Functional Reach: A New Clinical Measure of Balance

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A new clinically accessible measure of balance, functional reach (FR), is the difference between arm’s length and maximal forward reach, using a fixed base of support. The purposes of this study were to (a) establish FR as a measure of the margin of stability versus the laboratory measure, center of pressure excursion (COPE); (b) test reliability and precision, and (c) determine factors that influence FR, including age and anthropometrics. We evaluated FR in 128 volunteers (age 21–87 years). FR was determined with a precise electronic device and a simple clinical apparatus (yardstick). FR correlates with COPE (Pearson r = .71) and is precise (coefficient of variation = 2.5%) and stable (intraclass correlation coefficient across days = .81). Age and height influence FR. FR is portable, inexpensive, reliable, precise, and a reasonable clinical approximator of the margin of stability. FR may be useful for detecting balance impairment, change in balance performance over time, and in the design of modified environments for impaired older persons.

MAINTENANCE of upright posture is a complex task, requiring an individual’s center of gravity reside over a very small base of support. Highly sophisticated neuromuscular mechanisms are necessary in order to sustain this position (1). As postural control mechanisms deteriorate with age and disease, balance becomes increasingly tenuous resulting in an enhanced susceptibility to falls (2). Efforts to describe and comprehend balance impairment in older persons have led to the development of several methods of assessing balance (3–10).

Existing balance measures have a variety of limitations. Some, such as one-footed standing and tandem walking, are difficult to perform even by healthy older individuals. They are sensitive but not very specific for clinical balance problems. In general, dynamic balance measures, which assess the ability to maintain equilibrium in response to either self-motivated or external perturbation, are superior to static tasks such as one-legged stance and the Romberg test. Accepted dynamic balance tests include Wolfson’s postural stress test (PST) (10), center of pressure excursion (COPE) (11) and the platform perturbation test (1,6,7). The PST utilizes ordinal scoring, which is less sensitive than a continuous measurement system and may be unable to finely discriminate levels of postural impairment. Both the platform perturbation test and COPE require the use of sophisticated laboratory equipment, which limits their clinical accessibility. In addition, these tests assess postural responses to artificially created external stimuli rather than voluntary movements performed during routine activities. As such, extrapolation of results to the real world is difficult. We have chosen, therefore, to develop a new clinical dynamic balance measure that utilizes a continuous scoring system, is relatively simple to perform, and is clinically accessible.

Our new measure, functional reach (FR), is designed as a measure of the margin of stability similar to COPE. COPE is measured with the subject standing on a force platform; the center of pressure is recorded as he leans forward, backward, and sideways (11). For reasons that are incompletely understood, the center of pressure of elderly individuals tends not to approach the edges of their base of support as closely as that of younger subjects (11–13). The boundary of stability lies within a more limited area, which may reflect an effort to compensate for impaired postural control mechanisms.

One author (PD) has made the clinical observation that simple reach tasks represent the same kind of controlled center of pressure excursion within the base of support as do the leaning tasks examined traditionally with COPE. However, we believe that a reach task reflects a more functional aspect of COPE than does a lean task. We define FR as the maximal distance one can reach forward beyond arm’s length, while maintaining a fixed base of support in the standing position. Just as COPE deteriorates with advancing age, an individual’s functional reach might also deteriorate, thus serving as a protective mechanism to minimize disturbance of the center of gravity and prevent falling.

Although functional reach measures have never been systematically evaluated in the elderly, they have been used extensively in the field of transportation. The United States Automotive Industry, the National Highway Safety Administration (U.S. Department of Transportation), and the National Aeronautics and Space Administration (NASA) have all used functional reach measures in the sitting position to ensure the safety and functional utility of vehicle design (14,15). Standing functional reach, however, has not previously been quantitated. Our goals in this study were to: (a) establish in well individuals, across a wide range of age and performance, whether standing functional reach is a measure of the margin of stability related clinically to COPE, (b) test the reliability and precision of functional reach, and (c) evaluate the demographic and physical factors, including age and anthropometrics, that influence functional reach.

