



1995

A Review of Spinal ROM Measurement Tools

Dawn Kamihara
University of North Dakota

Follow this and additional works at: <https://commons.und.edu/pt-grad>



Part of the [Physical Therapy Commons](#)

Recommended Citation

Kamihara, Dawn, "A Review of Spinal ROM Measurement Tools" (1995). *Physical Therapy Scholarly Projects*. 249.
<https://commons.und.edu/pt-grad/249>

This Scholarly Project is brought to you for free and open access by the Department of Physical Therapy at UND Scholarly Commons. It has been accepted for inclusion in Physical Therapy Scholarly Projects by an authorized administrator of UND Scholarly Commons. For more information, please contact zeinebyousif@library.und.edu.

A REVIEW OF SPINAL ROM MEASUREMENT TOOLS

By

Dawn Kamihara
Bachelor of Science in Physical Therapy
University of North Dakota, 1994



An Independent Study

Submitted to the Graduate Faculty of the

Department of Physical Therapy

School of Medicine

University of North Dakota

in partial fulfillment of the requirements

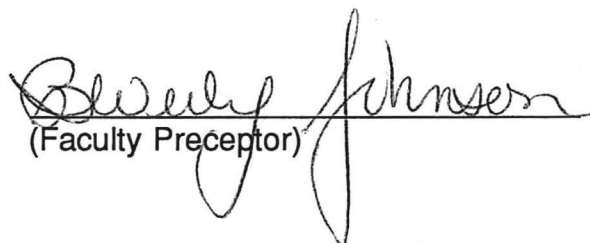
for the degree of

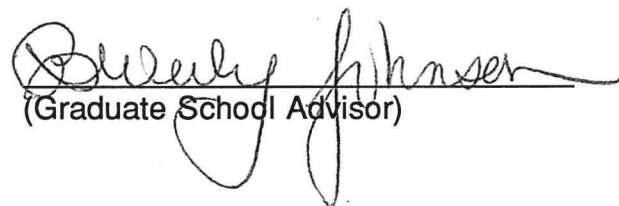
Master of Physical Therapy


Grand Forks, North Dakota

May
1995

This Independent Study, submitted by Dawn Kamihara in partial fulfillment of the requirements for the Degree of Master of Physical Therapy from the University of North Dakota, has been read by the Faculty Preceptor, Advisor, and Chairperson of Physical Therapy under whom the work has been done and is hereby approved.


(Faculty Preceptor)


(Graduate School Advisor)


(Chairperson, Physical Therapy)

PERMISSION

Title A Review of Spinal ROM Measurement Tools

Department Physical Therapy

Degree Master of Physical Therapy

In presenting this Independent Study Report in partial fulfillment of the requirements for a graduate degree from the University of North Dakota, I agree that the Department of Physical Therapy shall make it freely available for inspection. I further agree that permission for extensive copying for scholarly purposes may be granted by the professor who supervised my work or, in her absence, by the Chairperson of the department. It is understood that any copying or publication or other use of this independent study or part thereof for financial gain shall not be allowed without my written permission. It is also understood that due recognition shall be given to me and the University of North Dakota in any scholarly use which may be made of any material in my Independent Study Report.

Signature *Dawn Kamihara*

Date 5-4-95

TABLE OF CONTENTS

LIST OF FIGURES	v
ACKNOWLEDGMENTS	vi
ABSTRACT	vii
CHAPTER	
I INTRODUCTION	1
II SPINAL RANGE OF MOTION MEASUREMENT TOOLS .	5
Introduction	5
Goniometers	6
Flexible Rulers	14
Inclinometers	19
Motion Analysis System	27
B-200	32
Spinoscope	36
III DISCUSSION AND CONCLUSION	41
REFERENCES	46

LIST OF FIGURES

Figure		Page
1.	Trigonometric derivation of the angle representing the shape of the lumbar spine	16
2.	EDI 320	22
3.	Metrocom Skeletal Analysis System	29
4.	B-200	33
5.	Spinoscope	37

ACKNOWLEDGMENTS

I would like to express my appreciation to my graduate advisor, Bev Johnson, for her support, encouragement, and guidance in preparation and completion of this independent study. Also to Bev and the entire PT staff for all the support and help through three “quick” and very cold years of PT school. I also wish to thank Ms. Alyson White for her invaluable technical services in the completion of this project. To CHART of Hawaii for their generosity in allowing me the use of their clinical equipment. To my family and friend, Karyn Isono, for their support and generosity. Finally, to my best friend, Kyle Nakamura, for his patience, persistence, and belief in me.

ABSTRACT

Physical therapists rely on measurements to communicate with one another, establish patient status, predict treatment response, document treatment efficacy, and claim scientific credibility for the profession. Therefore, the quality of measurements should be of great concern to physical therapists and, hence, therapists should be able to examine the quality of measurement tools they are using critically. A variety of measurement tools are being utilized in physical therapy to quantify spinal mobility; however, there is no clarity as to which of the tools are optimal. In particular, the spinal range of motion measurement tools will be examined because of the high occurrence and high cost of low back injuries.

The spinal range of motion measurement tools reviewed in this study include goniometers, flexible rulers, inclinometers, motion analysis systems, the Isotechnologies B-200, and the Spinoscope. The use of each of these measurement tools has advantages and disadvantages in a clinical setting. The reliability and validity of a measurement tool should be the most important considerations, but individual clinical needs and available resources also need to be considered when choosing an appropriate spinal range of motion measurement tool. If all these factors are considered, the author recommends

the use of inclinometers since many studies show the inclinometer to be both reliable and valid. The EDI 320, in particular, is recommended for its ease of application. Finally, even if a tool is shown to be reliable and valid, established protocols for measurement techniques should be followed by each clinical staff member.

CHAPTER I

INTRODUCTION

The incidence of low back syndrome from 1960s to the 1980s has increased to epidemic proportions.¹ Low back injuries are the most frequent and costly of the musculoskeletal disorders.² Eight out of ten people will suffer from back pain at least once in their lives.³ To effectively treat low back syndrome, tools with adequate measurement characteristics are required for evaluation of impairment, functional abilities, and disability ratings.⁴ Spinal range of motion for lumbar flexion and extension is a measurement commonly required for an assessment. A variety of measurement tools are available to the physical therapist. The physical therapist must select the most appropriate tool considering reliability, validity, cost-effectiveness, and time-effectiveness of the instrument.

