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Literature review

A narrative review of manual muscle testing and implications for muscle testing research

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Abstract

Objective: Manual muscle testing (MMT) is used for a variety of purposes in health care by medical, osteopathic, chiropractic, physical therapy, rehabilitation, and athletic training professionals. The purpose of this study is to provide a narrative review of variations in techniques, durations, and forces used in MMT putting applied kinesiology (AK) muscle testing in context and highlighting aspects of muscle testing important to report in MMT research.

Method: PubMed, the Collected Papers of the International College of Applied Kinesiology–USA, and related texts were searched on the subjects of MMT, maximum voluntary isometric contraction testing, and make/break testing. Force parameters (magnitude, duration, timing of application), testing variations of MMT, and normative data were collected and evaluated.

Results: "Break" tests aim to evaluate the muscle's ability to resist a gradually increasing pressure and may test different aspects of neuromuscular control than tests against fixed resistances. Applied kinesiologists use submaximal manual break tests and a binary grading scale to test short-term changes in muscle function in response to challenges. Many of the studies reviewed were not consistent in reporting parameters for testing.

Conclusions: To increase the chances for replication, studies using MMT should specify parameters of the tests used, such as exact procedures and instrumentation, duration of test, peak force, and timing of application of force.

Introduction

Manual muscle testing (MMT) is used for a variety of purposes in health care by medical, osteopathic, chiropractic, physical therapy, rehabilitation, and athletic training professionals. Different techniques of testing have relevance in different contexts and are not always equivalent.[1-7]

The most commonly held viewpoint is that MMT is an attempt to assess the maximum force a muscle is capable of generating. However, this is not always the case. Given normal innervation, maximum force generated is to a great degree a function of the size of

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the muscle. Yet virtually every health care professional has learned to test muscles to differentiate between nerve root, peripheral nerve, and central nervous system lesions, regardless of the size of the muscle. Such tests are usually submaximal.

In addition to standard orthopedic and neurologic assessments, applied kinesiology (AK) practitioners use MMT to identify what are believed to be immediate neurological responses to a variety of challenges and treatments. Tests of maximum force are actually less relevant to this use. The purpose of this narrative review is to describe AK MMT and point out aspects of muscle testing that should be defined to properly interpret research that involves AK MMT.

Methods

References were found by selectively searching PubMed on the subjects of MMT, maximum voluntary isometric contraction (MVIC) testing, make testing, and break testing. The Collected Papers of the International College of Applied Kinesiology–USA (ICAK-USA) and a convenience sample of related books on AK and muscle testing were hand-searched for articles relating to muscle testing parameters such as force, duration, and timing of force application. The Collected Papers of the ICAK-USA are conference proceedings in which English-speaking AK practitioners initially present their observations before consideration for publication in peer-reviewed journals. Further references were found in the citations in articles identified in the above searches. References were selected if they addressed forces, durations, and technique variations in MMT including normative data. Scientific studies, texts, and theoretical/opinion articles were included. No date limits were used. Isokinetic testing throughout the full range of motion of a muscle's action was not included, as this form of evaluation is highly technical and not directly germane to manual testing. Forty references were included as relevant to this investigation.

Results

Results are summarized in Table 1.

Maximum voluntary isometric contraction

The maximum force a muscle can generate can be measured by MVIC. This is usually done with the

