Prediction of Ambulatory Performance Based on Motor Scores Derived From Standards of the American Spinal Injury Association

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Assessment of strength using motor scores derived from the standards of the American Spinal Injury Association (ASIA) was compared with assessment using motor scores based on biomechanical aspects of walking in the prediction of ambulatory performance. Measurements of strength, gait performance, and the energy expenditure were performed in 36 spinal cord injured patients. The ASIA scoring system compared favorably with the biomechanical scoring system. The ASIA score strongly correlated with the percent increase in the rate of O2 consumption above normal (p < .0005), O2 cost per meter (p < .0006), peak axial load exerted by the arms on crutches (p < .0001), velocity (p < .0001), and cadence (p < .0001). Patients with lower extremity ASIA scores ≤ 20 were limited ambulators with slower average velocities at higher heart rates, greater energy expenditure, and greater peak axial load exerted on assistive devices than patients with lower extremity ASIA scores ≥ 30 who were community ambulators. We conclude the ASIA motor score is a simple clinical measure that strongly correlates with walking ability.

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Determining the potential for ambulation is one of the most important evaluations a clinician must make in caring for a patient with spinal cord injury (SCI). A patient’s level of injury, conditioning, motivation, and severity of paralysis all contribute to ambulatory potential. Previous investigators have measured physiological parameters such as heart rate, respiratory rate, and oxygen consumption in SCI patients to describe their increased energy expenditure during walking.

In a 1989 study, we found that patients with progressively increasing degrees of lower extremity paralysis measured by the Ambulatory Motor Index (AMI) increasingly substituted for the loss of lower extremity muscle function by exerting greater upper extremity exertion on crutches and slowing the gait velocity. The magnitude of upper extremity exertion was proportional to the increase in physiological energy expenditure in comparison to normal walking.

The AMI is derived from manual muscle testing of five lower extremity muscles about the hip and knee that are important in the gait cycle from a biomechanical perspective. Muscle groups about the ankle are not represented in the AMI because prescription of an appropriate orthosis, from a biomechanical perspective, provides near normal substitution for ankle/foot paralysis with only a minimal increase in energy expenditure.

Recently the American Spinal Injury Association (ASIA) motor scoring system has become accepted as the international standard for reporting muscle strength and gauging paralysis after SCI. The ASIA lower extremity muscle score (LEMS) is derived from manual muscle testing of five lower extremity muscle groups representing each neurological level from L2 to S1. However, only two muscle groups are common to both the AMI and LEMS. This study determines the correlation of the LEMS to gait performance and energy expenditure and, in this regard, compares its effectiveness with the AMI. Although the AMI has been shown to be an effective predictor of ambulatory performance, the importance of using uniform standards is well recognized. Validation of the use of ASIA standards in prognostication of ambulation status is an important step in promoting the wider use and acceptance of these standards and fostering more reliable communication among investigators and clinicians.

SUBJECTS

Subjects

Thirty-six SCI patients (30 men, 6 women) were studied. The average age was 29.0 ± 10.1 years, height 1.72 ± 0.10m, and weight 66.1 ± 11.3kg. The average interval between SCI and testing was 0.5 ± 0.7 years. Each patient had completed a gait training program and was able to walk independently for 5 minutes.

Twelve patients were tetraparetic (incomplete cord lesions) with sufficient preserved motor strength in the lower limbs to ambulate. Of the remaining 24 patients, four were
paraplegic (complete cord lesions), and 20 had motor incomplete paraplegia or were paraparetic (incomplete cord lesions). Each patient’s trunk extension strength was sufficient to allow independent sitting without the use of arms for support.

The orthotic prescription followed standard clinical practices and was primarily based on the strength of the quadriceps. When quadriceps strength was less than 4/5, a knee-ankle-foot orthosis (KAFO) was prescribed with the knee locked in extension. Patients wore an ankle foot orthosis (AFO) if necessary. Indications for the use of an AFO included weakness in the ankle plantarflexors or dorsiflexors. Thirty-four patients used a reciprocating gait pattern, and two patients used a swing-through gait pattern.

Manual Muscle Testing

Manual muscle testing was performed for all lower extremity muscle groups in the study previously reported in which the AMI was found to strongly correlate with gait performance and energy expenditure. It was possible to derive the ASIA LEMS score from the original data and correlate it to gait performance and energy expenditure.