METHODS

Subjects. — Volunteers were recruited from three resources: (a) employees at the Duke University Medical Center and the Durham Veterans Administration Hospital; (b) students of the Duke University Physical Therapy Program;
and (c) the Duke Aging Center registry of community-dwelling elderly. Subjects were initially contacted by telephone and excluded if they were left-handed, carried a major orthopedic or neurologic diagnosis (e.g., amputation, fracture of any extremity within the past year, Parkinson’s disease, a history of cerebral vascular accident), had experienced any unexplained falls within the past 6 months, were unable to stand for 10 minutes without the use of an assistive device, or had pain that would limit their ability to stand or reach. Subjects were excluded by on-site evaluation if they demonstrated painful shoulder abduction, less than 90° of shoulder abduction, an elbow flexion contracture, asymmetry in the neurological examination, absent proprioception, or abnormal tone.

Instrumentation. — Instruments used in this study included a force platform, an electronic system for measuring functional reach, and a 48-inch measuring device, or “yardstick.” The platform and electronic reach device were designed and constructed by the Duke University Department of Biomedical Engineering. The platform consists of a 2-square-foot surface with separate foot plates. Each foot plate contains three load cells to measure vertical forces. The load cells output a voltage proportional to the force at each point, which easily translates to coordinates on the plate surface. The load cells are amplified by a strain gauge conditioning system and monitored by a computer oscilloscope. The center of pressure excursion (COPES) is calculated as the difference between the location of the center of pressure during relaxed standing and maximum forward reach. Center of pressure excursion is calculated as a function of the components of change in both the X (horizontal) and Y (vertical) axes.

The electronic functional reach device consists of a handle mounted on a sliding track, which is supported by two adjustable height tripods (Figure 1). As the handle is displaced, a wire moves along a spring-loaded output reel. Rotational potentiometers connected to opposite ends of the axis of the output reel turn in opposite directions as a wire pulls off the reel; this results in complementary resistance changes in the potentiometers. The potentiometers form two legs of a wheatstone bridge circuit. The output voltage of the bridge is amplified and converted to digital readouts by a computer software program. Calibration procedures reveal that the maximum error in measuring displacements is .16 inches and the greatest percentage error is 1.03.

Our clinically accessible measure of reach consists of a 48-inch “yardstick” attached to a level.

Procedure. — Following telephone screening and signing of informed consent, on-site evaluation was performed. Subjects proceeded sequentially through three testing stations. At Station 1, brief neurological and musculoskeletal examinations were performed. Range of motion of the right elbow and shoulder was tested. The neurological exam included testing of the biceps, patellar and Babinski reflexes, coordination (finger to nose and heel-knee-shin), great toe proprioception, and upper and lower extremity tone. Only subjects with normal neurological screens were included in this study. Anthropometric measures included height, weight, trunk length (measured from the spinous process of the seventh cervical vertebrae to the coccyx), right shoulder height (acromion to floor), right arm length (acromion to distal end of right third metacarpal), right and left foot length (heel to the end of the great toe), and anterior foot length (anterior aspect of the medial malleolus to the end of the great toe).

At Station 2, functional reach was measured using the electronic device. Subjects were asked to assume a position of normal, relaxed stance near the center of the force platform. Neither shoes nor socks were worn and the hands were held by the side. Subjects were asked to stand so that their shoulders were perpendicular to the reach measurement device. In order to maintain identical foot placement during all testing conditions, the foot position was traced on a sheet of paper attached to the surface of the platform. Stance width was obtained from the foot tracing by measuring the distance between the medial borders of the heels.

The electronic functional reach measurement device was elevated to the height of the acromion. Subjects then extended the right arm horizontally (approximately 90°) and placed a closed fist against the sliding handle (position 1; see Figure 2). Individuals were asked to slide the handle bar as far forward as they comfortably could without taking a step or losing their balance (position 2, see Figure 3). No attempt was made to control the subject’s method of reach. Each subject was given two practice trials and three test trials. Functional reach was defined as the mean difference between positions 1 and 2, over three trials.

