On the reliability and validity of manual muscle testing: a literature review

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Abstract

Introduction
A body of basic science and clinical research has been generated on the manual muscle test (MMT) since its first peer-reviewed publication in 1915. The aim of this report is to provide an historical overview, literature review, description, synthesis and critique of the reliability and validity of MMT in the evaluation of the musculoskeletal and nervous systems.
Methods
Online resources were searched including Pubmed and CINAHL (each from inception to June 2006). The search terms manual muscle testing or manual muscle test were used. Relevant peer-reviewed studies, commentaries, and reviews were selected. The two reviewers assessed data quality independently, with selection standards based on predefined methodologic criteria. Studies of MMT were categorized by research content type: inter- and intra-examiner reliability studies, and construct, content, concurrent and predictive validity studies. Each study was reviewed in terms of its quality and contribution to knowledge regarding MMT, and its findings presented.
Results
More than 100 studies related to MMT and the applied kinesiology chiropractic technique (AK) that employs MMT in its methodology were reviewed, including studies on the clinical efficacy of MMT in the diagnosis of patients with symptomatology. With regard to analysis there is evidence for good reliability and validity in the use of MMT for patients with neuromusculoskeletal dysfunction. The observational cohort studies demonstrated good external and internal validity, and the 12 randomized controlled trials (RCTs) that were reviewed show that MMT findings were not dependent upon examiner bias.
Conclusion
The MMT employed by chiropractors, physical therapists, and neurologists was shown to be a clinically useful tool, but its ultimate scientific validation and application requires testing that employs sophisticated research models in the areas of neurophysiology, biomechanics, RCTs, and statistical analysis.

Review

The role of the muscle system in spinal function has become increasingly well acknowledged. Manual muscle testing (MMT) as a method of diagnosis for spinal dysfunction has not been well utilized. This paper will present evidence that the MMT can be a legitimate and useful evaluation tool for the assessment of the musculoskeletal and nervous systems.

There are many ways of examining the nervous system and the musculoskeletal system. It has been proposed that the term neuromusculoskeletal system be adopted because examination of the one may reflect the status of the other [*1*,*2*]. The evaluation methods of many manipulative therapists often focus at either end of the nervous system, and this paper suggests that MMT provides a method of examining both (the central and the peripheral) ends.

MMT is the most commonly used method for documenting impairments in muscle strength. Limited muscle testing methods are taught in a number of chiropractic schools around the world, however in 2006 a major "stand alone" chiropractic technique that employs MMT for the evaluation of patients known as applied kinesiology chiropractic technique (AK), turned 42 years old. We propose in this review to look at the research status of MMT in the manual examination of the nervous system's status. The early years of the AK method are related elsewhere in detail [*3*]. The specific protocols and clinical objectives of the technique have been described in previous publications [*3*-*9*].

AK has therefore been used by a proportion of the chiropractic profession for over 42 years and is now used by other healing professions. In a survey by the National Board of Chiropractic Examiners in 2000, 43.2% of respondents stated that they used applied kinesiology in their practices, up from 37.2% of respondents who reported they used AK in 1991, [*10*-*12*] with similar numbers reported in Australia [*13*]. The general public's awareness of MMT and AK has also been increased worldwide by virtue of the patient education program Touch for Health (T4H) designed by an International College of Applied Kinesiology (ICAK) diplomate, John Thie. T4H was one of the first public self-help programs and there are claims that it is the fastest growing "body work" program in the world, used by over 10 million people [*14*].

For the purposes of this review we define MMT as a diagnostic tool and AK as a system for its use and therapy based on the findings of the MMT

In this paper we pose the following questions: 1) "Is the MMT approach worthy of scientific merit?" and 2) "How can new diagnostic and treatment techniques employing MMT be critiqued for scientific merit?" and 3) "Does this evidence add scientific support to chiropractic techniques (such as AK) that employ the MMT?"

Another main objective of this literature review was to investigate the evidence for intraexaminer reliability, interexaminer reliability, and validity of MMT in the assessment of patients.

Methods

Online resources were searched using Pubmed and CINAHL (Cumulative Index to Nursing and Allied Health literature). The search terms "manual muscle test", "manual muscle testing", and "applied kinesiology" found over 100 articles in which the MMT was used to document strength in patients with 17 (primarily pain related) diseases/disorders, ranging from low back pain and sacroiliac joint pain to neck pain, post-whiplash syndrome, knee, foot, and shoulder pain, and included MMT for the evaluation of patients with post-polio syndrome, amyotrophic lateral sclerosis, muscular dystrophy, cerebral palsy, Down syndrome, mastalgia, hypothyroidism, dysinsulinism, enuresis and several other disorders of childhood.