Table 1 Comparison of muscle testing techniques

Method	Force	Time	Scoring	Comments
MVIC[8-10]	Voluntary contraction against a fixed resistance	Until maximum observed 3-6 s	Peak force in pounds or newtons; fine gradations possible	Equipment intensive, time consuming, good stabilization possible
Manual make test[11,12]	Voluntary contraction against tester as "fixed" resistance	1-4 s	Grades 0-5 or as a perceived % of full strength.	Tester must be stronger than subject.[12]
Manual make test with dynamometer[12]	Voluntary contraction against tester as "fixed" resistance	1-4 s[13]	Peak force in pounds or newtons	Tester must be stronger than subject.[12]
Manual break test[11,14]	Resistance to increasing test pressure	1-4 s	Grades 0-5 or as a perceived % of full strength.	Test is stopped when full resistance perceived by tester.
Manual break test with dynamometer[11]	Resistance to increasing test pressure to breaking point	1-4 s[13] Nicholas et al[15] 14 to 60 s	Peak force in pounds or newtons	If test is taken to breaking point every time, tester must be stronger than subject.[12]
AK muscle test[16-23]	Submaximal break test, resistance to increasing test pressure	0.5-3 s	Facilitated/strong (grade 5) vs inhibited/weak (grades 0-4)	Tester may be weaker than subject. Test stopped when "lock" perceived by tester.
AK "G1" or "examiner-started test"[16,24,25,17-19,22,23]	Submaximal break test, resistance to increasing test pressure	≤1 s	Facilitated/strong (grade 5) vs inhibited/weak (grades 0-4)	Tester may be weaker than subject. Test stopped when "lock" perceived by tester.
AK "G2" or "patient-started test"[16,24,25,17-19,22,23]	Make test, with late added pressure	2.5-3.5 s	Facilitated/strong (grade 5) vs inhibited/weak (grades 0-4)	Tester acts as "fixed" resistance to a perceived maximum then adds pressure to attempt to break. May require tester to be stronger than subject.

patient stabilized in a standard position pressing as hard as possible against a relatively stationary strap or pad with a force transducer connected to a frame. The examiner's role is to properly set up the equipment, position the patient to isolate the muscle in question, and encourage the patient to exert maximum effort. This is not a manual test. The recorded force depends entirely on the patient's voluntary action.

The MVIC can demonstrate changes in muscle bulk as a result of rehabilitation or strength training as well as changes due to neurologic improvement or deterioration in nervous system disease or nerve injury.

Techniques for measuring MVIC are described in many studies. Some use strain gauges, and others have the subject press directly against some form of force transducer.[8,26-29]

MMT: make vs break tests

The muscle testing literature distinguishes between "make" or "active strength" and "break" or "passive strength" testing both in MMT and in handheld dynamometry. In both techniques, the muscle is tested relatively isometrically, either near its most shortened position or in the middle of its range of motion.

Table 2 Grading of MMTs

	Kendall and Kendall[14]	AMA Impairment Rating Guide[30]
Grade 0	No perceptible muscle contraction	No perceptible muscle contraction
Grade 1	Muscle contraction palpable, but no motion	Muscle contraction palpable, but no motion
Grade 2	Motion of the part only with gravity reduced	Motion of the part only with gravity reduced
Grade 3	"… a muscle can hold the part in test position against the resistance of gravity but cannot hold if even slight pressure is added."	Muscle can hold the part in the test position against gravity alone.
Grade 4	Muscle holds test position against some pressure but breaks away.	Patient can move the part through the full active range of motion against "some" resistance.
Grade 5	Muscle holds test position against "full pressure."	Patient can move the part through the full active range of motion against "full" resistance.

AMA, American Medical Association.

The form of manual testing most similar to MVIC is "make testing" or "active contraction testing," wherein the examiner acts as a fixed point against which the patient pushes.[11] This may be graded by the examiner's estimation of the amount of force generated, by the percentage of expected maximum compared bilaterally, or with a handheld dynamometer to measure the peak force. Make testing for maximum voluntary contraction (MVC) requires that the examiner be stronger than the subject to provide a truly fixed resistance to the patient's effort.

In break testing, the subject is asked to resist the tester's gradually increasing pressure. If the muscle breaks away, there is also eccentric lengthening. Break testing is described in Kendall and Kendall *Muscles Testing and Function*[14] and is graded on a 0 to 5 scale (Table 2).

Both make testing and break testing differ from isokinetic testing, such as using Cybex[7,31,32] equipment to test the muscle through an entire range of motion at a constant speed.

Dimensions of AK muscle testing

Applied kinesiologists test muscles before and after applying various challenges and treatments and make clinical judgments based on short-term changes in muscle tests after challenges.[16(pp37,71)] Applied kinesiology testing is generally considered to be break testing as described by Kendall and Kendall,[11,33] but using a binary grading system. Applied kinesiology practitioners usually refer to muscles as "facilitated" or "strong," corresponding to grade 5, or "functionally inhibited" or "weak," corresponding to roughly to grade 4 or less on the 0 to 5 scale in Table 2.