Widespread changes are presently occurring in the health care industry. These changes involve controlling costs of health care by integrating health services and improving the efficiency of the health care system. This integration will have an impact on all the health professions, including physical therapy. There already exists external pressures for accountability, cost-controls, cost-benefit analysis, and pressures for documenting efficacy by the

medical community. Therefore, it will be vital to the physical therapy profession to prove that physical therapists can efficiently and effectively provide rehabilitation services through scientifically sound outcome studies.

Without a scientific basis for the assessment (and measurement) process, physical therapists face the future as independent practitioners who are not able to communicate with one another, document treatment efficacy and claim scientific credibility for their profession. If physical therapists want to claim efficacy for their treatments, they must document change in their patients and, therefore, are entirely dependent on the quality of measurements. Like medicine and law, physical therapy will always partially remain an art, but without measurement, it can be nothing more.⁵

Science is characterized by the quality of and the degree to which it measures the parameters of its field.⁶ These measurements may give the impression of science and precision, but measurements can be misleading unless they are demonstrated to truly convey information (i.e., reliability and validity). A measurement will not yield meaningful information without being reliable and valid.⁵ Precise measurement is vital to the physical therapy profession because it is a basis for differential diagnoses, establishes patient status, assesses progress or decline of the patient's status, predicts treatment response, builds and tests theories, and conveys information across professions.⁶

Precise range of motion measurements are needed to determine disability, guide treatments, and provide patient feedback.⁷ Therefore, examining the quality of measurements should be of great concern to physical therapists since measurements are used to guide clinical decision making. "Therapists are coming to understand that if the validity of their instrumentation is questioned, so too will be the validity of their intervention."⁶ Therefore, therapists should be able to critically examine the quality of the measurement tools they are using.

The two fundamental requirements of measurement are reliability and validity.⁵ Reliability refers to the precision of the measurement or how consistent a measurement is when all conditions are held constant.⁸ Four types of reliability apply to physical therapy: intratester reliability, intertester reliability, parallel forms of reliability, and internal consistency. The scope of this paper will be limited to intratester reliability and intertester reliability. Intratester reliability refers to stability over time. Individual intratester reliability is assessed by having the same therapist measure the same element at different times. The factors that can affect intratester reliability include: the instrument, the person administering the test, and the subject being measured. Intertester reliability refers to stability between examiners. It assesses the agreement between different examiners measuring the same element.⁵

Validity refers to the ability of a test to measure what it is intended to measure and to assess whether judgments can be made from the results.⁸ A universal definition for validity is not readily available; therefore, the evidence for

validity is hard to secure.⁵ For measurements, only reliability is an essential factor, but if a measurement is reliable and not valid, there is no justification for its use or application.⁴

This paper will review a variety of different types of equipment used to measure spinal range of motion and examine their reliability, validity, cost-effectiveness, and time-effectiveness. "A science is only as good as the measurements on which it is based."⁵ This review is designed to help physical therapists make wiser, more knowledgeable, and "scientific" choices regarding spinal assessment range of motion equipment. Providing valid and reliable measurements will help move our profession from an inherently humanistic profession to one that is also based on science.

CHAPTER II

SPINAL RANGE OF MOTION MEASUREMENT TOOLS

Introduction

Measuring range of motion is an important aspect in determining physical impairment. The American Medical Association's⁹ Guide to Permanent Impairment considers range of motion measures to be the only objective measure of lumbar physical capacity.⁹ Deyo¹⁰ described ROM as "hard" versus "soft" data in clinical evaluations, meaning the measurements are observable physical findings which are preferred rather than information which is subjective and unreliable. Therefore, ROM assessments are traditionally given the greatest attention in impairment evaluations. Strength measures and lab data are also considered.

There are various tools which are used to assess joint motion and muscle function. These tools vary from visual estimation to advanced imaging systems. Because many techniques exist for measuring spinal motion, no single method has been fully developed. Choosing the proper tool involves examining the qualities of each tool and measuring specific benefits of each. Important qualities to assess are reliability, validity, ease of application, and cost-

effectiveness. The following spinal ROM measurement tools will be assessed for these qualities to assist the clinician in the selection of the evaluation tool.

- goniometers
- flexible rulers
- inclinometers
- motion analysis systems
- B200
- Spinoscope

Goniometers

Goniometry is the most popular method used to assess joint range of motion. Because it is so widely used in physical therapy, goniometry can be considered a fundamental part of the “basic science” of physical therapy. Over the last 60 years, the growth of goniometry has been paralleled to the growth of the physical medicine and rehabilitation field,¹¹ thus fostering the development of new goniometric instruments.

Physical therapists use goniometry for quantifying baseline ROM to decide on appropriate treatments and to document the effectiveness of the treatments.¹¹ According to the American Medical Association's Guide to Permanent Impairment, range of motion is the only objective measure of lumbar physical functional capacity⁹; however, Mayer¹² states that range of motion is a deficient assessment tool. A simple goniometric measurement, which is the technique described by the American Academy of Orthopedic Surgeons

instructions for measuring lumbar spinal range of motion, cannot distinguish between hip and spinal motion components.¹ Also, inexact upper limits of measure prevents the reproduction of the length of the segment measured. Finally, there are no standard methods which measure patient effort. Therefore, the “objective” measure may be worse than having no measurements, since it results in the evaluator having a false sense of the techniques’ objectivity.¹²

Types of Goniometers

A variety of goniometers that have been developed include the universal goniometer, the pendulum goniometer, the fluid goniometer, the gravity goniometer, the electric goniometer, and the computerized goniometer.^{13,14} The most commonly used goniometric instrument is the Universal Goniometer. This is due to the fact that it can be used to measure any joint in the body. Other joint-specific goniometers have also been developed for specified areas of the body.¹⁵

The universal goniometer is made up of a protractor with two arms extending from it. One arm is stationary relative to the protractor and one is moveable.¹⁴ The scale encompasses 360 degrees and can extend either from 0 to 180 degrees or 180 to 0 degrees. Advantages of the goniometer include its low cost, accessibility, and ease of application. Disadvantages include the universal goniometer’s questionable reliability and validity.¹⁶ A limitation of the universal goniometer when used to measure spinal ROM is that it represents

the multiaxial movement of several spinal joints as a uniaxial movement.¹⁷

Standard goniometry does not allow for lumbar motion to be measured separately from hip motion, since the derived measurement is a combination of the two.