After abstracts were selected for relevance and the papers acquired and reviewed, the literature was sorted according to relevance and quality. Inclusion criteria were that the report had a Cohen's kappa coefficient of 0.50 or higher (the magnitude of the effect size shown in the study to be significant) in regards to the intra- and inter-examiner reliability, and/or the validity (construct and content validity, convergent and discriminant validity, concurrent and predictive validity). This selection criteria is consistent with the one suggested by Swinkels et al for the evaluation of the quality of research literature [*15*]. Randomized clinical trials (n = 12), prospective cohort studies (n = 26), retrospective studies (n = 17), cross-sectional studies (n = 26), case control studies (n = 10), and single-subject case series and case reports (n = 19) were the types of studies reviewed. Studies with a control group (a randomized clinical trial), examiner blinding, and pre- and post-test design are indicated in the descriptions of each study. Duplicates and articles published in non-peer-reviewed literature were excluded.

Statistical presentations of the data are presented showing the average correlation coefficients of MMT examination upon the different patient populations for each study.

Operational Definitions and History of the Manual Muscle Test

In order to be meaningful, all measurements must be based on some type of operational definition. An operational definition is a description of the methods, tools, and procedures required to make an observation (i.e. a definition that is specific and allows objective measurement). Kaminsky and Fletcher et al provide clinicians with some strategies to critically analyze the scientific merit of manual therapies [*16*,*17*].

A basic understanding of operational definitions is required in order to make judgments about the methods used in articles and to know which research findings should be implemented in practice. For example, how should we judge the value of the MMT for the gluteus maximus or gluteus medius muscles in cases of sacroiliac joint pain and dysfunction, knowing that statements range from "weakness of the gluteals is usually present in dysfunction of the sacroiliac joint" (Janda 1964) [*18*] to "the results of this study cast doubt on the suitability of manual muscle testing as a screening test for strength impairments"? (Bohannon 2005) [*19*].

Within the chiropractic profession, the ICAK has established an operational definition for the use of the MMT:

"Manual muscle tests evaluate the ability of the nervous system to adapt the muscle to meet the changing pressure of the examiner's test. This requires that the examiner be trained in the anatomy, physiology, and neurology of muscle function. The action of the muscle being tested, as well as the role of synergistic muscles, must be understood. Manual muscle testing is both a science and an art. To achieve accurate results, muscle tests must be performed according to a precise testing protocol. The following factors must be carefully considered when testing muscles in clinical and research settings:

• Proper positioning so the test muscle is the prime mover

• Adequate stabilization of regional anatomy

• Observation of the manner in which the patient or subject assumes and maintains the test position

• Observation of the manner in which the patient or subject performs the test
• Consistent timing, pressure, and position
• Avoidance of preconceived impressions regarding the test outcome
• Nonpainful contacts – nonpainful execution of the test
• Contraindications due to age, debilitative disease, acute pain, and local pathology or inflammation"

In physical therapy research, the "break test" is the procedure most commonly used for MMT, and it has been extensively studied [*20-22*]. This method of MMT is also the main test used in chiropractic, developed originally from the work of Kendall and Kendall [*21*,*23*].

In physical therapy the "break test" has the following operational definition [*20-22*]. The subject is instructed to contract the tested muscle maximally in the vector that "isolates" the muscle. The examiner resists this pressure until the examiner detects no increase in force against his hand. At this point an additional small force is exerted at a tangent to the arc created by the body part being tested. The initial increase of force up to a maximum voluntary strength does not exceed 1 sec., and the increase of pressure applied by the examiner does not exceed a 1-second duration. "Strong" muscles are defined as those that are able to adapt to the additional force and maintain their contraction with no weakening effect. "Weak" muscles are defined as those unable to adapt to the slight increase in pressure, i.e., the muscle suddenly becomes unable to resist the test pressure.

For example in the seated test for the rectus femoris muscle, a seated subject is asked to flex his knee toward his chest 10 degrees; when that position is reached, the examiner applies resistance at the knee, trying to force the hip to "break" its hold and move the knee downward into extension. The ability of a muscle to lengthen but to generate enough force to overcome resistance is what is qualified by the examiner and termed "Strong" or "Weak."

The grading system is based on muscle performance in relation to the magnitude of manual resistance applied by the examiner. Scores are ranked from no contraction to a contraction that can be performed against gravity and can accept "maximal" resistance by the examiner, depending on the size of the muscle and the examiner's strength. However, in the AK use of MMT the implication of grades is limited to an interpretation of 'better' or 'worse', 'stronger' or 'weaker,' and no assumption is made about the magnitude of difference between grades.

