Test Methods to Detect Hip and Knee Muscle Weakness and Gait Disturbance in Patients With Hip Osteoarthritis

Anton Rasch, MD, Nils Dalén, MD, PhD, Hans E. Berg, MD, PhD


Objective: To evaluate test methods for hip and knee muscle weakness and gait disturbance.

Design: Test-retest.

Setting: Orthopedic university clinic.

Participants: Ten young (age, 36±6y) and 13 elderly (age, 69±8y) healthy volunteers and 11 patients (age, 69±8y) with unilateral hip osteoarthritis (OA) were tested for muscular strength. Twenty-five volunteers (age, 42±14y) underwent gait analysis.

Interventions: A dynamometer assessing maximal voluntary isometric force of hip and knee muscles and an optosensor walkway detecting limp were developed. Tests evaluated reproducibility and tolerance in patients with OA and elderly subjects.

Main Outcome Measures: Relative coefficient of variation (CV%) and force (in newtons).

Results: CV% for unilateral strength measurements ranged from 7% to 12% for specific muscle groups. CV% for gait parameters ranged from 4% to 8%, except for the double-support phase. Tests were well tolerated, and no patient had to discontinue because of fatigue. Differences related to sex, age, and disease were detected.

Conclusions: Our dynamometer system provides reliable measurements of hip and knee muscle strength in young and old people, and variation is comparable to previous data. Our photocell technique for gait analysis is reliable in people with normal gait. Both methods are attractive because they are affordable, nonstationary, and easy to use.

Key Words: Gait; Osteoarthritis, hip; Rehabilitation.

© 2005 by the American Congress of Rehabilitation Medicine and the American Academy of Physical Medicine and Rehabilitation

Although global scores and self-reported questionnaires that evaluate patient satisfaction after orthopedic or other treatment have received increased attention in recent years,1 the need remains for specific and quantitative tests of joint and muscle function. Strength and endurance capacity of muscles acting about the knee joint are well documented in healthy elderly2 or inactivate people,3 as well as in many patient categories, including osteoarthritis (OA).4 Data on hip muscle function, on the other hand, are limited, both for healthy people5,6 and for patients.7-9 To maintain the locomotive capacity of the lower limbs, however, the ability to perform powerful leg extensions—which involve both hip and knee muscles—is vital.2,10 The primary aim of this study, therefore, was to develop and evaluate the reliability of a new test apparatus and protocol for the measurement of both hip and knee muscle strength. In addition, because balance and gait are frequently impaired in patients and the elderly population, we suggest that a qualified test battery of lower-limb function should also include analysis of gait and postural control. We modified and used a photocell apparatus for gait analysis through contact times. Some information on the reproducibility of our equipment for gait analysis was also included in this study. A compound test of strength and gait is likely to have wide application for sedentary, elderly people and for many patients (ie, those with OA, stroke, cardiac disease).

To be clinically applicable, a test procedure for lower-limb function must meet certain requirements. First, the test should accurately assess relevant and important parameters. The measurement of voluntary force capacity of the major muscle groups of the hip and knee joints is suggested as a meaningful measure of the locomotive capacity in many patient groups. The test method must therefore accurately detect differences between groups of patients and healthy controls, changes over treatment time, and side differences between the disabled limb and healthy limb. Second, a test must be accepted by elderly, frequently frail people, both in terms of the demanded body positions and the exhaustive effort required throughout a full test session. This requirement becomes obvious when a patient has severe arthritic or posttraumatic pain. Third, any test must be time-effective in terms of both the duration of a single test session and the number of repeated sessions required to obtain accurate data. Our goal was to develop a test battery that could objectively evaluate physical performance capacity, although we anticipated that the ability to map out specific muscle groups would concur with the ability to evaluate overall capacity. In addition, we wanted to use equipment that was nonstationary and affordable.

Patients suffering from hip OA are typically elderly and, in addition, inactive because of the painful joint. A substantial muscular weakness has been observed on the affected side: 30% to 50% strength loss compared with the healthy side,7,8 a deficit that could be partly recovered after hip replacement surgery.8,11,12 Most earlier studies have evaluated hip abduction strength only, and we found no study that simultaneously measured hip and knee muscle strength in patients with OA. Our objective when creating this test method was to measure a complete set of muscle actions about both the hip and knee joints in a single test session, using 1 dynamometer system only. To encompass all these measurements in elderly subjects, we chose to perform isometric measurements, because the performance of repeated dynamic muscle actions was considered too physically demanding. A dynamometer was developed and designed for these tests, and this study evaluated the
reproducibility of the method. Additionally, a photocell system was adopted for temporal gait analysis and was evaluated in a group of healthy subjects and compared with a small group of patients with unilateral hip OA.