Another variation of the goniometer is the electrogoniometer. An electrogoniometer is a non-invasive, electromechanical device that is attached to the trunk and pelvis, giving amplitude, velocity, and acceleration of movements by means of a computer interface. It consists of a standard potentiometer fixed to a plate at the S_1 level and connected by a flexible slat to another plate at the T_8 level. Dynamic motion can be measured with the electrogoniometer. It is a more sophisticated instrument than a manual goniometer and is used primarily in research. Improper reading of the measurement by the practitioner is eliminated because of the electrogoniometer's computer based system. Its limitation is that it is uniplanar and, therefore, only sagittal plan measurements can be measured. Also, the resultant measurement represents global dorsolumbar motion without identifying individual spinal segment motion between T_8 and S_1 .¹⁸

Computerized goniometers, such as the CA-6000 Spine Motion Analyzer (Orthopaedic Systems Inc., Hayward, CA), consist of an instrumented linkage coupled between the pelvis and thorax. The linkage is made up of six joints which contain rotary sensors. The sensors allow the continuous measurement and calculation of the relative angular motions between the mounting points. A

computer records and reports these motions (anterior-posterior bending, medial-lateral bending, and axial rotation of the thorax relative to the pelvis) and the data are plotted as the angle changes with respect to time.¹³

Some advantages of the computerized goniometer include:

- 1) motion can be examined either individually or simultaneously with the use of computer graphics that are built into the system
- 2) a composite graph of all motions can provide insight regarding a specific pathological process of the spine
- 3) measurements can be measured as quickly as the patient moves versus having the patient hold a certain position
- 4) the base of the computerized goniometer can span an excess of five vertebrae
- 5) spine motion and posture can be examined without inhibiting the motion of the subject
- 6) all data are recorded on a computer, both graphically and numerically, with the appropriate calculations so that a computer printout can be made to be attached to charts for easy reference.¹³

Reliability

The spinal motion measurement with the least variability is the optimal method. Reliability in goniometry refers to consistently producing the same measurements under the same conditions¹¹ and is one of the most important factors affecting objective goniometric measurements. However, its reliability

has been a controversial subject among researchers. The reason for this could be due to the fact that various reliability indices have been established and different research formats have been used for the various reliability studies on goniometry.¹⁹ This diversity is not conclusive to the comparisons of results between reliability studies. Therefore, the results of different studies are included, but no comparisons will be made.¹¹

According to Gajdosik,¹¹ the most accurate reliability evaluation of instruments and procedures is determined when the classical "test-retest" design is used. This is due to the fact that there will be fewer uncontrolled variables between tests with shorter intervals between them. In spite of the fact that short interval test-retest studies best reflect a test's reliability, studies which are conducted over days and weeks are still important. These tests allow clinical assessments of stability of the measurements so comparisons can be made to evaluate patient progress.¹¹

Sources of error variance also influence reliability studies. These include motions measured, instrumentation, methods of applications and variations among patients.^{11,20} The sources of error should be assessed independently of reliability measurements if possible.²⁰ Accurately assessing bony landmarks is essential for repeatability of measurements. Salisbury²¹ reported that only 3% of nonmedical examiners tested failed to accurately locate the correct spinous process and, therefore, it is highly unlikely that inaccurate surface markings is a contributor to error in reliability studies. All of the aforementioned concepts

should be kept in mind as the literature is reviewed. Mayerson et al²⁰ concluded that an average of up to four degrees can be expected and attributed to instrument error. They went on to conclude that this magnitude of error should stay the same or increase in applied settings if additional sources of error exist. Furthermore, certain joints are more easily measured resulting in improved reliability.^{22,23} Low²⁴ reported that measurement with a typical goniometer is more reliable than estimating by eyesight. Fitzgerald et al²⁵ showed standard goniometry to be reliable in measuring thoracolumbar extension. However, it is difficult to restrict measurement to the lumbar region only with the standard goniometry method unless pelvic tilt is closely monitored.

The reliability study on electrogoniometers showed that measures of the sagittal dorsolumbar spine motions obtained with electrogoniometers are reliable. The study used the test-retest measurements and intraclass correlation coefficient statistics. For dorsolumbar flexion in particular, the variation between test-retest measurements is approximately 1.6 degrees. The range measured was from the upright position to about 50 degrees of forward flexion.¹⁸ Regarding the computerized goniometer, the CA-6000, Dop¹⁹ showed that interexaminer and intraexaminer reliability displayed a variability significantly lower ($p < .025$) when compared to other testing methods.

The general conclusion of researchers is that goniometric measurements, within a certain error margin, results in an acceptable level of reliability under controlled situations.^{14,20} However, caution should be taken

when generalizing the existing data to common applications of goniometry.²⁰ In all studies, intra-observer error was found to be notably less than inter-observer error. Hellebrandt et al²² originally found this to be true and since then, many other researchers,^{23,24} such as Low and Boone, have also come to this conclusion. Therefore, it is recommended that one person take measurements when using goniometric measurements. The reliability of goniometric measurements vary with different joints.²⁴ For this reason, Mayerson²⁰ suggested that separate reliability indices should be established for specific joints. To improve reliability, it has been suggested that clinicians adopt standardized testing methods.

