment (health care); Rehabilitation; Spinal cord injuries; Walking.

© 2007 by the American Congress of Rehabilitation Medicine and the American Academy of Physical Medicine and Rehabilitation
may be able to ambulate in the home without the cane. Therefore, someone may walk at a given WISCI level in the home but another (usually lower) WISCI level outdoors. If distance, speed, and efficiency are to be assessed within the context of the WISCI, it is important to employ a consistent rationale for determining the specific WISCI level at which to measure these parameters.

The WISCI is currently the only outcome measure devised specifically to measure the ambulatory capacity of people after SCI; however, despite its increasing usage, it is still unclear whether it is better to assess people at their self-selected level of function or alternatively at the maximum level possible in a controlled environment. We therefore decided to examine the distribution of self-selected and maximal WISCI levels, how often the 2 levels differ, and the magnitude of differences in people with chronic SCI. Because future investigators will also likely be interested in the speed and efficiency of gait, we were also interested in how these parameters differed for the 2 WISCI levels. It was our expectation that speed and efficiency would be better at the study subjects’ self-selected level of function.

**METHODS**

Study subjects were recruited from the patient pool of the Regional Spinal Cord Injury Center of the Delaware Valley, a partnership of Thomas Jefferson University Hospital and Magee Rehabilitation Hospital, Philadelphia, PA. Candidates were identified by using targeted mailings combined with bulletin board postings and staff involvement in appropriate outpatient clinics. Candidates who expressed an interest in study participation were then contacted by telephone for additional screening and scheduling if enrollment criteria were met. Inclusion criteria included a history of traumatic SCI at least 12 months previously, motor incomplete status (American Spinal Injury Association Impairment Scale [AIS] grade C or D), and a motor level of C4 to L1 inclusive by using the International Standards for Neurological Classification of Spinal Cord Injury. Neurologic status was confirmed by examination before testing. In addition, subjects had to provide a history of independent lower-extremity weight bearing (standing or ambulating), a minimum of once a week, to minimize the risk of pathologic fractures. Subjects were excluded (1) if they were taking medication that could affect heart rate (ie, ß-blockers or Ca++-channel blockers) or (2) if they had any history of heart disease, uncontrolled asthma, or other medical condition that could limit their ability to safely ambulate. The study protocol was approved by the institutional review board and informed consent was obtained from all subjects before testing.

Testing was performed by assigned physical therapists trained in the use of the WISCI. Before testing, the following WISCI levels were determined: self-selected WISCI and maximal WISCI. The self-selected WISCI was defined as the WISCI level that the subject used to walk in the community or alternatively the household if community ambulation was not possible. The maximal WISCI was defined as the highest level at which a subject could safely walk 10m, as determined by the study therapists. For WISCI levels requiring assistance of another person, no more than minimal assistance was allowed.

<table>
<thead>
<tr>
<th>Level</th>
<th>Devices</th>
<th>Braces</th>
<th>Assistance</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Patient is unable to stand and/or participate in assisted walking</td>
<td></td>
<td></td>
<td>&lt;10 meters</td>
</tr>
<tr>
<td>1</td>
<td>Parallel bars</td>
<td>Braces</td>
<td>2 persons</td>
<td>10 meters</td>
</tr>
<tr>
<td>2</td>
<td>Parallel bars</td>
<td>Braces</td>
<td>2 persons</td>
<td>10 meters</td>
</tr>
<tr>
<td>3</td>
<td>Parallel bars</td>
<td>Braces</td>
<td>1 person</td>
<td>10 meters</td>
</tr>
<tr>
<td>4</td>
<td>Parallel bars</td>
<td>No braces</td>
<td>1 person</td>
<td>10 meters</td>
</tr>
<tr>
<td>5</td>
<td>Parallel bars</td>
<td>Braces</td>
<td>No assistance</td>
<td>10 meters</td>
</tr>
<tr>
<td>6</td>
<td>Walker</td>
<td>Braces</td>
<td>1 person</td>
<td>10 meters</td>
</tr>
<tr>
<td>7</td>
<td>Two crutches</td>
<td>Braces</td>
<td>1 person</td>
<td>10 meters</td>
</tr>
<tr>
<td>8</td>
<td>Walker</td>
<td>No braces</td>
<td>1 person</td>
<td>10 meters</td>
</tr>
<tr>
<td>9</td>
<td>Walker</td>
<td>Braces</td>
<td>No assistance</td>
<td>10 meters</td>
</tr>
<tr>
<td>10</td>
<td>One cane/crutch</td>
<td>Braces</td>
<td>1 person</td>
<td>10 meters</td>
</tr>
<tr>
<td>11</td>
<td>Two crutches</td>
<td>No braces</td>
<td>1 person</td>
<td>10 meters</td>
</tr>
<tr>
<td>12</td>
<td>Two crutches</td>
<td>Braces</td>
<td>No assistance</td>
<td>10 meters</td>
</tr>
<tr>
<td>13</td>
<td>Walker</td>
<td>No braces</td>
<td>No assistance</td>
<td>10 meters</td>
</tr>
<tr>
<td>14</td>
<td>One cane/crutch</td>
<td>No braces</td>
<td>1 person</td>
<td>10 meters</td>
</tr>
<tr>
<td>15</td>
<td>One cane/crutch</td>
<td>Braces</td>
<td>No assistance</td>
<td>10 meters</td>
</tr>
<tr>
<td>16</td>
<td>Two crutches</td>
<td>No braces</td>
<td>No assistance</td>
<td>10 meters</td>
</tr>
<tr>
<td>17</td>
<td>No devices</td>
<td>No braces</td>
<td>1 person</td>
<td>10 meters</td>
</tr>
<tr>
<td>18</td>
<td>No devices</td>
<td>Braces</td>
<td>No assistance</td>
<td>10 meters</td>
</tr>
<tr>
<td>19</td>
<td>One cane/crutch</td>
<td>No braces</td>
<td>No assistance</td>
<td>10 meters</td>
</tr>
<tr>
<td>20</td>
<td>No devices</td>
<td>No braces</td>
<td>No assistance</td>
<td>10 meters</td>
</tr>
</tbody>
</table>