Manual muscle testing using the standard six-grade scale: absent = 0; trace = visible or palpable contraction = 1/5; poor = active movement through range of motion with gravity eliminated = 2/5; fair = active movement through range of motion against gravity = 3/5; good = active movement through range of motion against gravity and resistance = 4/5; and normal = 5/5.

ASIA uses the six-grade grading for five key muscles representing each neurological segment between L2 and S1 (hip flexion = L2, knee extension = L3, ankle dorsiflexion = L4, great toe extension = L5, and ankle plantarflexion = S1). The maximal LEMS obtained from the bilateral sum of muscle grades is 50 points.

In contrast, the AMI is calculated based on key muscles about the hip and knee (hip flexion, hip extension, hip abduction, knee extension, and knee flexion). Grades 1/5 and 2/5 as well as grade 4/5 and 5/5 are combined into single muscle grades as follows: 0 = 0, 1/5 or 2/5 = 1, 3/5 = 2, 4/5 or 5/5 = 3. The maximum bilateral AMI score is 30 points.

Energy Measurement

Energy expenditure testing was conducted on a level outdoor track and has previously been described in detail.11,13,16 The subjects wore their customary shoes and orthoses and were instructed to walk until they were fatigued or for a maximum of 20 minutes. Expired air was analyzed for physiological data using a lightweight (1.5 kg) air collection system harnessed to the subject’s shoulders and heart rate, respiratory rate, and cadence were monitored and transmitted using a portable FM radiotelemetry system.7

Energy expenditure during walking was expressed by three different parameters. The rate of $\text{VO}_{2}$/min (mL/kg < min) indicates the power requirement. The $\text{O}_{2}$ cost per meter (mL/kg × m) is the amount of oxygen needed to walk a unit distance and indicates physiological work. A comparison of $\text{O}_{2}$ cost per meter of a patient to the average value for normal walking enables determination of gait efficiency or the $\text{O}_{2}$ rate increase (percent). This is the percent increase in the SCI patient’s rate versus an able-bodied individual’s rate of $\text{VO}_{2}$/min at comparable speeds.

With regard to the $\text{O}_{2}$ rate increase, the relationship between $\text{VO}_{2}$ and speed during normal walking can be defined according to the equation

$$\text{VO}_{2} = 2.6 + (0.129 \times V)$$

where $\text{VO}_{2}$ equals the rate of oxygen consumption per minute and $V$ equals the walking speed. To control for differences in walking speeds among patients and able-bodied subjects, the velocity-adjusted value for the normal rate of $\text{VO}_{2}$/min was subtracted from the patient’s rate of $\text{VO}_{2}$ and expressed as a percentage of the normal value according to the equation

$$\text{O}_{2} \text{ rate increase} = 100 \times \left( \frac{\text{VO}_{2} \text{ Patient} - \text{VO}_{2} \text{ Normal}}{\text{VO}_{2} \text{ Normal}} \right)$$

Peak Axial Load

Preceding outdoor energy expenditure measurement, indoor gait analysis was performed along a 6-meter walkway to determine the peak force exerted by the subject’s arms on adjustable, instrumented upper extremity assistive devices. Patients were tested with the type of device (cane, crutch, or walker) they normally used. For the swing-through gait pattern, in which both assistive devices make floor contact simultaneously, the sum of the longitudinal forces exerted on the right and left devices was calculated and averaged over the recorded cycles. For the reciprocating gait pattern, the sum of the longitudinal forces exerted on the right and left assistive devices was divided by two to calculate the average maximal peak axial load (PAL) on each assistive device during the gait cycle. Both values were expressed as a percentage of the patient’s body weight.

Data Analysis

Regression analysis was used to determine the relationships between LEMS and velocity ($V$) cadence, $\text{O}_{2}$ rate increase, $\text{O}_{2}$ cost, and the PAL.

An examination of the data distributions associated with the regression analyses indicated that the means of various subgroups of the data, partitioned by the degree of neurological impairment, extended in logical patterns along the lines or curves which defined the relationships between both the LEMS and AMI. Furthermore, certain of these means appeared to cluster either below an LEMS score ≤20 (AMI score below ≤12), or above an LEMS score of 30 (AMI score ≥18), with an area between an LEMS score of 20 and 30 showing different cluster patterns depending on the measure (eg, velocity vs $\text{O}_{2}$ rate increase). Because of this we decided to examine the data according to these apparent thresholds: less than or equal to a LEMS of 20 points; LEMS of 21 to 29 points; and LEMS greater than or equal to 30 points.
RESULTS

Gait Characteristics
Both gait velocity and cadence were previously found to vary directly with the AMI and the same relationship was observed with the LEMS (figs 1 and 2). There was a strong ($r = 0.64, p < .0001$) linear relationship described by the equation

$$V = 17.2 + \text{LEMS}$$

where $V$ is in meters per minute.