"Patient-initiated" vs "doctor-initiated" MMT according to Schmitt

Within AK, there is a similar proposed dichotomy between muscle testing techniques. Schmitt[24] observed that subtle differences in timing seemed to yield different results in AK MMT. He described the usual AK muscle test as "doctor-initiated" (AKA "G1" or "Type 1")[25] or isometric-to-eccentric in which the subject is asked to resist the doctor's gradually increasing force. "Patient-initiated" or concentric-to-isometric ("G2" or "Type 2") testing begins in the same position, but the patient is asked to push against the examiner's hand as hard as possible and given verbal encouragement through the test. The examiner is described as adding pressure at the end of the test. In both techniques, the examiner attempts to break the patient's contraction, the difference being timing. Theoretically, "doctor-initiated" testing would be similar to physiotherapist's "break" testing. As described, "patient-initiated" testing would be similar to a "make" test that becomes a "break" test upon the addition of pressure by the examiner at the end. Schmitt's theoretical basis for these testing techniques is summarized in a previous article.[17]

Discussion

Maximum voluntary isometric contraction

In a study of normative values for MVIC in healthy subjects, Meldrum et al[8] summarize references comparing MVIC and MMT, concluding that, generally, MVIC shows better sensitivity than does MMT for small changes in quantitative muscle strength in the context of monitoring patients with neuromuscular disease. Manual muscle testing grading on a 5-point numerical scale does not allow for the fine objective gradations that can be done when measuring units of force. A muscle may fall within one grade at a range of forces so that small interval changes may be missed.[7] These concerns are important for evaluation of progress or deterioration in a patient in rehabilitation or with a neuromuscular disease. However, MVIC testing is equipment and time intensive and is not practical for many clinical applications. For a detailed discussion of strengths and weaknesses of instruments and methods of quantitative strength testing, see Sepega's[7] 1990 review.

MMT: make vs break tests

Manual muscle testing by handheld dynamometry has been compared with MVIC for inter- and intrarater reliability by Visser et al.[34] Both techniques were acceptably reliable and correlated well for longitudinal evaluation of muscle strength in patients with progressive lower motor neuron syndrome. Handheld dynamometry was limited by examiner strength and tended to underestimate strength greater than 250 N (~56 lb). However, manual dynamometry is inexpensive and rapid to use and so is acceptable in many contexts where fine gradations of change need to be assessed.

It appears that for a "make" test (where the examiner provides static resistance) to be truly different from a "break" test (where the examiner gradually increases pressure for the subject to resist), the examiner must be trained to offer unchanging, stable resistance, which is not necessarily a given. Accurate manual dynamometry requires that the examiner be stronger than the subject if the peak force of a muscle test is to be measured.[12]

A handheld dynamometer may be used for break testing. However, the element of examiner choice on when to stop a test that does not break away makes peak force comparisons between tests more problematic. Break tests are usually submaximal. To make matters more complex, the greatest force may be recorded after the breaking point. Similar reliability is reported for make and break testing.[8] Tests of breaking strength are frequently cited as yielding higher peak force measurements than make tests,[8,34] indicating that make tests are also usually submaximal.

Van der Ploeg and Oosterhuis[13] studied make and break MMT with a handheld dynamometer with and without encouragement. They compared subjects who were healthy, had known organic neuromuscular disorders, or had known "functional" or "conversion symptom" causes of muscle weakness. The unstated implication is that "functional" weakness is based on a psychological disorder. For healthy subjects and those with organic disorders, encouragement only increased the force by a small percentage, whereas for many functionally weak patients, encouragement increased force by more than 20%. Functionally weak patients also exhibited a greater difference between make and break tests than organically weak patients. The authors interpreted this as being due either to poor cooperation or to aberrant muscle spindle signaling between agonist and antagonist muscles.