**LEVEL ASSIGNED:** _________
Subjects were asked to ambulate at a comfortable speed for both the self-selected WISCI and maximal WISCI levels.

Once self-selected and maximal WISCI levels were defined, subjects ambulated back and forth along a marked 10-m length for a maximum of 10 laps (100m) or alternatively as far as possible (distance recorded) (fig 1). Because it was believed that fatigue was more likely to affect performance for the maximal WISCI level, maximal WISCI level testing was performed first. This also maximized the chance that study subjects would be able to complete the desired 100-m distance for the maximal WISCI level. Ambulatory capacity was then assessed at the less taxing self-selected WISCI level.

Testing was performed on a flat, hard surface. The continuous heart rate was recorded by using a Polar heart rate monitor. Polar heart rate data were synchronized to a stopwatch that had the capacity to time and save multiple intervals. It was therefore possible to identify the heart rate data corresponding to each lap and turn. The entire walking session was timed; however, the duration it took the patient to turn at the end of each length and the accompanying heartbeats were excluded from analysis. Subjects were allowed to rest between maximal and self-selected WISCI testing until the heart rate returned to the basal rate (±5 beats/min).

Ambulatory velocity (in m/s) was calculated by dividing the walking distance by time lapsed. The Physiological Cost Index (PCI) was calculated by using the following equation:

\[
\text{PCI (beats/m)} = \frac{\text{(steady-state heart rate)}}{\text{ambulatory velocity}}
\]

Steady-state heart rate was the average heart rate of the last 2 lengths, and resting heart rate was the initial heart rate. If subjects could not walk the full 100m, the average heart rate of the last 2 lengths was still used as steady-state heart rate. As a check on whether subjects reached steady-state heart rate during testing, we compared the calculated steady-state heart rate with the average heart rate of the previous length (the 8th length for those walking 100m). If steady-state heart rate was 3 or fewer beats higher than the prior lap, we considered the subject to be at steady state. Eighty percent of self-selected WISCI and 78% of maximal WISCI cases reached steady state based on heart rate. Tracings of the continuous heart rate were visually inspected, and the brief turns between laps did not appear to impact heart rate.

The total heart beat index (THBI) was calculated by using the equation: \( \text{THBI (beats/m)} = \frac{\text{total heart beats during testing}}{\text{total distance traveled}} \).

Both the PCI and THBI are parameters believed to reflect the energy efficiency of gait, and previous studies have been performed with study subjects ambulating at self-selected speeds. The PCI is generally calculated under steady-state conditions, but THBI is reported to be valid under both steady and non–steady-state conditions. All 50 study subjects underwent testing; however, additional analysis comparing differences between the self-selected and the maximal WISCI was limited to the 36 subjects for which the self-selected and maximal WISCI levels actually differed. Study parameters (ambulatory velocity, PCI, THBI) were analyzed for significant differences \((P<.05)\) using the paired \(t\) test or for nonnormally distributed data, the Wilcoxon signed-rank test.

**RESULTS**

Fifty ambulatory subjects with traumatic motor incomplete SCI, of greater than 1 year in duration, were enrolled and tested. In the United States, approximately 80% of SCIs affect men. Consistent with this, our study subjects were predominantly men \((43/50 [86%])\) with an average age of 47.4 ± 13.2 years \((range, 21–72y)\). There were slightly more tetraplegics \((28/50 [56%])\), and the predominant injury severity was AIS grade D \((45/50 [90%])\). The remaining 5 subjects were AIS grade C.