METHODS

General Strength Test Protocol
Using a dynamometer especially developed for measurements of muscles acting about the hip and the knee joints (see details in the next section), we measured maximal isometric voluntary strength. Thirteen healthy elderly (8 men, 5 women; age, 69±8y; height, 174±8cm; weight, 78±13kg) and 10 young (5 men, 5 women; age, 36±6y; height, 179±10cm; weight, 73±14kg) subjects were used to test the reproducibility of the muscle strength measurements. They were recruited from hospital staff (n=13) or from local recreational walking groups (n=10). Accepted subjects had no pain or limitation in hip movement and no previous surgery of the lower extremity. The subjects were tested on 2 separate days with an interval of at least 1 week, where test conditions and test leaders were maintained. Both right and left limbs were measured. A group of 11 patients (6 men, 5 women; age, 69±8y; height, 173±7cm; weight, 76±15kg) with unilateral hip OA was tested to evaluate the test procedure for this group. They were recruited from our waiting list for hip arthroplasty and were tested before planned surgery. The experimental protocol was approved by the Ethics Committee at the Karolinska Institute.

Hip and Knee Strength Dynamometer
A test device that allows measurement of hip or knee muscular strength was developed. In the seated position, unilateral isometric knee extension or flexion force is measured. Hip extension, flexion, abduction, or adduction force is measured with each subject in the standing semiprone position (fig 1). Traditional strain gauges4 are incorporated in padded sling latches that fixed around the distal ankle or thigh. With 4 different strain-gauge positions and the 2 alternative body positions, a total of 12 different isometric strength measurements can be obtained (see further descriptions in the next 2 sections). The dynamometer was calibrated before or after measurements using standardized weights. The dynamometer was connected to a data processing system (MuscleLab), where the force curve could be monitored during tests and accepted measurements stored for later processing.

Knee Strength Assessment
When measuring knee extension or flexion, a subject was seated with 90° of flexion of the hip and knee. The pelvis was stabilized with a strap and the arms crossed over the chest to minimize interference of accessory muscle groups. A second strap was used to stabilize the thighs to the flat seat. The strain gauge was attached to the sling around the ankle. Patients were first tested for right knee extension, then flexion. The procedure was then repeated on the left limb. Subjects began each test with a total of 5 submaximal contractions at 70% (×3), 80%, and 90% of the perceived voluntary maximum, respectively, to warm up and to become familiar with the testing device and procedure. Thereafter, 2 maximal isometric contractions were performed, approximately 3 to 5 seconds each, separated by at least 20-second rest. Similar verbal encouragement was given during all measurements. If force measurements differed more than 5%, then a third measurement was performed. The force signal was digitized at 200Hz into the MuscleLab system. From each maximum trial contraction, the peak force value (in newtons) of a 1.0-second window average was selected. Mean values of the 2 best trials were used for comparisons between test sessions.3

Hip Strength Assessment
When hip muscles were measured, each standing subject leaned forward 45° to rest the trunk and pelvis against an abdominal platform support (see fig 1). The pelvis was stabilized with a strap around the upper gluteus, and the subject kept a firm grip on 2 handles. While 1 limb supported the body weight, the other was attached to the dynamometer with the sling latch readjusted around the thigh just above the patella. The tested limb was held with semiflexed knee, and the support leg was straight. Patients were tested in the order of right hip extension, flexion, abduction, and adduction. The procedure was then repeated on the left limb. Warm-up and test procedures were identical to knee strength assessment.

Arch Phys Med Rehabil Vol 86, December 2005
Gait Analysis

With an optosensor walkway developed especially to detect limp (see details in the next paragraph), 25 healthy volunteers (10 men, 15 women; age, 42±14y; height, 177±9cm; weight, 73±14kg) underwent 2 sessions of gait evaluation with approximately 1 week between sessions. People with neurologic diseases or lower-extremity comorbidities—such as misalignment or OA at other joints—that could have affected gait were not included.