This is similar to Janda's[35] "muscle imbalance" theory combining "tightness-weakness" of the antagonist with "stretch-weakness" of the agonist. It does acknowledge that muscle testing results involve more than simple muscle bulk or simple nerve trauma. In some instances, tested muscle response could involve pain adaptation in which muscle inhibition is more prominent, based upon the observation that motor function in 5 chronic musculoskeletal pain conditions (temporomandibular joint disorders, muscle tension headache, fibromyalgia, chronic low back pain, and muscle soreness following exercise) is known to be impaired. In these instances, decreased activation of muscles is seen during movements in which they act as agonists; and increased activation is seen during movements in which they act as antagonists.[36]

One could interpret the van der Ploeg and Oosterhuis study to imply that psychological factors are at play in manual testing such as AK testing and that the variations we see are based solely on patient effort or patient expectation. Because AK tests are submaximal break tests and the "functionally" or psychologically weak patients actually did the best on "break" tests, this is an unlikely explanation. It is quite possible that at least some of the "functional" weaknesses studied by van der Ploeg and Oosterhuis are simply reversible, nonoptimum, manipulable neurological states that clinicians see and treat in chiropractic and AK rather than the result of aberrant psychology.

Timing of the break affects the examiner's perception of relative strength. Nicholas et al[15] studied examiners' perception of relative weakness of muscles, comparing right to left hip flexors and hip abductors in the same subject during break testing. Force was recorded continuously, along with the angle of the limb. Peak force was late in the progress of the break and was greater than breaking force. Seven different variables were considered. The examiner's perception of weakness was most affected by a product of force applied and duration of the test. Thus, a test with more force maintained over a shorter time could be rated as weaker by a tester than a test with less force over a longer time for the same range of motion.

This finding corresponds to the common statement in AK training that it is whether the muscle "locks" or "gives out" that is the outcome being evaluated, not the total force a muscle is capable of generating. Extrapolating from the results of Nicholas et al, in tests of equivalent time, force is the variable that would determine the level of perceived strength. Regardless of force, if the muscle contraction does not last, testers call it weak.

AK MMT

The range of parameters that yield similar results on AK's binary evaluation of MMTs is currently under investigation. This information is important in training accurate muscle testers and in evaluating the reliability and validity of other AK procedures based on muscle responses.

In a previous study,[18] we found that the range of duration of AK muscle testing of the middle deltoid for 41 experienced examiners was from 0.325 to 3.5 seconds (mean, 1.3 seconds). There was a suggestion of a bimodal distribution of durations longer than and shorter than about 1.5 seconds as examiners attempted to execute different techniques of muscle tests.

The same data set[19] showed a broad range of force used in these tests (0.55-23.6 lb). These forces are submaximal when compared with norms in the literature.[8,26] The force used was moderately correlated with the duration of the test ($r = .55$) but not with other parameters such as subject or examiner body size.

Intuitively, longer durations and higher forces would be expected to yield more muscles rated as "weak" or "functionally inhibited" if AK muscle testing is only measuring muscle bulk or local muscle injury. However, AK authors have suggested that what is actually being measured is a complex proprioceptive response to changing pressure, rather than the strength of the muscle itself.[14,16(p2),37]

MMT and fatigue

Leisman et al[9] compared AK MMT ratings to force/integrated electromyographic (EMG) data during muscle contractions at varying percentages of MVIC showing the effects of fatigue and task repetition. In this study, several muscles for each subject were manually tested and rated as "strong" or "weak." The description of the procedure matches Schmitt's "Type 2" or "patient-initiated" test. Further electrophysiological testing was then conducted with the examiners blind to the rating of the previous MMTs.

Maximum voluntary isometric contraction was determined for each subject. Subjects then were asked to do a series of isometric contractions at a series of increasing percentages of MVIC. Electromyographic data were recorded during all contractions.

The relationship between integrated EMG and force was clearly different between muscles rated as strong and muscles rated as weak at all force levels and durations. Weak muscles were associated with less efficient muscle activity, although the EMG output increased. These effects were shown to be different in several respects from the effects of fatigue demonstrated in long contractions.

Strong muscles could maintain 10% contractions for an average of 21.05 minutes descending to 0.53 minute for 75% MVC. The "weak" muscles were able to maintain the contraction an average of 16.03 minutes for 10% MVC down to 0.33 minute for the 75% MVC contraction.