MMT procedures are also commonly employed in clinical neurology as a means of subjectively evaluating muscle function. The examiner in the application of force to the subject's resistance evaluates the muscle groups being studied as subjectively "weak" or "strong" on a 5-point scale [*24*].

MMT is employed by physical therapists to determine the grades of strength in patients with pathological problems and neurologic or physical injuries (strokes, post-polio syndromes, fractures, post-surgical disabilities, etc.). The physical therapist's patients are often initially examined by a medical doctor who supervises the physical therapist's rehabilitation programs that may involve isometric, isokinetic, and isotonic muscle training regimes for the gradual rehabilitation of muscle function (often involving instruments and machinery).

In the absence of a pathological neurological deficit (pathological deficits were originally what physicians sought to find using MMT), [*25*,*26*] clinical inferences are made based upon the result of the MMT. This method of MMT is used in both chiropractic and physical therapy to determine a patient's progress during therapy [*3-9*,*20-23*].

MMT, when employed by AK chiropractors, is used to determine whether manipulable impairments to neurological function (controlling muscle function) exist. For example, chiropractic management using MMT for a patient with carpal tunnel syndrome could involve assessment of the opponens policis and flexor digiti minimi muscles (innervated by the median and radial nerves), and then adjustment as indicated to the carpal bones, the radius and ulna, attention to an inhibited (on MMT) pronator teres muscle, adjustment of the cervical or thoracic spines, and evaluation of cranial nerve XI through MMT of the sternocleidomastoid and upper trapezius muscles. Any or all of these factors may require treatment in order to strengthen the inhibited opponens policis and flexor digiti minimi muscles that are evidence of the carpal tunnel syndrome. This "continuous nervous system" thinking and testing may allow the identification of contributing sites to a pain state.

The expectation in a chiropractic setting is that the proper therapy will immediately improve muscle strength upon MMT, taking the patient from "weak" to "strong." This is the reason that in most chiropractic settings, the grading system of muscle evaluation does not have as much significance as it does in physical therapy settings. Chiropractic therapy may produce rapid responses for the innervation of muscles because the basic therapy required for chiropractic patients is decompression of the nervous system. It is purported that this can be done readily with chiropractic manipulative therapy (CMT) [*27-30*].

When performed by an examiner's hands MMT may not be just testing for actual muscle strength; rather it may also test for the nervous system's ability to adapt the muscle to the changing pressure of the examiner's test. A nervous system functioning optimally will immediately attempt to adapt a muscle's activity to meet the demands of the test. There appears to be a delay in the recruitment of muscle motor units when the nervous system is functioning inadequately [*66*,*71-73*,*82*,*90*,*102*]. This delay varies with the severity of the nervous system's impairment, and influences the amount of weakness shown during the MMT.

Determining the ideal operational definition of a MMT can be difficult given the large number of test variations that exist. All of the tests described by Kendall, Wadsworth, Goodheart, Walther and others [*3*,*20-23*] involve multiple joint movements and handling techniques. This results in a large number of variables that are difficult to control.

Because of the variability possible during a MMT, several studies examining MMT have used specialized instrumentation to provide support for the extremity tested and for standardization of joint position. Throughout its history manual muscle testing has been performed by practitioners' hands, isokinetic machines and other handheld devices.

However, isokinetic machines and dynamometers for more objective testing of muscles are still too expensive or cumbersome for clinical use, but this equipment is useful for research purposes [*20-23*].

Kendall et al (1993) [*21*] state:

"As tools, our hands are the most sensitive, fine tuned instruments available. One hand of the examiner positions and stabilizes the part adjacent to the tested part. The other hand determines the pain-free range of motion and guides the tested part into precise test position, giving the appropriate amount of pressure to determine the strength. All the while this instrument we call the hand is hooked up to the most marvelous computer ever created. It is the examiner's very own personal computer and it can store valuable and useful information of the basis of which judgments about evaluation and treatment can be made. Such information contains objective data that is obtained without sacrificing the art and science of manual muscle testing to the demand for objectivity."

According to Walther (1988) [*23*]:

"Presently the best 'instrument' to perform manual muscle testing is a well-trained examiner, using his perception of time and force with knowledge of anatomy and physiology of muscle testing."

Regardless of the methods or equipment one uses to standardize MMT in a clinical or research setting, it is most important that the test protocol be highly reproducible by the original examiner and by others.

