Chapter 7:
Outcome Assessment Measures in Chiropractic

Introduction

With the presentation of each new patient, clinicians are faced with the challenge of assessing clinical status, differentially diagnosing their condition, and monitoring patient progress. Within this mix of patient management, difficulty arises in objectively measuring patient clinical status. Aside from the primary objective of accurately understanding and describing a patient's clinical status, ever-increasing demands are placed on clinicians from a state and national regulatory standpoint as well as from the medico legal arena and third party reimbursement perspective. Assessing and identifying dysfunction is necessary in the development of objective outcome measures of spinal function. However, if an anatomical diagnosis for low back conditions is impossible 80% to 90% of the time[1], being able to differentiate normal spinal function from what is abnormal is fundamental to creating a diagnosis based on spinal function rather than aberrant anatomy. A diagnosis based on function and tools and techniques to quantify dysfunction provide a means to assess a patient's progress and current condition separate from their subjective perception of pain.

The chiropractic encounter has tended to be a high-touch, low technology health care model with more concern for the person than the disease[2]. Within this realm, *qualitative* assessments have predominated clinical assessments in chiropractic practice as well as medicine. Technological advances over the past few decades, however, have made a number of devices available for clinicians to objectively assess the spine and patient complaints. In addition, outcome assessment instruments have grown in popularity to document the effect a condition has on the patient's activities or quality of life. These advances have begun to bridge the gap between *qualitative* and *quantitative* assessments serving to raise the bar of objectivity in monitoring patient clinical status.

Building on the knowledge gained from patient history and physical examination, this chapter presents the progression of outcome assessment measures used in clinical practice. Through a review of the literature, the benefits and shortcomings of outcome measures are presented with specific emphasis upon usage and *clinical utility*. In this manner, perceptual, structural, functional, and physiological spine measurements will be introduced and characterized relevant to patient management. Herein, a rationale is presented for ordering and performing spinal assessments within the context of clinical decision-making. Through this discussion new insights serve to assist the clinician in more effectively managing patients with spinal complaints.

Introduction of Key Terms

Clinical Utility

Prior to discussing spine instrument measures, it is necessary to present several important key terms that will be used throughout this chapter. Because measurements made during the patient encounter provide the clinician with information to describe the patient's health, the usefulness of these measures must be clarified in order to base meaningful clinical decisions. Usefulness is known as *utility* and thus in the realm of clinical practice, the term *clinical utility* applies. Determining the *clinical utility* of a measure is perhaps the most important consideration in test selection. Clinicians must evaluate if a test is able to:

1) provide an accurate diagnosis;

2) provide evidence supporting the use of a specific treatment or treatment approach; or

3) enable the clinician to determine the true outcome or effectiveness of the treatment or intervention[3].

To choose the right test for the right patient at the right time is as much of an art as it is a science. To assist the clinician in this decision making process, an introduction of key terms will be discussed within the context of spine instrument measures.

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Qualitative vs. Quantitative Measures

Qualitative assessments determine the nature, as opposed to the quantity of the elements composing a test or measure. Inspection, palpation, and visual observations of patient structure or function are all examples of *qualitative* assessments used by clinicians. Whether the clinician is judging muscle strength by his or her kinesthetic sense, visually estimating range or quality of spinal motion through observation, or attempting to define tissue characteristics through palpation, such qualitative assessments can only estimate the clinician's perceived judgment.

Quantitative assessments, in contrast, express a numerical amount relative to the proportionate quantities of a test or measure. In the context of spine measurements, range of motion can be described in units of degrees, spinal displacements can be described in units of inches or centimeters, and physiological changes can be expressed, for instance, in units of temperature (degrees) or electrical signals (volts) or other relevant descriptors. *Quantitative* measures thus allow us to objectify clinical assessments in order to understand and communicate information in absolute terms as opposed to those that are ambiguous. Table 1 provides a comparison of commonly used qualitative measures in the chiropractic practice and their quantitative
counterparts using spine instrument measures.

Reliability

Because *quantitative* assessments use numbers to describe the entity being tested, they tend to be more reliable than *qualitative* measures. *Reliability* is the degree of stability exhibited when a measurement is repeated under identical conditions. *Inter-examiner reliability*, thus, refers to the agreement between clinicians performing identical tests. Along similar lines, *intraexaminer reliability* concerns the ability of a single examiner to achieve the same results each time a test is performed. Consistencies of results are dependent upon a number of factors including instrument error, the skill and proficiency of the clinician, patient compliance and the environment in which the test is performed. These considerations will be further discussed in context with the spinal measurements being presented in this chapter.

Validity

Reliability, however, must not be confused with *validity*, the extent to which a test, measurement or study measures what it purports to measure. Although a test or measure may be *reliable*, does not necessarily mean that it is *valid*. For example, it would be invalid to use a measure of leg length inequality to describe a patient's pain because such an assessment isn't intended to quantify pain. *Reliability* is a necessary but not sufficient condition for *validity*. For instance, if the dial of the scale is five pounds away from zero, one would over-report their weight by five pounds. Is the measurement consistent? Yes, but it is consistently wrong. The selection of the appropriate test is thus necessary for *validity*. The range of interpretations that can be put upon a test is another way to describe validity. Subcategories of validity further dissect the question of validity. Types of validity appear in Table 2.

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Table 1.
Qualitative clinical assessments and their quantitative counterparts

Test	Qualitative (Findings)	Quantitative (Units of Measurment
Perceived Pain, Disability, and/or Functional Status	Patients' subjective description (Patient demeanor)	-Outcome Assessment Instruments (numerical score compared to normative values)
Pain threshold or Pain tolerance	Palpation for pain (tenderness, grading of trigger points)	-Pressure Algometry (psi, kg/cm2, or Pa)
Posture	Visual postural analysis (i.e. Head tilt, high shoulder, etc.)	-Postural grid photography -Surface topographical measures -Computer assisted digitization -Diagnostic Imaging (x-ray, MRI, CT) (millimeters or degrees)
Range of Motion	Visual estimation (restricted mobility, pain production or reproduction)	-Inclinometric Measurement -Goniometric Measurement (degrees)
Intersegmental Range of Motion	Motion palpation (articular fixation, pain)	-Spinal stiffness assessments -Static/Quasi-static (N/m) -Dynamic (Kg-1, Kg, m/Ns, Ns/m, m/N) -Instantaneous axis of rotation (degrees) -Instantaneous helical axis (radians)
Muscle Strength	Muscle testing (grading 0-5)	-Dynamometric Measurement (kg or lbs.) -Computerized and Digital Equipment (kg or lbs.) -Load cell or Strain gauge types -B200 (kg or lbs.) -EMG (mV)
Muscle Endurance	Muscle testing (grading 0-5)	- Biering-Sorensen Test (Time duration, sec., of task performance) - EMG (median frequency analysis) (Hz)
Muscle Spasm	Palpatory myospasm Assessment	-Surface Electromyography (mV)
Nerve Function	Orthopedic/Neurologic Exam (i.e. mechanical tests, stretch tests, deep tendon reflex, dermatomal sensation)	-Nerve Conduction Velocity (ms) -Needle Electromyography (mV) -H-Reflex (mV) -Somatosensory Evoked Potentials (mV) -Current Perception Threshold (mV) -Thermography (degrees C or F)
Pathology	History, Inspection, Palpation (mass, rubor, calor, dolar)	-Diagnostic Imaging -Laboratory Analysis -Biopsy

**** Some Of The Listed Procedures In This Table and in this chpter May Not Be Conducted By Licensed Chiropractors (like needle EMG).*

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Table 2.
Types and definitions of validity measurements

Content validity	The extent to which the content of the test sufficiently covers the area it purports to measure
Construct validity	The degree to which inferences can legitimately be made from the measure or study
Concurrent validity	The ability of a measure to indicate an individual's present standing on the criterion variable
Convergent validity	The degree to which the validity of a measurement correlates to another measurement that is different, but related, and performed at the same time
Discriminant validity	The ability to correctly discriminate the findings into categories such as positive or negative, normal or abnormal, etc.
External validity	The extent to which the results of a test provide a basis for generalizations to other circumstances
Face validity	The degree to which a measurement fits with accepted theory
Internal validity	The approximate truth about inferences regarding cause-effect or causal relationships from the measure or study
Predictive validity	The extent to which the results of a test are predictive of the future nature of events

Accuracy and Precision

Also important to consider in test selection are the *accuracy* and *precision* of a measurement device. *Accuracy* is the degree to which a measurement represents the true value of the attribute that is being measured. The *accuracy* of a test is determined when possible by comparing results from the test in question with results generated from an established reference method. Weighing an object with a known mass, for example, can assess the accuracy of a weight scale. The ability to calibrate a device and regular calibration of equipment is therefore required to maintain *accuracy*. The *accuracy* of an instrument, however, cannot be adjusted beyond its *precision*. *Precision* is the reproducibility of a quantifiable result or an indication of the random error. To cite an example of the importance of *precision*, consider an inclinometry measure. If an inclinometer system has a standard error of five degrees for measuring range of motion, then differences significantly greater than five degree must exist to make any judgment about the significance of the results. Both the *precision* and *accuracy* of spine measurement instruments are important considerations when deciphering test results.

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Sensitivity and Specificity

Also important in understanding the meaningfulness of spine instrument measures are *sensitivity* and *specificity*.

Sensitivity represents the proportion of truly afflicted persons in a screened population who are identified as being afflicted by the test. In other words, *sensitivity* is a measure of the probability of correctly diagnosing a condition, or the true positive rate of a test. Consider, for instance the *sensitivity* of an MRI documented disc protrusion among back pain patients. Because disc protrusion is a common finding among asymptomatic individuals[4], the *sensitivity* of disc protrusion in back pain patients is low.

Specificity, on the other hand, is the proportion of non-afflicted persons who are so identified by the screening test. It is a measure of the probability of correctly identifying a non-afflicted person, or the true negative rate of a test. Laboratory evaluations commonly have high *specificity* in ruling out a diseased state. Ideally, a test should have 100% *sensitivity* and 100% *specificity*. In other words, the test always correctly identifies the disease state of the population tested. However, instruments used in physical examinations are imperfect and subject to both inherent and human error.

Interpretations from physical examination measures thus must be interpreted with caution and correlated with other significant findings.

Discriminabilty and Responsivity

Finally, clinicians must take into account whether the information gained from an instrument allows the clinician to distinguish between healthy and unhealthy patients. This characteristic, *discrimination*, is determined by making comparisons to normative database. Further considerations such as the number of healthy persons that test as diseased (f*alse-positive*) and the number of unhealthy persons who test as negative (*false-negative*) additionally assist in determining a measure's *discriminabilty*. Ideally, a highly discriminating test would have few *false-positive* and few *false-negative* results (Table 3).

Another term, *responsivity* or *response stability*, refers to the test's ability to provide consistent measurements with repeated use, over time. Without this attribute, it is difficult for a clinician to understand the value of a prescribed treatment regimen in pre-post assessment. Important in assessment of *responsivity* is whether the observed change that occurred is, in fact, in reality reflective of the change that actually occurred. Along these lines, if a measure was found to have a certain range of variability among days of the week, and a test was not performed on the same day, then the variability must be taken into consideration when making any meaningful interpretation from the test comparisons. For the clinician, it's understanding the benefits and limitations of the spine instrument measure that are of most importance in both test selection and interpreting results in the realm of clinical practice.

Table 3.
Relationships between sensitivity and specificity among tests for disease states

Test Result	Disease State	
	Disease	**No Disease**
Positive	True Positive (Sensitivity)	False Positive
Negative	False Negative	True Negative (Specificity)

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Clinical Considerations of the Pain Patient

Observations made from the moment a patient enters the office can reveal much about their condition. Antalgic postures, altered gaits and guarded movements are examples of presentations that reveal important information. After reviewing the patient history, even more knowledge is gained. Does the patient have pain or paresthesia in a dermatomal distribution suggesting possible nerve root involvement? Conversely, does the patient have local or referred (scleratogenous) type pain possibly arising from somatic structures such as the disc, facet, ligament, muscle, or viscera? While a standard neurological examination may help to confirm the presence of nerve root involvement, the same examination is poor in *discriminating* patients with somatic pain. Even more complex, are the uncertainties regarding psychosocial factors and patient motivations to consider when evaluating the pain patient. Within this context, this chapter will present a number of spine instrument measures that are designed to assist the clinician in quantifying patient presentation and outcomes.

In recent years, there have been significant advances in the understanding of the physiologic and biochemical processes that are involved in pain processing at a spinal level. The elucidation of these multifaceted processes has meant a shift away from the conceptualization of pain as a simple, "hard-wired", system with a pure, "stimulus-response", relationship. In fact, many patients report pain in the absence of tissue damage or any likely pathophysiological cause, which may be due to psychosocial factors[5], or be related to plastic changes within the nervous system[6].

The International Association for the Study of Pain defines pain as an unpleasant sensory and emotional experience associated with actual or potential tissue damage or described in terms of such damage[5]. Naturally, pain is subjective, and highly individualistic. Theorists view pain as not simply a sensation, but as a multidimensional phenomenon involving sensory, evaluative, emotional, and response components[7]. Each person learns the meaning of the word, pain, through experiences related to injury in early life[5], and personal, social, and cultural influences all are thought to play important roles in the pain phenomenon. Because pain, particularly persistent pain, is not often directly tied to specific pathophysiology, but rather is linked to integrated perceptions arising from neurochemical input, cognition, and emotion, the mind greatly influences the intensity of the pain[8]. Moreover, there is a poor association between objective measures of physical pathology and the amount of pain and disability that a patient may express[9]. These factors must be taken into consideration in the realm of patient management.

Clinical decision-making is based upon securing a working diagnosis from a review of the patient history, physical examination, standard tests, and imaging studies. In the center of this mix lays the patient and their complaints. While this chapter is not intended to provide a comprehensive review of the patient encounter, understanding the role that the patient plays in arriving at a diagnosis is of prime importance. Patient evaluations are not as simple as looking at test results. Comorbid factors such as patient motivation can further influence patient responses on a number of levels, from questionnaire responses to actual test performance. Patients have been known to amplify symptoms or functional status for a variety of reasons based in the human nature. Anxiety, stress, and emotional disturbances such as depression or hysteria may be responsible for elevated pain scores[10]. In addition, the effects of compensation, litigation, and employment have been named as influences in patient status and outcome[11,12]. It is clear that comorbid factors exist in patient status and recovery, thus, attentiveness in assessment of the *big picture* is important for clinicians to consider.

A great deal can be learned about a patient through observation. Test results should be interpreted in conjunction with observations made while the test is performed[13]. Observing characteristics such as quality of movements, facial expressions, and performance efforts combined with some standardized approaches to patient evaluation will assist in drawing meaningful conclusions of test results. A common misconception is the assumption that a single measurement is reflective of the patient's legitimate performance capacity. The use of repeated measurements and the use of related tests serve to validate whether test results are reflective of the organic lesion, or are influenced by

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patient motivation. Such procedures will be reviewed in the framework of the spine instrument measures presented in this chapter.

Recent models of spinal pain have been proposed to assist clinicians and researchers in developing useful evaluation and management protocols. Waddell[14] conceptualized the back pain problem as possessing three distinct elements:

Pain: an unpleasant sensory and emotional experience associated with actual or potential tissue damage, or described in terms of such damage;

Disability: diminished capacity for everyday activities and gainful employment; and

Impairment: an anatomical or physiological abnormality leading to loss of normal bodily ability.

While the three elements may be related, it is noteworthy that the strength of the relationship is not perfect and disassociation of the elements can occur.

Another model of disablement has been adapted to the physiotherapy management of low back pain[15]. This model is slightly different to Waddell's as it makes the distinction between a functional limitation and a disability.

Functional Limitations: restrictions in performance at the level of the individual (i.e., the ability to perform a task of daily living);

Disability: restrictions in the ability to perform socially defined roles and tasks expected of an individual (i.e., inability to work or participate in family social functions).

The distinction between functional limitations and disability helps explain why two patients with similar impairments and functional limitations may have very different levels of disability[15]. In common, however, is the fact that clinicians must make decisions based on interpretation of a multitude of test results.

Four kinds of measurements provide relevant information about patient clinical status and/or response to treatment. In general, they are:

1) *perceptual measurements* (i.e. reports of pain severity and pain tolerance),
2) *structural measurements* (i.e. anomalies, pathology, or posture),
3) *functional measurements* (i.e. range of motion, strength, stiffness, activities of daily living), and
4) *physiologic measurements* (i.e. neurologic assessment, laboratory examinations) (Figure 1).

The most prevalent complaint among patients presenting to a chiropractic office is musculoskeletal pain[16]. Thus, issues relevant to pain and patient motivations are noteworthy to understand the meaningfulness of spine instrument measures. Research aimed at assessing the quality and effectiveness of health care as measured by the attainment of a specified end result, or outcome is known as *outcomes assessment*. Such measures include parameters such as improved health, lowered morbidity or mortality, and improvement of abnormal states (perceptual, structural, functional, and/or physiological).

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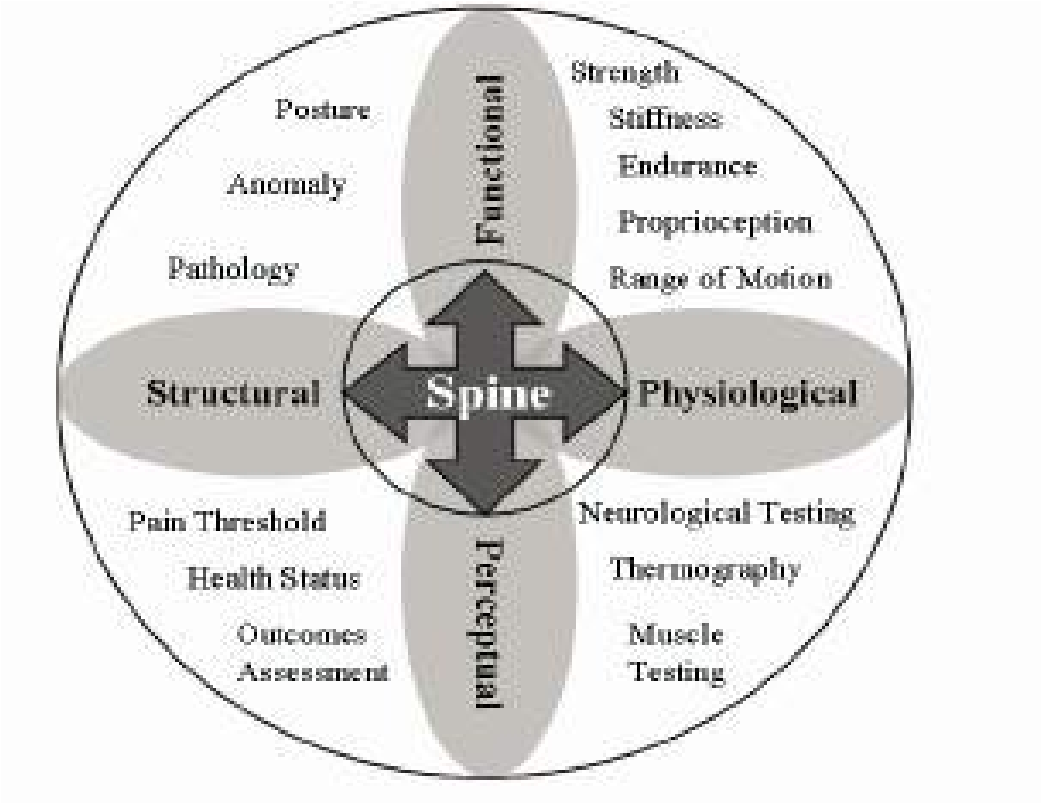
Figure 1.
Categorization of spine instrument measures (perceptual, structural, functional, and physiological) and the associated tests in each category



PERCEPTUAL MEASUREMENTS

Patients' perspectives are widely recognized as being essential in making medical decisions and judging the results of treatment[17]. Acknowledging the multi-factorial facets of the pain phenomenon, a number of instruments have been developed to assist the clinician in better understanding patient presentation and monitoring response to treatment. Measurements can be further divided into those tests that are primarily patient-driven (perceptual measurements) and those primarily clinician-driven (structural, functional, and physiological measurements). In this section, two useful perceptual measurements are presented, outcome assessment and disability questionnaires and algometry. *Perceptual measures* are based upon the conscious mental registration of a sensory stimulus. Thus, results from perceptual measurements are highly dependent on the patient's conscious responses to the question or stimulus.