Similarly, a strong ($r = 0.75, p < .0001$) linear relationship between the LEMS and cadence was seen, as follows:

$$C = 35.2 + (1.47 \times \text{LEMS})$$

where cadence is in steps per minute.

The above equations are graphed in figs 1 and 2 along with equations previously derived using the AMI.

Energy Expenditure
To control for $V$, the $O_2$ rate increase was determined according to the methods discussed previously. There was a significant ($r = .56, p < .0001$) linear relationship between the LEMS and $O_2$ rate increase characterized by the equation

$$O_2 \text{ rate increase} = 207 - (4.4 \times \text{LEMS})$$

where $O_2$ rate increase is the percent increase in the rate of VO2/min in comparison to the value for an able-bodied subject walking at the same speed (fig 3).

The $O_2$ cost per meter was also significantly ($r = .55, p < .0006$) related to the LEMS (fig 4). This relationship was best defined by the equation

$$O_2 \text{ cost} = 0.99 - (0.02 \times \text{LEMS})$$

The previous equations regarding energy expenditure are graphed in figures 3 and 4 along with equations previously derived from the AMI.

Peak Axial Load
There was a strong ($r = .80, p < .0001$) relationship between the PAL and the AMI, which was defined as follows:

$$\text{PAL} = [7.27 - (0.14 \times \text{LEMS})]^2$$
Fig 5—The relationship between the LEMS and the PAL is defined by the equation, \( \text{PAL} = 7.27 - 0.14 \times \text{LEMS}^2 \) (solid line). This equation is similar to the data fit previously reported using the AMI defined by the equation, \( \text{PAL} = 82.75 - (1.72 \times \text{AMI}) + (0.009 \times \text{AMI}^2) \) (dotted line).

where \( \text{PAL} \) is expressed as a percent of total body weight. This equation, based on the LEMS, and the equation previously reported derived from the LEMS, are depicted in figure 5.

### LEMS Versus AMI

A comparison of the LEMS to the AMI showed an extremely robust (\( r = 0.93, p < .0001 \)) linear relationship (fig 6). This relationship is described by the equation

\[
\text{LEMS} = (0.96 \times \text{AMI}) - 0.90
\]

Because of the extremely close relationship between the LEMS and AMI, it is not surprising that the equations relating muscle paralysis to gait velocity, cadence, rate of energy expenditure, oxygen cost, and peak axial load on crutches using either the LEMS or AMI as the dependent variable are quite similar. The equations based on the LEMS and the AMI are graphed in figures 1-5. A comparison of the quality of data fit using the LEMS and AMI can be judged by the value of the correlation coefficient, \( r \), tabulated in table 1. Slightly higher values were obtained for the LEMS than for previously reported values using the AMI for the equations derived for the PAL (0.80 versus 0.73) and cadence (0.75 versus 0.73). Although the correlation coefficient was lower for the LEMS than for the AMI regarding the equations describing velocity (0.64 vs 0.75), \%O\textsubscript{2} rate increase (0.56 vs 0.68) and O\textsubscript{2} cost (0.55 vs 0.77).

### Ambulatory Motor Index Thresholds

Patients were divided in three groups according to the LEMS: group 1, \( \leq 20 \) points; group 2, 21-29 points; and group 3, \( \geq 30 \) points. There were highly statistically significant differences in the parameters of gait performance and energy expenditure between groups. The data are summarized in table 2. All patients in group 3 achieved community ambulation status. All patients in group 1 were household ambulators.

### DISCUSSION

The ASIA I LEMS closely correlates with the parameters of gait performance (velocity and cadence), energy expenditure (rate of O\textsubscript{2} uptake, heart rate, O\textsubscript{2} cost), and the peak axial load exerted by the arms on crutches. The quality of data fit using the LEMS as determined by the calculation of the correlation coefficient, \( r \), was approximately the same as using the AMI.