Even at 75% of MVC, weak muscles did not give out until 20 seconds, which is much longer than the MMT in any AK study reporting muscle testing durations.[17-25,38] The manual test was able to distinguish a difference in muscle function between strong and weak muscles rapidly and accurately, without taking the muscle to the point of fatigue. Electrophysiological differences in muscle state were evident at a broad range of force and duration levels.

In our study[22,23] of muscle tests of different durations, even subjects whose muscles manually tested weak were able to maintain MVIC contractions for 5 to 10 seconds until told they could stop. Taking this and the data of Leisman et al into account, it is highly unlikely that muscle fatigue is what is being measured in a manual test.

"Patient-initiated" vs "doctor-initiated" MMT according to Schmitt

Hsieh and Phillips[38] did a frequently-cited reliability study with a computerized dynamometer comparing doctor-initiated and patient-initiated testing. The authors concluded that patient-initiated testing was more reliable than doctor-initiated testing with this instrument.

However, when the details of this study are examined, problems with this conclusion are revealed. Only peak force was recorded, rather than a continuous recording of force over time, making it impossible to determine the actual timing of each method. There is no record of the duration of these tests. Because the examiners were free to stop the "doctor-initiated" test whenever they were satisfied that the muscle had "locked" or "broken away," it is not surprising that these tests demonstrated quite a wide variation in peak force. There is no reason to expect that different examiners would make this judgment at the same point. In fact, our own studies indicate that they do not. The "patient-initiated" tests required the examiner to maintain pressure until an apparent maximum was achieved. It seems likely that this point would be more similar tester to tester and test to test. The authors also state that different testers appeared not to have been testing equivalently for each testing method. Subjects were tested by one or the other style of testing instead of both, making comparison between techniques problematic.

Two studies[18,19] were done to try to define what was actually being done when experienced AK testers attempted to test in these different ways. We used surface EMG to identify when the examiner's and subject's muscle contractions started. These studies failed to demonstrate a clear difference between "patient-initiated" and "doctor-initiated" MMT based on starting times and raised the question of whether there was another parameter that differentiated testing techniques. Forces varied widely and correlated only with duration of the test. Durations seemed to fall into a bimodal pattern, suggesting that, perhaps, duration was the actual differentiating factor between the techniques of testing that Schmitt reported.

Vasilyeva et al[21] describe 2 stages of muscle contraction. In phasic contraction, the length of the muscle changes concentrically or eccentrically; but its tonus remains the same. The balance between agonists and antagonists determines the length of the muscle. This is the initial type of contraction in voluntary movement, regulated by the cerebral cortex. Tonic contraction involves no change in length of the muscle (isometric) but a change in tone. Vasilyeva et al cite Bernstein's 1929 and 1947 work stating that these 2 phases are also seen in an isometric contraction. The initial contraction is phasic/voluntary. Tonic contraction appears after 3 seconds of an isometric contraction, fatigues slowly, and is involuntary. It is regulated at the striatopallidal level.

Vasilyeva et al[20,21] have done several studies demonstrating differences between normal and dysfunctional muscles based on testing in two or three 3-second increments with force and surface electromyography (sEMG) recordings. Electromyographic findings paralleled the perception of the manual muscle tester. Vasilyeva[20] also used vector EMG to demonstrate that, in muscular pain syndromes, a weak agonist is activated late in relation to its hyperactive antagonists and synergists.

Applied kinesiology muscle testing in practice, especially undifferentiated or examiner-started techniques, is shorter than 3 seconds[18]; so, per Vasilyeva's model, we appear to be testing primarily the phasic stage of the muscle contraction. "Patient-started" tests are more likely to be longer and may approach the tonic phase according to this model.

In our study comparing peak force during MVICs and 1-second and 3-second MMTs of the middle deltoid,[22,23] although there were few weak muscles in the 42 subjects tested, 3 subjects had weakness on the long tests that was not evident on the short tests. Short and long MMTs do sometimes yield different results, supporting the hypothesis that the differences observed by Schmitt between "patient-started" and "examiner-started" tests may be differences in duration of tests. The 2 durations of testing potentially measure different aspects of neuromuscular function—the initial rapid response to external pressure and the ability to sustain a contraction as suggested by Vasilyeva's work.