Outcome Assessment & Disability Instruments

Outcomes assessment involves the collection and recording of information relative to health processes in an effort to quantify patient status or a change in patient status over time. A variety of questionnaires have been developed to take into account the patients self-report of their physical function and health. Important properties of any outcome assessment instrument include practicality (how long it takes to complete; how understandable it is to the patient; acceptability to the population being tested), precision (cross-sectional and test-retest reliability), validity, and responsiveness[18]. Although the field of patient-based outcome measures is relatively young, the number and types of measures are growing exponentially[19]. Outcome assessment instruments can be categorized into six

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classes: general health, pain perception, condition-specific, psychometric, disability prediction, and patient satisfaction outcome assessment instruments[20].

General Health Outcome Assessment Instruments

General health status measures are designed to broadly assess the concepts of health, disability, and quality of life[21]. One benefit of generic health status instruments is their practicality in terms of use in all patients, regardless of the illness or condition. Although generic health status is less responsive to changes in specific conditions than condition-specific measures, they are important for expansive comparisons of the relative impact of different conditions or treatments on the health of the population[21]. Developed from the Medical Outcomes Study (MOS), the *Health Status Questionnaire*[22], also known as the short form (*SF-36*) or *SF-12* (denoting its number of questions) is a commonly used instrument in managing patients with spinal complaints. A number of other general health assessment instruments are available to clinicians including the *Sickness Impact Profile* (*SIP*)[23], the *Nottingham Health Profile* (*NHP*)[24], the *Duke Health Profile* (*DUKE*)[25], instruments developed out of the *Dartmouth Primary Care Cooperative Information Project* (*COOP*)[26], and the *Quality of Well-Being Scale*[27]. Table 4 describes these general health outcome assessment instruments.

The *SIP*, *NHP*, *DUKE*, and *COOP* charts have been used to some extent in the study of patients with back pain and appear to measure similar concepts of health. These and have been reasonably well studied in terms of their reliability and validity. Of the available general health outcome assessment instruments, *The Health Status Questionnaire* (*SF-36*) appears to have several advantages over the other generic measures due to its ease of use, acceptability to patients, and its fulfillment of stringent criteria of reliability and validity. McDowell and Newell[28] describe the *SF-36* as having a, "meteoric rise to prominence." Population and large-group descriptive studies and clinical trials to date demonstrate that the *SF-36* is very useful for descriptive purposes such as documenting differences between sick and well patients and for estimating the relative burden of different medical conditions. In fact, the *SF-36* has been the topic of study in over 1,000 publications[29]. The usefulness of the *SF-36* is illustrated in articles describing more than 130 diseases and conditions. Among the most frequently studied conditions are arthritis, back pain, depression, diabetes, and hypertension with more than twenty *SF-36* publications dedicated to each[29]. The SF-36 appears to strike the best balance between length, reliability, validity, responsiveness, and experience in large populations of patients with back pain[30]. Because it is short, the *SF-36* leaves ample room for administration of other more precise general and specific measures at the same sitting.

Pain Perception Outcome Assessment Instruments

Pain Intensity

Pain intensity is a quantitative estimate of the severity or magnitude of perceived pain. The three most commonly used methods to assess pain intensity are the *verbal rating scales* (*VRS*), *visual analog scale* (*VAS*), and *numerical rating scale* (*NRS*)[31]. These pain intensity scales are described in Table 5. Positive and negative attributes of the pain intensity scales are discussed elsewhere[20,31]. *VAS* and *VRS* instruments have been found to correlate well, but have differences in the range of categories relative to the VRS[32]. NRS instruments have been found to be easy to administer and score, and can therefore be used in a greater variety of patients (*e.g.*, geriatric patients, patients with marked motor difficulties) than is possible with the VAS. Additionally, the validity of the NRS has been well documented in demonstrating positive and significant correlations with other measures of pain intensity[33]. Comparing the *VRS*, *VAS*, and 11-point *NRS*, Bolton et al.[34] further recommended the 11-point NRS for most types of outcome studies, given the advantages of responsive evaluative measures. Noteworthy was their finding that asking patients to report their usual pain levels, rather than current levels, enhances the responsiveness of the measures and is a more representative perspective of their pain experience[34].

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Table 4.
General Health Outcome Assessment Instruments

Instrument	Description
Health Status Questionnaire (HSQ) (SF-36, Rand-36, MOS-36)	Multipurpose, short-form health survey with 36 Questions (shortened version, SF-12 has 12 questions). It yields an eight-scale profile of scores as well as physical and mental health summary measures.
Sickness Index Profile (SIP)	136 items grouped into 12 categories: ambulation, mobility, body care and movement, social interaction, alertness behavior, emotional behavior, communication, sleep and rest, eating, work, home management, and recreation.
Nottingham Health Profile (NHP)	38 item questionnaire grouped into six dimensions: physical abilities, pain, sleep, social isolation, emotional reaction, and energy.
Duke Health Profile (DUKE)	17 questions grouped into six health and four dysfunction scores. The health scores are physical health, mental health, social health, perceived health, and self-esteem (physical, mental, and social health scores are further aggregated into a general health summary score). The dysfunction scores are anxiety, depression, pain, and disability
Dartmouth COOP Chart (COOP)	6 single-item scales including physical fitness, feelings (mental wellbeing), daily or usual activities, social activities, overall health and change in health.
Quality of Well-Being Scale	Preference-weighted measures of symptoms and functioning to provide a numerical point-in-time expression of well-being, ranging from 0 for death to 1.0 for asymptomatic optimum functioning

Pain Affect

Aside from quantifying pain intensity, *pain affect* is the degree of emotional arousal or changes in action readiness caused by the sensory experience of pain. This dimension of pain relates to the distress of an individual and can lead to fear-avoidance behaviors and interference with daily activities. The most widely used measure of pain affect is the affective subscale of the *McGill Pain Questionnaire* (*MPQ*)[35]. The *MPQ* has come to be known as a *gold-standard* as a pain assessment tool with established reliability and validity[31]. The *MPQ* consists of twenty category scales of verbal descriptors of pain categorized in order of severity and grouped into four subscales: sensory discrimination, affective, evaluative, and miscellaneous. In this manner, a total score or separate sub-scores for each subscale can be calculated. A short form of the *MPQ* has also been studied with positive results[36].

As previously noted, pain is not an independent dimension, but dependent upon the emotional, motivational and somatosensory attributes of the patient. Thus, a score on a pain rating scale is not a pure measure of the patient's pain, but is heavily influenced in unknown ways by the patient's emotional and motivational state[37]. Clinicians should take into account the factors that influence pain

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scores to improve validity. Taking the average of several pain measures across time or across measures can assist in the reduction of erroneous reports of pain.

Table 5.
Pain intensity scales

Pain Intensity Instrument	Description
Verbal Rating Scale (VRS)	Patients read over a list of adjectives describing levels of pain intensity and choose the word or phrase that best describes their level of pain. (0-3 score, 3=worst).
Visual Analog Scale (VAS)	Patients place a mark on a 10 cm line (on paper, or using a mechanical device), with ends labeled as the extremes of pain (10=worst), to denote their level of pain intensity. A quantifiable score is derived from millimetric measurement (0-100).
Numerical Rating Scale (NRS)	Patients verbally (or using a pencil) rate their pain from 0-10 (11-point scale), 0-20 (21-point scale), or 0-100 (101-point scale) to rate their pain intensity (highest score worst).

Pain Location

Observing the location of a patient's pain can give important clues of its etiology or source. The *pain diagram* allows the patient to visually communicate the perception of the location and distribution of their symptoms pictorially (Figure 2). The pain diagram consists of the front and back outlines of a body onto which the patient draws using different symbols to indicate the quality of pain they are experiencing. A score can be derived from points totaled from the number of body regions marked as painful, and the number of different pain qualities reported by the patient. In addition, the size of the painful areas can be quantified. Ohnmeiss[38] studied the repeatability of pain drawings in a chronic low back pain population and found high intraobserver reliability and stability over time. Pain diagrams have also been found to be related to intervertebral disc pathology revealed on diagnostic imaging studies[39;40]. A number of other studies have also demonstrated the reliability and clinical usefulness of the pain diagram in the evaluation and management of patients with musculoskeletal complaints[41-43].

Condition-Specific Outcome Assessment Instruments

To determine the effect a patient's condition has on their activities of daily living, a variety of condition-specific outcome assessment instruments have been developed. While pain quality, intensity, timing, and distribution, reveal important qualities of the patient's condition, the effect that the condition has on the patient's function or disability is of prime importance. The hallmark of a condition-specific measure is the attribution of symptoms and functional limitations to a specific disease or condition[44]. Unlike items in a generic measure, items in a disease-specific measure assess only those aspects of health that tend to be affected by the disease. The goal is to achieve high relevance and responsiveness of the scales without undue burden to the patient[45].

A number of instruments specific to the spine or spine related complaints have evolved out of the need for reliable and valid measures of patient functional status in clinical trials. What have developed are a number of condition-specific instruments for spine related complaints that are suitable for use in everyday clinical practice (Table 6). While it is not the purpose of this chapter to provide a comprehensive review of the numerous condition-specific outcome assessment questionnaires, some of the most commonly used indices are presented.

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Figure 2.
Pain diagram depicting the body region method of scoring described by Margolis et al. (Reprinted, with permission, from Margolis RB, Tait RC, Krause SJ. Pain 1986;24:57– 65.13
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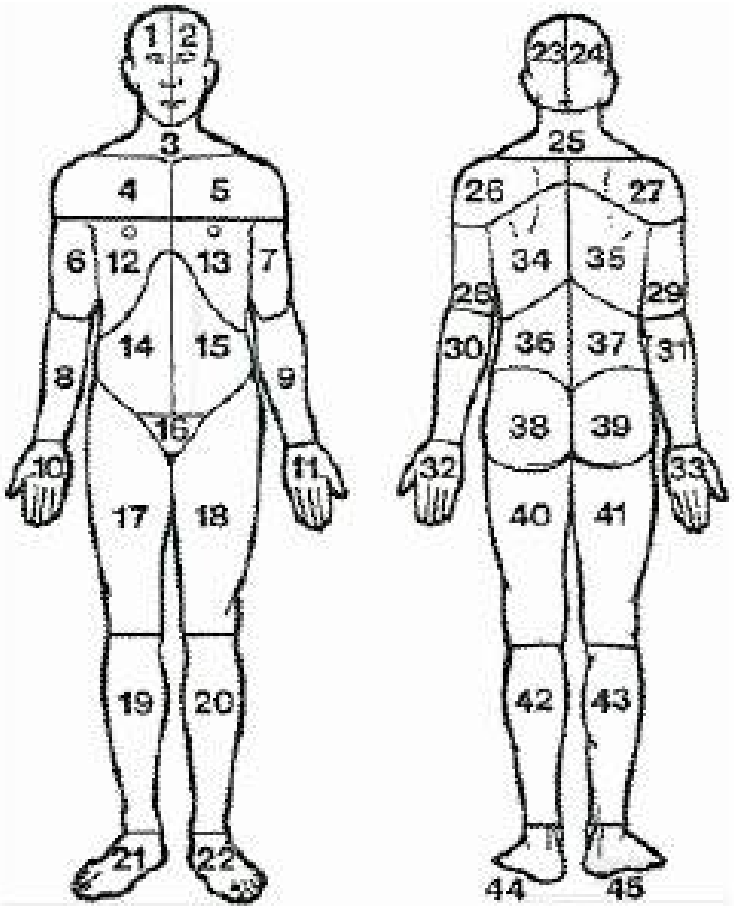

Among the many reliable and valid instruments presented in Table 6 the following questionnaires are emphasized due to their ease of use and implementation in clinical practice. The Oswestry Disability Index (ODI), was developed by Fairbank et al.[46] and later revised[47]. The ODI consists of 10 items assessing the level of pain and interference with several physical activities, sleeping, self-care, sex life, social life, and traveling. The scale is one of the most widely used outcome measures for patients with low back pain. Roland and Morris[48] created a back-specific scale, the Roland-Morris Disability Questionnaire (RMDQ) by selecting 24 items from the SIP (*e.g.*, "I avoid heavy jobs around the house," "I sleep less well," "I stay at home") and adding the phrase, "because of my back." The scale has become popular among back pain researchers and has been translated into several languages[44].

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Table 6.
Condition-specific outcome assessment questionnaires pertaining to the spine

Back
- Oswestry Disability Index[46;47]
- Million Visual Analogue Scale[257]
- Roland–Morris Disability Questionnaire[48]
- Waddell Disability Index[258]
- Low Back Outcome Score[259]
- Clinical Back Pain Questionnaire (Aberdeen Low Back Pain Scale)[260;261] (applies to the neck also)
- Low Back Pain Rating Scale[262]
- Quebec Back Pain Disability Scale[263]
- North American Spine Society Lumbar Spine Questionnaire[264]
- Resumption of Activities of Daily Living Scale[265]
- Bournemouth Questionnaire[266;267]
- Functional Rating Index[268] (applies to the neck also)

Neck
- Neck Disability Index[50]
- Headache Disability Inventory[52]
- Copenhagen Neck Functional Disability Scale[269]
- Migraine-Specific Quality of Life Questionnaire[53]

While the RMDQ can be used in chronic back pain patients, often it is the preferred measure for administration to acute low back pain suffers as its questions appear to be more applicable to those with more recent pain. The RMDQ may be better suited to settings in which patients have mild to moderate disability and the ODI to situations in which patients may have persistent severe disability[49]. Both the ODI and RMDQ instruments have been recommended by experts as a prime choice for clinicians managing patients with back pain[30]. Similar to the ODI, The Neck Disability Index (NDI)[50] also consists of 10 items assessing the level of neck pain and inference with activities of daily living. The NDI possesses stable psychometric properties and provides an objective means of assessing the disability of patients suffering from neck pain[51]. For general use, the Headache Disability Inventory (HDI)[52] is useful in assessing the impact of headache and its treatment on daily living, although other specific headache questionnaires are available[53].

Psychometric Outcome Assessment Instruments

Researchers and health care providers alike attest to the importance of the role that psychosocial factors play in influencing the effectiveness of treatment regimens. By definition, psychosocial influences are those issues involving both psychological and social aspects (i.e. age, education, work, marital and related aspects of a person's history). Such influences can have an effect upon pain perception, adaptation to pain, functional status, and ultimately quality of life. In addition, patient motivation, conscious or subliminal dimensions of attitude and belief systems among patients further co-found health related predicaments.

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Depression, anxiety, and personality disorders have been identified as the most frequently occurring psychiatric conditions associated with persistent pain[20]. Incorporation of psychometric outcome assessment tools may assist in understanding these comorbid factors. With such a variety of instruments available, it is confusing for chiropractors to determine which tool is best for use in their practice. As a general recommendation, the Health Status Questionnaire used in conjunction with the patient history may serve as general screening tools for the presence of significant psychosocial factors relating to a patient's condition. Once identified, further assessment of specific conditions or disorders can be conducted with more sensitive indices. Table 7 lists several psychometric outcome assessment instruments available for use in clinical practice.

Table 7.
Selected psychometric outcome assessment instruments. (Adapted from Yeomans[20] Table 4-6).

Psychometric Instrument	**Evaluative Conditions**
Beck Depression Inventory	*Depression*
Modified Zung Depression Index	*Depression*
Health Status Questionnaire	*Depression, Health Perception*
Modified Somatic Perception Questionnaire	*Perceived Depression*
Waddell's Non-organic Low Back Pain Signs	*Non-organic Low Back Pain*
Somatic Amplification Rating Scale	*Non-organic Low Back Pain*
Fear Avoidance Beliefs Questionnaire	*Chronic Pain/Fear Avoidance Behavior*
Anxiety Sensitivity Index	*Anxiety*
Distress and Risk Assessment Method	*Depression, Anxiety*
Symptom Checklist-90 (SCL-90)	*Anxiety and Depression*

Patient Satisfaction Outcome Assessment Instruments

The growing regulation of health care has created ever-increasing requirements of accountability from health care providers. Patient satisfaction measures have been developed to assess the health care experience in the eyes of the patient. Common areas of inquiry include the patients' satisfaction with their visit, satisfaction with their overall care, convenience, technical quality of care, continuity of care, and satisfaction with the financial policies of the office. Because these measures begin to distance themselves from the focus of this chapter, the reader is directed elsewhere for further discussion of patient satisfaction issues.

Implementing outcome assessment tools into clinical practice is as easy as employing any other procedure into the office environment. Many of the questionnaires are easy to use, understand and implement without compromising valuable time and staffing resources. To gain information on treatment outcomes, it is necessary to administer outcome assessment instruments before, during and after a treatment plan.

Algometry

Among the most commonly used physical examination procedures, palpation is used for a number of clinical indicators, such as temperature, texture, passive mobility, and pain response. Due to the qualitative nature of palpation, more objective means have been developed to compliment traditional palpation procedures. Pressure algometry (dolimetry, palpametry, algesiometry, or pressure threshold measurement) was introduced in 1949[54] as a method to quantify and document the sensitivity of pain, and the term algometer was later coined in 1954[55]. In the past 20 years, algometry has become increasingly used in both research and clinical settings to objectively assess *pain threshold* and *pain tolerance*.

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Pain threshold is defined as the minimum amount of pressure that induces pain or discomfort.

Pain tolerance, in contrast, is the maximum amount of pressure that a patient can tolerate under clinical conditions.

