CHAPTER 2

Relevance and Limitations of Manual Muscle Testing

Relevance and Limitations

Introduction

Manual muscle testing (MMT) is well recognized as the most common strength-testing technique in physical therapy and other health professions, having first appeared during the poliomyelitis epidemic in New England before World War I. A brief history of MMT is described elsewhere in this text. MMT serves unique purposes that can vary according to the setting in which it is practiced. Although MMT is an essential and foundational skill in a therapist's examination techniques, it also has its limitations. Appreciating these limitations and learning how to compensate for them helps to make MMT as relevant nowadays as it was when first conceptualized during the polio era.

The Examiner and the Value of the Muscle Test

The knowledge and skill of the examiner determine the accuracy and defensibility of a manual muscle test. Specific aspects of these qualities include the following:

- Knowledge of the location and anatomic features of the muscles in a test. In addition to knowing the muscle attachments, the examiner should be able to visualize the location of the tendon and its muscle in relationship to other tendons and muscles and other structures in the same area (e.g., the tendon of the extensor carpi radialis longus lies on the radial side of the tendon of the extensor carpi radialis brevis at the wrist).
- Knowledge of the direction of muscle fibers and their alignment in each muscle.
- Knowledge of the function of the participating muscles (e.g., synergist, prime mover, agonist, and antagonist).
- Consistent use of a standardized method for each test procedure.
- Consistent use of proper positioning and stabilization techniques for each test procedure. Stabilization of the proximal segment of the joint being tested is achieved in several ways. These include patient position (via body weight), the use of a firm surface for testing, patient muscle activation, manual fixation by the examiner, or external fixation such as with a belt.
- Ability to identify patterns of substitution in a given test and how they can be detected based on a knowledge of which other muscles can be substituted for the one(s) being tested.
- Ability to detect contractile activity during both contraction and relaxation, especially in the minimally active muscle.
- Sensitivity to differences in contour and bulk of the muscles being tested in contrast to the contralateral side or to normal expectations based on such things as body size, occupation, or leisure work.

• Awareness of any deviation from normal values for range of motion and the presence of any joint laxity or deformity.
• Understanding that the muscle belly must not be grasped at any time during a manual muscle test except specifically to assess muscle mass.
• Ability to identify muscles with the same innervation that will ensure a comprehensive muscle evaluation and accurate interpretation of test results (because weakness of one muscle in a myotome should require examination of all muscles within that myotome).
• Relating the diagnosis to the sequence and extent of the test (e.g., the patient with C7 complete tetraplegia will require definitive muscle testing of the upper extremity but only confirmatory tests in the trunk and lower extremities).
• Ability to modify test procedures when necessary while understanding the influence of the modification on the result and thus not compromising the accuracy of the test result.
• Knowledge of fatigue on the test results, especially muscles tested late in a long testing session, and a sensitivity to fatigue in certain diagnostic conditions such as myasthenia gravis or multiple sclerosis.
• Understanding of the effect of sensory and perceptual loss on movement. The examiner also may inadvertently *influence* the test results and should be especially alert when testing in the following situations:
    - The patient with open wounds or other conditions requiring gloves, which may blunt palpation skills.
    - The patient who must be evaluated under difficult conditions such as in an intensive care unit with multiple tubes and monitors or immediately after surgery, the patient in traction, the patient for whom turning is contraindicated, the patient on a ventilator, and the patient in shackles or restraints.
    - The patient with limited understanding of the test, such as in the presence of delirium or dementia.
    - The patient who cannot assume test positions, such as the prone position.
• The previous situations require careful documentation of the assessment of strength and any limitations encountered.
• The therapist must avoid the temptation to use shortcuts or "tricks of the trade" before mastering the basic procedures, lest

such shortcuts become an inexact personal standard. One such pitfall for the novice tester is to inaccurately assign a lower muscle grade when the patient could not successfully perform a test at a higher grade without actually testing in the position required for the lower grade.

For example, when testing trunk flexion, a patient just partially clears the scapula from the surface, with the hands resting lightly on the side of the head (the position for the Grade 5 test), thus not earning a Grade 5. The temptation may exist to assign a grade of 4 to this test because the patient could not achieve a Grade 5, but this may "overrate" the true strength of trunk flexion unless the patient is actually tested with the arms across the chest to confirm Grade 4.