Validity

The second most important factor affecting objective goniometric measurements is validity. In order to be valid, measurements must first be reliable. Reliable measurements, however, do not ensure the measurements are valid. Validity is defined as the degree to which a meaningful interpretation can be inferred from a measurement.²⁶ When the term is applied to an instrument, it is the instruments' ability to measure what it is purported to measure, including appropriateness, meaningfulness, and usefulness of a test. It is also the extent to which an instrument fulfills its purpose.^{27,28}

In goniometry, the primary purpose is to measure the range of motion of the human musculoskeletal system. Therefore, confidence should be ensured that the goniometer and measurement procedures are accurate and also that

the meaning of the measurement results are understood. Since the goniometer is a modification of the protractor, the measurements obtained are limited to the degree units of a circle. The use of a goniometer, therefore, assumes the movements measured have fixed axes of motion about which the movements occur.¹¹ It is known that the axes of motion are, in fact, not fixed because of the other motions within the joints, such as articular sliding and rotation.²⁹ Strictly speaking, since goniometry is representing movements of body parts by units of a circle, its validity can be challenged.¹¹

According to Gajdosik,¹¹ the limitation of measuring movements using degree units of a circle have limitations, but are generally accepted since range of motion measured closely approximates movements around a central point. Goniometers are generally accepted as valid clinical tools. A study done by Pacquet et al¹⁸ indicated that the electrogoniometer displays very good concurrent validity when measuring sagittal dorsolumbar spine movements.

Contrary to the study done by Gajdosik, Mayer¹² states that using a goniometer to measure lumbar spine range of motion is simply incorrect. According to Mayer,¹² simple goniometric measures cannot be used because it is unable to distinguish between hip motion and spinal motion components, it prevents reproducibility due to an inexact upper limit of measure, and no standard method exists for measuring patient effort. Furthermore, when a universal goniometer is used, the multiaxial motion in the spine is represented by a uniaxial measurement.

The “gold standard” or the most powerful method to study the validity of range of motion measurements is radiography.¹¹ However, this is a costly, time consuming, impractical clinical procedure. It also poses a potential health hazard to the patient and, therefore, other valid methods need to be considered.³⁰

Gajdosik¹¹ emphasized that the validity of range of motion measurements is very specific. Range of motion is measured in degrees but the factors that may affect range of motion must be measured by different methods. Other factors, such as edema, pain, and strength deficits, may affect range of motion measurements but range of motion measurements are never measures of factors other than range of motion. Therefore, therapists should interpret and report range of motion measurements for what they are and not as measurements of factors that may affect range of motion.¹¹

Flexible Ruler

The flexible ruler has been described by Burdett²⁵ and Fitzgerald³² as one objective technique for measuring the mobility of the spine. Because it is pliable, the flexible ruler permits recording of the spinal contour in any assumed posture. In general, the flexible ruler is a 36 cm pliable ruler which is encased in soft plastic.³² To assess lumbar mobility, the ruler is molded to the lumbar spine. Then the contour is traced on a sheet of paper. This contour will assess the lumbar curvature as it is reflected on the skin surface. From the contour trace, tangents are drawn to obtain angles of measurement.³³

The method to determine measurement of lumbar lordosis as reported by researchers involve first palpating the spinous process of L₃ and S₂³⁴ or L₂ and PSIS.³⁵ These bony landmarks are then transferred onto the flexible ruler that is shaped to the contour of the lumbar spine. The flexible ruler is then carefully removed so that its shape is not distorted. The outline of the curve is traced onto a sheet of paper and the markings corresponding to the L₃ and S₂³⁴ or L₂ and PSIS³⁵ levels are labeled. The flexible ruler angle is determined by drawing a vertical line (l) intersecting the two points and is measured in centimeters. A parallel line (h) is then drawn from the center of the vertical line (l) to the curve and is also measured in centimeters. The parallel line (h) is the height of the lordosis curve and the vertical line (l) is the length of the curve. An index of lumbar lordosis is calculated using the formula: θ (theta) = $4[\arctan(2h/l)]^{32}$ (fig. 1).

This method of measuring lumbar curve is laborious, time consuming, and also introduces a secondary source of error (drawing the tangents).^{33,36,37} Another disadvantage of the use of the flexible ruler is the reliance on the examiner's palpation skills. Precise identification of the spinous processes can be affected by other factors such as excess subcutaneous fat. Also, because it is a surface measurement, it is an assessment of the lumbar curve as it is reflected by the skin.³⁵ This method becomes impractical as the subject's lordosis flattens because the tangent lines do not converge. Conversely, if the lordosis increases, the redundant skin and subcutaneous tissue mound up and

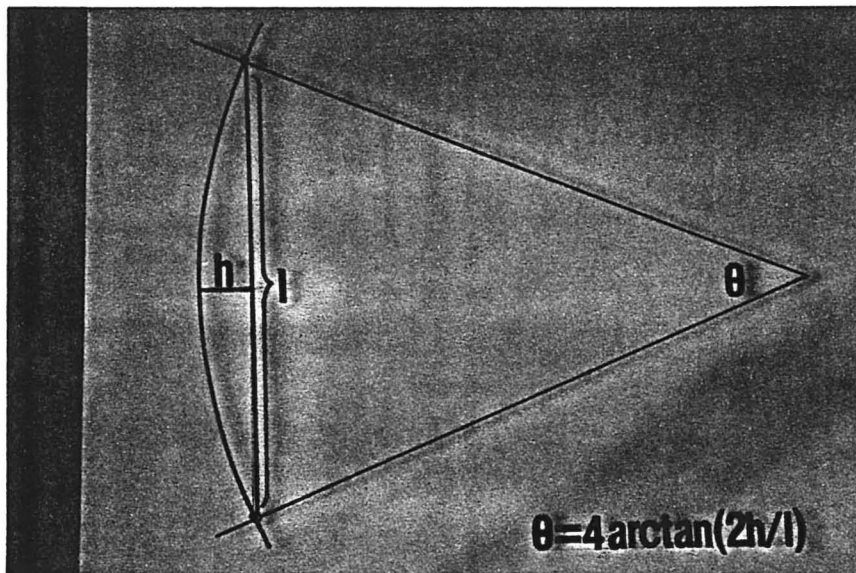


Fig 1.--Trigonometric derivation of the angle representing the shape of the lumbar spine.

complicate placement of the ruler.³⁷ Also, sacralization or lumbarization can change the level of movement at the lowest level by one segment up or down. Other spinal variations, such as excessive downward slope of the spinous processes, overlapping spinous processes, and height variation between individual's spinous processes can make accurate measurements more difficult.³⁵

The advantages of the flexible ruler, according to Israel,³⁸ are that it is inexpensive, readily available, easy to use, non-invasive, and it poses no safety problems to the patient. In fact, Frey and Tecklin³⁹ suggested the flexible ruler to be the most concise alternative to the radiograph to measure lumbar lordosis. In addition, Burton⁴⁰ states that the flexible ruler offers a simple, reliable technique which is easy to learn. According to Burton,⁴⁰ the traces take approximately three minutes to record the contour, draw tangents, and measure angles.