Pain threshold assessment is a more reasonable approach to utilize in clinical practice as it does not cause any undue pain or harm to the pain patient and will be the focus of this section.

Pain pressure thresholds are obtained through the use of an algometer. The algometer consists of a force gauge (typically 11 kg range) attached to a plunger with a 1 cm^2 rubber disc surface[56] (Figure 3). Today, various hand-held algometer devices are available on the market from simple force and strain gauges to more complex digital and computerized systems (Table 8). These devices can be used to assess pain threshold or tolerance of any musculoskeletal body part or region including the spine and paraspinal musculature and are usually applied over areas of muscle tenderness or trigger points. Typically, the algometers are calibrated in Newtons (N), recorded in kg/cm2 which can be converted to units of pressure, Pascals (N/m2) by multiplying by the acceleration of gravity in ms–2 and by dividing by the cross-sectional area in m2. In the case of a device with an 11 kg range, the stress range is 11 kg/cm2 or 1.08 MPa (1.08 million Pascals). The algometry devices also allow for the recording of measurements and resetting the device in between uses.

Figure 3.
Hand-held algometer (Neuromechanical Innovations, Phoenix, AZ) (Left) and Commander PainTrack™ (J-Tech Medical Industries, Salt Lake City, UT) (Right) being administered to the lumbar spine

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Table 8.
Algometer devices

Device, Manufacturer	Characteristics
Algometer, Neuromechanical Innovations, Phoenix, AZ	Hand-held spring loaded force gauge
Pressure Threshold Meter, Pain Diagnostics & Thermography, Great Neck, NY	Hand-held spring loaded force gauge
Pain Track, J-Tech Medical Industries, Salt Lake City, UT	Hand-held load cell with digital read out or computerized software
Pressure Algometer, Somedic Sales AB, Farsta, Sweden	Hand-held digital strain gauge

Algometry Examination

To administer an algometry examination, patients are first informed of the procedure by explaining the nature and purpose of the test to be performed. Patients are first shown the device and explained that a gradually increasing pressure will be applied to their perceived areas of pain by placing the instrument stylus against the skin. Patients are instructed to say, "yes" or "now" when they begin to feel pain or discomfort, at which time the examiner ceases applying pressure. Tests can be applied to skin overlying the spinous processes, or over the adjacent spinal musculature to assess differences from side to side or among spinal levels or spinal regions[57]. A number of studies have found the use of algometry to be a reproducible, reliable, and valid measure of pain perception[58-62].

Several factors should be considered in minimizing sources of error in algometry testing. Identification of spinal landmarks is of specific importance in side to side testing. The use of a skin-marking pencil can help to improve accuracy of measures and repeated measures. Another important factor in algometry is the rate of force application. During testing, the force should be applied at a rate of 1 kg/sec, and no additional pressure should be applied after the patient signals a painful response.

Clinical Significance of Algometry Results

Fischer has been responsible for a number of investigations into the use of algometry. Normative data for pain pressure *threshold* has been determined among genders and for side-to-side differences[58]. In addition, normal values have been reported for pain pressure *tolerance* over both muscle and bone[59]. In general, pain pressure thresholds of less than 3 kg/cm^2 or side to side differences exceeding 2 kg/cm^2 are deemed clinically relevant indicators tenderness or pathology[63]. In the instance of bilateral pathology, Fischer recommends comparing values to an adjacent normal area as a reference, or using data one standard deviation below mean normal values (84% cutoff). Women appear to have significantly lower pressure pain thresholds than men[58;64]. Among spinal levels, the cervical region has been found to have lower pain pressure threshold scores than thoracic and lumbar regions respectively[65]. Normative values for pain pressure tolerance adapted from Fischer are shown in Table 9. Using the patient as their own control may be more useful than comparison to standard normative values[66]. Algometry is a useful clinical indicator of pain sensitivity in a variety of musculoskeletal conditions including headache[67], whiplash injury[68], fibromyalgia[69], and myofascial syndromes[70].

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Table 9.
Mean pain pressure threshold values (kg/cm^2) obtained from right and left sides in normal persons (From Fischer[58])

Muscle	Females		Males		Gender Difference
	Mean	S.D.	Mean	S.D.	
Upper Trapezius	3.7	1.9	5.4	2.8	2.5*
Pectoralis Major	-	-	5.4	2.4	-
Levator Scapulae	4.6	1.9	5.6	2.2	2.2*
Teres Major	4.2	1.5	6.4	2.3	3.9**
Supraspinatus	4.6	2.2	6.7	3.0	2.8**
Gluteus Medius	6.5	2.8	6.8	2.7	0.5^{NS}
Infraspinatus	5.4	2.8	7.3	2.8	2.4*
Middle Deltoid	5.1	2.3	7.7	2.7	3.6**
L4 Paraspinals (2 cm lateral to midline)	6.1	2.4	8.8	2.4	3.9**
L4 Paraspinals (4cm lateral to midline)	6.8	3.0	9.0	2.7	2.6*

*p<0.05; **p<0.01; NS = not statistically significant

STRUCTURAL MEASUREMENTS

Structural measurements of the spine consist mainly of visual observations, surface topographical instrumentation, and diagnostic imaging techniques. Inspection of the human frame in general entails a postural assessment, which will be discussed in greater detail below. Imaging techniques such as plain film radiography, magnetic resonance imaging (MRI), and computed tomography (CT) allow for assessment of hard and soft-tissue pathology as well as the global and intersegmental structure of the spine. Dimensional (mm) measurements can be used to objectively define anatomy or pathology such as denoting the size of a disc protrusion, or quantifying spinal conditions such as spinal stenosis. Further attempts to quantify structural measures in this regard include recent implementation of grading criteria in the evaluation of disc protrusion[71] and degeneration[72]. Diagnostic imaging also provides visualization of spinal anomalies. Both spinal anomalies or variants and pathology have relationships to spinal structure and function.

Surface Topography

Radiographic measurements provide a quantitative assessment of spinal conditions such as scoliosis in units of degrees which is held as a gold-standard[73]. Aiming to reduce radiation exposure, surface topographical assessments of the spine have also been used in scoliosis monitoring. Although not as valid or reliable as radiographic methods, surface topographic methods do provide an inexpensive non-invasive means to assess the human frame[74]. Recently however, extremely sensitive computerized equipment has been developed to quantify 3-D surface topography of humans and objects. Such technology has been put to use in the field of animations within the motion picture industry, while other applications have included the biomechanics laboratory. The cost of these systems makes them cost-prohibitive for the clinical practice.

Moiré Topography

Moiré topography is a photographic technique highlighting surface contours of the body[75]. Using this method, contour shadows are produced by using a grid placed between an angled light source and the patient. The relative number of resulting concentric contour lines on a Moiré

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photograph are proportional to the elevation of a landmark with respect to a reference surface[76]. Inasmuch, accurate patient positioning to maintain the grid-to-patient distance constant is essential for comparison to follow-up evaluations. Benefits of Moiré topography include its ease of use and inexpensive cost[77] and the recent aid of computerized enhancement of Moiré images has been found to improve upon its reliability and validity[78]. Shortcomings of Moiré topography include its lack of clinical utility and ignorance among students and practitioners of its application and use in private practice.

Scoliometer

The Scoliometer (National Scoliosis Foundation, Watertown, MA) consists of an inclinometer used to measure axial trunk rotation during forward bending. While the Scoliometer has been found to have acceptable interexaminer reliability, the measurement error shows poor precision for thoracic and lumbar Scoliometer measurements[79]. Coté et al.[79] found that the qualitative Adam's forward bend test is more sensitive than the Scoliometer in detecting thoracic curves measuring 20 degrees or more by the Cobb method leading the authors to believe that it remains the best noninvasive clinical test to evaluate scoliosis. The forward bending test, widely used in scoliosis screening, is associated with high false-positive rates, thus, direct surface measurement of the spinal curvature by digitization of the spinous processes used
in combination with the forward bending test has been found to increase the predictive value of detecting scoliosis without sacrificing sensitivity[80].

Karachalios et al.[81] investigated the diagnostic accuracy of the Adams forwardbending test was further compared with radiography and Moire topography, the Scoliometer, and the Humpometer in 2700 pupils aged 8 to 16 years screened for scoliosis initially and at 10 year follow-up. For scoliosis, the Adams forward-bending test showed a number of false negative results (in five cases), for a sensitivity of 84.37% and specificity of 93.44%. The sensitivities of Moiré topography, the humpometer, and the scoliometer were 100%, 93.75%, and 90.62%, respectively, and specificity was 85.38%, 78.11%, and 79.76% respectively. The negative predictive value of the forward-bending test was inferior to those of the other methods. The authors concluded that the wide-spread use of school scoliosis screening with the use of the forward-bending test must be questioned.

Flexicurve

Another device to measure surface contour is the Flexicurve device, a clinical adaptation of an architect's drafting tool used to accurately approximate curved lines. A study using the flexicurve has reported intraobserver variability of 3-4 degrees of movement, was not significantly influenced by intrasubject variability, and provided measurements typically within 6 degrees of radiographic measurements[82]. Caution is needed in inferring vertebral alignment from observed surface contours due to variances in tissue thickness and spinous process lengths[83]. Nevertheless, postural assessment plays an important role in spinal measurements.

Posture

Human posture may be defined as the position or carriage of the body as a whole having both genetic and habitual influences. Posture literature has often held that the relationship of the line of gravity to the body has a functional significance to the musculoskeletal system since rotational moments are created if the line of gravity and the centers of weight-bearing joints do not coincide[84]. While the relationship between posture and musculoskeletal pain is controversial, a number of studies have determined an association between posture and musculoskeletal pain[85-87]. Abnormal posture increases load on pain sensitive discoligamentous tissues causing extraneous efforts to be endured by the muscular stabilizing system of the spine[88]. Increased muscular activity of the trunk muscles has been associated with back pain[89-91]. Posture also has an effect on resultant spinal function including coupling patterns[92; 93] and range of motion[94]. Postural changes and sustained loading on the spinal joints have further been found to increase stress concentrations in the intervertebral discs[95-97], and

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posterior elements of the spine[98]. Increased loading and spine injury have been found to be a precursor to spinal degeneration[99; 100]. This concept of abnormal posture, has led to a number of investigations to define normal posture[101-104].

Postural Analysis

There have been numerous methods of posture evaluation in the literature. These include simple plumb line analysis, degree measurements on photographs, computer goniometers, optoelectric devices with computer, 2-D computerized digital analysis, and 3-D computerized digital analysis[105-107,108,109;110]. Until the late 1980s, these postural assessments were mostly qualitative. General terms such as head tilt, high shoulder, and low hip have often been used to describe body stature. Attempts to quantify posture include plumb-line analyses to determine the amount of postural asymmetry and bilateral weight scales to measure weight differences on each limb.

Biomechanical principles (applying mechanics to a living organism) can be applied in assessment of posture. A basic theorem in physics and engineering holds that the movement of any object can be decomposed into a *rotation*, *translation*, and *deformation*. *Rotation* can be defined as a circular movement in degrees, *translation* as a linear or straight-line movement, and *deformation* as a change in size or shape of an object. By the 1970s, researchers were using this fundamental engineering principle to describe the motion of spinal segments as rotations and translations in 6 degrees of freedom (DoF). The possible movements of a spinal segment are illustrated in Figure 4. These movements can be qualitatively classified as rotations (R) on each axis denoted with the listings of Rx, Ry, and Rz and translations (T) along each axis, listed as Tx, Ty, or Tz[111].

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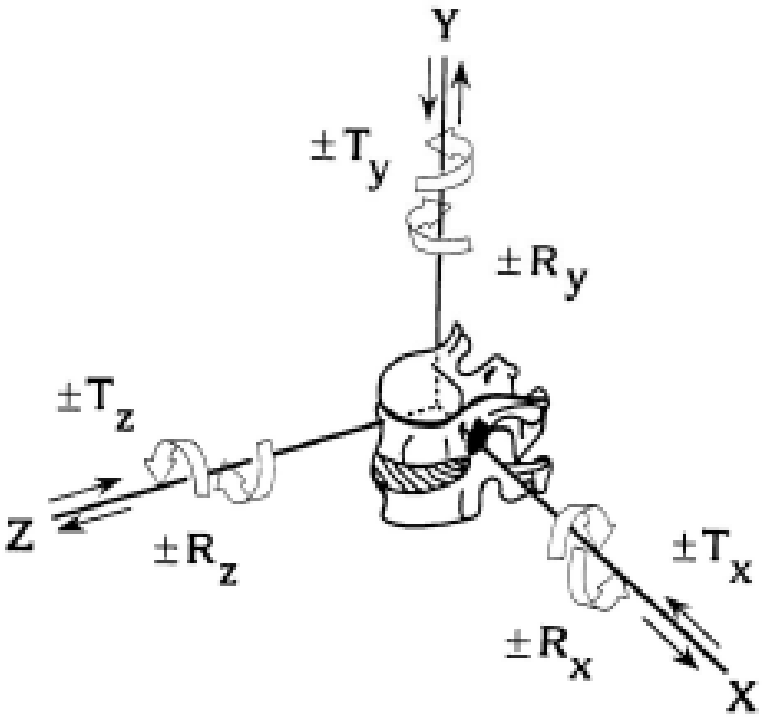
Figure 4.
Degrees of freedom of a typical lumbar vertebra. A vertebra can rotate (Rx, Ry, Rz) around the three axes of a 3-dimensional Cartesian coordinate system. It can also translate (Tx, Ty, Tz) along these axes. This provides 6 degrees of freedom. (Reprinted with permission from Harrison DE et al. Three-dimensional spinal coupling mechanics: Part I. A review of the literature. J Manipulative Physiol Ther 1998; 21(2): 101-113)



In the early 1980's, Harrison applied the Cartesian coordinate system to upright posture in categorizing the possible permutations as combinations of the simple postural rotations (Rx, Ry, Rz) and translations (Tx, Ty, Tz) of the head (H), thoracic cage (TC), and pelvis (P)[112]. Breaking posture down into an assessment of rotations and translations of the head to thorax, thorax to pelvis, and pelvis to feet in 6 DoF is Harrison's original contribution to the knowledge base of postural assessment[112]. As opposed to qualitative assessments describing a head tilt or a high shoulder, posture can be quantitatively described as measures of the rotations (Rx, Ry and/or Rz) (in units of degrees), and translations (Tx, Ty, and/or Tz) (in millimeters or centimeters) can be made. Figure 5 illustrates the possible single static AP and lateral postures. Combining single postures in combination provides *128 million* possible upright human postures in static equilibrium.

To perform a postural analysis, anatomical landmarks are viewed visually, or marked on photographic images and digitized using computer software to quantify each posture from defined points. The suggested landmarks are medial and lateral maleolus, mid-knee, mid-lateral thigh, pubic symphysis, mid-ASIS in AP view, ziphoid, episternal notch, upper lip, glabella, EAM, the shoulder AC joint, medial elbow, hand, and posterior gluteus muscles. Figure 6 illustrates most of these

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anatomical landmarks used for postural evaluation of global rotations and translations. In Figure 6, the global postural regions (head, thoracic cage, and pelvis) are measured relative to an origin in the global part immediately below.

Using grid photography, a quantitative analysis of posture can be performed utilizing fixed reference points. In this manner, translational displacements can be measured in degrees and rotations can be measured in degrees to quantify postures of the head, thorax and pelvis. Figure 7 provides an example of grid photography for common postures of the head in relation to the thorax. Postural analysis requires training and skill, as many postures present as combined postures of two or more main motions. For example, since the mass of the thoracic cage is large, as mentioned above, the anterior/posterior translations of the thoracic cage (±TzTC) not only will cause mid thorax to be displaced a perpendicular distance from a vertical line through mid-pelvis in the lateral view, but will also cause the opposite pelvic translation with concomitant pelvic tilt. Inasmuch, this may be cause for confusion when looking at a superior global body part without determining the position of the immediate inferior global part. Using a consistent postural assessment protocol, the global object being evaluated can be systematically compared to the global object below.

Table 10 lists common postural presentations and the postures they represent. Certain postures require radiographic confirmation for differentiation. For instance, thoracic cage flexion/extension is more difficult to visualize, without checking vertical alignment of T1 and T12 on a lateral radiograph, and will also cause the opposite pelvic forward/backward translation concomitantly. Vertical translations of the thoracic cage (±TyTC) are difficult to decipher without noting a straightening or hyper-lordosis of lumbar spine on a lateral radiograph. Extremity joint positions and anomalies can also be responsible for errors in postural analysis.

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Figure 5A.
Degrees of Freedom of the global postural parts. Similar to a typical vertebra in Figure 5, the head, thoracic cage, and pelvis have 6 degrees of freedom in 3-D, i.e., three rotation (R) axes (x,y,z) (A) and three translation (T) axes (x,y,z) (B) are possible. (Reprinted with permission: Harrison DE, Harrison DD. Spinal Biomechanics for Clinicians. Evanston, WY: Harrison CBP Seminars, Inc., 2002)

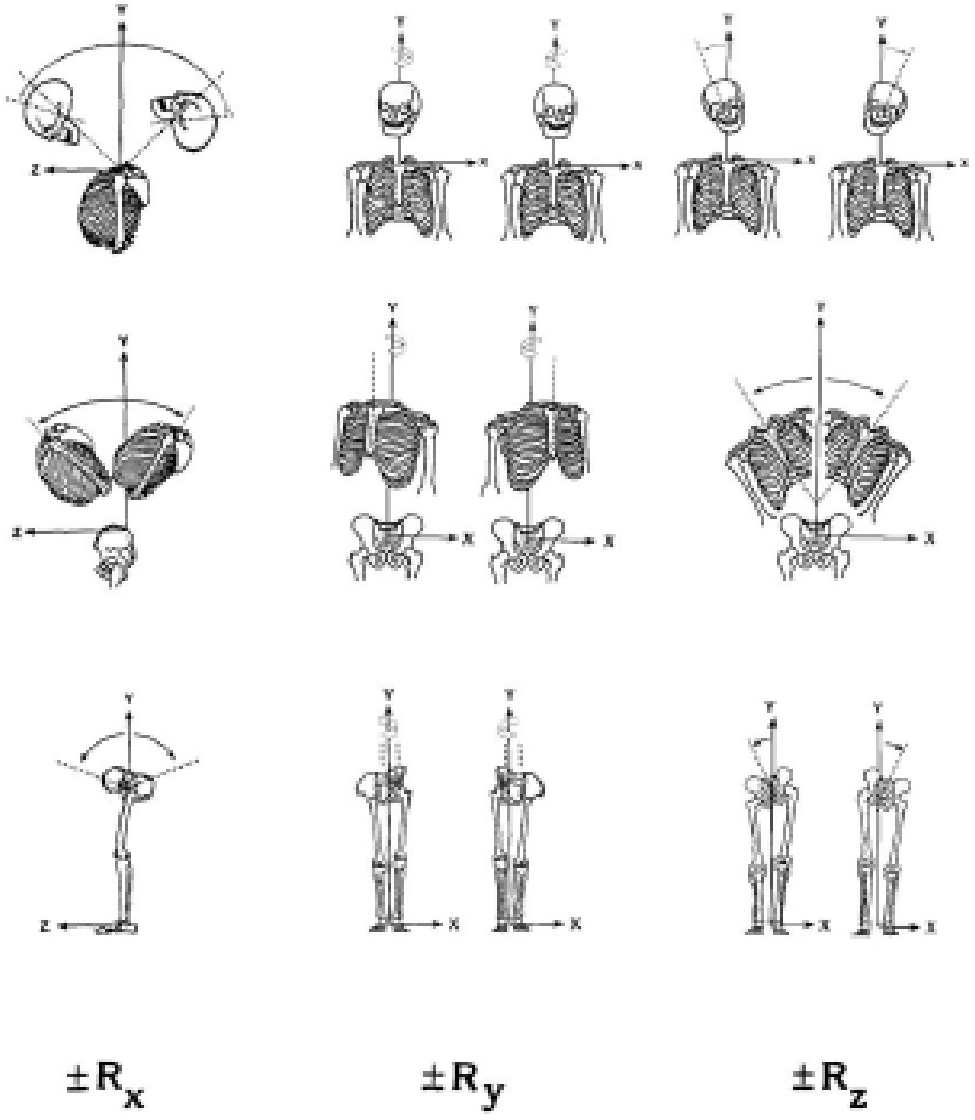

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Figure 5B.