Although only two muscle groups are common to both the LEMS and AMI (hip flexion and knee extension) the reason for the excellent correlation using either the LEMS and AMI as the dependent variable in relation to the parameters of gait performance and energy expenditure is that both systems represent similar neurological segments of the spinal cord. The muscle groups unique to the AMI are the hip extensors (S1, S2), hip abductors (S1, S2), and knee flexors.

### Table 1: Correlation Coefficient (r) LEMS Versus AMI

<table>
<thead>
<tr>
<th>Parameter</th>
<th>LEMS r</th>
<th>AMI* r</th>
</tr>
</thead>
<tbody>
<tr>
<td>Velocity</td>
<td>0.64</td>
<td>0.75</td>
</tr>
<tr>
<td>Cadence</td>
<td>0.75</td>
<td>0.73</td>
</tr>
<tr>
<td>% O\textsubscript{2} rate increase</td>
<td>0.56</td>
<td>0.68</td>
</tr>
<tr>
<td>O\textsubscript{2} Cost</td>
<td>0.55</td>
<td>0.77</td>
</tr>
<tr>
<td>Peak axial load</td>
<td>0.80</td>
<td>0.73</td>
</tr>
</tbody>
</table>

*Waters*

### Table 2: ASIA Lower Extremity Motor Score (Mean ± 1 SD)

<table>
<thead>
<tr>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEMS 20</td>
<td>LEMS 21-29</td>
<td>LEMS 30</td>
</tr>
<tr>
<td>(n = 13)</td>
<td>(n = 9)</td>
<td>(n = 13)</td>
</tr>
<tr>
<td>O\textsubscript{2} rate (mL/kg min)</td>
<td>15.2 ± 3.4</td>
<td>13.2 ± 3.6</td>
</tr>
<tr>
<td>Heart rate (bpm)</td>
<td>100.4 ± 24.1</td>
<td>118.1 ± 3.5</td>
</tr>
<tr>
<td>O\textsubscript{2} rate increase (% normal)</td>
<td>158 ± 114</td>
<td>110 ± 60</td>
</tr>
<tr>
<td>O\textsubscript{2} cost (mL/kg/m)</td>
<td>0.76 ± 0.61</td>
<td>0.51 ± 0.25</td>
</tr>
<tr>
<td>Velocity (m/min)</td>
<td>30.5 ± 15.6</td>
<td>31.4 ± 11.4</td>
</tr>
<tr>
<td>% body weight</td>
<td>36.4 ± 16.1</td>
<td>17.2 ± 11.5</td>
</tr>
</tbody>
</table>
The ankle dorsiflexors (L4), great toe extensors (L5), and ankle plantarflexors (S1) are unique to the LEMS. Nevertheless, because the muscle groups exclusive to each motor scoring system are innervated by approximately the same neurological segments, there is an extremely strong linear relationship ($r = 0.93$) between the two scoring systems despite differences in their derivation.

There were differences in the physiological and gait performance parameters between subgroups partitioned according to the LEMS as previously noted for the AMI. As shown by Hussey and Stauffer, walking ability is directly related to motor power. At least "fair" hip flexor strength and at least "fair" knee extensor strength unilaterally was required to enable a patient to achieve a reciprocal gait pattern. Using the LEMS, patients who met these criteria had a LEMS $\geq 30$, group 3. Their mean walking velocity was 57.5m/min, mean heart rate was 108bpm, average rate of $\text{VO}_2$ was 14.6mL/kg min, and the average peak axial load exerted on assistive devices was 8.1% body weight. These values regarding gait performance and energy expenditure are reasonably close to comparable values for able-bodied control subjects examined previously. The values for able-bodied control subjects were 80m/min, 99.6bpm, and 12.1mL/kg/min, respectively. This similarity accounts for the fact that all group 3 patients were community ambulators and did not rely on wheeling as a primary mode of transportation. In contrast, most patients in group 1 with a LEMS $< 20$ required two KAFOs and two crutches to ambulate. Their mean V was 30.5m/min, mean heart rate was 130bpm, average rate of $\text{VO}_2$ was 15.2mL/kg/min and the average peak axial load exerted on assistive devices was 36.4%. Consequently it is not surprising that wheeling was the primary means of mobility outside the home for these patients.

We conclude that calculation of the ASIA LEMS provides the clinician with a simple method of estimating ambulatory capability for determining ambulatory potential in SCI patients.

References