As many AK examiners use tests of 1 second or less in practice, muscle weaknesses that develop later may be missed. Applied kinesiologists may want to consider using MMT of 3 seconds or longer when results are equivocal. Future studies of MMT should record and report durations of tests. Maximum voluntary isometric contraction testing is completely under the control of the subject, especially when done against a fixed force transducer rather than by a strong manual tester. It has been shown to be better than manual testing for discriminating small degrees of interval change in muscle strength in neurological disease. Manual testing, especially where the force continues to ramp up during the whole test (as we have observed in AK testing), requires the subject's proprioceptive system to continually assess the tester's changing pressure and to continually adjust the muscle contraction to meet it. This is fundamentally different from MVIC and appears to be better suited than MVIC to reflect transitory changes in the central integrative state of the nervous system in response to the mechanical or chemical challenges used in AK. As has been postulated elsewhere, muscles act as the reflection of a peripheral or central neural change; and treatment therefore will only be effective if it is directed at the correct neural disruption.[39]

Implications for research design

Applied kinesiology MMT does not involve the full force that a muscle is capable of generating, even when the muscle tests weak or inhibited. This seems paradoxical at first but does support the long-held opinion of applied kinesiologists that what is being tested is not the total or peak force of the muscle test, but rather the ability of the neuromuscular system to adapt to changing pressure.

Applied kinesiology appears to be the only discipline working with short-term changes in muscle function in response to sensory challenges. Thus, it is understandable that those unfamiliar with AK but familiar with muscle strength testing such as dynamometry or MVIC would have doubts about AK claims of nearly instantaneous changes in muscle tests.[40] A continuing effort to develop ways of objectively recording these rapid changes is vital to allowing thorough investigation of the procedures of AK.

Muscles that break away exhibit higher peak forces during manual testing than muscles that can hold an isometric contraction. This may simply reflect a tendency of the examiner to allow the force to plateau or ramp more slowly when it is apparent that the muscle is holding, or it may reflect a recruitment of more fibers in a dysfunctional muscle to try to avoid failure. It is consistent with the observations of Nicholas et al that break tests generate higher peak forces than make test and that the peak force occurs after the breaking point. This means that dynamometry is of limited use in day-to-day AK practice and of limited relevance if used as the sole parameter in AK research. Recording force over time and evaluating the shape of the force curve are better, if not perfect, options for research. Leisman et al observed that weak muscles exhibit higher EMG output and less efficient contractions than strong muscles. Thus, EMG measurements of amplitude alone to compare "strong" and "weak" muscles are likely to yield unclear results.

On especially strong muscles and for weaker testers, it is possible that clinicians may miss subtle changes in strength with MMT, particularly with short test durations. These factors need to be considered in training testers and in designing studies involving MMT.

Limitations

This study was conducted as a narrative review limited to studies directly relevant to research design concerns for AK studies, rather than an extensive systematic review of all issues related to MMT. Rather than offer a complete critical, intrinsic appraisal of each study cited, the emphasis of this particular effort was to identify the varying parameters from recent investigations that are involved in MMT, so that their respective effects upon the results of MMT may be more clearly determined. This investigation thus provides guidelines for future research. In this manner, the validity of MMT and its attributes, the core principles of AK, need to be evaluated. Research needs to be completed to evaluate the diagnostic accuracy, reliability, and clinical relevance of AK MMT.

Conclusion

The AK literature suggests that MMT evaluates the net result of activation of complex neurological pathways. It is also suggested that MVIC may discriminate interval changes in muscle strength; it is equipment intensive and not practical for day-to-day monitoring of therapy. Applied kinesiology MMT attempts to use submaximal forces and measure the neurological response to gradually increasing pressure, rather than the total force that the muscle is capable of generating.

Because of variations in muscle testing techniques in the literature, the greatest likelihood of replication for any research study reporting MMT will be achieved by specifying exact procedures and instrumentation, if any, along with parameters of the tests used, including duration of tests, peak force if measured, and timing of application of force, particularly when testing before and after diagnostic or therapeutic interventions and challenges.