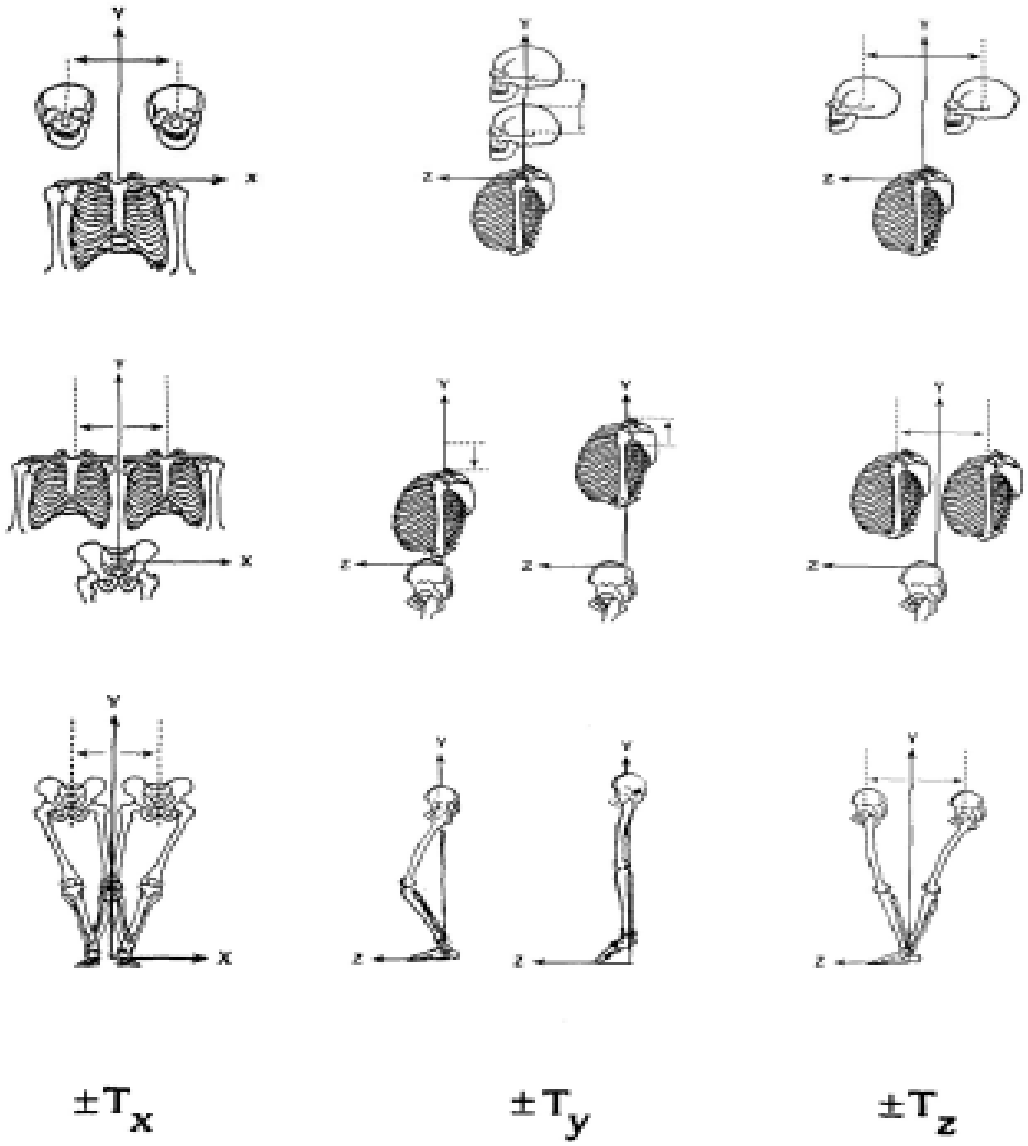

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Figure 6.
Anatomical points of reference used for postural assessment to determine rotations and translations of the head, thoracic cage, and pelvis. (Reprinted with permission from Harrison DD. Chiropractic: The Physics of Spinal Correction. CBP Technique. Evanston, WY: Harrison CBP Seminars, Inc., 1994)

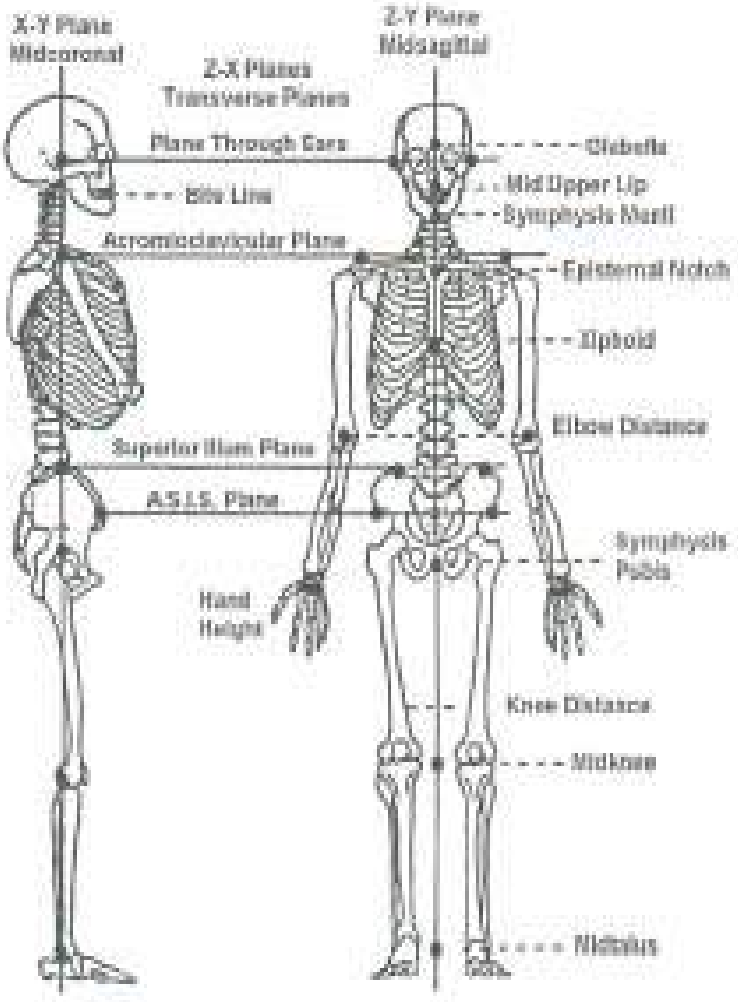

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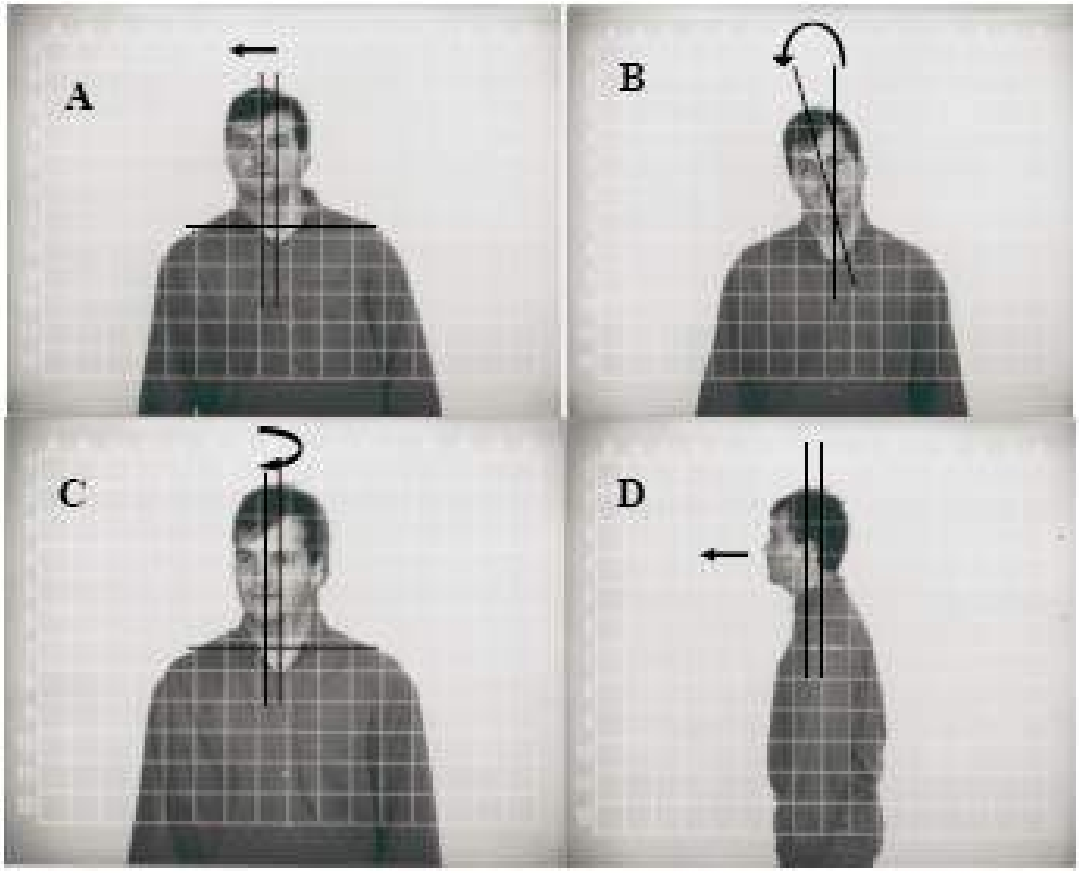
Figure 7.
Quantitative postural assessment using grid photography. A) Right lateral translation of the head in relation to the thorax (+RxH) is noted as straight line movement of the head about the x-axis. B) Right lateral flexion of the head to thorax (+RzH) is viewed as an angulation of the head about the vertical or y-axis. C) Right rotation of the head to thorax (-RyH) is visualized where the glabella and upper lip are both off center from the episternal notch. D) Anterior translation of the head (+TzH) is appreciated where the head is displaced forward upon the thorax. Using grid photography, translations can be measured as displacements in millimeters and rotations as angles measured in degrees to referenced points on the grid. (Photograph with permission from Lyndon Greco, D.C., Elk Grove, CA.)



FUNCTIONAL MEASUREMENTS

Assessment of spinal function across various dimensions of mobility, strength, endurance, and coordination provides a rational approach to clinical assessment, rehabilitation strategies, and determination of return-to-work potential for injured employees[113]. Objective, quantitative measurements of function provide he clinician with a definition of the patient's physical capacity, and succeeding tests document changes in performance with treatment. Understanding the benefits and limitations of the different functional measurements their clinical utility and generalizability serves to assist the clinician better managing patients.

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Table 10.
Key anatomical signs in the qualitative performance of postural assessment

Anatomy	View	Observation	Posture
Feet	AP/Lat	Flat feet, high arch, in-toeing, or out-toeing	Pronation (Pes planus), supination (Pes cavus), internal (Pes varus) or external rotation (Pes valgus)
Knees	AP/Lat	Bow legged, knock knees, or knee sway back	Genu varus, Genu valgus, or knee hyperextension
Pelvis	AP	Pubic symphysis deviation (left or right) and legs slanted	Lateral pelvic translation ($\pm Tx^{P}$), possible short leg
Pelvis	AP	Pubic symphysis deviation and one hip forward	Pelvic rotation ($\pm Ry^{P}$)
Pelvis	Lat	Pelvis forward of the feet	Anterior translation of the pelvis ($\pm Tz^{P}$)
Thoracic Cage	AP	Shoulders level, but extra spacing between the elbow and the pelvis	Thorax translation ($\pm Tx^{TC}$)
Thoracic Cage	AP	Low shoulder or hand	Thoracic lateral flexion ($\pm Rz^{TC}$)
Thoracic Cage	Lat	Plane of the shoulders not parallel with the plane across the buttocks	Axial rotation of the thorax ($\pm Ry^{TC}$)
Thoracic Cage	Lat	Thorax anterior / posterior to pelvis	Thoracic translation ($\pm Tz^{TC}$)
Head	AP	Both the upper lip and glabella displaced laterally from a vertical line through the episternal notch	Lateral translation of the head ($\pm Tx^{H}$)
Head	AP	An angle of the line through the glabella and upper lip compared to vertical	Lateral flexion of the head ($\pm Rz^{H}$)
Head	AP	Asymmetrical appear of the face; one side of the face will be wider as the opposite side ear is hidden	Axial rotation of the head ($\pm Ry^{H}$)
Head	Lat	Horizontal displacement of the EAM from a vertical line through the shoulder AC joint	Anterior/posterior translations of the head ($\pm Tz^{H}$)
Head	Lat	Inferior or superior position of the hardpalate, bite line, and gaze angle of the eyes	Flexion/extension of the head ($\pm Rx^{H}$)

Range of Motion

Assessment of spine mobility in the most basic sense involves the visual observation of a patient during motion. Whether it is assessment of ambulation or gait, performance of physical tasks or athletic performance, or spinal range of motion, observing for abnormalities or restrictions have traditionally provided qualitative assessments of a patients' mobility or spinal flexibility[114]. During qualitative assessment of range of motion both the amount and quality of spinal motion should be observed and determination should be made of movements that reproduce or aggravate symptoms. Reproduction of symptoms or an increase in the intensity of local or referred symptoms upon spinal

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motion can help to differentiate mechanical back pain from a visceral source. In addition, the reproduction of pain or paresthesia symptoms in a dermatomal distribution can serve to identify the presence of an inflamed or compromised spinal nerve root. Along similar lines, spinal motions have been put to use in a functional attempt to challenge the symptom production capacity of spinal anatomy.

Centralization describes the phenomenon of distally referred or radicular symptoms resolving toward midline during changes in posture or spinal loading.

Peripheralization, is the term used to describe the distal infiltration of symptoms during specific spinal motions.

Investigations into the correlations of symptom distribution upon mechanical testing and pathological conditions such as disc protrusions, and correlations to prediction of clinical outcome have shown promise in recent work[115;116].

Inclinometry

In the course of clinical practice, range of motion is often examined using goniometers, inclinometers and optical based systems. Most devices quantify the regional movement of a spinal region and express it as an angular displacement (in degrees) about a center of rotation[13]. *Goniometers* are 180° or 360° protractors joined by a movable arm used to quantify the motions of extremity joints. Range of motion of the spine or trunk, however, requires the use of *inclinometers*, devices that are used to measure angular motions with reference to gravity. Inclinometers have been found to be more reliable than goniometers for measurement of spinal motions as goniometers require alignment of one axis with the center plane of a joint. Inclinometers, in contrast, can be simply rested against a body part for assessment of motion about an axis relative to the constant of gravity.

Mechanical inclinometers use a fluid level or a gravity-weighted needle or pendulum to signal angular motions. Examples of mechanical inclinometers popular in chiropractic practice are the CROM and BROM devices (Performance Attainment Associates, St. Paul, MN) that are used to measure cervical and lumbar ranges of motion. The CROM device has 3 inclinometers, one to measure in each plane, rests on the subjects face similar to a pair of eyeglasses and is strapped to the head. One gravity dial meter measures flexion and extension, another gravity dial meter measures lateral flexion, and a compass meter measures rotation via 2 magnets placed over the subject's shoulders (Figure 8). The advantage of the CROM over a single inclinometer method is that it does not need to be moved to measure movement in another plane. The CROM has demonstrated greater reliability than visual estimates or use of a universal mechanical inclinometer in measuring range of motion[117]. Research has also shown that the CROM has acceptable intratester and intertester reliability[118] and was found to be valid for measurements of cervical flexion and extension in another study[119]. In testing passive range of motion testing using the CROM device, Nilsson noted that combining movements in the same plane gives more reliable results[120] and further noted that the experience of the examiner may be an important factor in reliability testing[121]. The more cumbersome BROM II device uses straps to hold the inclinometers in place and inasmuch, this may contribute to the less reliable intertester reliability results that have been reported in the literature[122;123]. The CROM and BROM have many benefits including their affordable cost and ease of application.

The American Medical Association's *Guides to the Evaluation of Permanent Impairment, 5th edition,* recommends a *Range of Motion Model* when assessing physical impairments. According to AMA Guides[124], performance of spine range of motion entails the use of two inclinometers to account for accessory spinal motions during spine flexion, extension, lateral flexion, and rotation. The use of two inclinometers is termed dual inclinometry (Figure 9). Table 11 provides information about patient positioning, inclinometer placement, and normative values for range of motion testing according to AMA Guides[124]. In measuring range of motion, the examiner should select at least three consecutive measurements and calculate the mean or average of the three. If the average is less than 50°, three of the measurements must fall within 5° of it; if the average is greater than 50°,

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three measurements must fall within 10% of it. Such methodology accounts for more accurate readings in accounting for the standard errors of measurement inherent in the device. Measurements may be repeated up to six times to obtain three consecutive measurements that meet these criteria in order for the test to be valid. Electronic dual inclinometers come in both digital and computerized forms. Advantages of this technology include quick calibration, automatic subtraction of accessory motions from the second inclinometer, and hands free documentation.