A flat walkway with 2 separate lanes, instrumented with photocells to assess right and left foot contact times, was used. This system was originally designed for measuring contact and flight times in runners using 1 lane only and did not discriminate data from right or left feet. We have developed this system further, and our custom version allows the measurement of touchdown and lift-off of both feet separately when walking on the parallel right and left foot lanes without crossing the midline. Briefly, 1 bar containing 4 light transmitters is placed at the end of each lane. They send infrared light beams that are individually received by 4 matching photocells mounted in a bar at the start of the walkway. Transmitters and photocells are placed approximately 6mm above the flat walkway and 50mm apart, allowing the detection of touchdown and toe-off of the right and left feet across two 150-mm wide lanes. Ground contact times below 0.2 seconds are filtered and thus not registered, to block false data input because of shuffling. The above 4 detected signals are streamed to an electronic box and later ported and stored on a laptop computer.

Each test session comprised 3 trial runs without the use of shoes. Starting with the right foot, subjects maintained a relaxed walking speed while not crossing the midline, and at least 10 steps (5 gait cycles) were measured per run. A typical gait cycle consists of 4 phases. During the first double-stance phase, both feet are in contact with the floor. During the second phase, the right foot is lifted (right swing phase), whereby the left foot is in the single-support phase. The third phase (another double stance) starts as the right foot touches down. Finally, in the fourth phase, the right single-stance phase (ie, the left swing phase) starts as the left foot is lifted and ends at touchdown. Step frequency (in steps/s), single- and double-stance phase durations (in seconds or as a percentage of the gait cycle), standard deviations, and the relative coefficient of variation (CV%) were calculated. Means of each variable were derived from 5 gait cycles, from which the first cycle of each run was excluded because many subjects swayed in their first steps.

Statistics

Repeated-measures analysis of variance was performed on force data from healthy test subjects, and single contrast means comparisons were made for the selected factors. Absolute force divided by body weight (in N/kg) was used to correct for differences related to age or sex. Comparisons between patients with OA (affected limb) and elderly volunteers (right limb) were performed using the Student t test. Average knee force, hip force, or total limb force were formed by calculating the arithmetic means of individual measurements. The variance of force data was calculated for each subject across the 2 consecutive trials or between means of trials across the 2 test sessions, respectively. The square root of that group average, in percentage of the overall mean, expressed the CV%. Statistical significance was set at P less than .05.

RESULTS

Isometric Muscle Strength

Force values for the young and elderly volunteers and the patients with OA are presented in figure 2. Based on means of all measurements, young volunteers were stronger by 22% when compared with the elderly healthy volunteers, and patients with OA were weaker by 24% in their affected limb when compared with healthy elderly subjects (P<.05). Healthy men displayed an overall 44% larger force than healthy women. There was no difference (P=.77) between left and right limb for either overall strength or individual muscle groups in healthy subjects.

No differences were found (P=.38) in isometric force between the first and second test sessions in either overall muscle strength or unilateral measurement of individual muscle groups (fig 3). We did not see any differences in test reproducibility (CV%) between the 2 age groups of healthy subjects. These groups were therefore merged for comparisons between trials and sessions. The CV% varied between 7% and 12% for a specific muscle group when tested unilaterally (tables 1, 2), where knee extension seemed to show the lowest values. Variation was somewhat lower when force values averaged for the 2 limbs were used for comparisons (6%–11%). Variation of unilateral measurements was further reduced when averaged for the knee (4%–5%) or hip (5%–6%) or the total 6 measurements of the limb (3%–4%; see table 2). Variations between individual trial repetitions (3%–6%) on 1 test session were generally lower than between sessions (7%–12%).

Gait Analysis

Gait parameters for the group of healthy volunteers are presented in table 3. We observed no tendency for differences
between the first and second test sessions in any parameter. Except for the double-support phases, the CV% ranged from 5% to 8% (see table 3). Nominal values, including the single-support phase, are similar to earlier reported data.

**DISCUSSION**

We conclude that our dynamometer system provides reliable measurements of hip and knee muscle strength in both limbs in young and elderly people. This is supported by the fact that we found marked differences of similar magnitudes to those previously reported between men and women and between elderly and young subjects. The relative variation for unilateral measurements (7%–12%; see table 1) was comparable to that in previous studies that used commercial dynamometers. We also found that a single test session is sufficient to assess maximal voluntary isometric strength, because a second test did not differ in absolute force values or variation. The substantial muscle weakness in limbs of OA hip patients reported here and by others (20%–50%), in relation to the presented methodologic error, indicates that our dynamometer would be capable of detecting such differences in patient groups under treatment. We also conclude that our redesigned photocell technique for gait analysis is able to collect reliable data in middle-aged adults with normal gait. This suggests that the system might be used to identify gait disturbance (limp).