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References

1. Pothmann R, von Frankenburg S, Hoicke C, Wingarten H, Ludtke R. Evaluation of applied kinesiology in nutritional intolerance of childhood. Forsch Komplement Med 2001;8 (666):336-44.
2. Hall T, Quinter J. Responses to mechanical stimulation of the upper limb in painful cervical radiculopathy. Aust J Physiother 1996;42(4):277-85.
3. Dvir Z, Prushanksky T. Cervical muscle strength testing: methods and clinical implications. J Manipulative Physiol Ther 2008;31(7):518-24.
4. Kenney JJ, Clemens R, Forsythe KD. Applied kinesiology unreliable for assessing nutrient status. J Am Diet Assoc 1988;88(6):698-704.
5. Harms-Ringdahl K. Muscle strength. Edinburgh. Scotland: Churchill Livingstone; 1993.
6. Haas M, Cooperstein R, Peterson D. Disentangling manual muscle testing and applied kinesiology. Chiropr Osteopat 2007:11.
7. Sepega AA. Muscle performance evaluation in orthopedic practice. J Bone Joint Surg Am 1990;72:1562-74.
8. Meldrum D, Cahalane E, Conroy R, Fitzgerald D, Hardiman O. Maximum voluntary isometric contraction: reference values and clinical application. Amyotroph Lateral Scler 2007;8: 47-55.
9. Leisman G, Zenhausern R, Ferentz A, Tefera T, Zemcov A. Electromyographic effects of fatigue and task repetition on the validity of estimates of strong and weak muscles in applied kinesiological muscle-testing procedures. Percept Mot Skills 1995;80:963-77.
10. Meldrum D, Cahalane E, Conroy R, Fitzgerald D, Hardiman O. Maximum voluntary isometric contraction: investigation of reliability and learning effect. Amyotroph Lateral Scler other Mot Neuron Disord 2003;4(1):36-44.
11. Rarick L, Gross K, Mohns M. Comparison of two techniques of measuring strength of selected muscle groups in children. Res Q 1955;26:76-9.
12. Wilkhom JB, Bohannon RW. Hand-held dynamometer measurements: tester strength makes a difference. J Orthop Sports Phys Ther 1991;13(4):191-7.
13. van der Ploeg RJ, Oosterhuis HJ. The “make/break test” as a diagnostic tool in functional weakness. J Neurol Neurosurg Psychiatry 1991;54(3):248-51.
14. Kendall FP, Kendall McCreary E, Provance PG. Muscles—testing and function. 4th ed. Baltimore: Williams and Wilkins; 1993. p. 179-90.
15. Nicholas J, Sapega B, Kraus H, Webb J. Factors influencing manual muscle tests in physical therapy. J Bone Joint Surg 1978;60-A(2):186-90.
16. Walther DS. Applied kinesiology synopsis. 2nd ed. Pueblo, CO: Systems DC; 2000.
17. Conable K, Corneal J, Hambrick T, Marquina N, Zhang J. Investigation of methods and styles of manual muscle testing by AK practitioners. J Chiropr Med 2005;4(1):1-10.
18. Conable K, Corneal J, Hambrick T, Marquina N, Zhang Q. Electromyogram and force patterns in variably timed manual muscle testing of the middle deltoid muscle. J Manipulative Physiol Ther 2006;29(4):305-14.
19. Conable K, Corneal J, Hambrick T, Marquina N, Zhang J. Analysis of peak force in applied kinesiology manual muscle testing. Proceedings of the Annual Meeting of ICAK Vol. 1, 2007-2008. Shawnee Mission, KS: International College of Applied Kinesiology; 2007. p. 53-8.
20. Vasilyeva LF. Clinical and experimental substantiation of the functional muscle weakness phenomenon. Proceedings of the International College of Applied Kinesiology Annual Meeting [CD-ROM]. Rome, Italy [CD-ROM]-Shawnee Mission, KS: ICAK; 2004.
21. Vasilyeva LF, Chernysheva TN, Korenbaum VI, Aukhtina TO. About peculiarities of the effect of muscle functional weakness. Proceedings of the Annual Meeting of the International College of Applied Kinesiology-USA, Volume 1, 2001-2002. Kansas City: International College of Applied Kinesiology; 2001. p. 63-6.
22. Conable K. Duration and force variations in applied kinesiology manual muscle testing [masters thesis]. Bundoora (Australia): Royal Melbourne Institute of Technology; 2008.
23. Conable K. Intraexaminer comparison of applied kinesiology manual muscle testing of varying durations: a pilot study. J Chiropr Med 2010;9:3-10.
24. Schmitt WH. Muscle testing as functional neurology: differentiating functional upper motor-neuron and functional lower motor-neuron problems. Selected papers of the International College of Applied Kinesiology; 1986. p. 21-32.
25. Schmitt WH, Yanuck SF. Expanding the neurological examination using functional neurological assessment part II: neurologic basis of applied kinesiology. Int J Neurosci 1999;97:77-108.
26. National Isometric Muscle Strength Database Consortium. Muscular weakness assessment: use of normal isometric strength data. Arch Phys Med Rehabil 1996;77:1251-5.
27. Colombo R, Mazzini L, Mora G, Parenzan R, Creola G, Pirali I, et al. Measurement of isometric muscle strength: a