Figure 8.
The CROM device used for measuring cervical range of motion. Mechanical inclinometers mounted in a plastic head harness on the front and sides of the device enable testing of flexion, extension, and lateral bending, whereas a horizontally mounted top inclinometer is enabled through magnets placed around the neck for polarization of the inclinometer

The reliability of spinal range of motion measurements using electronic inclinometers has been substantiated in several studies[125-127], while other studies have attributed unreliable results to examiner error[128]. Mayer et al.[129] also has emphasized that the clinical utility of range of motion measurements are highly sensitive to test administrator training and measurement accuracy (bony landmarks, "rocking" of inclinometer on landmarks, etc.). Standardizing examiner techniques such as avoidance of tilting the inclinometer during testing, applying adequate manual pressure to keep the inclinometer in good contact with the anatomical landmark without slipping, and proper stabilization with use should assist in obtaining more reliable results with testing. Electronic digital and computerized inclinometers offer several advantages, such as the automatic calculation and recording of range of motion, allowance for comparisons of multiple tests for validity criterion, and calculation of impairment from the results (Tracker, J-Tech Medical Industries, Salt Lake City, UT).

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Table 11.
Patient positioning, inclinometer placement and normative data for range of motion testing with dual inclinometry according to AMA Guidelines[124].

Spinal Region	Motion	Patient Position	Inclinometer #1 Placement	Inclinometer #2 Placement	Normal Degrees
Cervical	Flexion	Seated	Top of Head (Sagittal Plane)	T1 (Sagittal Plane)	50
	Extension	Seated	Top of Head (Sagittal Plane)	T1 (Sagittal Plane)	60
	Lateral Flexion	Seated	Top of Head (Frontal Plane)	T1 (Frontal Plane)	45
	Rotation	Supine	Forehead (Coronal Plane)	Epistemal Notch (Coronal Plane)	80
Thoracic	Flexion	Standing	T1 (Sagittal Plane)	T12 (Sagittal Plane)	25
	Extension	Standing	T1 (Sagittal Plane)	T12 (Sagittal Plane)	25
	Rotation	Standing in Forward Flexion	T1 (Coronal Plane)	T12 (Coronal Plane)	30
Lumbar	Flexion	Standing	T12 (Sagittal Plane)	S1 (Sagittal Plane)	60
	Extension	Standing	T12 (Sagittal Plane)	S1 (Sagittal Plane)	25
	Lateral Flexion	Standing	T1 (Frontal Plane)	S1 (Frontal Plane)	25

Regardless of the instrument used, a number of factors can influence the reliability and validity of range of motion measurements. Youdas et al.[130] found a significant linear decrease in cervical spine range of motion as patients' age from the 1st through 8th decades. Criteria such as age, sex, body weight, and athletic activity also influence the range of motion of the spine[131]. While strict application of previous editions of the AMA Guides Range of Motion model can lead to unreliable and invalid impairment scores[132-134], the 5th edition of the AMA Guides published in 2000, attempts to address these concerns through the incorporation to other disability measures. In 2001, Zuberbier et al.[135] reported that convergent validity research has shown inconsistent relations between inclinometric and radiographic lumbar range of motion measurements. Some studies showed strong relation, whereas others showed essentially no relation between the two techniques. Correlations between lumbar range of motion scores and spinal disability and function were similarly inconclusive. Studies reporting mean scores and standard deviations for lumbar range of motion measurements showed a high degree of overlap between the scores of participants with low back injuries and those without such injuries. The authors concluded that convergent and discriminant validities of the lumbar range of motion tests currently require further substantiation.

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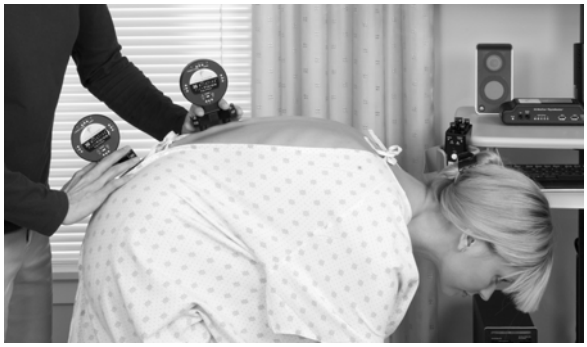
Figure 9.
Dual Inclinometry. Dual inclinometry performed with electronic dual inclinometers can be used for measurement of cervical (A), thoracic, or lumbar (B) range of motion. Incorporating the use of a second inclinometer allows for accounting of accessory spine motion to improve the validity of the test. Photographs courtesy of Precision Biometrics, Inc. / MyoVision, San Carlos, CA.

A.  **B.** 

Higher Order Kinematics

Kinematic assessments of spinal function require the measurement of the spine's position in space. This is typically done through two means, video analysis and electrogoniometer techniques. Both methods can provide three-dimensional dynamic tracking of the spine's movements[136;137]. In addition to simple end range of motion, these techniques can provide a movement profile in all three planes about each axis of motion. The displacement data generated from the film or electrogoniometer signal can be differentiated to provide the higher order kinematics of velocity and acceleration during dynamic movements. Three types of kinematic measures have been investigated during various tasks to determine what differences exist between low back pain sufferers and pain free individuals.

1. Assessment of end range of motion measures;
2. Assessing higher order kinematics during various tasks; and
3. Assessment of spinal proprioception.

In an effort to improve the assessment of spinal function and develop objective and valid outcome measures researchers have recently performed more sophisticated assessments of spinal function to delineate the differences between low back pain sufferers and normals.

One method, a functional performance protocol[138;139], assesses spinal range of motion, velocity and acceleration, in all three planes, (six degrees of freedom – three translations and three rotations) during complex flexion and extension tasks. This protocol requires subjects to maximally flex and extend their trunk at 5 different positions of trunk rotation (0 degrees of rotation, 15 degrees clockwise and counter clock wise and 30 degrees clock wise and counter clock wise). Lumbar kinematics are measured with a specially designed electrogoniometer that provides a dynamic assessment of the lumbar spine's position in space. The six degree-offreedom measures of displacement, velocity and acceleration data are extracted and used to create a model that evaluates the functional performance of the spine. Trunk motion features are normalized as a function of age and gender. This functional performance model generates a probability of the functional performance of an individual being asymptomatic. The reported sensitivity of the functional performance model is 86% and the specificity is 94%[140]. This model has further demonstrated its ability to detect impairment magnification making it possible to detect insincere efforts during the performance of the functional performance protocol[141].

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Analyzing the shape, velocity and symmetry of complex movements to create an artificial neural network which classifies patients into a low back pain or asymptomatic group has also shown 85% accuracy in identifying patients with low back pain[142]. A *neural network*. is a computer process which learns complex correlations between inputs and outputs during exposure to input patterns and desired output patterns. The input for the neural network in this study was velocity and displacement during flexion/extension, lateral bend, rotation and circumduction. The neural network, based on the previous motion measures collected from a low back pain and control group, learns to classify patients into groups based on the complex kinematics found during the assessment protocol. This study found that subjects with low back pain had decreased simple rotation and lateral bend (no difference in flexion) and decreases in velocity, in all planes, during the trunk circumduction procedure. This work suggests a complex task and more complex analyses are necessary in the discrimination of low back pain patients. Patients evaluated with the same neural network technique have demonstrated significant improvements over the course of a rehabilitation program; however, the relationship to other outcome measures was not investigated[143].

Analysis of coupled motion in the cervical spine has also been investigated for its use in identifying injuries and dysfunction[137;144;145]. These methods have been developed for an existing opto-electronic device employed for the non-invasive measurement of movement in the upper spine. This instrument consists of a high resolution motion analysis system which tracks small active infrared emitting diodes (IREDs). Kinematic data for the motion of the markers is processed and absolute coordinates for the location of each IRED at any time are tabulated; coupled motion with respect to a fixed calibration frame, as well as for vertebrae relative to each other, is deduced from the kinematic data[144]. Characterization of coupled motion, in this manner, involves a series of plots showing principal versus secondary motion. Principal movements include flexion-extension, lateral bending, and axial rotation, corresponding to motion in the sagittal, transverse, and horizontal planes, respectively. Mobility is represented in terms of the direction angles made by virtual vectors orthogonal to the planes made by markers on the head, neck, and shoulders. Precision of the deduced angles is found to be approximately 1 degree[144]. This representation of coupled motion is expected to be valuable in improving the accuracy of attempts to identify normal versus pathological motion in the cervical spine. By exploring these biomechanical assessments of lumbar function clinicians and researchers may attain a better understanding of lumbar dysfunction and subsequently improve patient care.

Proprioceptive Measures

Proprioception is the awareness of body position in space, or the mechanism involved in the self-regulation of posture and movement through stimuli originating from neural receptors embedded in the joints, tendons, muscles and labyrinth. Much like other joints following injury[146], the proprioceptive sense of the spine may be impaired. Spinal proprioception can be determined using a simple spine kinematic technique. Spinal displacement is measured using an electrogoniometer, video or any other motion tracking system. Once spinal position is established, a spinal assessment protocol can be performed which requires a patient to attempt to position the spine into a position set by the experimenter (The Target Position). During this repositioning the spinal curvature or displacement is measured and the accuracy of the patient's ability to reach the target position can be quantified. The difference between the target spinal position and the patients attempted spine repositioning is termed the ***Repositioning error.***

Repositioning error used to assess spinal proprioception has been less rigorously tested than kinematic assessments of complex movements. No sensitivity or specificity analyses have been performed nor has its ability to function as an outcome measure been tested. Its relationship to other outcome measures is still unknown. However, the resent research has demonstrated differences in repositioning error between low back pain patients. Newcomer et al.[147] investigated whether differences in spinal repositioning error existed between 20 low back pain sufferers and 20 controls

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during flexion/extension and lateral bending tests. Spinal position was measured using a 3Space Tracker System (Polhemus, Inc., Colchester, VT). The 3Space tracker is an electromagnetic tracking device consisting of one source box (emits and electromagnetic field) and at least 2 sensors. The source box is secured near the patient and the sensors are fixed on the back of the subject. The x,y,z position in space of the two sensors is tracked and the difference between the sensors can be calculated providing dynamic angles of flexion, lateral bend and rotation of the spine. In the Newcomer et al. study the sensors were placed on T1 and S1 resulting in a global measure of the entire spines position. Participants stood with their legs and pelvis partially immobilized and performed repositioning tasks in flexion, extension, right-sided lateral bend and left sided lateral bend. Target positions were 30%, 60% and 90% of the maximum for each movement tested. The authors found that patients with low back pain had greater repositioning errors during flexion, no differences during lateral bend and a smaller repositioning error during extension. There was no relationship between repositioning error and pain level. Gill & Callaghan[148] demonstrated a difference in the repositioning error between subjects with low back pain and controls in both a standing and four point kneeling posture. Participants were required to reproduce a position of 20 degrees of flexion from neutral 10 times in 30 seconds. Low back pain subjects demonstrated a greater repositioning error than controls in both movement tasks. Extension was not evaluated. The repeatability was shown to have an ICC > .85 for both tasks.

Other research in this area includes that of Brumagne et al.[149] who investigated spinal proprioception in low back pain sufferers and controls and found differences in accuracy between the two groups during a seated sacral tilting procedure. In this work, an electrogoniometer was placed on the sacrum which measured its degree of tilt during anterior sacral tilt (increasing lordosis) and posterior sacral tilt. Starting from maximal anterior sacral tilt participants were required to position their spine to a target position identified by the experimenter. This procedure results in little to no movement of the upper torso thereby targeting the lumbar spine and pelvis, similar to the four point kneeling protocol. The low back sufferers showed a significantly larger repositioning error during lumbar flexion compared to controls. Extension was not evaluated. Previous work with this technique showed an Intra class correlation coefficient of .51[150]. The high repeatability, the simplicity of data collection and the finding that low back pain sufferers can have deficits in repositioning error (proprioception) suggest this biomechanical assessment technique should be further evaluated to determine its utility as an outcome measure.

In the cervical spine, the ability to reposition the head to the same position following movement is termed *cervicocephalic kinesthetic sensibility*. Research attempting to use this methodology to discriminate between injured cervical spine patients and controls has revealed differences among whiplash injured patients who apparently suffer less precise repositioning abilities[151-153].

In addition to repositioning error, other techniques have been used to assess spinal proprioception. These involve measurement of postural sway[154-156] and identification of spinal movement. Despite different measurement protocols those patients suffering from low back injury show a decreased proprioceptive functioning. Patients with low back pain have shown greater postural sway during stance compared with symptom free individuals[154-156]. Postural sway is measured using a force plate that calculates the center of pressure during stance. Typically, center of pressure, or the summation of all downward forces considered to be acting through one point remains outside the center of gravity acting to, “chase”, the center of gravity to a stable position during stance. With more instability greater movement of the center of gravity and concomitantly center of pressure occurs. An increase in sway or movement of the center of pressure in patients with low back pain has also been demonstrated during sitting on varying levels of unstable surfaces[157].

Another protocol to assess spinal proprioception requires participants to determine when their spine has been moved. Participants are seated in a jig that controls rotational trunk movement and are rotated at a rate of one degree per second. Subjects release a button when they perceive spinal movement. Taimela et al.[158] demonstrated a decreased ability in low back pain patients to sense spinal

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rotational movement compared with healthy controls. This same decrease in sensing movement has been documented in patients with lumbar stenosis[159]. Between trial repeatability of this procedure had an ICC of .77 for low back pain patients and .84 for controls[158]. Assessing lumbar proprioception is exceedingly simple and combined with an assessment of the higher order kinematics of the spine may provide great insight into a patients functioning.

Muscle Strength

Segmental instability, pathology, or dysfunction are believed to produce abnormal patterns of motion and forces which may play a role in the etiology of musculoskeletal pain. Muscle tension is a function of muscle length and its rate of change and thus can be altered by the level of neural excitation. These relationships are called the length-tension and velocitytension relationships. The central nervous system appropriately excites the muscle, and the generated tension is transferred to the skeletal system by the tendon to cause motion, stabilize the joint, and/or resist the effect of externally applied forces on the body[113]. The ability to quantify spine segment motion or *kinematics*, together with the concomitant forces, or *kinetics*, is therefore of clinical significance in terms of both diagnosis and treatment of spinal disorders and back pain. Before discussing the use of spine instrument measures in evaluating muscle strength, a review of some key terms provides a better understanding of some of the biomechanical principles in this area.

Types of Muscle Contractions

An *isotonic* shortening (*concentric*) contraction occurs under conditions in which the load on a muscle remains constant but the muscle length shortens because the muscle force is greater than the effects of the external forces. An example of a shortening contraction is what happens to the biceps when a person lifts a heavy box. The beginning of the lift would actually be *isometric*, until the force generated by the muscle(s) becomes greater than the load of the box and the box starts moving upwards. *Isotonic* lengthening (*eccentric*) contractions occur when the load on a muscle is greater than the tension being created by the cross bridges, and the muscle is pulled to a longer length in spite of the opposing force being produced by the cross bridges. In other words, the muscle is stretched out while contracting. For an example of a lengthening contraction, consider the person holding the heavy box in the previous example. If the box is now lowered back to its original position, the biceps will lengthen due to the load of the box, and the muscle will stretch, even though it is still contracting.

Skeletal Muscle and Dynamic Movement

For *anisometric*, or dynamic studies of muscular exertion, terms such as *isokinetic* and *isoinertial* are used to describe body or body segment motion. An *isokinetic* muscle contraction movement occurs at a constant velocity; therefore, the kinetic energy remains constant[160]. Similarly, an *isoinertial* muscle contraction movement occurs when the moment of inertia is constant; for example, when the muscle contracts against a constant load or resistance.

These two descriptions of motion can be related back to the different types of muscle contraction. During either *isokinetic* or *isoinertial* motion, if the torque generated by the muscle is less than or equal to the resistance, then the muscle length will not change. However, if the torque is greater than the resistance, then the excess torque and the length changes will be factors in determining the acceleration of the limb[161]. Muscle performance can be quantified in terms of the basic dimensions of performance: *strength*, *speed*, *endurance*, *steadiness*, and *coordination*[113]. Smidt et al.[162] defined muscle strength as the ability of a muscle or muscle group to generate a moment about a body axis, whereas muscle endurance is the ability to generate moments repetitively. Therefore, muscle *strength* is the capacity to produce torque or work by voluntary activation of the muscles whereas, muscle *endurance*, in contrast, is the ability to maintain a predetermined level of motor output over time[113]. Other terms that are noteworthy include *fatigue,* or the process under which the capacity of a muscle diminishes, and *coordination*, the temporal and spatial organization of movement and the recruitment patterns of the muscle synergies.

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Assessment of Muscle Strength

Qualitative measures of muscle strength include manual muscle testing techniques that rely on grading criteria to clinically assess patients (Table 12). Chiropractic clinicians commonly rely on manual muscle testing to evaluate extremity joint injuries, and to grade the motor strength of potential spinal nerve root involvement in patients with radicular symptomatology (Table 13). Due to the qualitative nature of these assessments their clinical usefulness is limited since the ability of even skilled clinicians to determine strength differences is rather restricted[13].

In manual muscle testing performance, relative muscle strength is judged more on the basis of the total force and duration of effort that the examiner uses to overcome the patient, than on the actual force generated by the patient. Accuracy in such manual assessment techniques requires differences in strength of 35% or more[163]. Hence, instruments have been introduced to clinical practice to improve the objectivity of muscle strength assessments. In general, trunk strength and/or trunk muscle strength has been shown to vary with many different factors as shown in Table 14.

Table 12.
Qualitative manual muscle strength grading[124]

Grade	Description	% of Deficit
5: Normal	Complete active range of motion against gravity with full resistance	0
4: Good	Complete active range of motion against gravity with some resistance	1-25
3: Fair	Complete active range of motion against gravity only, without resistance	26-50
2: Poor	Complete range of motion with gravity eliminated	51-75
1: Trace	Slight muscle contraction with no joint motion	76-99
0: Zero	No evidence of muscle contraction	100

Ultimately, the measured force is a function of the individual's motivation, environmental conditions (muscle length, rate of change of muscle length, nature of the external load, metabolic conditions, pH Level, temperature, etc.), prior history of activation (fatigue), their understanding instruction and description of the tasks to be performed, control strategies and motor programs employed to satisfy the demands of the task, and the biophysical state of the muscles and fitness (fiber composition, physiologic cross-sectional area of the muscle, and cardiovascular capability[113]). The complexity of these processes and their interrelationships cannot be overemphasized. Moreover, an individual's strength is reduced by 10-30% when exertions are performed dynamically as compared to isometric strength[164].