A strenuous leg extension, whether performed by an athlete in a jump or by an elderly person when rising from a chair, demands effective activation of hip extensor muscles. Hip joint disease adds painful limitation to such movement. A basic test of muscular strength in hip patients includes force measurements of hip extension, flexion, abduction, and adduction. But there are several reasons to also incorporate knee muscle strength. For example, the primary knee flexor muscles (hamstrings) are of major importance also for performing effective hip extension. Moreover, the adaptation to hip joint disease, including the physical inactivity due to pain on weight-bearing, probably affects multiple lower-limb muscles. Also, for comparisons with the vast scientific database on the adaptation of knee joint muscles, including knee OA, the ability to map out muscular changes along the limb would clearly add scientific value.

Difficulties when measuring muscular strength about the hip constitute limitations to clinical research and to rehabilitation after hip arthroplasty, and it is essential to develop methods that are easy to apply and could be accepted by those typically sedentary and immobile patients. Most patient studies report only isometric hip abduction force, which is readily obtained in the supine position using a handheld strain gauge. Measurements of multiple muscle groups have typically been performed in healthy people, and only a few studies exist on patients with OA. These studies used commercial isokinetic dynamometers with specific adaptors for hip torque measurement, where a patient is placed in the supine position—among other positions—and the resulting test protocol is extensive. It is a true challenge to reduce the number of physically demanding, painful, and time-consuming repositionings of frail patients yet still allow multiple measurements of muscular strength in both limbs. We used 2 different body positions only

### Table 1: Mean Values for Right Limb in Maximal Voluntary Isometric Muscle Strength in Healthy Volunteers (n=23) and CV% Between Repetitions and Sessions (Test-Retest)

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Test 1 (N)</th>
<th>Test 2 (N)</th>
<th>CV% (between reps) Unilat</th>
<th>CV% (test-retest) Unilat</th>
<th>CV% (test-retest) Bilat</th>
</tr>
</thead>
<tbody>
<tr>
<td>KE</td>
<td>614±229</td>
<td>614±205</td>
<td>3.2</td>
<td>7.0</td>
<td>5.6</td>
</tr>
<tr>
<td>KE</td>
<td>256±97</td>
<td>250±92</td>
<td>4.3</td>
<td>11.9</td>
<td>10.3</td>
</tr>
<tr>
<td>HE</td>
<td>536±180</td>
<td>557±224</td>
<td>5.9</td>
<td>9.6</td>
<td>7.1</td>
</tr>
<tr>
<td>HF</td>
<td>348±130</td>
<td>359±131</td>
<td>2.9</td>
<td>11.4</td>
<td>8.5</td>
</tr>
<tr>
<td>Abd</td>
<td>253±75</td>
<td>252±103</td>
<td>4.0</td>
<td>12.4</td>
<td>10.5</td>
</tr>
<tr>
<td>Add</td>
<td>341±107</td>
<td>357±118</td>
<td>4.1</td>
<td>7.6</td>
<td>6.5</td>
</tr>
<tr>
<td>Ktot</td>
<td>435±151</td>
<td>432±144</td>
<td>2.4</td>
<td>5.1</td>
<td>4.1</td>
</tr>
<tr>
<td>Htot</td>
<td>370±108</td>
<td>381±126</td>
<td>2.6</td>
<td>5.5</td>
<td>4.8</td>
</tr>
<tr>
<td>Tot</td>
<td>391±117</td>
<td>398±126</td>
<td>1.9</td>
<td>4.0</td>
<td>3.4</td>
</tr>
</tbody>
</table>

**NOTE.** Values are mean ± standard deviation (SD) or as indicated. Abbreviations: Abd, abduction; Add, adduction; Bilat, for the 2 measured limbs; HE, hip extension; HF, hip flexion; Htot, average hip extension, flexion, abduction, and adduction; KE, knee extension; KF, knee flexion; Ktot, average knee extension and flexion; Tot, average of all 6 measurements; Unilat, for 1 limb.