Results

Research on the Reliability of the MMT

One-way researchers determine if a clinical test is consistent and repeatable over several trials is to analyze its reliability. The reliability of a diagnostic method is the consistency of that measurement when repeated. Depending on the type of measurement that is performed, different types of reliability coefficients can be calculated. In all coefficients, the closer the value is to 1, the higher the reliability. For instance, calculating Cohen's kappa coefficient allows the researcher to determine how much agreement existed between two or more doctors performing MMT on patients with low back pain. A value greater than .75 indicates "excellent" agreement, a value between .40 and .75 indicates "fair to good" agreement, and a value less than .40 indicates "poor" agreement [*31*]. The advantage of the kappa coefficient is that it is a measure of chance corrected concordance, meaning that it corrects the observed agreement for agreement that might occur by chance alone. There are difficulties with the interpretation of kappa and correlation coefficients that have been described by Feinstein and Brennan [*32*,*33*]. To examine the reliability coefficients calculated by the authors of MMT studies, see Table *1*.

Table 1. Characteristics of 10 studies of the intraexaminer and interexaminer reliability of manual muscle testing (RCTs indicated by **)

This review of the literature shows the importance of clinical experience and expertise, and this factor has been highlighted in many papers discussing the reliability of the MMT [*20-23*,*34-36*]. The skills of the examiners conducting studies on MMT and their skills in interpreting the derived information will affect the usefulness of MMT data. The examiner is obliged to follow a standardized protocol that specifies patient position, the precise alignment of the muscle being tested, the direction of the resisting force applied to the patient, and the verbal instruction or demonstration to the patient. All of these precautions have proven necessary to reliably study the validity of the MMT in the diagnosis of patients with symptomatology.

There was significant improvement in the degree of consistency of a given examiner's scores (as noted by Florence et al 1984) [*34*] when the examiner had more clinical experience and training in MMT. Mendell and Florence (1990) [*35*], Caruso and Leisman (2000), [*36*] and many other researchers of MMT have discussed the importance of considering the examiner's training on the outcomes of studies that assess strength via MMT [*20*-*23*].

Interexaminer reliability of the MMT has been reported by Lilienfeld et al (1954) [*37*], Blair (1955)[*38*], Iddings et al (1961) [*39*], Silver et al (1970) [*40*], Florence et al (1984) [*34*], Frese et al (1987) [*41*], Barr et al (1991) [*42*] and Perry et al (2004) [*43*]. Test-retest reliability has been examined by Iddings et al (1961), [*39*] Jacobs (1981) [*44*], Florence et al (1984) [*34*], Wadsworth et al (1987) [*45*], Mendell and Florence (1990) [*35*], Hsieh and Phillips (1990) [*46*], Barr et al (1991) [*42*], Florence et al (1992) [*47*], Lawson and Calderon (1997) [*48*], Caruso and Leisman (2000) [*36*], and Perry et al (2004) [*43*]. The levels of agreement attained, based upon +/- one grade were high, ranging from 82% to 97% agreement for interexaminer reliability and from 96% to 98% for test-retest reliability. The results of these studies indicate that in order to be confident that a true change in strength has occurred; MMT scores must change more than one full grade. In clinical research studies on chiropractic treatment, the change from an "inhibited" or "weak" muscle to a "facilitated" or "strong" muscle is a change in at least one full grade, and is a common result of successful treatment.

In the latter 11 studies, correlation coefficients are reported. These coefficients ranged from 0.63 to 0.98 for individual muscle groups, and from 0.57 to 1.0 for a total MMT score (comprised of the sum of individual muscle grades).

Using force measurements from both practitioner and patient, Leisman and Zenhausern demonstrated a significant difference in "strong" versus "weak" muscle testing outcomes and showed that these changes were not attributable to decreased or increased testing force from the practitioner performing the tests [*49*].

Table *1* provides a brief synopsis of several studies that investigated the reliability of MMT in both healthy and symptomatic subjects. The Table does not show the substantial amount of normative data that exists regarding muscle strength relating to patient age, position, tasks performed, and so on [*51*,*52*]. There also exists a large body of data demonstrating how electromyographic signals are used as an objective representation of neuromuscular activity in patients. The EMG is a valid index of motor unit recruitment and reflects the extent to which the muscle is active; however there are some difficulties with the sensitivity and specificity of electrodiagnosis [*53*]. All of these studies using MMT and instrumentation have collectively made a significant contribution to the study of neuromuscular function and represent different aspects of the muscular activity going on in patients.