The good clinician never ignores a patient's comments and must be a good listener, not just to the patient's questions but also to the meaning of the words the patient uses. This quality is an essential element of good communication and is the primary means of encouraging understanding and respect between therapist and patient. The patient is the best guide to a successful muscle test.

Early Kendall Examination

Accuracy in giving examinations depends primarily on the examiner's knowledge of the isolated and combined actions of muscles in individuals with normal muscles, as well as in those with weak or paralyzed muscles.

The fact that muscles act in combination permits substitution of a strong muscle for a weaker one. For accurate muscle examinations, no substitutions should be permitted; that is, the movement described as a test movement should be done without shifting the body or turning the part to allow other muscles to perform the movement for the weak or paralyzed group. The only way to recognize substitution is to know normal function and realize the ease with which a normal muscle performs the exact test movement.

Kendall HO, Kendall FP

From Care During the Recovery Period in Paralytic Poliomyelitis. Public Health Bulletin No. 242. Washington, DC: U.S. Government Printing Office; 1939: 26.

Influence of the Patient on the Test

The intrusion of a living, breathing, feeling person into the testing situation may distort scoring for the unwary examiner. The following circumstances should be recognized:

- There may be variation in the assessment of the true effort expended by a patient in a given test (reflecting the patient's desire to do well or to seem more impaired than is actually the case).
- The patient's willingness to endure discomfort or pain may vary (e.g., the stoic, the complainer, the high competitor).
- The patient's ability to understand the test requirements may be limited in some cases because of cognitive impairments, comprehension, and language barriers.
- The motor skills required for the test may be beyond those possessed by some patients, making it impossible for them to perform as requested.
- Lassitude and depression may cause the patient to be indifferent to the test and the examiner.

- Cultural, social, and gender issues may be associated with palpation and exposure of a body part for testing.
- Size and available force differences between big and small muscles can cause considerable differences in grading, although not an individual variation (e.g., the gluteus medius versus a finger extensor). There is a huge variability in maximum torque between such muscles, and the examiner must use care not to assign a grade that is inconsistent with muscle size and architecture.

Use of Manual Muscle Testing in Various Clinical Settings

MMT is used in many different types of health care settings. In this section, we will discuss some of the more common applications of MMT in various clinical and therapeutic settings, with emphasis on the specific challenges often seen in each. The reader should be aware that the examples provided here are not limited to these settings only.

Acute Care Facilities

Often patients seen in acute care facilities are either acutely ill or are seen postoperatively. In the acutely ill patient, MMT may be used to assess the patient's mobility status to inform a discharge plan. A manual strength exam performed as part of a general assessment may provide information concerning the amount of assistance the patient requires and whether the patient will need an assistive device. Assessing the patient's strength to help ensure safe transfers from bed to chair, to a standing position, or on and off the toilet is an essential part of the acute-care patient management process. A strength assessment may also inform the therapist of the patient's ability to follow directions and/or to verbalize concerns such as following a stroke or in the presence of delirium or other cognitive loss.[1,2]

Strength assessment may also indicate the presence of pain. Identifying painful muscles before asking a patient to do an activity, such as transfers, will save time in the long run (and potential embarrassment). Strength assessment can take the form of active movement followed by resistance, such as in a manual muscle test or in a 10-repetition maximum such as in a seated shoulder dip.

Strength assessment in the postoperative patient informs the therapist of the integrity of the patient's nervous system. The therapist may be the first person requiring the patient to move actively after surgery and thus may be the first one to observe the patient's ability to contract a muscle. Although this scenario is rare, clearly the consequences of assuming an attitude of "all is well" and finding out during a transfer that the patient cannot use part of an extremity would have avoidable consequences. Strength testing in this scenario might take the form of isometric contractions, especially if there are contraindications to joint movement, suspected postsurgical pain as in a newly repaired fractured hip, or in restricted range of motion such as in a total hip arthroplasty. If testing is done in a manner that differs from the published directions, documentation should describe how the test was performed. For example, if isometric testing was done at the hip because the patient was not permitted to move the hip through full range after a hip arthroplasty, the therapist should document the test accordingly: "Patient's strength at the hip appeared to be under volitional control, but pain and postsurgical precautions prevented thorough assessment."

Key movements that should be assessed for viability and for the strength necessary to perform transfers or gait include elbow extension, grip, shoulder depression, knee extension, hip abduction, ankle plantar, and dorsiflexion. Functional tests that might be useful in assessing the patient include gait speed, chair stand, timed transfer, or the timed up-and-go test (see Chapter 8).