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Table 13.
Spinal nerve root evaluation of motor function

Spinal Nerve Root Level	Muscle Test
C5	Shoulder Abduction
C6	Elbow Flexion
C7	Elbow Extension, Wrist Flexion, Finger Extension
C8	Finger Flexion
T1	Finger Abduction, Finger Adduction
T12-L3	Hip Flexion
L2-L4	Hip Adduction, Leg Extension
L4	Foot Dorsiflexion, Foot Inversion
L5	Hip Abduction, Great Toe Dorsiflexion
L5-S2	Leg Flexion
S1	Hip Extension, Foot Plantar Flexion, Foot Eversion

Table 14.
Factors influencing trunk strength

Gender
Age
Body (or body segment) Weight
Body Position
Exercise & Nutrition
Hormonal or Genetic Factors
Motivation
Motor Learning & Movement Coordination
Physiologic Factors
(i.e., muscle fatigue, and muscle co-contraction)
Cross-Sectional Area of Muscle
Type of Contraction
Speed of Contraction
Duration of Contraction
# of Warm-up and Learning Trials
Rest Between Trials
Joint Limitation
(Pathology, pain, or dysfunction)

Dynamometry

There are many different methods used by researchers and clinicians to study trunk strength. No direct measures are available, but intradiscal pressure (IDP) measurements and intrabdominal pressure (IAP) measurements are two *in vivo* methods of direct measurements used to estimate trunk

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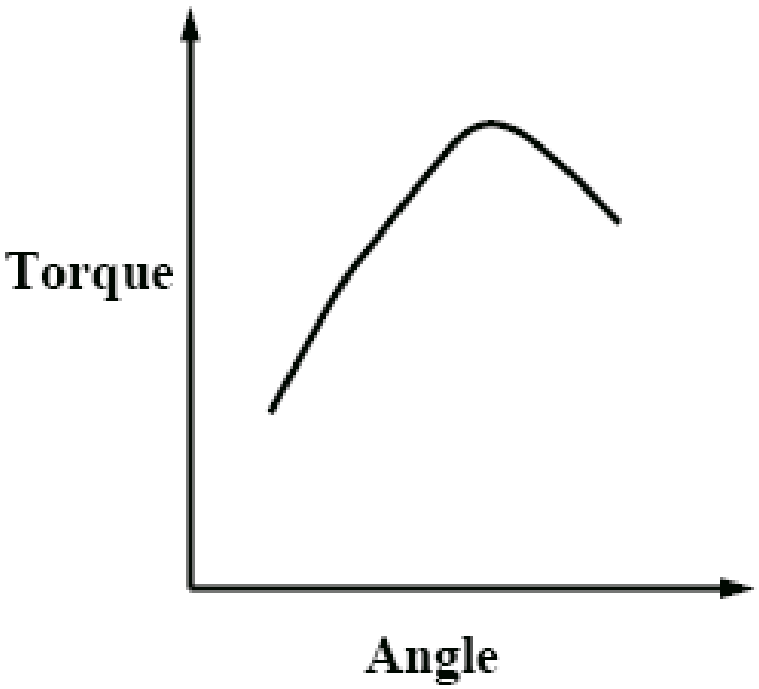
strength[165]. Two ex vivo, or non-invasive, methods currently used to quantify strength changes are dynamometry, and electromyography.

Traditionally, dynamometers are tension-measuring devices in which the stretching of a spring or a strain gauge is used; today, a dynamometer can be defined as any instrument used to measure torque or force. As a whole, dynamometers are clinically convenient and simple, with good reliability as long as positioning is consistent. There are many different kinds of dynamometers used to measure different types of muscle contractions and muscle-induced motions. Some measure only isometric force or torque production; others assess dynamic (i.e., isokinetic or isoinertial) motion as well. Function is usually assessed in one or more of 3 planes: extension- flexion (E/F), rotation (R), and lateral flexion (LF). Because trunk strength is different at different joint angles, isometric strength test data is normally reported using a "strength curve," a plot showing the force or torque generated by the trunk as a function of the changing angle of the trunk (Figure 10).

Figure 10.
Strength curve



Isometric Testing

When performing isometric assessments, a sustained effort of 2 seconds has been proposed to meet standardized minimum criteria. Averaging three consecutive tests can also be helpful in identifying insincere efforts. Any variation greater than 10-15% between trials may be suggestive of voluntary holding back in performance. Computer software has been developed to calculate consecutive efforts and further determine a coefficient of variation to indicate whether the test performed was valid. Fatigue, is another factor that may cause a reduction in strength upon multiple

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trials. Inasmuch, variations in strength of up to 20% or more is necessary to determine a clinically relevant disparity in muscle strength[13]. Easy to use hand-held dynamometry systems have been developed by several commercial companieswhich allow for quantitative manual muscle strength assessment of the extremities (Figure 11) and trunk (Figure 12). To minimize variables associated with and examiner performing the manual strength testing, such equipment can be mounted to a frame for assessment of isometric muscle strength testing. Other dynamometers include instruments to evaluate grip and pinch strength (Figure 13).

Figure 11.
Manual muscle testing of elbow flexion with dynamometry. (Photograph courtesy of J-Tech Medical Industries, Salt Lake City, UT)

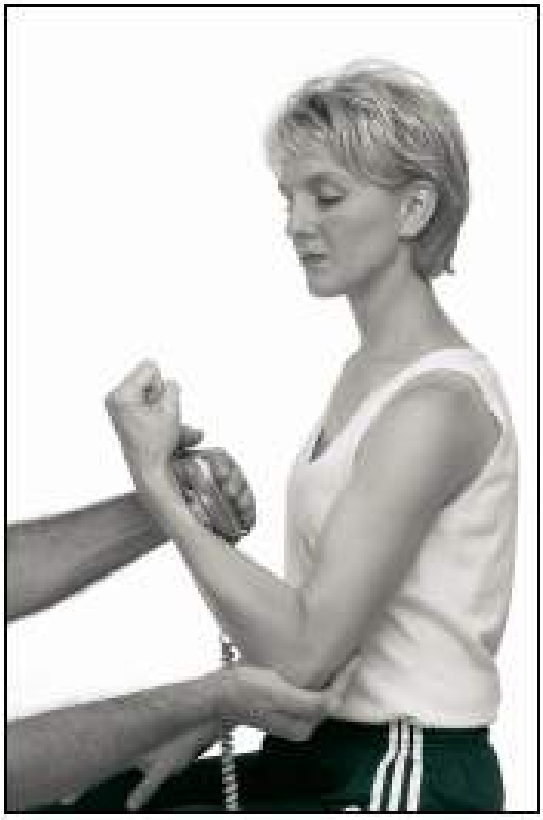

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Figure 12.
Manual muscle testing of trunk extension with a hand-held dynamometer. With this particular dynamometer (PowerTrack, JTech Medical Industries), maximum force is digitally displayed on a wrist mounted LCD panel, or alternatively, strength curves are plotted by computerized software. (Photograph courtesy of J-Tech Medical Industries, Salt Lake City, UT)

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Figure 13.
Quantitative grip and pinch (inset) strength evaluations can also be performed using dynamometers. (Photograph courtesy of J-Tech Medical Industries, Salt Lake City, UT)

Isokinetic Testing

Isokinetic dynamometers measure dynamic force or torque throughout a range of motion at various constant, preset velocities. Isokinetic tests thus require specialized instrumentation that contain either hydraulic or servomotor systems to provide constant velocity. Specific examples of isokinetic dynamometers include Cybex II (Cybex Inc, a division of Lumex Inc., Ronkonkoma, NY), KIN/COM (Chattecx Corporation, Chattanooga, TN), Biodex (Biodex Corporation, Shirley, NY), and LIDO (Loredan Biomedical Inc., Davis, CA). Triano et al. note that the primary measurement obtained in isokinetic testing is the torque generated during the controlled part of the motion, and is only valid during the controlled part of the motion. In principle, the resistance offered by the machine is equivalent to the applied muscle torque over the entire range of movement. This represents the

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patient's muscular capacity[13]. Sources of eror that shuld be taken into account with isokinetic testing include inertial error, or the change in limb or trunk orientation through the range of measurement. Inertial error can alter the amount of torque registered by the machine. Torque overshoot is another error that can occur with isokinetic testing representing a machine artifact that arises from the inertial effect of motion as the preset velocity is achieved[13]. To eliminate these errors, highly specialized machines have been developed.

Isoinertial Testing

Isoinertial strength testing requires the control of torque values that the patient will be permitted to use during movement. Isoinertial systems can be made capable of monitoring position, velocity, and torque simultaneously while they independently vary. The B200 Triaxial Isoinertial Dynamometer (B-200) (Isotechnologies, Inc., Hillsborough, NC) is a commercially available isoinertial dynamometer. The B-200 measures isoinertial strength against a preset resistance where the subject's velocity varies with the amount of force or torque the subject applies. In other words, the subject's movements (accelerations and decelerations) are made against a constant resistance. If the torque generated by the subject is greater than the machine resistance, the surplus torque will determine acceleration[166]. The B-200 is unique in that movement about all 3 axes (E/F, R and LF) can be measured simultaneously by a single machine. Quantifying dynamic motions are important as three-dimensional trunk velocity has been found to significantly increase low back pain risk[167;168].

The B-200 outputs each subject's trunk position (3-D), angular velocity, and torque. Position is measured from 0° upright. Sign convention dictates forward flexion as positive (therefore, backward extension is negative). Velocity output is angular velocity of the upper body, with the axis of rotation considered to be through the hips or L5/S1. Trunk Moment (Torque) output by the B-200 includes the torque of the machine, and must be corrected for the effects of gravity. The B-200 also enables measurement of isometric exertions at various trunk postures in addition to its dynamic testing capabilities. Isoinertial and isometric trunk strength testing with the B-200 provides reliable measures of torque and velocity parameters[169] and recent research has identified demographic parameters important to such testing in chronic low back pain patients[170]. In addition, a normative database has been developed to assist in the clinical utility of these measures[171].

Although somewhat controversial, trunk weakness has often been described as a contributor to low back pain. In fact, several investigations have revealed stronger trunk muscles in asymptomatic subjects as compared to patients with low back pain[172-175]. In addition to weaker trunk muscles, there also appears to be differences observed in the ratio of flexion-toextension trunk strength[166;176]. Other studies using isoinertial techniques have reported that patients with low back pain tend to have slower movements than normal subjects[164;177]. Until more evidence is available, however, correlation of trunk strength to other objective measures of trunk function and perceptual measures is necessary to discriminate between symptomatic patients.

PHYSIOLOGICAL MEASUREMENTS

In the presence of clinical findings suggestive of an underlying neurological condition, numerous tests and measures are available to the clinician to further evaluate the patient. Clinicians have become increasingly dependent on neuroimaging studies such as MRI, CT or bone scans, but more reluctant to order specific physiological tests including thermography, electromyography, nerve conduction, and evoked potentials studies (Figure 14). The clinician may either not be aware of the precise applications and limitations of these studies, or not be familiar their use or interpretations. While diagnostic imaging studies are valuable in demonstrating pathology such as disc protrusion, the clinical utility of such studies are limited without clinical correlation. For example, large disc herniation or other structural abnormality may exist without causing nerve compression, and many structural abnormalities are present in asymptomatic individuals[4]. Alternatively, in other situations a relatively small disc protrusion may result in neurologic deficits and radiating pain. The increasing

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complexity of imaging studies has therefore led to increased necessity for more sophisticated functional tests to look for neurologic deficits[178].

Physiological assessments allow the clinician to passively or actively measure resting or functional responses of the body (i.e. electromyography or thermography), or evoke responses through monitoring responses of various nerves and muscles to electrical stimuli. Incorporation of specialized testing such as electrodiagnosis substantially alters clinical impressions in a large percentage of patients[179]. The complex relationship between clinical information, the extent of testing, and final diagnostic certainty suggests that specialized medical knowledge is required for accurate physiological assessments. Although this chapter is not intended to provide a comprehenisive review of the available spectrum of electrodiagnostic tests, and their interpretations, it is hoped that this discussion provides the clinician with valuable information to assist in understanding the rationale behind some of the more commonly used physiological measurements in clinical practice.

Electromyography

Electromyography (EMG) measures the electrical signals generated by muscle contraction, which are proportional to the degree of neuromuscular activity and therefore also to the strength of muscle contraction. A brief overview of the properties of skeletal muscle will provide important background information of the physiological properties for which electromyography is derived.

Skeletal Muscle

The structural unit of skeletal muscle is the muscle cell also referred to as muscle fiber. Groups of muscle fibers are termed fasciculi that aggregate to form a whole muscle. A fasciculus can include only a few muscle fibers, as seen in smaller muscles such as the lumbricales, or as many as 100 to 150 or more in larger muscles such as the biceps brachii or gluteus maximus. This unique arrangement of muscle fibers within the fasciculus accommodates independent functioning of the muscle fibers from their respective activation. This is important because the fibers belonging to a motor unit are spread throughout a muscle. A motor unit is defined as a group of homogenous muscle fiber types innervated by a single axon. Activation of a motor unit, therefore, results in the contraction of single muscle fibers within many different fasciculi[180].
Myofibrils are surrounded by a sarcoplasmic reticulum that plays an essential role in both the storage and release of ionic calcium to signal contractile proteins. The contractile proteins of skeletal muscle are organized into cylindrical organelles, termed myofibrils, each organized into sacromeres, its fundamental contractile unit. Skeletal muscle is also called striated muscle, resulting from its histological appearance from the repetitive series of transverse bands in each sarcomere, the most prominent being the Z, A, and I bands. The distance between two Z bands is defined as the sarcomere which will vary with the state of contraction or relaxation in the muscle.

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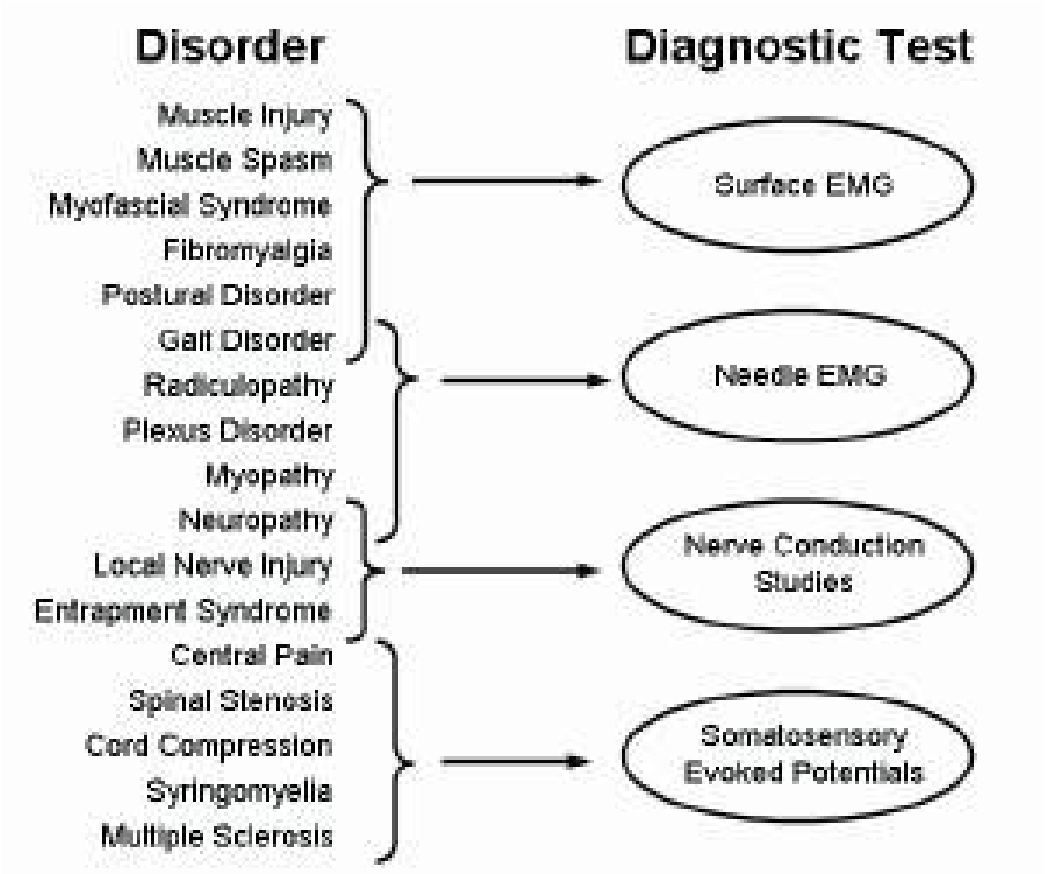
Figure 14.
Neuromusculoskeletal disorders and commonly used corollary diagnostic tests



The dark A bands of the sarcomere are formed by thick myofilaments, termed myosin filaments, and interdigitated thin myofilaments named actin. During contraction the actin filament slides over the myosin. A second set of transverse bridges is the M band serving to connect adjacent myofilaments. Huxley[181] demonstrated that thick myofilaments are arranged in a hexagonal lattice and that thin filaments interdigitate with the thick filaments at each trigonal point, producing what is now termed the double hexagonal lattice of myofilaments.

Motor units can also be classified[180]. Slow twitch motor units can fire continuously at low frequencies for long periods of time. Fast twitch fatigue resistant units can produce greater forces than slow twitch motor units, but cannot fire continuously for long periods of time. Fast twitch fatigable fibers produce the greatest force, but only are capable of doing so for short periods. The force that a muscle produces and the speed of movement is controlled by the type of motor unit found in the muscle, and the motor unit recruitment. Slow twitch motor unit recruitment is responsible for maintaining posture and slow movements. Slow twitch fibers are thus recruited first, and the fast twitch fatigable units are only recruited when a fast powerful movement is required. For each muscle contraction motor units are recruited at the same force level. During high force demands, after all motor units have been recruited, additional force is generated by increasing the firing frequencies of the motor units. The tension created by a muscle also depends upon the geometric configuration of the muscle fibers, the length of the muscle, and the velocity of the contraction.

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EMG Instrumentation

The inside of a muscle fiber has a resting potential of about –80 mV which remains in equilibrium until stimulated. A significant stimulus causes a rapid depolarization followed by repolarization termed an action potential. The temporal and spatial summation of action potentials are responsible for the waveforms observed on oscilloscopes or computers during electromyographic testing. There are several factors to consider when measuring muscle activity via electromyography (Table 15), which necessitates a basic understanding of the component parts involved.

The main components of a basic EMG system consist of *electrodes*, a preamplifier, a *main amplifier*, a *display*, and *recording/storage elements*.

Table 15.
Factors that influence the signal information content of electromyography (Adapted from[208],pp.45.).

Factor	Influence
Neuroactivation	-the number of motor units recruited; -the firing rate of motor unit action potentials -the synchronization of firing
Muscle Fiber Physiology	-the conduction velocity of muscle fibers
Muscle Anatomy	-the orientation and distribution of muscle fibers of motor units -the total number of motor units -the diameter of muscle fibers
Electrode Size and Orientation	-the number of muscle fibers within the pickup area of the electrode -the number of motor units within the pickup area of the electrode detection surface relative to the muscle fibers
Electrode-Electrolyte Interface	-the material and preparation of electrode and electrode site -the electrode impedance decrease with increasing frequency (highpass filter)
Electrode Configuration	-the type of electrode used: needle or surface, monopolar or bipolar -the effect of distance between electrodes and bandwith (band pass filter) -the orientation of electrodes relative to axis of muscle fibers

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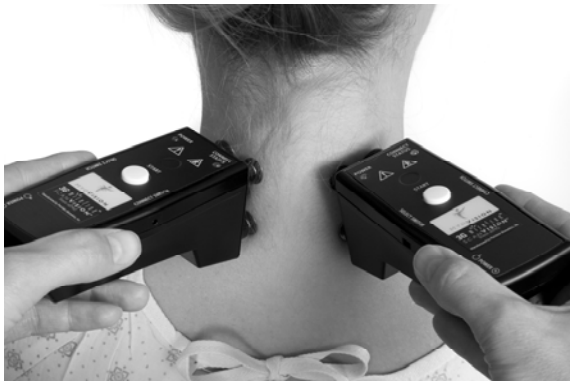
Figure 15.
Static Scanning Surface Electromyography System with Scanning Graphic (A & B).
Photo Courtesy of Precision Biometrics, Inc / MyoVision, San Carlos, CA.