Research On the Validity of MMT

The next section of Results looks at the relationship between muscle strength as measured by MMT findings and the functional status of patients with a variety of symptoms.

Validity is defined as the degree to which a meaningful interpretation can be inferred from a measurement or test. Payton (1994) [*58*] states that validity refers to the appropriateness, truthfulness, authenticity, or effectiveness of an observation or measurement. In examining research studies and examination techniques using MMT and spinal manipulative therapy (SMT), clinicians need to become familiar with several different types of validity.

Construct and content validity of MMT

Construct and content validity are two types of theoretical or conceptual validity. Generally, construct and content validity are proven through logical argument rather than experimental study. Construct validity is the theoretical foundation on which all other types of validity depend. Construct validity attempts to answer the questions, "Can I use this measurement to make a specific inference?" and "What does the result of this test mean?"

From the original work of Lovett (1915) [*25*,*26*] who developed MMT as a method to determine muscle weakness in polio patients with damage to anterior horn cells in the spinal cord, to the measurement of physical weakness from faulty and painful postural conditions, injuries, and congenital deformities [*20*-*23*,*59*,*60*], to neurologists who adopted MMT as part of their physical diagnostic skills, [*24*] to the use of MMT by some chiropractors beginning with AK technique to diagnose structural, chemical, and mental dysfunctions, the concept of manually examining the nervous system's status through MMT continues to evolve and gain adherents to this method [*61*]. The validity of Lovett's original MMT methods was based on the theoretical construct that properly innervated muscles could generate greater tension than the partially innervated muscles present in patients with anterior horn cell damage.

AK extends Lovett's construct and theorizes that physical, chemical, and mental/emotional disturbances are associated with secondary muscle dysfunction affecting the anterior horn of the spinal cord – specifically producing a muscle inhibition (often followed by overfacilitation of an opposing muscle and producing postural distortions in patients). Goodheart suggested, contrary to the physiotherapeutic understanding of the time, that muscle spasm was not the major initiator of structural imbalance [*3*,*6*]. According to Goodheart, the primary cause of structural imbalance is muscle weakness. Goodheart theorized that the primary weakness of the antagonist to the spastic muscle to be the problem. Muscle weakness (as observed by MMT) is understood as an inhibition of motor neurons located in the spinal cord's anterior horn motor neuron pool [*62*].

Chiropractic AK research has also suggested that there are five factors or systems to consider in the evaluation of muscle function: the nervous system, the lymphatic system, the blood vascular system, cerebrospinal fluid flow, and the acupuncture system [*3*,*6*].

Lamb states (1985) that MMT has content validity because the test construction is based on known physiologic, anatomic and kinesiologic principles [*63*]. A number of research papers have dealt with this specific aspect of MMT in the diagnosis of patients [*64*,*65*].

There have been a number of papers that have specifically described the validity of MMT in relationship to patients with low back pain. The correlation between "inhibited" or "weak" MMT findings and low back pain has been well established in the research literature. Several papers have shown that MMT is relevant and can be employed in a reliable way for patients with low back pain [*63*,*66*]. In a paper by Panjabi, it is proposed that the function of muscles, as both a cause and a consequence of mechanoreceptor dysfunction in chronic back pain patients, should be placed at the center of a sequence of events that ultimately results in back pain [*67*]. This paper argues that as a result of spinal dysfunctions (articular dysfunction, spinal lesions, and somatic dysfunction are terms also employed), muscle coordination and individual muscle force characteristics are disrupted, i.e. inhibited muscles on MMT. The injured mechanoreceptors generate corrupted transducer signals (that research suggests may be detected by EMG, dynamometers, and

MMT), which lead to corrupted muscle response patterns produced by the neuromuscular control unit.

This article may be important for those in the manipulative professions who are evaluating the existence and consequences of spinal dysfunction. The key technical factor in this hypothesis would be the MMT that makes the detection of the muscular imbalances and spinal dysfunction cited by Panjabi identifiable. Another paper by Hodges et al (2003) suggests this hypothesis also [*68*]. Pickar has also shown there is a substantial experimental body of evidence indicating that spinal manipulation impacts primary afferent neurons from paraspinal tissues, immediately effecting the motor control system and pain processing [*69*].

Lund et al (1991) [*70*] reviewed articles describing motor function in five chronic musculoskeletal pain conditions (temporomandibular disorders, muscle tension headache, fibromyalgia, chronic lower back pain, and post-exercise muscle soreness). Their review concluded that the data did not support the commonly held view that some form of tonic muscular hyperactivity maintains the pain of these conditions. Instead, they maintain that in these conditions the activity of agonist muscles is often reduced by pain, even if this does not arise from the muscle itself. On the other hand, pain causes small increases in the level of activity of the antagonist. As a consequence of these changes, force production and the range and velocity of movement of the affected body part are thought to be reduced.