Special considerations for the acute care setting may include the patient's rapid fluctuations in response to medications, illness, or pain. Reassessment may be necessary when any changes in strength are documented along with therapist's insights into why the changes are occurring. Clearly, strength gains are not possible in the short time a typical patient is in acute care but rather should be attributed to increased confidence in moving, less pain, better understanding of the

movement to be performed, motor learning, and so forth.

Acute Rehabilitation Facilities

Strength assessment in the acute rehabilitation setting may be performed as a baseline assessment to determine progress over time and to identify key impairments that affect the patient's mobility-related and other functional goals. Knowledge of community-based norms for mobility such as chair stands, distance walked, stair climbing speed, floor transfer ability, and gait speed will inform the therapist's clinical decision-making. (See Chapter 8 for a more complete description of these tests.) A standard manual muscle test and/or a 10-repetition maximum strength assessment are other methods used to assess relevant strength abilities.

As in the acute care setting, assessment of strength for mobility tasks is critical in the acute rehabilitation setting. Recognition of the importance of key muscle groups in specific mobility tasks, such as the plantar-flexors in gait speed, is key to informed clinical decision-making.

Special considerations for the acute rehabilitation setting often include rapid change over a short period. Positive changes may be attributed to increased comfort and less pain, less apprehension, neuroplasticity, and a change in medications. Negative changes may be attributed to, for example, a decline in medical status, pain, or depression. Muscle fatigue resulting from an extended inpatient stay, poor fitness, and excessive sedentary behavior or general body fatigue related to frailty or post–acute care implications may affect the perception of strength. The patient may not be able to assume a proper test position because of postsurgical restrictions or a lack of range of motion, requiring the therapist to do a strength-screen rather than a strength test. Although a screen may be appropriate, the screen cannot serve as an accurate baseline because of the lack of standardization. Functional testing may be more informative and accurate in these situations. The therapist should take special care to document any deviations from the standardized manual muscle test.

Long-Term Care Facilities

Strength testing and assessment approaches used in long-term care settings are similar to those used in acute rehabilitation. Strength assessment can serve as a baseline to identify key impairments that impact a patient's fall risk, mobility, and other functional goals as well as to determine the patient's progress over time. Strength screening can be part of a required annual assessment for long-term residents. Strength in the form of a chair stand test or grip strength is a key component of the diagnosis of frailty and therefore can inform prognosis.[3]

Frailty is a common geriatric syndrome, characterized by decreased reserve and increased vulnerability to adverse outcomes, including falls, hospitalization, institutionalization, and death.[4] The majority of residents in long-term care are considered frail.[5] A profound loss of strength is a significant cause of frailty and serves as a diagnostic criterion. Box 2.1 lists the diagnostic criteria for frailty. Based on these criteria, strength assessment and functional testing are essential in the examination and intervention of nursing home residents.[4]

Box 2.1

Diagnostic Criteria for Frailty

Diagnostic criteria for frailty include the presence of three or more of the following[4,10]:

1. Unintentional weight loss (>10 lb in past year)
2. General feeling of exhaustion on 3 or more days/week (self-report)
3. Weakness (grip strength in lowest 20%; <23 lb for women; <32 lb for men)
4. Slow walking speed (lowest 20%; ≤0.8 m/s)
5. Low levels of physical activity (in kcal/week lowest 20%; = 270 kcal/week for women; 383 kcal/week for men—equivalent to sitting quietly and/or lying down for the vast majority of the day)

The presence of one or two of these characteristics indicates prefrailty.

Although a natural consequence of aging is a gradual loss of strength and power, it should not be

assumed that older adults are functionally weaker than younger adults.[6-8] Because MMT has a ceiling effect, the therapist should not have lower expectations or overestimate strength in frail older adults. *Criteria for grading remain the same for people of all ages and conditions.* Because the ceiling effect of a manual muscle test can be so profound, especially in regard to function, functional testing is a better option for strength testing and assessment in the long-term care setting.[9] Community criterion reference values exist that guide the long-term care therapist in establishing appropriate goals and expectations (Box 2.2). Older adults might be better served with strength training options such as a leg press or latissimus pull down rather than the cuff weights or a recumbent bicycle or cross-trainer that are commonly used in long-term care settings. The reader is referred to Chapter 7 for alternative strength measurement options.