Both the self-selected and maximal WISCI levels ranged from 6 to 20, with a median self-selected WISCI level of 15 and a median maximal WISCI level of 19. For the self-selected WISCI, common levels included 19 \((n=16)\) followed by 13 \((n=9)\), 12 \((n=8)\), and 15 \((n=6)\), respectively (fig 2). For the maximal WISCI, 24 subjects attained the highest possible level, 20. Additional maximal WISCI levels that occurred in 5 or more subjects included 13 \((n=6)\), 15 \((n=5)\), and 19 \((n=5)\). For 14 subjects, the self-selected and maximal WISCI levels were the same; this included 3 subjects whose self-selected WISCI levels were already 20 and were therefore incapable of having a higher maximal WISCI level. For the remaining 36 \((72\%)\) subjects, the maximal WISCI level was greater than the self-selected WISCI level. For 15 subjects, the maximal WISCI increased 1 to 2 levels compared with the self-selected WISCI, whereas 21 subjects showed an increase of 3 levels or more.

---

**Fig 2. Distribution of self-selected (self-WISCI) and maximal WISCI (max-WISCI) levels in subjects.**
Thirty-three of the 6 subjects completed the entire 100-m testing distance at maximal WISCI, whereas 35 of the 36 subjects walked 100m at self-selected WISCI.

A closer examination of the 36 subjects whose maximal WISCI exceeded their self-selected WISCI level revealed that average ambulatory velocity at self-selected WISCI was significantly higher than at maximal WISCI (.68±.29m/s; range, 0.21–1.33m/s vs .56±.31m/s; range, 0.11–1.40m/s; paired t test, \( P < .001 \)) (fig 3). Both parameters of energy efficiency, the PCI and THBI, were significantly lower for self-selected WISCI compared with maximal WISCI (PCI: .99±.57 beats/m; range, 0.33–5.87 beats/m vs 1.48±1.24 beats/m; range, 0.22–5.55 beats/m; Wilcoxon signed-rank test, \( P < .001 \); THBI: 3.39±1.77 beats/m; range, 1.26–9.16 beats/m vs 4.75±3.42 beats/m; range, 1.25–16.98 beats/m; Wilcoxon signed-rank test, \( P < .001 \)) (figs 4, 5). Subjects with chronic SCI therefore walked faster with less energy expenditure at the self-selected WISCI level compared with the maximal WISCI level (see figs 3–5).

**DISCUSSION**

The capacity of people to walk with different combinations of braces, devices, and physical assistance is an important issue to consider when planning SCI trials in which the capacity to ambulate will be a measured outcome. Our study confirmed what many clinicians have intuitively recognized, that subjects with chronic SCI are capable of ambulating with varying degrees of bracing, assistive devices, and/or physical assistance. This is likely influenced by the specific environment, energy requirements, and other less defined variables. In this study, we assessed walking under 2 conditions: (1) the WISCI level used in the community or alternatively the home if the patient was not capable of community ambulation and (2) the highest WISCI level that could be safely attained on a flat-level surface in our physical therapy department. Of the 47 subjects with a self-selected WISCI less than 20, 36 were able to ambulate safely at a higher WISCI level. For subjects with higher self-selected WISCI levels, the magnitude of the difference was, as expected, limited by a ceiling effect. The quality of ambulation at the maximal WISCI level was adversely affected, as reflected by decreased speed and increased energy expenditure.

Because inpatient lengths of stay have decreased, more neurologic and functional recovery occurs during the postdischarge period. In the United States, the average duration of inpatient rehabilitation after traumatic SCI declined from 115 days in 1974 to 39 days in 2004. Therefore, not all patients have the opportunity to continue therapy until recovery has reached a plateau, and their capacity may be more than real-
reaching level 20 (see fig 2). This ceiling effect could limit the cluster at the upper end, with a large proportion of people Second, the maximal WISCI levels for chronic SCI tend to self-selected WISCI, it is the level actually used in the com-

 devices, bracing, and physical assistance. Our data indicate that the combination of braces and assistive devices is common (WISCI levels 6, 7, 9, 10, 12, 15), and we believe that it is important to differentiate when 1 or both are used. For the validation studies of both timed walking tests, subjects were tested at their self-selected level of walking rather than maximal capacity. It will be important for future studies to determine which level of walking (self-selected vs maximal) correlates better to the underlying motor impairment associated with SCI.