This paper describes with fascinating similarity one of the major hypotheses in MMT and chiropractic, namely that physical imbalances produce secondary muscle dysfunction, specifically a muscle inhibition (usually followed by overfacilitation of an opposing muscle). A paper by Falla et al (2004) described a similar model but involving patients with chronic neck pain [*71*]. A paper by Mellor et al (2005) presented this model in relationship to anterior knee pain [*72*], and Cowan et al (2004) in relationship to chronic groin pain with another paper demonstrating this mechanism in patellofemoral pain syndrome [*73*,*74*].

According to several studies, patients with low-back pain have lower mean trunk strength than asymptomatic subjects (Nummi et al 1978, Addison & Schultz 1980, Karvonen et al 1980, MacNeill et al 1980, Nordgren et al 1980, Mayer et al 1985, Triano 1987, Rantanen et al 1993, Hides et al 1996, Hodges et al 1996) [*75*-*83*]. Lifting strength is also decreased in persons disabled with chronic low-back pain (Chaffin & Park, 1973, Biering-Sorensen 1984, Mayer et al 1988) [*84*-*86*]. Pain itself is possibly a strength-reducing factor, as is the duration of back pain (Nachemson & Lindh 1969) [*87*].

These studies do not always clarify whether a muscle weakness or imbalance is primary or secondary to low-back pain. In spite of this, muscle weakness has frequently been cited as a primary factor in the etiology of low-back pain. (See Table *2*) This is one of the bases on which Lamb argues that MMT has content validity [*63*].

Table 2. Characteristics of 8 Studies showing the prevalence of muscle dysfunction in patients with back pain (RCTs indicated by **)

A number of general MMTs have been employed by all primary contact practitioners for the examination of patients with sciatic neuralgia. Dorsiflexion of the foot and the great toe, plantar flexion of the foot and great toe, quadriceps weakness, and peroneal muscle tests are each indicative of the status of the sciatic nerve and its branches [*88*,*89*].

To test the construct validity of these original hypotheses, researchers have attempted to quantify the muscle weakness that occurs with specific clinical conditions such as low back pain and soft tissue injuries. (See Table *2*)

The Convergent and Discriminant Validity of MMT

Convergent validity exists when a test, as predicted, demonstrates a strong correlation between two variables. Discriminant validity exists when the test, as predicted, demonstrates a low correlation between two variables. These tests, when found to have the proper correlations, lend support to the construct validity of the method of testing.

The convergent and discriminant validity of MMT was examined in a study by Jepsen et al (2006) [*93*]. They examined the relationship between MMT findings in patients with and without upper limb complaints. The examiners were blinded as to patient-related information, and examined 14 muscles in terms of normal or reduced strength. With a median odds ratio of 4.0 (95%CI, 2.5–7.7), reduced strength was significantly associated with the presence of symptoms.

Perry et al (2004) showed excellent convergent and discriminant validity of MMT in 16 patients with and 18 patients without post-polio syndrome pathology. Subjects with pathology showed significant differences in mean muscle strength ($P < 0.01$). The predictive validity of MMT in patients with symptomatic post-polio syndrome affecting the hip extensor muscles was found to be excellent [*43*].

Pollard et al (2006) also studied the convergent and discriminant validity of MMT in order to determine if a positive correlation of therapy localization to the "ileocecal valve point" producing weakness on MMT could predict low back pain in patients with and without low back pain [*54*]. The study also aimed to determine the sensitivity and specificity of the procedure. Of 67 subjects who reported low back pain, 58 (86.6%) reported a positive test of both low back pain and ICV point test. Of 33 subjects, 32 (97%) with no back pain positively reported no response to the ICV point test. Nine (9) subjects (13.4%) reported false negative ICV tests and low back pain, and 1 subject (3%) reported a false positive response for ICV test and no low back pain. Their results demonstrated that the low back pain group had significantly greater positive results (inhibited MMT) than those of the pain free group. Assuming this study is sound it may demonstrate the convergent validity of the method of MMT in relationship to patients with low back pain. The discriminant validity of MMT was shown in this study by its ability to find a low number of positive test results in the pain free groups. However, before accepting these results it would be important for them to be reproduced in another study.

Studies like the ones described above and later in this review (that examine whether MMT can discriminate between abnormal and normal spinal function and pain states) contribute to the evidence available to clinicians supporting the validity of MMT.