Box 2.2

Community Mobility Requirements

To be considered mobile, an individual should be able to:

- Walk 300 m minimum per errand[12]
- Perform multiple errands during one trip outside the home[13]
- Carry a package weighing 7.5 lb[13]
- Change direction while walking[14]
- Step onto and off of a curb without support
- Achieve a gait speed of >0.8 m/s
- Make postural transitions including stooping, lifting, reaching, and reorientation of head—independent of change in direction[13]
- Climb stairs
- Navigate slopes and uneven surfaces[13]
- Step over objects

Home Health Setting

Strength testing and assessment of home health patients for the purpose of comparison with community-based norms and for identification of impairments related to function are the primary purposes of MMT and alternative strength-testing methods in the home health setting. Returning a patient to community-based mobility may prevent frailty and increase the patient's quality of life. Lower-extremity strength is a primary component of these goals. Box 2.2 lists community mobility requirements that can be used as outcome goals for home health patients and serve to guide strength testing. In addition, for a homebound patient to receive home health services, the Centers for Medicare and Medicaid Services require patients to demonstrate "considerable and taxing effort in leaving the home," a criterion that has strength implications.[11]

Outpatient Clinics

Strength testing and assessment in outpatient clinics provide essential information, such as the (1) origin of the patient's pain, (2) quality of the contraction, (3) symmetry between sides and between the primary mover (agonist) and opposing muscles (antagonist), and (4) weakness within a kinetic chain (body segments linked by a series of joints).[15] This information aids in making a differential diagnosis. It can also provide a baseline assessment for changes over time, such as in the case of sciatica-induced weakness.[16] Challenges of MMT in the outpatient setting can include the presence of pain that prohibits a full, voluntary contraction and limitations of range of motion, such as with retraction and upward rotation of the scapula at the shoulder. Although a weak and painful or strong and painful contraction can be diagnostic, it can preclude the assessment of quantitative strength.[17] The ceiling effect of MMT often prevents an accurate assessment of strength quantity. Therefore we recommend that quantitative strength be assessed through a 1-RM or 10-RM strength assessment when pain permits (see Chapter 7). It is useful to assess the noninvolved side to ascertain asymmetry.

Careful differentiation is required to use strength assessment and testing for diagnostic (as opposed to quantification) purposes. For example, the Cyriax method (see Chapter 7) of

maintaining the joint in a neutral, relaxed position while assessing the muscle's contraction in various directions can reveal the presence of a contractile lesion if pain is produced during a contraction, while keeping noncontractile (e.g., connective tissues) elements on slack.[17] Alternatively, if the contraction is not painful while the joint is in a neutral position, an inert lesion, such as a bone spur or capsular inflammation, may be implicated.

The presence of pain, joint restriction, or muscle tightness may prevent the patient from assuming the correct testing position for accurate assessment of muscle testing. Although this text advocates testing the muscle in a pain-free position, substitution patterns are more difficult to discern; thus specific muscle strength quantification may not be possible. However, the therapist can document asymmetric differences, points in the range where pain exists or does not exist, and the nature of the pain that may aid the therapist in making an accurate diagnosis.

Another challenge for therapists in outpatient settings is the variety of patients seen in a given day. For example, a therapist may see a college or professional athlete in the same afternoon as a frail older adult. Careful discernment of appropriate strength testing is critical to avoid overestimation or underestimation of strength limitations. Using alternative muscle strength assessments as described in Chapters 7, 8, and 9 may be useful to avoid biases.

Wellness Clinics

Muscle screening provides feedback to participants regarding their abilities relative to age-matched normative samples that may impact functional abilities such as gait speed and chair stands. Although individual MMT is not routinely done as part of a wellness screening, functional movements such as floor transfers, 30-second sit-to-stands, or hand grip tests are useful to ascertain individual fitness levels and risk of disability. The information gleaned from a wellness assessment may indicate the need for an individualized physical therapy assessment of strength to maintain age-based expectations of function.[18,19]

Summary

MMT has utility in all clinical settings. However, it is incumbent on the therapist to judiciously use MMT when and if appropriate and to choose alternative forms of testing (e.g., functional and instrumented tests) when the information obtained from MMT is inadequate.

Even though muscle testing has tremendous value, there are situations in which it is not particularly informative, nor even accurate. Some of the clinical scenarios in which muscle testing is not optimal have already been discussed (e.g., in the presence of pain), but more detail will be presented in the next section.