### Table 2: Mean Values and Differences in Maximal Voluntary Isometric Muscle Strength Divided by Body Weight for Right Limb in Elderly Healthy Controls (n=13) and Affected Limb in Patients With OA (n=11)

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Aged (N/kg)</th>
<th>OA (N/kg)</th>
<th>Diff (%)</th>
<th>P</th>
<th>CV%</th>
<th>Diff/CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>KE</td>
<td>6.86±0.48</td>
<td>4.56±0.52</td>
<td>−34</td>
<td>.004</td>
<td>7.0</td>
<td>4.9</td>
</tr>
<tr>
<td>KE</td>
<td>2.97±0.26</td>
<td>2.41±0.29</td>
<td>−19</td>
<td>NS</td>
<td>11.9</td>
<td>1.6</td>
</tr>
<tr>
<td>HE</td>
<td>6.18±0.47</td>
<td>4.68±0.51</td>
<td>−24</td>
<td>.040</td>
<td>9.6</td>
<td>2.5</td>
</tr>
<tr>
<td>HF</td>
<td>4.60±0.31</td>
<td>3.38±0.34</td>
<td>−27</td>
<td>.014</td>
<td>11.4</td>
<td>2.4</td>
</tr>
<tr>
<td>Abd</td>
<td>3.29±0.29</td>
<td>2.25±0.32</td>
<td>−32</td>
<td>.027</td>
<td>12.4</td>
<td>2.6</td>
</tr>
<tr>
<td>Add</td>
<td>4.17±0.30</td>
<td>4.25±0.32</td>
<td>2</td>
<td>NS</td>
<td>7.6</td>
<td>0.3</td>
</tr>
<tr>
<td>Ktot</td>
<td>4.91±0.31</td>
<td>3.48±0.34</td>
<td>−29</td>
<td>.005</td>
<td>5.1</td>
<td>5.7</td>
</tr>
<tr>
<td>Htot</td>
<td>4.56±0.27</td>
<td>3.64±0.29</td>
<td>−20</td>
<td>.030</td>
<td>5.5</td>
<td>3.6</td>
</tr>
<tr>
<td>Tot</td>
<td>4.68±0.27</td>
<td>3.58±0.29</td>
<td>−24</td>
<td>.013</td>
<td>4.0</td>
<td>6.0</td>
</tr>
</tbody>
</table>

**NOTE.** Values are mean ± SD or as indicated. Abbreviations: NS, not significant.
and tried to optimize comfort during test and rest periods. The seated position was used for knee extension and flexion, whereas for hip exercises subjects were in the upright position, using an abdominal trunk support and a foot support for the contralateral limb (see fig 1). Because limb segments below the measured joint are maintained in the vertical position, there is no need for gravity correction. Exhaustion when performing repeated maximal voluntary contraction is another major concern for the design of a test. Although the isometric test situation does not resemble the typical dynamic joint movement during locomotion, previous studies have shown that isometric measurements are comparable to dynamic force measurements when describing deconditioning due to inactivity or disease.3,7 The lower energy demand and joint load of isometric muscle contractions allows the performance of repeated trials with limited rest even by an untrained person. With our strength test protocol measuring both knee and hip muscle force in both limbs, a full test session including 12 exercises was executed within 45 minutes, and no one had to break because of fatigue. Clearly, the duration and exhaustion of isokinetic or other dynamic force measurements using our extensive and diverse protocol would exclude repeated testing of frail patients, such as those with joint disease, muscular fatigue, or cardiac limitation.

Earlier studies have reported similar results, both in terms of reproducibility and muscle weakness in patients with OA. Arokoski et al7 found relatively young hip patients to be 16% reproducibility and muscle weakness in patients with OA. Fatigue, or cardiac limitation.

According to the present protocol suggested that there is no consistent improvement between sessions. We therefore conclude that only 1 test session is required to collect correct values when monitoring muscle function in these groups. It seems reasonable to hypothesize, however, that repeat baseline sessions could reduce variation even further when multiple comparisons are planned to evaluate changes over time. Using the same test procedure and vocal reinforcement during contractions is probably important and should be emphasized.