Concurrent Validity of MMT

The concurrent validity of MMT has also been examined in several studies comparing strength scores obtained by MMT with strength readings obtained using quantitative instruments. The concurrent validity of a test refers to a test's ability to produce similar results when compared to a similar test that has established validity. The concurrent validity of the MMT would be examined when the MMT is compared to a "gold standard" confirmation diagnosis using EMG and/or dynamometer testing, for instance.

Many studies have compared the findings of MMT with dynamometer tests favorably. (See Table *3*)

Table 3. Characteristics of 8 studies examining the concurrent validity of MMT

Marino et al (1982) [*50*] and Wadsworth et al (1987) [*45*] showed significant reliability between handheld dynamometers and MMT. Scores measured with the dynamometers were consistent with the examiner's perception of muscle weakness (P less than 0.001) in both studies.

Leisman et al (1995) showed that chiropractic muscle testing procedures could be objectively evaluated through quantification of the electrical characteristics of muscles, and that the course of chiropractic treatments can be objectively plotted over time [*49*]. The use of EMG or dynamometers as a gold standard is arguable however because false positive or negative findings may exist, and these instruments measure different aspects of muscular activity [*20*]. Even the MRI (another diagnostic "gold standard") has been found to lack sensitivity and specificity. MRI can identify a lesion but cannot detail the relationship of the finding with the patient's symptoms [*94*].

There is increasing demand for objectivity in regard to muscle testing measurements. Electromyograms are expensive machines, and setting patients up on the machines in the clinical setting is time-consuming. A review of the literature on dynamometers reveals some of the problems associated with their use. These include problems with the actual forces measured by a hand-held dynamometer (HHD); providing the stabilization that is essential for controlling variables and for standardization of the testing technique; as even a slight tipping of the devise during testing can alter its results [*20-22*,*93*]. These are important factors when considering the cost-effectiveness and clinical usefulness of these other testing procedures for muscle strength assessment.

Predictive Validity and Accuracy of the MMT

A second form of validity is called predictive validity. Comparing a test to supporting evidence that is obtained at a later date assesses predictive validity.

The accuracy of a diagnostic test is usually determined by examining the ability of the test to assist clinicians in making a correct diagnosis. A good diagnostic test minimizes the probability of the clinician finding a positive response in healthy people and negative test results in people with dysfunction or pathology. A good diagnostic test therefore minimizes the probability of either a false positive or a false negative result. The accuracy of the test is defined as the probability that people who truly should have the positive response receive a positive response when the test is performed. The accuracy of the test is also defined as the probability that people who should truly have a negative response correctly receive a negative response when the test is performed.

Table *4* provides a brief summary of several studies that examine the presence of positive MMT in suspected disorders of neural origin.

Table 4. Characteristics of 14 studies examining the Clinical Relevance, Predictive Validity and Accuracy of MMT (RCTs indicated by **)

The Emerging Construct in the Research on MMT

In order to evaluate the scientific merit of MMT we have discussed the importance of the operational definitions, reliability and validity in MMT research. The original construct of the MMT was that it documented impairments in muscle strength. Muscle inhibitions (detected by MMT) are understood in chiropractic and AK to be reflective of an inhibition of motor neurons located in the spinal cord's anterior horn motor neuron pool as a result of dysfunction involving one or more of the "5-factors of the IVF" [*3-9,62*].

A complication to the original construct of MMT from Lovett and others has emerged with the increasing awareness that the responses to the MMT are not solely due to the denervation effects on neural tissues in conditions like polio, but also co-existing inputs to the spinal cord's anterior horn and the processing state of the CNS [*62*]. Chiropractic research and anecdotal evidence from clinical practice have also suggested that there are five factors or systems to consider in the evaluation of muscle function: the nervous system, the lymphatic system, the vascular system, cerebrospinal fluid flow, and the acupuncture system [*3-9,62*]. Chiropractic clinical experience and research has also suggested that dysfunction in a muscle may be caused by a failure of any of these systems and that the MMT response may provide important clues regarding the origin of that dysfunction. Applying the proper manipulative therapy may then result in improvement in the inhibited muscle, pain, movement and posture. (See Table *5*) However RCTs and other substantive research studies are required before we can assert with confidence the relevance of each of these factors.

Table 5. Characteristics of 19 case reports of positive experiences for patients (n = 1 – 88) treated with chiropractic AK technique

To be valid in this new model the MMT would have to reliably sample components of both the central and peripheral nervous systems and be performed in the context of a new, more holistic conceptual model of functional neurology. The future of chiropractic MMT research will depend upon demonstrating the validity and reliability of the MMT for evaluating these types of dysfunctions affecting the anterior horn motor neuron pool.