Limitations of Manual Muscle Testing

As alluded to in Chapter 1, MMT has significant limitations. When it was first developed, the majority of patients seen by physical therapists had polio. The current patient population has changed enormously, and therapists now see hundreds of patient types who range in age from infancy to 100-plus years. Muscle examination has changed concomitantly to more accurately reflect the needs of clients, and MMT is only one approach among many. Each form of testing has its advantages and disadvantages, as will be noted in this chapter and elsewhere in this book. The major limitations of MMT are discussed in the following section.

Population Variation

Many articles that report MMT results are based on studies of normal adults or specific subpopulations such as athletes, sedentary individuals, and aged adults. Children occupy a separate category. In addition, results of muscle testing values are reported in individuals with a wide variety of pathologies, including Parkinson disease, cerebral palsy, and muscular dystrophy. Because of this wide variation, it is necessary to modify grading procedures but not testing technique. Thus test grades are not consistent from one patient population to another. Some testers also erroneously believe that the assigned grade should be modified based on age or ability, which should not be the case. Rather, MMT interpretation requires knowledge of the strength requirements of the task.

Objectivity

MMT, as originally described, suffers from a lack of objectivity, where objectivity is defined as a test not dependent primarily on the judgment of the examiner.[20,21] As discussed in Chapter 1, the ordinal scale of 5-0 as used to assign muscle strength grades is not objective and the use of qualitative terms such as good and fair further reduces its objectivity. However, it does provide useful information in a physical therapy assessment. Although clinical judgment is inherently a subjective assessment and cannot be discounted, the examination aspect of the patient encounter should primarily consist of objective measures.

Validity and Reliability

Reliability in MMT varies considerably according to the muscle tested, the experience of the examiner, the age of the patient, and the particular condition being tested. For example, in a study of 102 boys ages 5 to 15 years with Duchenne muscular dystrophy, intrarater reliability ranged from 0.65 to 0.93, with the proximal muscles having the higher reliability values.[22] The muscles with gravity minimized also had higher reliability values. In another study of physical therapists comparing MMT to handheld muscle dynamometry in 11 patients, reliability was high and differentiated between grades at all levels.[23] Frese and colleagues performed a reliability study among therapists on the middle trapezius and gluteus medius muscles and found 28% to 45% agreement for the same grade and 89% to 92% agreement within one grade.[24] They found the reliability to be poor, as measured by Cohen-weighted Kappa. In muscles with grades less than 3, reliability declined.[24-27] Reliability also decreased for the muscles of the lower extremity.[27]

Clearly, the reliability of MMT is of concern, and yet MMT remains an important screening and diagnostic tool. Therapists, especially novices, must be cautious about their test procedures and make vigorous attempts to standardize their methods. Reliability is increased by adhering to the same procedure for each test (for one or several examiners), by providing clear instructions to the subject, by having a quiet and comfortable environment for the test, and by being conscious of age or gender biases. To further enhance the reliability of the manual muscle test, the following steps should be taken[28-30]:

- Ensure proper positioning so the test muscle is the prime mover
- Ensure adequate stabilization of regional anatomy
- Observe the way the patient or subject assumes and maintains the test position
- Use consistent timing, pressure, and position
- Avoid preconceived impressions regarding the test outcome
- Use nonpainful contact and provide for a nonpainful execution of the test

Sensitivity

MMT also lacks sensitivity. Years ago, Beasley reported that patients with various neurologic disorders who had Grade 4 knee extension forces were only approximately 43% of normal, rather than the traditionally defined 75% of normal.[25] The Grade 3 group generated force that was only 9% of Grade 5, rather than 50% of Grade 5 usually assigned with MMT.[25] Similarly, inadequate sensitivity was reported for detecting muscle force deficits when comparing compromised muscles to those that are normal.[26]

Because MMT as originally described is subjective, the historical and conventional acceptability for reliability is that, among examiners, and in successive tests with the same examiner, the results should be within one-half of a grade (or within a plus or minus of the base grade).[29] Others maintain that within the same grade is acceptable, pluses and minuses notwithstanding.[30] However, even if this historical convention is used, therapists are unreliable in differentiating between the grades of 4 and 5.[9,26]