Reliability

Reliability studies on the flexible ruler show intratester reliability to be good, in general, when measuring lumbar lordosis.^{32,36,40} Hart and Rose³² found a high coefficient of intratester reliability (0.97, N = 23) using the flexible ruler to measure lumbar lordosis. Hazard³⁷ found the flexible ruler to be only moderately reliable (coefficient value between .60-.79) when comparing methods to measure prone extension. Anderson⁴¹ found flexible rulers to give repeatable measures, but stated that inaccurate measurements may be

produced if patients are obese because of excess skinfolds. Intertester reliability, however, was found to be doubtful.³⁶ Another study found a 15% intertester error for the lower lumbar spine when measuring lumbar lordosis with the flexible ruler.⁴⁰ Some of the confounding variables that affect reliability studies of the flexible ruler include the tester's expertise in using the flexible ruler, the amount of time available to take the measurement, and the effect of subject fatigue.

Validity

The validity of an external method to measure spinal motion is tested by correlating the angle derived from the flexible ruler with the angle measured roentgenographically. Research on the validity of the flexible ruler has demonstrated a high correlation between radiographic and surface measurements taken on the lumbar spine.⁴²⁻⁴⁴ Hart and Rose³² compared angles obtained with the standard roentgenographic technique with angles taken with a flexible ruler and found a +0.87 validity coefficient and, therefore, reported it to be a valid clinical tool. However, their results were based on a very small sample size (N = 8) and, therefore, cannot necessarily be applied to a large population. Burton⁴⁰ also reported a correlation of +0.87 for the flexible ruler's validity. In a larger study (N = 45) done by Bryan³⁵ which investigated the flexible ruler as a noninvasive measure of lumbar lordosis, a low correlation ($r = 0.30$) was found between the flexible ruler and roentgenographic measures. Bryan³⁵ states that measurements taken with the flexible ruler should be

interpreted with caution since validity must be established across a wide population. Therefore, ongoing research is necessary. The validity of the flexible ruler is questionable, though most studies show the flexible ruler to be reliable (intratester).^{32,36,40} Further validation studies of measurements taken using the ruler are necessary.

As mentioned previously, the validity and accuracy of the flexible ruler are questionable as lordosis increases. This is due to the difficulty of ruler placement (secondary to increased subcutaneous fat in the area). Also, because the measurement attained using the flexible ruler represents an external surface measurement, it can be correlated to a roentgenographic measurement, but should not be mistaken for the same measurement.³⁵

Inclinometers

Inclinometers, also known as angle finders, are devices used by carpenters, mechanics, and health practitioners to measure small angles. These measuring instruments operate on the principle of gravity and, therefore, work only in the vertical plane. This allows the sensor of the inclinometer to freely move in response to gravity and indicates the deviation of alignment from the vertical. If the inclinometer is in a tilted position, it will not operate properly and in a horizontal position, the inclinometer is nonfunctional.⁹

According to the AMA Guide to Evaluation of Permanent Impairment, spiral inclinometry is a feasible and potentially accurate method to measure spinal mobility and is the measurement method considered valid for spinal

impairment rating. This is due to the fact that bony structures of the upper and lower boundaries of the three spinal regions can be palpated easily.⁹ The inclinometer can be used to measure the coronal and sagittal movements of the spine. Mayer¹² concluded that range of motion measurements taken with an inclinometer is a simple, effective, and quantitative technique for assessing disability and measuring rehabilitation progress.

As with goniometers, a variety of inclinometers are available. They include mechanical inclinometers, fluid inclinometers, and electronic inclinometers. Mechanical inclinometers have a zero position indicated by either a fluid level, pendulum, or weighted needle. A simple builder's inclinometer is an example of a mechanical inclinometer.⁹

Fluid filled inclinometers allow for rotation of the face of the inclinometer; therefore, any number can be set as the initial position. The needle is counterweighted so the vertical position is constantly indicated. The fluid filled inclinometer allows the subject to execute flexion and extension of the lumbar spine in a very slow and controlled manner. Because these are precision instruments, they must be cared for properly. Exposure to extreme heat and cold or dropping of the instrument may affect the accuracy of the instrument.

One variation of the fluid filled inclinometer is the BROM (Back Range of Motion) (Performance Attainment Associates, St. Paul, MN). The BROM combines the use of inclinometers and magnets to measure spinal range of motion. It uses a fluid damped inclinometer which permits fast readings without

waiting for oscillations to damp. The ease of application allows the examiner to have at least one hand free to guide the subject's movements.

Electronic inclinometers have a greater precision than mechanical inclinometers.⁹ They use a gravity sensor to indicate and determine angles. Measurements are displayed automatically and the zero position can be set quickly. However, the electronic inclinometer must be calibrated to zero degrees for each measurement. It may contain a microprocessor and memory component that can store readings and calculate compound joint motions. The Cybex Electronic Digital Inclinometer (EDI) 320 (Cybex, Division of Lumex, Inc., 2100 Smithtown Avenue, Ronkonkoma, NY) is an example of an electronic inclinometer (fig. 2). The EDI 320 is a portable, hand-held inclinometer that is able to separate components of hip and lumbar movement. The EDI 320 displays angular displacement measurements with one degree accuracy and repeatability. The EDI 320 was also found to be a quick, easy to use, relatively inexpensive, and versatile method for measuring lumbar sagittal range of motion.^{33,45}

Method

Three different methods using inclinometry can be employed to determine lumbar range of motion: the single, double, and BROM inclinometer techniques. The single inclinometer method involves palpating the T₁₂ spinous process and sacral midpoint. The inclinometer is aligned at T₁₂ in the sagittal plane with the subject standing erect, knees straight, and weight evenly