reproducibility study of maximal voluntary contraction in normal subjects and amyotrophic lateral sclerosis patients. Med Eng Phys 2000;22(3):167-74.
28. Great Lakes ALS Study Group. A comparison of muscle strength testing techniques in amyotrophic lateral sclerosis. Neurology 2003;61(11):1503-7.
29. Stoll T, Huber E, Seifert B, Michel BA, Stucki G. Maximal isometric strength: normative values and gender-specific relation to age. Clin Rheumatol 2000;19(2):105-13.
30. American Medical Association: guides to the evaluation of permanent impairment, 6th edition, 2007:510.
31. Blaich RM, Mendenhall EI. Manual muscle testing and Cybex machine muscle testing, a search for a correlation. In: Schmitt Jr WH, editor. 1984 Selected papers of the International College of Applied Kinesiology. Park City, UT: International College of Applied Kinesiology; 1984. p. 1-10.
32. Lin HT, Hsu AT, Chang JH, Chien CS, Chang GL. Comparison of EMG activity between maximal isometric testing of the quadriceps femoris. J Formos Med Assoc 2008;107(2):175-80.
33. Cuthbert SC, Goodheart Jr GJ. On the reliability and validity of manual muscle testing: a literature review. Chiropr Osteopath 2007;15(1):4.
34. Visser J, Mans E, deVisser M, van den Berg-Vos RM, Franssen H, DeJohn JM, et al. Comparison of maximal voluntary isometric contraction and hand-held dynamometry in measuring muscle strength of patients with progressive lower motor neuron syndrome. Neuromuscul Disord 2003;13 (9):744-50.
35. Janda V. Muscle strength in relation to muscle length, pain and muscle imbalance. International Perspectives in Physical Therapy 8. Churchill Livingstone: Edinburgh, London, Madrid, Melbourne, New York and Tokyo. 1993: 83-91. In Janda Compendium Volume II. Distributed by OPTP, Minneapolis, MN. undated.
36. Lund JP, Donga R, Widner CG, Stohler CS. The pain-adaptation model: a discussion of the relationship between chronic musculoskeletal pain and motor activity. Can J Physiol Pharmacol 1991;69(5):683-94.
37. Leisman G, Shambaugh P, Ferentz AH. Somatosensory evoked potential changes during muscle testing. Int J Neurosci 1989;45:143-51.
38. Hsieh C, Phillips R. Reliability of manual muscle testing with a computerized dynamometer. J Manipulative Physiol Ther 1990;13(2):72-82.
39. Bullock-Saxton J, Murphy D, Norris C, Richardson C, Turnnel P. The muscle designation debate: the experts respond. J Bodyw Mov Ther 2000;4(4):225-41.
40. Haas M, Peterson D, Hoyer D, Ross G. Muscle testing response to vertebral challenge and spinal manipulation. J Manipulative Physiol Ther 1994;17(3):141-8.