At Station 3, functional reach was measured using the simple clinical apparatus consisting of a leveled “yardstick” secured to the wall at right acromion height. The platform foot tracing was placed on the floor and subjects were asked to assume the identical foot position as in Station 2. Individuals were asked to make a fist and extend their arm forward as in the previous test (position 1, Figure 4), and the placement of the end of the third metacarpal along the yardstick was recorded. Subjects were then asked to reach as far forward as they could without losing their balance or taking a step (position 2), and the placement of the end of the third metacarpal was again recorded. The upper extremity
was not allowed to contact the wall during this maneuver. If subjects touched the wall or took a step during testing, the trials were repeated. No attempt was made to control the subjects’ methods of reach. Functional reach was defined as the mean difference between positions 1 and 2 over three trials. During both the electronic and "yardstick" functional reach tasks, subjects were guarded by a research assistant in case of loss of balance. In addition, at station 2, all subjects wore a safety harness.

To test reliability of the clinical functional reach measurement at Station 3, two individuals, who were blinded to each other’s results, recorded reach on 17 of the 128 subjects. To assess test-retest reliability of all measures, 14 subjects returned for testing within one week of their original testing date.

Data analysis. — Center of pressure excursion was defined as the two-dimensional vector solution of the difference between the start and maximum reach position of the center of pressure by the formula: \[ \text{COPE} = \sqrt{(X_f - X_i)^2 + (Y_f - Y_i)^2}. \]

Simple descriptive statistics employed means and standard deviations. Reliability (both interobserver and test-retest) was evaluated using the intraclass correlation coefficient [1,3] (16). Precision was estimated using the coefficient of varia-
FUNCTIONAL REACH

Analysis of the test-retest reliability of the three primary measures of postural control (COPE, electronic functional reach, and "yardstick" reach) suggests that functional reach is highly reproducible. The intraclass correlation coefficient (ICC 1, 3) for center of pressure excursion was .52, electronic functional reach .81, and "yardstick" reach .92. The coefficient of variation was 7.5% for COPE, 4.4% for electronic functional reach, and 2.5% for "yardstick" functional reach. The intraclass correlation coefficient (ICC 1, 3) for interobserver "yardstick" reach measurements was .98.

Age influenced all three measures. As age increased all measures decreased (Table 2). The range for electronic functional reach was 6.5 ins. to 20.8 ins. and for yardstick reach the range was 1.6 ins. to 19.3 ins. Controlling for height, the partial correlation coefficient for age with COPE was -.57, age with electronic functional reach -.54, and age with "yardstick" functional reach -.45.

Anthropometric measures (height, arm length, foot length, trunk length) were all highly associated (r > .80). No single anthropometric measure added significantly to estimates of reach after controlling for age and height by variable withdrawal methods of regression. Table 3 represents the effects of selected anthropometric measures (right foot length, stance width, and height), as well as age and sex on reach. The coefficient describes the effect that one unit of change has on reach; for example, if age increases 10 years, electronic functional reach decreases .7 ins.

**DISCUSSION**

The high prevalence of falls and dysmobility in older individuals requires that geriatric assessment include a reliable, easily administered measure of balance. Several measures of dynamic postural control have recently been developed in order to understand this complex problem (6,10,12,19). We offer functional reach as a new dynamic

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Table 1. Descriptive Characteristics of Subjects by Age Category