Diagnostic Validity

MMT is useful in the assessment of weakness of muscles directly involved with pain, injury, and

neuromusculoskeletal disorders.[28] The Cyriax method of discerning between contractile and noncontractile tissue is an example of muscle testing on the painful limb (see Chapter 7). In a study to detect differences between sides using MMT, the test accuracy as measured by sensitivity ranged from 62.9% to 72.3%, increasing with more pronounced strength differences.[28]

Ceiling Effect

MMT has wide variability in the range of forces reported for a given grade, especially in the upper range of the scale, further reducing its sensitivity. For example, in a subset of four studies, men with an MMT grade of 5 (by a negative break test) for knee extension and tested with handheld muscle dynamometry concurrently demonstrated values ranging from 85.4 to 650.0 Newtons.[9] In addition, the four studies analyzed represented all settings with a variety of patient types. The Grade 5 represented 86% of the range of measurable forces (Grades 3 to 5). Knee extension forces of more than 800 Newtons are not unusual for young men.[28] Thus MMT suffers from a profound ceiling effect. Many patients may be classified as having Grade 5 (normal) strength when they may have strength deficits only appreciated through more objective means. This ceiling effect may mask changes in strength that have functional and prognostic consequences. Thus it is not recommended that MMT be used as an objective measure of progress greater than the grade of 3 because it is not an accurate measure.

Another concern of the applicability of MMT is its lack of accuracy to identity impairments related to function, secondary to the curvilinear relationship. The curvilinear relationship suggests that strength gains are not apparent when greater than a relative threshold because the threshold of a strength demand for some lower level functional task (feeding oneself or standing from a chair) has been exceeded by the strength gain. Alternatively, traditional MMT may not reflect the great amount of strength needed to perform functional tasks such as getting up from the floor or throwing a baseball because they exceed what a therapist can manually resist. When a basic manual muscle test screen reveals test grades that are greater than Grade 3 and in particular, where there are side-to-side differences, the therapist should rely on instrumented or functional testing to further clarify deficiencies and to differentiate between Grades 4 and 5 (see Chapters 7 through 9).

Handheld dynamometry (HHD) may address some of the aspects of reliability. Because HHD records a number, it does not require the therapist to execute a judgment about a grade. However, other issues of MMT still hold true for HHD, such as tester strength, discussed later. HHD is further discussed in Chapter 9.

Tester Strength

A break test in MMT requires the tester to exert greater force than the patient in any given muscle. When testing a very strong individual, such as a weightlifter or football player, a great amount of force on the part of the tester is required. Women traditionally have 35% less upper body strength than men, and differences have been recorded in MMT forces between female and male testers, leading to an underestimation of the patient's quadriceps strength.[26,31] For example, Beasley found in a sample of female therapists testing the quadriceps in patients with polio that of those muscles graded a 5, the mean force generated was only 53% of normal subjects.[25] Mulroy and colleagues also found that female therapists overgraded the strength of the quadriceps in 14 of 19 patients, in part because of patient strength greater than the therapist's.[31] Male therapists assigned too high a grade in 2 of 19 patients.[31]

Summary

MMT appears to be both reliable and valid in the presence of profound weakness, such as that seen in neuromuscular diseases. However, when used in individuals with near-normal levels of strength, it is recommended that MMT be used as a screening tool that informs alternative forms of strength testing such as those described in Chapters 7 and 9.