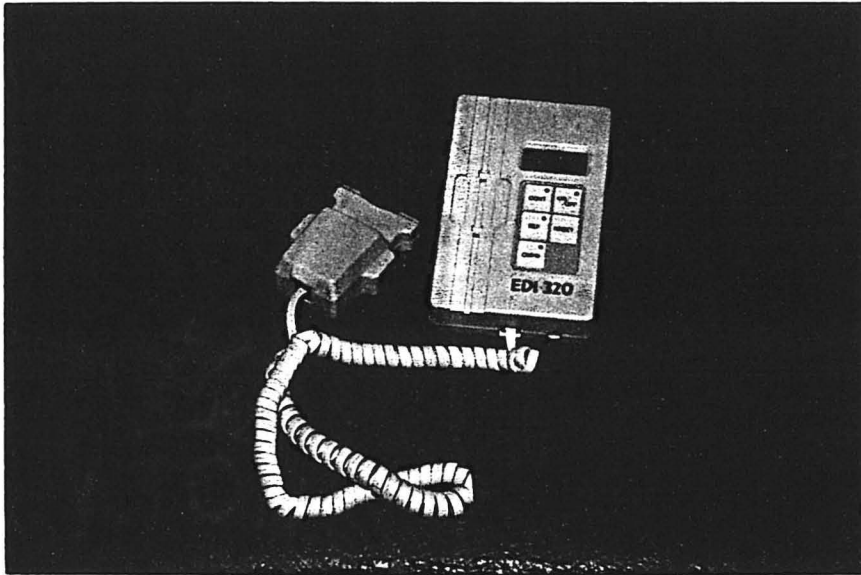


Fig 2.--EDI 320

distributed on both feet. A zero reading is obtained in this neutral position. The inclinometer is then moved to the sacral midpoint and a second zero reading at the sacral position is obtained without moving the position of the inclinometer. This is a measure of sacral flexion. The inclinometer is repositioned over T₁₂ and the angle is recorded. The measurement of sacral flexion is subtracted from the T₁₂ inclination measurement and the true lumbar flexion angle is obtained.⁹ The EDI 320 works on this principle, but the differences between T₁₂ inclination and sacral flexion are automatically calculated.

The double inclinometer technique is similar to the single inclinometer method except two inclinometers are used. Both inclinometers are aligned in the sagittal plane and zero readings are obtained. After the patient obtains maximal forward flexion, both angles are recorded and again true lumbar flexion is derived by subtracting sacral flexion from the T₁₂ inclination angle. For extension measures of the lumbar spine, the same method is used for each technique respectively, except the patient maximally extends. The procedure should be repeated at least three times for flexion or extension to obtain a valid measurement.⁹ The BROM inclinometer method to determine lumbar range of motion is an established protocol.

Reliability

Reliability of inclinometers, using various methods and types, has been the subject of many studies. Results of these studies have been highly variable. For the dual inclinometer technique, intratester reliability is generally

been high. Keeley et al⁷ reported correlation coefficients about $r = 0.90$ for lumbar flexion and extension in a study consisting of 11 normal patients and 9 chronic low back patients. Mellin⁴⁶ reported high intrarater reliability for lumbar flexion in sitting ($r = 0.97$) and for extension ($r = 0.95$) for normal subjects. Gill et al⁴⁷ tested 10 normal subjects with the dual inclinometer method and reported low coefficients of variations for intrarater reliability for flexion and extension, but found that upper inclinometer measurements displayed a high variability in forward flexion.

Regarding interrater reliability, Keeley et al⁷ found high correlation coefficients for normals ($r = 0.90$) and for chronic low back patients ($r = 0.96$) using the dual inclinometer technique for measuring flexion and extension. Mellin's⁴⁶ study of normal subjects resulted in a high interrater reliability for measuring lumbar flexion in sitting ($r = 0.86$) and lumbar extension in quadruped ($r = 0.93$). These studies used the same skin markings for repeated measures. Therefore, the variability in measurement due to inconsistent palpation skills may be negated in these studies. Chiarello⁴⁵ states that the reliability of the two inclinometer technique relies on the accuracy and repeatability of the tool and also on the accuracy and repeatability of palpating spinal landmarks. Therefore, the numbers obtained by these previous studies may not reflect current clinical techniques.

Other researchers have done similar reliability studies on the dual inclinometer techniques but have had each observer independently localize

surface markings. A study by Williams et al⁴⁸ measuring patients with chronic low back pain resulted in low reliability coefficients, $r = 0.60$ and $r = 0.48$ for flexion and extension, respectively, for interrater reliability. The results of the Williams et al⁴⁹ study regarding reliability coefficient values shows the dual inclinometer technique to have questionable reliability. Rondinelli et al⁵⁰ also found low interrater reliability for both the single and double inclinometer techniques in eight healthy subjects for lumbar flexion. Hazard³⁷ found that inter-observer reliability to be significant ($r = 0.83$) in 15 patients with low back pain when measuring prone lumbar extension with dual inclinometry. Hazard stated that measuring lumbar extension in the prone position may be easier than in standing. An intrarater reliability study done by Rondinelli⁵⁰ displayed good reliability for the single ($r = 0.93$) and the double ($r = 0.83$) inclinometer for forward flexion.

Chiarello⁴⁹ researched the EDI 320 for interrater reliability. For the purpose of describing interclass correlations in this study, interclass correlations of 0.80 to 1.0 were considered highly reliable, .60 to .79 were considered moderately reliable, and correlations below .60 were questionably reliable. The EDI 320 was shown to be moderately reliable in flexion and extension ($r = 0.74$ and $r = 0.65$) and very reliable in prone ($r = 0.85$) for normal subjects ($N = 12$). When testing patients ($N = 6$), the EDI 320 was moderately reliable for flexion and prone ($r = 0.64$ and $r = 0.75$) and very reliable in extension ($r = 0.83$). Chiarello⁴⁵ concluded that the EDI 320 exhibited acceptable reliability in several

positions for both patients and normal subjects. Newton and Waddell³³ also found the EDI 320 to be a reliable method of measuring lumbar mobility in people without symptoms (N = 10) and also in people with low back pain (N = 50).