<table>
<thead>
<tr>
<th></th>
<th>Age 20-40</th>
<th>Age 41-69</th>
<th>Age 70-87</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males</td>
<td>16</td>
<td>22</td>
<td>20</td>
</tr>
<tr>
<td>Females</td>
<td>28</td>
<td>28</td>
<td>14</td>
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<tr>
<td>Height (inches)</td>
<td>67.4±3.7</td>
<td>66.6±3.7</td>
<td>65.8±3.5</td>
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<tr>
<td>Weight (lbs)</td>
<td>154.8±35.4</td>
<td>160.7±29.5</td>
<td>156.9±33.3</td>
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<tr>
<td>Arm length (inches)</td>
<td>24.6±1.4</td>
<td>24.5±1.9</td>
<td>24.5±2.3</td>
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<tr>
<td>Right foot (inches)</td>
<td>9.4±.7</td>
<td>9.6±.7</td>
<td>9.7±.9</td>
</tr>
<tr>
<td>Stance width (inches)</td>
<td>5.5±1.5</td>
<td>5.1±1.2</td>
<td>4.8±1.6</td>
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</tbody>
</table>

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Table 2. The Effects of Age on Reach Measurements and Center of Pressure Excursion (COPE)

<table>
<thead>
<tr>
<th></th>
<th>Age 20-40 (n = 16)</th>
<th>Age 41-69 (n = 22)</th>
<th>Age 70-87 (n = 14)</th>
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<tbody>
<tr>
<td></td>
<td>Min  Max  Mean  SD</td>
<td>Min  Max  Mean  SD</td>
<td>Min  Max  Mean  SD</td>
</tr>
<tr>
<td>Yardstick functional reach</td>
<td>10.83  18.83  16.73  1.94</td>
<td>10.33  19.17  14.64  2.18</td>
<td></td>
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<tr>
<td>COPE</td>
<td>4.12  6.65  5.52  0.82</td>
<td>2.86  7.05  4.79  0.96</td>
<td></td>
</tr>
</tbody>
</table>

Note. All measurements given in inches.

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Table 3. Factors That Affect Reach

<table>
<thead>
<tr>
<th>Dependent Variable: Electronic Functional Reach</th>
<th>df</th>
<th>Coefficient</th>
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<th>p</th>
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</thead>
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<tr>
<td>Right foot</td>
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<td>-.05</td>
<td>.03</td>
<td>.6866</td>
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<tr>
<td>Stance</td>
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<td>-.08</td>
<td>.49</td>
<td>.4866</td>
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<tr>
<td>Height</td>
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<td>.14</td>
<td>6.08</td>
<td>.0151</td>
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<tr>
<td>Age</td>
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<tr>
<td>Sex</td>
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<td>-.64</td>
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<table>
<thead>
<tr>
<th>Dependent Variable: Yardstick Reach</th>
<th>df</th>
<th>Coefficient</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right foot</td>
<td>1</td>
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<tr>
<td>Stance</td>
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<tr>
<td>Sex</td>
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<td>3.3</td>
<td>.0693</td>
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</tbody>
</table>

Analysis of the reach capabilities by gender reveals that females have a shorter reach than males (Table 2). However, regression analysis demonstrates that differences in height rather than gender contribute to the shorter reach observed in women. In fact, when controlling for other factors (Table 3), males appear to have a smaller but not significantly different reach than females. Perhaps this suggests a gender effect, but the gender effect appears marginal compared to age and height.

Standing functional reach is a reliable measure of balance that may be useful in the clinical assessment of instability. Its use, however, is not universally applicable. Functional reach may be difficult to perform in patients with severe dementia, extreme spinal deformities, severely restricted upper extremity function, and frail individuals who are unable to stand unsupported.

Our measure of functional reach assesses only anterior and posterior dynamic stability. It is possible to map out full three-dimensional estimates of the range of standing reach, but these data are very complex. For the purpose of developing a clinical tool, we believe that repeated measures of a similar paradigm across a wide range of ages are preferable to testing a range of directions and angles.

Having established functional reach measurement characteristics, we are now in the process of examining functional reach as a measure of frailty in the elderly. We hope to determine its predictive value in assessing falls risk and identify the etiologic components that contribute to impaired reach. Other potential future applications include its use as a measure of change in balance (both spontaneous and in response to intervention) and in environmental design to accommodate the restricted reach of frail elderly.

Acknowledgments

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References


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