Gait pattern is typically measured using walkways instrumented with forceplates15 or 3-dimensional kinematics16 to assess the temporal and spatial aspects of gait. Costs for this sophisticated and stationary equipment and for the necessary data processing and interpretation limit such studies to centers specialized in biomechanics. More affordable and simple equipment has been suggested using a conductive contact mat and electronic sensors on the shoes used.19

Our values for the control group (see table 2) confirm earlier studies in great detail, where healthy subjects typically spend about 40% of the gait cycle supported by each foot—the right or left single-support phases—and the remaining 20% divided on the 2 double-support phases (9%–13% for each double-support phase). Moreover, all gait parameters were equal for the right and left sides, and no learning effect between the separate test sessions was observed. The CV% between separate tests for the single-support phase was 4% to 7% when expressed in relative length (in percent) of the gait cycle and thus was somewhat decreased compared with absolute values (in seconds) (see table 2). This indicates that previously shown differences in response to disease (≈10%), including hip OA, would be detected. Patients with hip OA typically have a reduced single-stance duration on the affected side,17,20,21 which has been ascribed to pain and reduced ability to sustain load of the affected joint.22 The double-stance phases presented both methodologic and theoretical problems. We found it difficult to accurately assess these phases, as indicated by a large and vocal reinforcement during contractions is probably important and should be emphasized.

Gait pattern is typically measured using walkways instrumented with forceplates15 or 3-dimensional kinematics16 to assess the temporal and spatial aspects of gait. Costs for this sophisticated and stationary equipment and for the necessary data processing and interpretation limit such studies to centers specialized in biomechanics. More affordable and simple equipment has been suggested using a conductive contact mat and electronic sensors on the shoes used.19

Our values for the control group (see table 2) confirm earlier studies in great detail, where healthy subjects typically spend about 40% of the gait cycle supported by each foot—the right or left single-support phases—and the remaining 20% divided on the 2 double-support phases (9%–13% for each double-support phase). Moreover, all gait parameters were equal for the right and left sides, and no learning effect between the separate test sessions was observed. The CV% between separate tests for the single-support phase was 4% to 7% when expressed in relative length (in percent) of the gait cycle and thus was somewhat decreased compared with absolute values (in seconds) (see table 2). This indicates that previously shown differences in response to disease (≈10%), including hip OA, would be detected. Patients with hip OA typically have a reduced single-stance duration on the affected side,17,20,21 which has been ascribed to pain and reduced ability to sustain load of the affected joint.22 The double-stance phases presented both methodologic and theoretical problems. We found it difficult to accurately assess these phases, as indicated by a large
variation (see table 2), especially at higher walking speeds. Previous studies22,23 confirm that these phases are indeed short and might, at higher speed or when using short steps, be less than 0.1 second. It seems doubtful if assessments of the double-support phase add further information to gait analysis. In our opinion, the assessment of the single-support phases, whether in absolute time, percentage, or ratios between the left and right sides, seems the most intuitive and accurate measure of gait disturbance.

Gait function is an objective measurement of the functional status about the hip and reflects the probable activity level. Tests are performed very quickly (<10min) and are neither painful nor demanding for most patients. The equipment could therefore be used in clinical practice to evaluate gait disturbances in many different patient categories. A methodologic problem is that any photocell technique demands an extremely flat and nonflexing walkway. We used wooden boards adjusted to the somewhat uneven floor with wedges with good result. Alternative approaches include molded floors, although it would cause extra cost and make the equipment stationary.

CONCLUSIONS

Our dynamometer provides reliable measurements of hip and knee muscle strength in young and elderly people, and a single test session is sufficient to assess maximal voluntary strength. The substantial muscle weakness reported for patients with hip OA would be detected using our developed dynamometer system. Our redesigned photocell technique for gait analysis is able to collect reliable data. Our methods are attractive because they are reliable and yet affordable, nonstationary, and easy to use. The acceptance of multiple strength measurements along the lower limb suggests its applicability in many patient groups of elderly and frail patients.

Acknowledgments: We greatly appreciate the technical assistance provided by Helena Rohman, MD, and Suzanne Ahlstrom, PT, at the Department of Physical Therapy, Danderyd Hospital.

References

Suppliers
a. Burster Gmbh, Talstr 1-5, Gernsbach, D-76593, Germany.
b. Ergotest Technology AS, PO Box 65, N3993 Langesund, Norway.
c. IVAR Jump & Speed Analyzer; Spin Test Ou, Academic Tee 21G-307, 12618, Tallinn, Estonia.