Lastly, the reliability of the Back Range-of-Motion (BROM) was researched by Dayhuff et al.⁵¹ Thirty patients experiencing low back pain were measured for forward flexion using the BROM. Intertester reliability was found to be fair to high ($r = 0.76$ to 0.95) and intratrial reliability was found to be good to high ($r = 0.89$ to 0.98). Another study researching the reliability of the BROM found high intratester reliability ($r = 0.87$) for lumbar flexion, but interrater reliability was found to be low ($r = 0.77$).⁵⁰

Reliability of instruments can be enhanced by standardization of measurement procedures and palpation techniques within a clinical setting.⁴⁵ Uniform methods and vigorous training in measurement techniques need to be implemented in clinics since errors can be increased by unskilled or untrained observers. Another source of error may occur with patients whose effort and flexibility vary.

Validity

The single and double inclinometer techniques were the methods found to be valid and recommended by the American Medical Association Guide to Permanent Impairment.⁹ A study done by Mayer et al.⁵² reported no statistical difference between the two inclinometer method and the radiographic sagittal

spinal range of motion measurement. These methods can be expected to give a measurement within 10% of radiograph measurements except in relatively obese subjects where palpation of bony landmarks may be difficult. Keeley et al⁷ also compared the inclinometer with radiographic assessments of sagittal lumbar range of motion measures and reported a very good correlation coefficient between the two. Newton and Waddell³³ reported the EDI 320 as a valid method to measure lumbar mobility. Overall, the inclinometer has been accepted as a valid tool for measuring spinal range of motion.

Motion Analysis System

Lumbar sagittal range of motion can be measured and documented through the use of a computer aided motion analysis system.⁵³ Its development has made human motion study more available in research and clinical settings and allows a more quantifiable method to describe human movement.⁵⁴ These systems were initially designed for gait analysis but programs are now available to analyze spinal movement, foot motion, lifting, and sport activities.⁵⁵ The motions of the spine are analyzed using retro-reflective markers placed on specific surface landmarks and are recorded on videotape. The computer systems then digitize the recorded video image. Examples of motion analysis systems include SPINETRAX (Motion Analysis Corporation, Santa Rosa, CA), Peak performance Technologies Motion Analysis System (Peak Performance Technologies, Inc., Englewood, CO), WATSMART (Waterloo Spatial Motion

Analysis System (Northern Digital, Inc., Ontario, Canada), and the Metrocom Skeletal Analysis System (Faro Medical Technologies, Lake Mary, FL) (fig. 3).

Method

For the SPINETRAX, in particular, a video camera records a sagittal view of spinal motion. Markers are placed on the subject at T_1 , T_{12} , S_2 , the greater trochanter, and 10 cm below the greater trochanter. The subject stands erect in a neutral position with feet shoulder width apart and hands clasped in front of the body. At the sound of a tone, the subjects flex as far forward and then extend as far backward as comfort allows. This motion is performed five times as fast as is comfortable for the patient. The images are recorded and digitized by a video processor provided with the apparatus. For each set of five repetitions, an average range of motion and velocity are calculated by dividing the total degrees/ second by the number of repetitions.^{53,55} The Metrocom Skeletal Analysis System uses an electrogoniometric linkage system to obtain coordinate data. Software programs provide linear and angular measures. Its components include a probe, a linkage arm with six potentiometers (digitizer), a support column, an IBM compatible computer, and a computer program. The arrangement of the potentiometers allows for movement with six degrees of freedom.⁵⁶

Advantages of motion analysis systems include the ability to analyze free standing flexion and extension motion which is dynamic and unrestricted. This advantage allows the system to be considered a functional assessment tool.⁵³

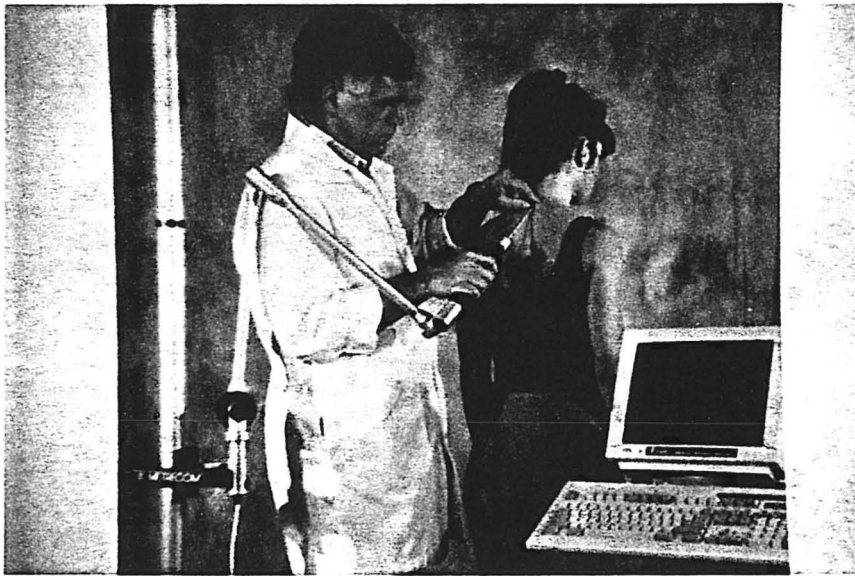


Fig 3.--Metrocom Skeletal Analysis System

Velocity measurements can also be obtained with the system. The system has good clinical implications since loss of range of motion is used to set impairment ratings.^{53,55} Some advanced systems, such as the Peak Performance Technologies Motion Measurement System, store video images of patients which can then be replayed with future sessions for comparison.

Disadvantages of the motion analysis system includes its high costs, time consumption for measurement, and, finally, the average range of motion may not express the client's single best effort. The patient's actual spinal range of motion may be underestimated because the patient's comfort zone may decrease over five repetitions with acceleration and deceleration components.^{53,55} Another disadvantage of the motion analysis system is that it differs from the currently established AMA Guide to Permanent Impairment regarding measurement of range of motion.⁹ The relationship of functional ability to motion analysis is yet to be determined.^{53,55} Other disadvantages, according to VanderLinden,⁵⁴ are that each marker needs to be tracked to ensure the computer does not become confused in marker identification. Because of this, the automated computer processor may become confused by too rapid a movement, a movement that causes two markers to come close together, or obstruction of a marker by another body part.