References

1. Bittner EA, Martyn JA, George E, et al. Measurement of muscle strength in the intensive care unit. *Crit Care Med*. 2009;37:S321–S330.
2. Andrews AW, Bohannon RW. Short-term recovery of limb muscle strength after acute stroke. *Arch Phys Med Rehabil*. 2003;84:125–130.
3. Vermeulen J, Neyens JC, van Rossum E, et al. Predicting ADL disability in community-dwelling elderly people using physical frailty indicators: a systematic review. *BMC Geriatr*. 2011;11:33.
4. Fried LP, Tangen CM, Walston J, et al. Frailty in older adults: evidence for a phenotype. *J Gerontol A Biol Sci Med Sci*. 2001;56A:M146–M156.
5. Fried TR, Mor V. Frailty and hospitalization of long-term stay nursing home residents. *J Am Geriatr Soc*. 1997;45:265–269.
6. Bortz WM. A conceptual framework of frailty: a review. *J Gerontol*. 2002;57A:M283–M288.
7. Visser M, Kritchevsky SB, Goodpaster B, et al. Leg muscle mass and composition in relation to lower extremity performance in men and women aged 70-79: the health, aging and body composition study. *J Am Geriatr Soc*. 2002;50:897–904.
8. Schwartz RS. Sarcopenia and physical performance in old age: introduction. *Muscle Nerve Suppl*. 1997;5:S10–S12.
9. Bohannon RW, Corrigan D. A broad range of forces is encompassed by the maximum manual muscle test grade of five. *Percept Mot Skills*. 2000;90:747–750.
10. Xue QL, Bandeen-Roche K, Varadhan R, et al. Initial manifestations of frailty criteria and the development of frailty phenotype in the women's health and aging study II. *J Gerontol A Biol Sci Med Sci*. 2008;63:984–990.
11. U.S. Department of Health and Human Services. *Centers for Medicare & Medicaid Services, Medicare benefit policy manual; Home Health Services*. [ch 7; pp 61–64] http://www.cms.gov/Regulations-and-Guidance/Guidance/Manuals/downloads/bp102c07.pdf; 2011.
12. Chang M, Cohen-Mansfield J, Ferrucci L, et al. Incidence of loss of ability to walk 400 meters in a functionally limited older population. *J Am Geriatr Soc*. 2004;52:2094–2098.
13. Shumway-Cook A, Patla AE, Stewart A, et al. Environmental demands associated with community mobility in older adults with and without mobility disabilities. *Phys Ther*. 2002;82:670–681.
14. Perry J, Garrett M, Gronley JK, et al. Classification of walking handicap in the stroke population. *Stroke*. 1995;26:982–989.
15. Maffiuletti NA. Assessment of hip and knee muscle function in orthopaedic practice and research. *J Bone Joint Surg Am*. 2010;92:220–229.
16. Balague F, Nordin M, Sheikhzadeh A, et al. Recovery of impaired muscle function in severe sciatica. *Eur Spine J*. 2001;10:242–249.
17. Cyriax JH. 8th ed. Bailliere Tindall: London; 1982:14–21. *Textbook of Orthopaedic Medicine: Diagnosis of Soft Tissue Lesions*. Vol. 1.
18. Rikli R, Jones J. Development and validation of a functional fitness test for community-residing older adults. *J Aging Phys Act*. 1999;7:129–161.
19. Rikli R, Jones J. Functional fitness normative scores for community-residing older adults, ages 60-94. *J Aging Phys Act*. 1999;7:162–181.
20. Knepler C, Bohannon RW. Subjectivity of forces associated with manual muscle test scores of 3+, 4-, and 4. *Percept Mot Skills*. 1998;87:1123–1128.
21. Bohannon RW. Objective measures. *Phys Ther*. 1989;69:590–593.
22. Florence JM, Pandya S, King WM, et al. Intrarater reliability of manual muscle test (medical research council scale) grades in Duchenne's muscular dystrophy. *Phys Ther*. 1992;72:115–122 [discussion 122–126].
23. Wadsworth CT, Krishnan R, Sear M, et al. Intrarater reliability of manual muscle testing and hand-held dynametric muscle testing. *Phys Ther*. 1987;67:1342–1347.
24. Frese F, Brown M, Norton BJ. Clinical reliability of manual muscle testing: middle trapezius and gluteus medius muscles. *Phys Ther*. 1987;67:1072–1076.
25. Beasley WC. Quantitative muscle testing: principles and application to research and clinical

services. *Arch Phys Med Rehabil*. 1961;42:398–425.
26. Wintz M. Variations in current manual muscle testing. *Phys Ther Rev*. 1959;39:466–475.
27. Cuthbert SCJ, Goodheart GJ. On the reliability and validity of manual muscle testing: a literature review. *Chiropr Osteopat*. 2007;15:4.
28. Bohannon RW. Manual muscle testing: does it meet the standards of an adequate screening test? *Clin Rehabil*. 2005;19:662–667.
29. Lamb R. Manual muscle testing. Rothstein JM. *Measurement in Physical Therapy*. Churchill-Livingstone: New York; 1985:47–55.
30. Palmer ML, Epler ME. *Fundamentals of Musculoskeletal Assessment Techniques*. 2nd ed. Lippincott Williams & Wilkins: Philadelphia; 1998.
31. Mulroy SJ, Lassen KD, Chambers SH, et al. The ability of male and female clinicians to effectively test knee extension strength using manual muscle testing. *J Orthop Sports Phys Ther*. 1997;26:192–199.