Understanding normal neuromuscular mechanisms is essential to identifying abnormal and also being able to physically test them. In this way the practitioner may be able to specifically determine areas of dysfunction and thereby individualize the treatment given. More importantly, MMT may allow the neuromuscular system to be used interactively (by examiner and patient) and as a key element in the assessment and treatment of the functional disorders of the patient. This ability to "manipulate" the neuromuscular system, with an aim of changing the patient's muscular function, postural balance and strength, and to measure the outcome is conceptually an important component of the chiropractic and AK approach to health care. If a patient's injury causes pain and dysfunction, an effective therapy may not only be in the elimination of pain but also an improvement in muscle function as evidenced by the same method of assessment originally used to diagnose the problem. This may add an important measure of objectivity to clinical practice, and potentially increase a patient's awareness about their body and their body's ability for improvement as a result of the therapy given.

To provide the strongest evidence for the use of chiropractic MMT techniques, more randomized controlled clinical trials (RCTs) and systematic reviews will be essential. Although RCTs will be required to document a cause-effect relationship between treatment and outcome, they are frequently impractical projects for the practicing clinician. This is frustrating because it is the clinician who depends on scientific proof that these techniques work.

One alternative is for groups such as ICAK and those who use AK and MMT methods to organize and fund these RCT's. Work so far in this area remains largely limited to reliability and observational studies. Unfortunately, there have not been significant efficacy studies in this area, nor have there been many significant efficacy studies conducted in the chiropractic research arena in general [*108*].

Nineteen examples of peer-reviewed published case reports using MMT and chiropractic AK protocols are presented in Table *5*. These 19 case studies demonstrate how the practicing clinician may help narrow the gap between practice and research.

Although case reports cannot prove a treatment's effectiveness, they can describe the performance of techniques in a way that can initiate an hypothesis for a future RCT. More case reports may also add to the body of knowledge in the field of chiropractic AK and MMT.

Conclusion

After 42 years of development and research, the chiropractic profession's use of MMT and AK chiropractic technique has become one of the many diagnostic methods from which some doctors of chiropractic draw their clinical procedures.

In the last forty years we have become more aware of the nervous system. This awareness has allowed us to evaluate patients more completely and from an integrated neuromuscular perspective. This holistic system of approach for the evaluation of neuromuscular function continues to be updated on a regular basis with new and exciting research. Much of the evaluation and treatment of patients using MMT and manual methods remains and will always remain an art. However, we must provide these artistic endeavors with a solid scientific foundation.

Although this narrative literature review offers considerable evidence about the reliability and validity of MMT as an examination tool, most of the rigorous, systematic research on this form of examination has emerged in just the past 30 years. Although evaluation of patients using MMT methods have been investigated with RCTs, prospective (cohort) studies, retrospective studies, single-subject case series and case reports, many questions about the MMT remain unanswered.

One shortcoming is the lack of RCTs to substantiate (or refute) the clinical utility (efficacy, effectiveness) of chiropractic interventions based on MMT findings. Also, because the etiology of a muscle weakness may be multifactorial, any RCT that employs only one mode of therapy to only one area of the body may produce outcomes that are poor due to these limitations.

A limitation of this review may involve research published outside the main databases searched, as well as research articles involving some form of muscle testing but not using the terms manual muscle test, manual muscle testing, or applied kinesiology as they may not have been accessed and included here. In addition this paper has not critically rated each study for its internal and external validity. Such a systematic review should be the subject of future research.

Throughout this paper we have tried to answer the question, "Are AK and MMT worthy of scientific merit?" In order to evaluate the effectiveness of MMT in the diagnosis of patients with musculoskeletal and nervous system problems, it is necessary to survey the full range of research studies that have addressed the topic, giving due consideration to the strengths and weaknesses of the studies in the literature.

Hopefully this literature review has stimulated a desire for others to review the current MMT literature and become an effective user of and contributor to chiropractic MMT research [*125*,*126*].

Competing interests

SCC is a Board Member for the International College of Applied Kinesiology (I.C.A.K.). GJG is the Research Director and Founder of the I.C.A.K. SCC and GJG both employ MMT and AK methods in their evaluation and treatment of patients.

Authors' contributions

SCC and GJG conceived the research idea. SCC acquired the papers and constructed the literature review. SCC and GJG critically appraised the studies. SCC and GJG drafted the manuscript and approved the final version for publication.

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