A. 

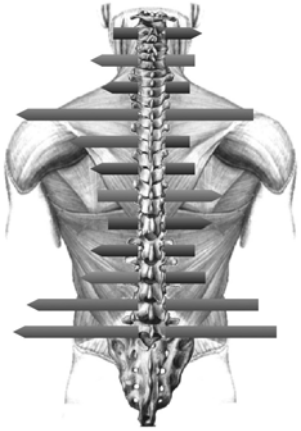
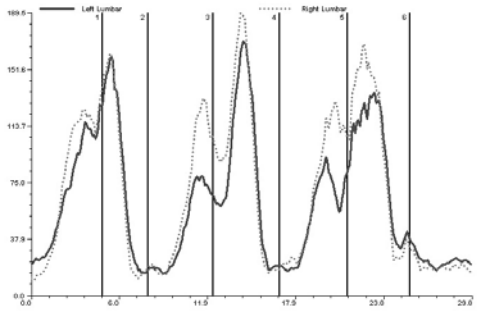
B. 

Figure 16.
Dynamic Surface EMG System with Dynamic Graphic (A & B). Courtesy, Precision Biometrics, Inc. Photographs courtesy of Precision Biometrics, Inc. / MyoVision, San Carlos, CA.

A. 

B. 

EMG Electrodes:

The EMG signal is actually a recording of the fluctuations of potential that occur between two conducting surfaces due to the muscular electrical activity. Electrode performance factors depend on the location of the electrodes, their area and shape, the materials of which the electrodes are comprised, and their sterilization and maintenance. There are two main categories of electrodes most frequently used: inserted electrodes and surface electrodes.

Inserted Electrodes. Wire and needle electrodes are the two types of electrodes that are actually inserted into the muscle to be tested. Although the use of inserted electrodes can be uncomfortable to the subject being studied, they are advantageous for study of individual muscle fibers or motor units because they offer a relatively small exploring surface to be placed near the active tissue that discriminates against distant activity. The technique involves the placement of needles, either bipolar (with two electrodes) or monopolar (one electrode) into the selected muscle or region. Most commonly, needle EMG is utilized for documentation or correlation of a suspected

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radiculopathy as performed by neurologists and physical medicine specialists. A more detailed discussion of needle EMG will follow in the section entitled, Neurodiagnostics.

Surface Electrodes. When surface electrodes are used, the apparent duration of an action potential is slowed due to the increased distance from the origin of action potentials, and complications from various tissue components, such as skin, other muscle, connective tissue, and blood vessels. Therefore, surface electrodes are not used to record the details of motor unit potentials, but they are quite sufficient for use in recording gross EMG activity. Surface electrodes have been found to be more reliable than wire electrodes for study of static muscle contraction and dynamic phasic activity[182;183]. Surface electrodes have also been recommended over needle electrodes for recording time-force relationships of EMG signals[184]. Besides being used to evaluate gross activity, surface electrodes are usually also used as ground (zero reference potential) and reference electrodes during testing.

EMG Preamplifier. The preamplifier is the component of an EMG system that increases the magnitude and the power of the signals picked up by the electrodes so that they can be conducted to the amplifier without being influenced by undesirable electrical effects that might cause distortion and error. The differential amplification property of the preamplifier permits the desired (typically small) potentials to be amplified and prevents against interference from unwanted (often larger) potentials. The three main factors that influence the preamplifier are: internal noise level, input impedance, and differential performance.

EMG (Main) Amplifier. The EMG amplifier usually contains the sensitivity control (calibrated in units of microvolts per degree of forward flexion, for example) of the trace of the computer monitor or display screen. The output of the EMG amplifier is a filtered representation of the potentials picked up by the electrodes, adjusted to appropriate amplitudes and power levels so that the output can be used to drive any auxiliary equipment that may be used to further process the EMG signals.

Display. The display component of a basic EMG system allows visualization of the action potentials. It has traditionally been a cathode ray tube, but is now usually a computer display screen. Typically, the potentials are represented as dynamic amplitude versus time graphs.

Processing the EMG Signal (Time Domain Analysis)

The EMG signal is a time- and force- dependent signal, and its amplitude varies randomly above and below the zero value. Typically, simple averaging of the signal will not provide any useful information. Although there are many ways to process EMG signals, two common ways to process the raw EMG signal include rectification and integration.

Rectification. This method involves simply rendering only positive deflections of the signal. This may be accomplished either by eliminating the negative values ("half-wave rectification") or by inverting the negative values ("full-wave rectification"). Full-wave rectification is the preferred procedure because it retains all the energy of the original signal. This rectified signal can be further smoothed using different methods.

Integration. The definition of integration is the calculation of the area under a signal or a curve. In signal processing the units of this parameter are V-s or mV-ms. Integration can only be applied to already rectified EMG signals, since an unrectified EMG signal has an average value of zero, and therefore will also have a total area (the integrated value) of zero.

Relationship Between EMG Signal Amplitude and Trunk Strength

The relationship between EMG and muscle force naturally arises when viewing an electromyogram. It seems to reason that if there is little to no signal, there will be no active muscle force and alternatively, the more muscle fibers that are active and the more frequently they fire, the higher the force responsible for the signal. The electromyogram can be quantified and used to classify the electrical activity level that produces a certain muscular tension based upon changes in amplitude and frequency. In other words, an EMG-force measurement seeks to quantify the average number and firing rate of motor units contributing to an actual muscle contraction and to relate the quantity to the

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actual force produced. The myoelectric signal represents the temporal and spatial summation of all active motor units within the recording area of the electrodes. EMG thus, is not a direct assessment of muscle force, but of muscle electrical activity, and other relationships need to be established (calibration of electrical output and force produced) before reasonable muscle force estimates can be made.

The change in the myoelectric signal is based on the motor unit recruitment and firing rate within the muscle. In general, as more force is demanded, more motor units are recruited, and the motor units already firing increase their frequency of firing. Electromyographical measurements thus generally show a relatively monotonic (1:1) relationship between muscle force and trunk muscle activity. However, this relationship varies from muscle to muscle and has been shown to be linear, curvilinear, or other, due to the various roles or responsibilities of different muscles (i.e., posture or locomotion). There is a monotonic relationship between the EMG signal amplitude and muscle force[184]. A quasi-linear relationship between EMG and force has been reported for smaller muscles whereas a non-linear EMG-force relationship has been determined for larger muscles where the increase in EMG signal is greater than the increase in force[185]. The use of EMG as a biomechanical analysis has been found to reveal physiological impairments that have not been routinely identified with standard clinical tests[186].

Measuring the EMG activity of trunk musculature is commonly used in an attempt to assess dysfunction of the lumbar spine. The majority of assessments have focused on quantifying the EMG amplitude differences between low back pain patients and control subjects. The rationale behind these investigations is to identify, "spasm", or increased muscle activity in low back pain populations as a result of muscle splinting or aberrant neural control. The research on this use of EMG as a spinal assessment technique and outcome measure is mixed. This review will not go into detail reviewing studies which assessed the discriminant validity of trunk muscle EMG amplitude assessments (For a review see[187]), rather we will focus on the newer EMG techniques and data collection protocols which may provide a better assessment of spinal function.

The use of the erector spinae EMG signal has been researched in an attempt to discern differences between those with low back injury and asymptomatic subjects. Unfortunately, a general consensus on the use of surface EMG in clinical practice is lacking. It is often postulated that those with low back pain have an increased level of muscle activity relative to controls. Some studies show no difference between groups[90] while others show an increase in EMG activity in those suffering low back pain[188;189].

Reliability

In order for measurements obtained from surface EMG recordings to be useful they must be reliable. Finucane et al.[190] measured the intra- and intertester reliability of surface EMG measures of submaximal concentric and eccentric contractions of the quadriceps femoris muscles. They reported respective ICC values of intra- and intertester reliability ranging from 0.62 to 0.91 and 0.66 to 0.96 for concentric and from 0.84 to 0.97 and 0.78 to 0.90 for eccentric contractions. Yang and Winter[191] reported the reliability of average surface EMG recordings of submaximal isometric contractions within and between days and determined within day errors ranging from 8-10% and from 12-16% between days. Lehman also reported excellent repeatability (ICC's > 0.75) in measuring EMG activity of the erector spinae muscles on three separate days during quiet stance[192].

Normalization

Efforts have been made to normalize surface EMG recordings in an attempt to facilitate comparisons between individuals. Because there is not an exact one-to-one relationship between myoelectric signal and muscle contraction force, a standard of reference must be established for such comparisons and comparisons among muscles or activities. This process, a form of force calibration, is referred to as *normalization*.

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Various factors are responsible for changes of the myoelectric signal such as slight change in electrode locations, tissue properties, or temperature. After applying the electrodes at the appropriate site, a normalization test is performed where contractions are performed within the context of the type of examination. The most common method of normalization is to perform one reference contraction, usually an isometric maximal voluntary contraction (MVC). The myoelectric values subsequently obtained are expressed as a percentage of the MVC. Because of the variability of MVC's, research has demonstrated significantly reduced errors in using submaximal MVC's for normalization techniques[192;193].

The Flexion-Relaxation Phenomenon

There is some evidence to suggest that differences exist between among back pain patients and normal subjects during dynamic flexion tasks at peak flexion[194;195] and between the ratio of activity during forward flexion and re-extension[196]. Several studies have examined the apparent myoelectric silence of he low back extensor musculature during a standing to full flexion maneuver, or the *Flexion-Relaxation Phenomenon* (*FRP*). The electrical signal reduction or "silence" that occurs in health subjects during lumbar spine flexion has been hypothesized to represent the extensor musculature being relieved of its moment supporting role by the passive tissues, particularly the posterior ligaments[197]. Likewise, a failure of the muscles to relax is thought to be indicative of heightened erector spinae resting potentials or underlying back muscle spacticity.

Watson et al.[189] assessed the test-retest reliability of the FRP measure in a group of CLBP patients (n=11) and further compared the results between a group of normal healthy controls (n = 20) and a group of CLBP patients (n = 70). Repeated measurements over 4 weeks demonstrated between session reliability of between 0.81 and 0.98 for the dynamic activity. The levels of sEMG activity in the fully flexed position were significantly greater in the fully flexed position in the CLBP group than the controls. The flexion relaxation ratio (FRR), a comparison of the maximal sEMG activity during 1 s of forward flexion with activity in full flexion, demonstrated significantly lower values in the CLBP than the control group. The combined discriminant validity for the FRR for all four sites resulted in 93% sensitivity and 75% specificity. These results indicate that dynamic sEMG activity of the paraspinal muscles can be reliably measured and is useful in differentiating CLBP patients from normal controls. The authors concluded that the FRR clearly discriminated the patients from the healthy controls.

Shirado et al.[198] also found that the FRP could discriminate between chronic back pain patients and normal subjects. In their study of 20 chronic low back pain patients, none exhibited the FRP, as compared to its clear demonstration in 25 healthy subjects prior to maximum flexion. The FRP has also been investigated in the cervical spine[199], however, no work has been performed relevant to its ability to discriminate between patients with cervicogenic disorders. Ahern et al. recommended that clinicians pay close attention to qualitative aspects of patient behavior to improve the sensitivity of the physical examination in detecting bona fide impairment when assessing the FRP[200].

Paraspinal Muscle Asymmetry

It has also been suggested that a difference in the amplitude symmetry between left and right trunk muscles may exist in the low back pain population. Again the research is mixed with the majority of studies finding no differences between groups[201;202] and other studies finding a greater EMG amplitude asymmetry in the low back pain group[203]. Studies reporting inconsistent results may be due to the many factors that modulate measured EMG activity level which are not related to the level of neural drive. Electrode placement, skin temperature, moisture, cutaneous fat distribution, muscle fibre type and size can all influence measured EMG activity level. Non-homogeneity in these factors between sides of the body may relegate asymmetry in measured EMG activity to be the norm even though it is possible that bilateral muscles are contracting at equal intensities. With so many factors modulating EMG activity a large variation in EMG amplitude is seen across subjects[204]. A patient may have an elevated EMG level relative to their normal activation level whereas their EMG

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activity level may still be within a range considered normal. Alternatively, not all patients with back pain have a condition that presents with an elevated EMG trunk muscle activity.

One recent study[205] compared the EMG activity of the trunk muscles between normal subjects and chronic low back pain patients during standardized trunk movements controlling for the many variables including age, sex, weight and skin fold thickness below the attached electrodes. In this study, the EMG amplitude analysis revealed significant differences between groups for some muscles (left lumbar and thoracic erector spinae). The authors further noted that the abnormal (asymmetric) EMG patterns detected among the chronic low back pain patients were not explained by postural asymmetries.

Other EMG analyses compare the changes in the muscle activation level over time making it possible to compare the shape of the EMG linear envelop (activation profile) across subjects or within a subject to compare bilateral muscle group symmetry. Grabiner[206] found a greater degree of erector spinae bilateral asymmetry in a low back pain population (n=6) compared with a control group during an isometric exertion. A similar difference between populations was found by Lehman[192] during dynamic flexion tasks. This study quantified the symmetry in the bilateral erector spinae (upper T9 and lower L3) EMG linear envelope using a cross correlation function which assesses the similarity between the left and right EMG waveforms. They found that the left and right lower erector spinae linear envelopes (activation profile) were less similar (correlated) in low back sufferers compared with normals.

Assessing EMG Frequency Spectrum (Frequency-Domain Analysis)

EMG spectral parameter assessment refers to different ways of measuring and representing the frequency content of the raw EMG signal, which is composed of different frequencies between 10 and 500 Hz. One measure of the frequency content in a signal is the median frequency (ie, the frequency of the EMG signal that divides the signal into two halves of equal power[207]. Assessing the frequency spectrum of an electromyogram is helpful in evaluations of muscle fatigue. Several investigators have demonstrated a decrease of power density in the high frequency region of the high frequency region and an increase in the low frequency region during fatiguing contractions[208]. Lindstrom et al.[209] have demonstrated that frequency shifts were almost entirely dependent upon the propagation velocity of the action potentials which have been linked to the production and accumulation of acid metabolites[210].

The median or center frequency of the power density spectrum is usually used as the variable to measure the frequency shift associated with muscle fatigue. During isometric fatiguing contractions a compression of the power density spectrum of the EMG signal toward lower frequencies occurs. The rate of the decrease in the Median frequency (MF) provides an index of fatigue for the task performed[211].

Unfortunately, the protocol for some of these studies to measure lumbar musculature fatigue is equipment intensive. In many investigations the protocol requires the pelvis and lower limbs to be stabilized and supported while the spine is held in a consistent position of neutral or thirty degrees flexion. The subject then is asked to exert an extension force either against a pad behind them or against a chain that is secured to a vest they are wearing. Subjects perform a maximum voluntary contraction (MVC) to determine the amount of force they will exert during the fatiguing trials that require the subject to exert 40, 60 or 80% of their MVC for a period of 30 seconds. A rest period of 60 seconds occurs and the exertion is repeated for 10 seconds. A similar protocol has been found to be reliable in between-days testing[212].

By assessing the changes in median frequency of the erector spinae musculature researchers have been successful in discriminating between low back pain symptomatic populations and pain free populations with sensitivity scores ranging from 76% to 88%[207;213-218]. Monitoring the spectral parameters of the EMG signal of the lumbar erector spinae, and multifidus during fatigue has shown superior discriminant validity than isometric strength measurements and range of motion

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assessments[215]. Other research has documented a significant correlation of patients' subjective perception of fatigue with mean and median power frequency during back extensor endurance tests[219].

While assessing EMG spectral parameters during fatigue has strong support for discriminant validity its ability to track changes during a rehabilitation program and its relationship to other outcome measures has been less well evaluated. Mannion et al.[220] found that over the course of three different therapies the Biering-Sorensen time to fatigue increased 18% but no change in the spectral parameters were seen. This is contrasted in the study by Roy et al.[214] who found that over the course of a 4 week rehabilitation program participants showed an improvement in the spectral EMG measures of the lumbar musculature. Such improvement in spectral EMG parameters was also reported by Kankaanpaa et al.[221] in a chronic low back pain population following 12 weeks of active therapy at a one year follow up. Researchers have also shown an increased fatigueability of the gluteus maximus relative to healthy controls[222]. Increased fatigueability of the gluteus maximus may compromise SI joint stability as evidenced by the work of Vleeming et al.[223] and possibly contribute to low back pain. Reduced back muscle endurance has also been correlated with an increased inhibition of the knee extensors in golfers with chronic low back pain[224].

For the average clinician, performing endurance tests can be a challenge due to factors such as equipment necessary to adequately constrain the and force transducers to quantify the MVC and monitor force production. In addition, the use of MVCs in a clinical population may have safety implications concerning iatrogenic injury. A modified technique has been used which sees the participant adopting the Biering-Sorenson trunk endurance position. This position requires the subject to lie prone on a table with their trunk overhanging the edge and their lower body strapped to the table. The subject then maintains the trunk parallel to the ground. This test has been shown to approximate between 40 and 52% of Maximum Voluntary Contraction[225;226]. These values are comparable to the percent MVC values used in the standard protocol used by others.

Electromyography provides the clinician with additional data regarding muscle activity that may be useful when performed and interpreted properly. Several considerations must be considered in the course of incorporating EMG assessments in clinical practice. EMG equipment is relatively expensive, and training is required for proper performance of EMG assessments. In addition, the evaluation is time consuming. Clinicians should be wary of EMG systems that are being marketed within the chiropractic profession that recommend protocols that do not include proper normalization or signal processing. Along the same lines, extrapolation of EMG findings without clinical correlates should be cautioned as well.

Neurodiagnostics

Conventional electrodiagnostic evaluation, including needle EMG and a variety of nerve stimulation tests has a proven and long established place in the evaluation and diagnosis of disorders of muscle and nerve[227]. Ongoing research into the more standard electrodiagnostic tests has resulted in the ability to better define the sensitivity, specificity, and theoretical basis of these tests, in turn, leading to an improved understanding of how neurodiagnostic testing can influence diagnostic and treatment outcomes[228]. Numerous neurophysiological tests are available to the clinician managing spinal disorders as shown in Table 16.

Several questions can be answered by clinical neurophysiologic such as whether a neurologic deficit exists and the extent of its nature, severity, chronicity, and progression. Haldeman and Dvořák[228] have presented the natural progression of tests that add information to the clinical examination. The clinical examination is often capable of accurately defining both the presence and the nature of a neurologic deficit. If motor, sensory, and reflex abnormalities all follow well-defined, consistent patterns, the presence of a particular neurologic deficit can be assumed with a high degree of confidence. Unfortunately, however, in many patients with back pain, such findings are not easily discernable. Moreover, no single test has been developed to document all types of neurologic deficit.