In this study, we used 2 easily calculated parameters, the PCI and THBI, to estimate the efficiency of walking. The direct measurement of oxygen consumption requires specialized equipment not generally available in rehabilitation clinics; measures of gait efficiency, therefore, often use ambulatory velocity and heart rate to estimate oxygen consumption. The PCI was proposed as an alternative to oxygen consumption \( V\dot{O}_2 \) measurements because a linear relation exists between heart rate and \( V\dot{O}_2 \) at submaximal loads.22 However, some studies have found that subjects with impairments such as SCI may fatigue before reaching steady state or that walking may not be a submaximal task.23,26 In our study, 80% of self-selected WISCI and 78% of maximal WISCI cases reached steady state based on heart rate. The THBI was developed as an alternative to the PCI. The THBI has been reported to be very sensitive of the maximal WISCI for detecting a therapeutic response to an intervention. Alternatively, it might be possible to test subjects at maximal WISCI and then differentiate subjects at the higher end of the scale using other parameters (ie, gait efficiency, velocity). Future studies would need to validate such an approach. If investigators are more interested in velocity or gait efficiency than the actual WISCI level obtained, it might be preferable to evaluate subjects at maximal WISCI where a wider range of values was observed.

Assessing patients at maximal capacity requires an understanding of the relation of bracing, assistive devices, and physical assistance to the underlying motor impairment and walking ability. As noted earlier, several scales developed to assess functional gains during rehabilitation (eg, the MBI, FIM, and SCIM) do not clearly describe the use of braces and devices. The WISCI was developed specifically to evaluate walking capacity based on degree of impairment, and as a result, considers these elements. The intent was to maximize sensitivity for detecting changes in walking capacity, rather than defining what constitutes a clinical meaningful change. Morganti et al10 retrospectively compared the WISCI with the MBI, FIM, and SCIM to determine their sensitivities for detecting differences in walking function after SCI. There were significant correlations between all the scales, with the highest correlation found between the WISCI and the SCIM (Spearman \( \rho = .97 \)). The sensitivity of the WISCI for detecting differences in walking abilities was greater than that of other scales. This may be caused in part by the burden of care focus of the MBI and FIM, with an accompanying emphasis on physical assistance rather than devices. The SCIM includes several levels of walking ability but gives limited consideration to the use of leg braces.

Two timed walking tests, the 6MWT and 10MWT, have recently been validated for the measurement of walking capacity after SCI; neither test, however, specifies the required bracing or assistive devices.11,12 Our data indicate that the combination of braces and assistive devices is common (WISCI levels 6, 7, 9, 10, 12, 15), and we believe that it is important to differentiate when 1 or both are used. For the validation studies of both timed walking tests, subjects were tested at their self-selected level of walking rather than maximal capacity. It will be important for future studies to determine which level of walking (self-selected vs maximal) correlates better to the underlying motor impairment associated with SCI.

Study Limitations

Our study generalizability is limited by the fact that study subjects had primarily higher WISCI levels. Twenty subjects had self-selected WISCI levels over 18, but only 3 subjects had self-selected WISCI levels below 10. This might be a function of our chosen study population, which consisted of subjects with chronic SCI, as well as our inclusion criteria that required subjects to weight bear at least once a week. Chronic subjects at lower WISCI levels are likely to be largely nonambulatory because these levels are not practical for household or com-

Arch Phys Med Rehabil Vol 88, June 2007
munity ambulation. In contrast, subjects who eventually recover the ability to ambulate, may transiently progress through the lower WISCI levels after acute SCI. Although the average duration from injury was unclear, van Hedel et al\(^2\) found that there was a good correlation between the WISCI level and the 10MWT (Spearman \(\rho = -0.78\) for levels 11 to 20, but a poor correlation (\(\rho = -0.24\)) for WISCI levels below 11. Future studies are needed to assess and contrast the distribution of WISCI levels in acute and chronic populations and determine the inter- and intrarater reliability of the self-selected and maximal WISCI.

**CONCLUSIONS**

Most subjects were able to walk at a higher WISCI level than their usual level (ie, with less use of devices and/or physical assistance). Gait velocity was lower and energy cost higher at the higher WISCI levels. This finding has important implications for assessing changes in ambulation capacity within the context of clinical trials. Study protocols should explicitly state whether subjects should be tested by using their usual devices or braces or alternatively by using the least amount of devices and assistance possible. Subjects may improve by requiring less adaptations (braces, devices, physical assistance) and/or by improving speed and efficiency. To avoid confounding by a change in devices or assistance, assessment of ambulation should document required adaptations and include a measure of how the subject walks, such as the WISCI, in addition to parameters such as velocity and energy cost.

**Acknowledgment:** We thank Harry Schwartz, MD, of Moss Rehabilitation Hospital, Philadelphia, PA, for his assistance in identifying study subjects and the performance of the study.

**References**


**Suppliers**

a. Polar Electro Oy, Professorintie 5, FIN-90440 Kempele, Finland.

b. Version 11; SPSS Inc, 233 S Wacker Dr, 11th Fl, Chicago, IL 60606.