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Table 16.
Primary clinical neurophysiologic tests and their utilization.
(Adapted from[228], pp.142.)

EMG	Acute & Chronic Denervation Myopathies
Motor Nerve Conduction	Peripheral Neuropathies Entrapment Neuropathies
Sensory Nerve Conduction	Peripheral Neuropathies Entrapment Neuropathies Postganglionic Nerve Injuries
H Reflex	S1 Radiculopathies Cauda equine lesions Sciatic Neuropathies Peripheral Neuropathies
F Responses	Motor Neuropathies Sciatic Neuropathies Peripheral Neuropathies
Mixed Nerve Somatosensory Evoked Potentials (SEPs)	Peripheral and Sciatic Neuropathies Myelopathies Brainstem and Cortical Lesions
Small Sensory Nerve Evoked Responses	Sensory Radiculopathies Sensory Peripheral Neuropathies Myelopathy
Dermatomal SEPs	Root-specific Sensory Radiculopathies Sensory Peripheral Neuropathies Myelopathies
Cortical and Nerve Root Evoked Potentials	Myelopathies Radiculopathies
Muscle Evoked Responses	Myospasm
Thermography	Reflex Sympathetic Dystrophy

Another consideration upon test selection involves the timing of the condition or injury. EMG measures of denervation and reinnervation are slow, ongoing processes taking approximately 3 to 4 weeks after injury for the muscle membrane to react to denervation[228]. Hypersensitive responses in the form of spontaneous electrical activity as is seen in fibrillation potentials and positive sharp waves thus are not observed with needle EMG until nearly a month after injury. Direct nerve conduction tests, however, become abnormal immediately after the onset of a neuronal injury[229].

Needle EMG

Needle EMG (nEMG) evaluation appears to be the most useful electrophysiological technique in the diagnosis of radiculopathy[230;231]. Needle EMG is used to measure single motor unit potentials. Spontaneous activity is measured during and after the insertion of the electrodes into the muscle to be examined and again once activity has equilibrated. The patient is also requested to perform varying degrees of muscular contraction intensities. The characteristics of the duration, amplitude and phases

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of the action potential are examined for abnormalities associated with disease. Some phenomena associated with neurological disorders include synchronization for motor unit potentials, fibrillation potentials, positive sharp waves and fasciculations. Myopathies often demonstrate the common characteristic of a diminished mean duration of action potentials. Other findings include spontaneous activity, increased polyphasic potentials and reduced motor unit field[13].

Needle EMG has proven useful in distinguishing false-positive radiologic studies as normal persons have few, if any electromyographic abnormalities in the paraspinal muscles[232]. Needle EMG, in particular, can be a sensitive test for radiculopathy and neuronal deficits[228]. Such testing, however, requires a high level of technical experience and expertise.

Nerve Conduction Velocity

Nerve conduction velocity (NCV) testing provides information about the speed, or latency, of neural transmission along a known distance of a sensory or motor nerve fiber. By stimulating a nerve at two different points, two latencies can be obtained and a velocity calculated using the following equation: NCV= D/(Lproximal – Ldistal). The distance (D) in millimeters between the two electrodes divided by the difference in latency time (L) in milliseconds equals the conduction velocity of the nerve (NCV) in meters per second. Measurements may be made at several points along the nerve to identify the location of a lesion. Nerve conduction velocities can be compared with known values for interpretation.

In understanding nerve stimulation studies, one must remember that a nerve fiber is a cluster of variable size nerves which will respond to different stimuli. The wave of propagation that results can be *orthodromic* (from proximal to distal) or *antidromic* (from distal to proximal). In this manner, the response of a nerve can be identified using recording electrodes and the relationship between stimulus and response can be displayed and recorded. The applied stimulus is graded as subthreshold, threshold, submaximal, maximal, or supramaximal.

H-Reflex

The Hoffman Reflex, or H-reflex, is an electrical analog of the sensory-motor monosynaptic stretch reflex that is elicited by selectively stimulating Ia fibers of the posterior tibial or median nerve. Such stimulation can be accomplished by using slow (less than 1 pulse/second), long-duration (0.5-1 ms) submaximal stimuli with gradually increasing stimulation strength which bypasses the muscle spindle and directly stimulates the afferent nerves. The H-reflex can be thought of as a controlled version of the classic deep tendon reflex where mechanical stimulation to the tendon containing sensory receptors elicits a subsequent motor response. Studying H-reflex modulation provides insight into how the nervous system centrally modulates stretch reflex responses.

In the lower extremity, the H-reflex is traditionally performed by applying the electrical pulse over tibial nerve the poplitial fossa which produces a burst of action potentials traveling both orthodromically and andromically from the site of stimulation[233]. The first impulses to reach the recording electrodes are a direct motor response termed the M-wave. The H-wave is delayed due the reflex duration from the time it takes for the stimulus to travel along the Ia fibers, through the dorsal root ganglion, across the spinal cord to the anterior horn cell which then propagates the impulse along the alpha motor axon to the muscle. H-reflex latency can be determined easily from charts, according to height and sex or from published normal values[234]. The best normal value, however, is perhaps the patient's asymptomatic limb as the difference in latency between both sides should not exceed l ms.

The H-reflex can be obtained at low stimulation levels without any motor response (Mwave) preceding it. As the stimulation strength is increased, the M-wave appears. With further increases in stimulation strengths, the M response becomes larger and the H-reflex decreases in amplitude. When the motor response becomes maximal, the H-reflex disappears and is replaced by a small late motor response, the F-wave. The H-reflex can normally be seen in many muscles but is easily obtained in the soleus muscle (with posterior tibial nerve stimulation at the popliteal fossa), the flexor carpi radialis muscle (with median nerve stimulation at the elbow), and the quadriceps (with femoral nerve

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stimulation). The H-reflex is useful in the diagnosis of S1 and C7 root lesions as well as the study of proximal nerve segments in either peripheral or proximal neuropathies. The H-reflex has been shown to have a high correlation with the Achilles tendon reflex and measures the presence or absence of an S1 radiculopathy with a high degree of accuracy[235;236].

The use of a magnetic stimulator more recently in conducting H-reflex tests allows the recording from stimulation of nerves at multiple levels from the popliteal fossa to the spine[237]. Dishman et al have utilized H-reflex testing protocols in addition to transcranial magnetic stimulation in the investigation of the effects of lumbar spinal manipulation on the excitability of the motor neuron pool[238-241] with encouraging results and applicability to understanding the mechanisms of spinal manipulative therapy.

F-Response

The F-response is a long latency muscle action potential seen after supramaximal stimulation to a nerve. The F-wave results from a centrifugal volley in an alpha motor neuron, following antidromic excitation of the nerve cell body in the ventral horn of the spinal cord. This test is performed by stimulating a motor nerve in the leg or forearm resulting in an impulse back to the anterior horn in an orthodromic response in the same motor nerve which in turn can be recorded in the muscle to which the nerve travels[242]. Unlike the H-reflex, the F-wave is always preceded by a motor response and its amplitude is rather small, usually in the range of 0.2-0.5 mv. Although it can be elicited in a variety of muscles, it is best obtained in the small foot and hand muscles. The data obtained from the F-wave have been used in many different ways to determine proximal or distal pathology. The normal values can be determined from charts or published data and, in unilateral lesions, the best normal values remain those of the patient's asymptomatic limb. The difference between both sides' shortest latencies should not exceed l ms.

Clinical applications of F-Response are conditions such as entrapment neuropathies and root compression syndrome and estimation of motor neuron excitatibility. Toyokura et al.[243] evaluated the sensitivity of the F-Response in 100 patients with lumbosacral radiculopathy and confirmed disc herniation and reported a 70% positive response rate. It should be remembered, however, that because this response is independent of the sensory nerve root, F-Responses are not sensitive for sensory radiculopathy or neuropathies. Bobinac-Georgijevski et al.[244] performed H or F wave latencies of medial head of gastrocnemius muscle in 97 patients with suspected S1 radiculopathy with or without additional L5 radiculopathy. Needle EMG of the medial gastrocnemius muscle was supplemented by H or F wave latency measurement bilaterally by percutaneous stimulation of tibial nerve in cubital fossa. EMG abnormalities indicating S1 radiculopathy were followed by H or F wave latencies abnormality in 63% of patients. The rest of 37% of patients of these groups showed mild EMG abnormalities followed by normal H or F wave. Normal EMG finding was followed by normal H or F wave. Normal EMG finding was followed by normal H or F wave in 64% of patients. Increased latency of H or F wave without EMG abnormalities in gastrocnemius muscle was present in 36% of patients. The results of this study indicated that measurements of H of F latencies provide the objective evidence of S1 radiculopathy, presenting with the unilateral increase of latency or the absence of response. The authors additionally noted that abnormal H response latencies without EMG abnormality confirm the condition of sensory root affection only.

Evoked Potentials

Evoked potentials are electrical signals generated by the nervous system in response to sensory stimuli. Auditory, visual, and somatosensory stimuli are among those often used for clinical evoked-potential studies. Somatosensory evoked potentials (SEPs) consist of a series of waves that reflect sequential activation of neural structures along the somatosensory pathways following electrical stimulation of peripheral nerves. SEPs can be used to compliment the F wave response in determining the sensory component of a radiculopathy. The easiest and most commonly used method of eliciting an SEP is by stimulating large mixed nerves, such as the median nerve at the wrist, the common

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peroneal nerve at the knee, or posterior tibial nerve at the ankle[228]. Upon stimulation of these nerves it is possible to obtain a well-defined and reproducible response over both the spinal cord and the scalp through the use of computer averaging of the time-locked potentials. By measuring the latency of these responses and relating them to normative values that account for patient demographics, it is possible to document disturbances in the primary sensory pathways from the point of stimulation to the scalp[245].

SEP abnormalities can reveal a reduced amplitude or impaired morphology of the signal. SEPs are used for clinical diagnosis in patients with neurologic disease and for intraoperative monitoring during surgeries that potentially compromise the somatosensory pathways[246]. Abnormal SEPs can result from dysfunction at the level of the peripheral nerve, plexus, spinal root, spinal cord, brain stem, thalamocortical projections, or primary somatosensory cortex. Since individuals have multiple parallel afferent somatosensory pathways (ie, anterior spinothalamic tract, or dorsal columns), SEP recordings can be normal even in patients with significant sensory deficits[245]. SEPs are characteristic of the functional integrity of the fast-conducting, large-diameter group IA muscle afferent fibers and group II cutaneous afferent fibers, which travel in the posterior column of the spinal cord. When a mixed peripheral nerve (containing both sensory and motor fibers) is stimulated, both group IA muscle afferents and group II cutaneous afferents contribute to the SEP response. SEPs, thus, provide information concerning the integrity of the pathway through the brain, brainstem, spinal cord, dorsal nerve roots, and peripheral nerves.

SEPs from physical stimuli administered in either the upper or lower extremity are detectable in the brain or the spine simply by placing electrodes over the spinous processes at multiple levels and over the scalp to evaluate the somatosensory pathway[228]. In this manner, it is possible to determine the level within the spinal cord at which a suspected lesion is interfering with the primary sensory pathways. SEPs may be useful in assessing suspected spinal stenosis or pathology proximal to the spinal nerve root[229] in addition to being helpful during intraoperative monitoring during spinal surgery[247].

Thermometric Instruments and Thermography

Principles of conduction and radiant emission of heat energy from the body have been employed to develop instruments to measure temperature at different body regions. D.D. Palmer, the Founder of Chiropractic, is said to have used the back of his hand to locate "hot boxes" along the spinal column in an effort to detect differences in surface temperature from one side to the other[248]. A number of devices have been developed to record regional body temperature differentials. Thermometric devices include thermocouple instruments that measure skin temperature by conduction, and infrared devices which do not make contact with the skin. Thermography is a physiologic imaging technology that provides information on the normal and abnormal functioning of the sensory and sympathetic nervous systems, vascular dysfunction, myofascial trauma and local inflammatory processes. Currently there are two recognized methods of thermographic imaging; infrared thermographic (IRT) and liquid-crystal thermography (LCT) which will be discussed in this section.

Thermometric Instruments

Chiropractic's developer B.J. Palmer became interested with the Neurocalometer (NCM), a device invented in 1924 by Dossa D. Evans, D.C., and developed by Otto Schiernbeck, a consulting engineer on the staff of Palmer College of Chiropractic[249]. The device consisted of two heat-detecting probes (thermocouples) connected to a meter that registered whether points on each side of the spine had different temperature differentials (Figure 17). Electrically, the thermocouples are differentially connected and their output drives a strip-chart recorder. When the dual thermocouple is moved along the paraspinal skin by the examiner, the recorder trace represents a scan of differential temperatures. The Nervo-Scope (Electronic Development Labs, Inc. Danville, VA), a next-generation of the NCM, contains a battery, a meter, and thermocouples at the end of its dual probes.

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To examine a patient with these instruments, the sensing head is centered with moderate pressure on the spine at S2 and moved slowly to C1. If there is no side-to-side temperature difference, the voltage output remains zero. Some have reported, however, that that the readings were greatly influenced by how hard the thermocouples were pressed against the skin[250]. Measurement error using thermocouple devices can be attributed to many factors in such testing[251], including:

1. Inadequate heat exchange between the skin and the temperature detector;
2. Variations in glide speed;
3. Combined mechanoceptive and thermoceptive neuronal function which tends to rapidly alter skin temperature;

Figure 17.
Original Neurocalometer (c.1924) (Left) and a later version (c.1960, inset). The present day version, the Nervoscope and Analyagraph (Electronic Development Labs, Inc., Danville, VA) are shown on the Right.

4. Non uniform pressure;
5. Inadequate "dwell" time;
6. Path-of-travel variations; and
7. Non uniform starting and ending points.

There has been a paucity of research published using these devices, and among published reports, such paraspinal measures have not been shown to have good discriminability, and both their validity and reliability of measurement are doubtful[76]. This was more recently confirmed in a study of infrared thermoraphy performed in patients suffering chronic lumbosciatic pain during spinal cord stimulation[252].

Thermography

Infrared thermography measures infrared electromagnetic energy emitted from the object. Cholesteric liquid crystals are special compounds that display specific color changes in response to variations in temperature. Their responses can be graphically demonstrated by means of color

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thermography[253]. Measurement of temperature differentials through enhanced thermographic imagery has long been employed in the evaluation of pathologies including breast cancer, detection of deep vein thrombosis, identification of allergic reactions, qualification of vascular phenomena, and the identification of pain[13]. Some seeking to attempt to better quantify the patient's physiology have incorporated the use of thermography in chiropractic practice. Accurate and repeatable thermographic examinations, however, are rather time consuming and dependent upon standardized procedures[13]. For example, the examination room must be windowless, draft free, maintained at a constant temperature of 20º C, with specific lighting requirements. An adaptive period is required to account for the rapid drop in skin temperature that occurs immediately following patient gowning. Time of day is another variable upon thermography assessment.

Thermography has been investigated for clinical evaluation of the musculoskeletal system in a number of studies with varying results of clinical utility. The role of thermography for diagnosing lumbar radiculopathy was evaluated by literature review and meta-analysis in 1991[254]. From 81 relevant citations, 28 studies could be analyzed for diagnostic-accuracy data (sensitivity and specificity) and method. Twenty-seven studies had major methodologic flaws including biased test interpretations, faulty cohort assembly, poor clinical descriptions, and small sample size. The only study of reasonably high quality found no discriminant value for liquid-crystal thermography. The authors concluded that the role of thermography remains unclear and rigorous clinical research is required to establish its diagnostic accuracy and clinical utility. Thermography cannot be recommended currently for routine clinical use in evaluating low-back pain.

McCulloh et al.[255] investigated the premise of thermography supporters, that: (a) normal patients have normal thermograms of their lower extremities, and (b) abnormal patients (with disk ruptures causing sciatica) have abnormal thermograms. To test these two hypotheses, 56 patients with clinically documented disc protrusion/prolapse and acute sciatica had presurgical thermograms and one-year follow-up thermograms. These 56 patients were then matched with 56 control (normal) patients who had electronic thermograms. The 112 thermograms were then interpreted blindly by two thermographers and the sensitivity and specificity of thermography as a diagnostic aid in sciatica were statistically analyzed. The results of this study determined that the sensitivity of thermography (its ability to be positive when sciatica was clinically obvious) was 60% and 50% for the two thermographic readers. The specificity of thermography (its ability to be negative in asymptomatic patients) was 45% and 48% for the two thermographers. The authors concluded that their results are the same as those previously published, that thermography is not useful as a diagnostic aid in sciatica.

In reviewing the literature on the use of thermometric and thermography relevant to chiropractic practice, in 1992 Plaugher[256] noted,

> "There has been a general lack of high-quality research design (e.g., blinding) throughout the thermographic literature base. The sensitivity of the various thermographic instrumentation has shown encouraging results, although this must be tempered with the generally poor design of many studies. Specificity, in contrast, has shown mixed results. The review indicated telethermography to be a sensitive diagnostic procedure for detecting abnormalities, such as disc protrusion, of the lumbar and cervical spine. Liquid crystal thermography effectiveness is difficult to determine due to the paucity of blinded investigations, although normative data for the cervical spine and upper extremities is present. Literature on the various hand-held instruments has revealed moderate levels of examiner reliability for infrared devices, with less information available for thermocouple instruments. Normative data for hand-held instruments is absent."

Plaugher's conclusions relevant to this area are still applicable today,

> "Continued investigation is needed in the area of thermographic research in light of the paucity of blinded and/or controlled investigations. More sensitive neurophysiological and anatomical measures must be used when comparing the results from thermography. The lack of an available gold standard for

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comparing thermographic findings has been problematic. Future research should focus on thermography as a noninvasive outcome measure and interpreter reliability[256]."

Conclusions

A wide range of instruments have been developed through the years to assist the clinician in transforming a once qualitative-only practice to one that seeks to obtain quantitative objective findings in patient management. Spine measurement instruments include perceptual, structural, functional, and physiological dimensions with numerous instruments designed to evaluate specific facets of each dimension. Varying degrees of reliability and validity as well as sensitivity and specificity exist in many of the measures of each dimension. As noted in the earlier version of this chapter[13], some measures are generally accepted, well established, and widely used, while others have no proven value or are developmental in nature. The chiropractic clinician must discern which measures to best serve the interests of their patients from both a utility and financial standpoint.

As in many other health care professions, technological advances continue to bring new instruments to the marketplace in chiropractic. The main features of any instrument can be evaluated to ascertain clinical utility can be evaluated on the basis of discriminability and normative data[13]. Claims of efficacy of any instrument or technology and clinical utility must be soundly based in the peer-reviewed indexed literature and be properly scrutinized to be worthy of use in chiropractic practice to establish a diagnosis, monitor clinical outcomes, and be reimbursable from third-party payers.

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