Reliability and Validity

A reliability study conducted by Robinson et al⁵⁵ on the SPINETRAX Motion Analysis System resulted in intraclass correlations for spinal range of

motion measures ranging from $r = 0.77$ to 0.96 . It was found to be reliable for measuring spinal range of motion of patients with chronic low back pain. The Peak Performance Technologies Motion Analysis System was evaluated by Scholz and Millford for its accuracy and precision for three dimensional angle reconstruction. The results of the study indicated that acceptable accurate and reliable angular measurements is a reasonable expectation of the Peak Performance Technologies Motion Analysis System in many clinical and experimental contexts. All computed interclass correlations in this study were at or above 0.999 .⁵⁷

VanderLinden et al⁵⁴ have also shown computer assisted joint measurements to be reproducible and accurate under static conditions. The WATSMART was shown to be reliable and valid if adequate precautions are taken to reduce unwanted light reflections.⁵⁸ Despite these cumulative findings, motion analysis systems differ from the currently established devices used in the AMA Guide to Permanent Impairment.⁹ Motion analysis systems need to be comparable to the currently validated tool, inclinometers, if they are to be used in establishing percent impairments.⁵³ Potential sources of error for data obtained with the motion analysis system include application of markers, multiple applications by various practitioners, skin movement over bony landmarks, and instrumentation error.⁵⁵

B-200

Another instrument which can be used to measure spinal motion is the Isostation B-200 (Isotechnologies, Hillsborough, NC) (fig. 4). The B-200 is a three-dimensional computer assisted instrument which is able to measure an individual's low back capabilities and also provides rehabilitation for functional losses of the low back. The B-200 measures motion in the sagittal, coronal, and transverse planes and documents the low back the way it moves, three-dimensionally. It has the ability to store measurements in computer files so they can be analyzed in different modes. The B-200 also has the capability to measure torque and velocity in the evaluation of the low back.⁵⁹

Method

To measure the range of motion, the subject stands on a platform which is height adjustable. The subject's pelvis is fixated by two pads placed over the anterior superior iliac spines (ASIS) at 45 degrees to the sagittal plane. A posterior pelvic pressure is applied through a pad over either the ischial tuberosities or lower sacrum, depending on the subject's height. The upper trunk is then fixed by a harness. This restraint system attempts to limit the subject's movement to the lumbar region of the back. Potentiometers build into the device record ranges of motion for all three planes. The neutral position established by the instrument is defined by the subject's erect posture at the beginning of each trial.⁵⁹ To test range of motion for flexion and extension, the unresisted mode is used and the subject flexes the trunk forward as far as

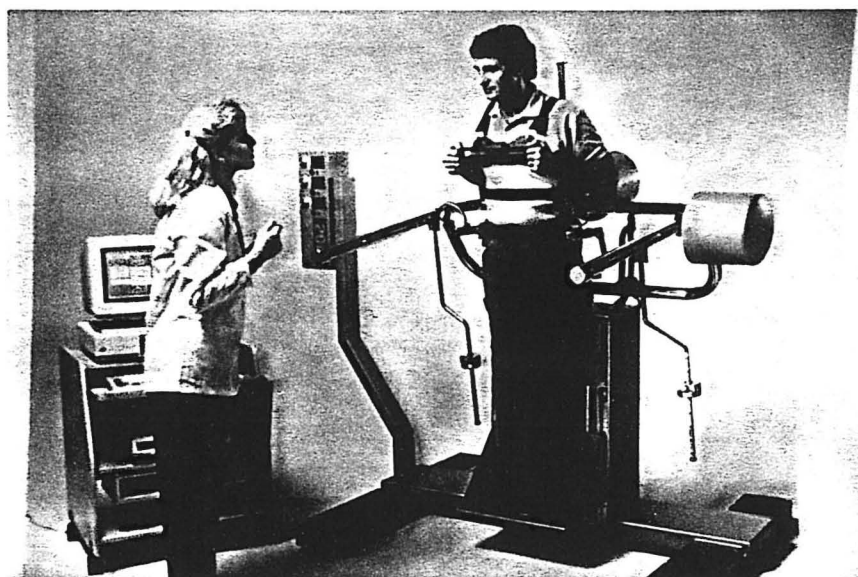


Fig 4.--B-200

possible. The subject then extends as far back as possible. However, there is a limiting stop at approximately 38 degrees of extension. A study by Gomez et al⁶⁰ involving the B-200 had subjects perform full range of motion at low velocity to the limit of their flexibility four times in flexion and extension.

Advantages of using the B-200 to measure range of motion include its fixed point of reference and its capability to test all three planes of movement dynamically. It also removes the effect of extremity range of motion in spinal measurements. As mentioned previously, the B-200 also measures motion in three planes.⁶⁰ Disadvantages include a limiting stop in trunk extension at approximately 38 degrees,⁵⁹ its high cost, time for patient set-up, and amount of space required for equipment. The B-200 is also unable to completely fix the pelvis. Therefore, some free motion of the pelvis, in terms of sagittal rotation, is possible.

Reliability

A study by Dillard et al⁶¹ compared the reliability of B-200 and the reliability of the double inclinometer to measure the motion of the lumbar spine. Test-retest measurements were used to determine the reliability of each method. The results of this study showed the B-200 to have poor reproducibility in flexion and extension ($r = 0.183$ and $r = 0.220$, respectively) particularly when each motion was measured separately. When flexion and extension were combined (full sagittal range of motion) and analyzed, the reliability results were slightly better ($r = 0.466$). The authors concluded that the

discrepancy between the reliabilities indicates that the instrument does not establish a consistent zero point relative to the subject's upright posture in the machine. They also attributed the B-200's poor reproducibility in measuring trunk range of motion to the method of fixation of the subjects during measurement. The double inclinometer method used in this study produced somewhat better reliability results ($r = 0.671$). From these results, the authors determined that an expensive instrument such as the B-200 should not be used to measure range of motion since inexpensive tools are currently available to measure trunk flexion and extension more reliably.

Other studies also showed the B-200 to give unreliable measures of range of motion.⁶² Szpalski et al⁶³ initially found highly consistent readings in all planes with the B-200 when testing low back pain patients.⁶³ However, in another study done by Szpalski⁶⁴ on normal subjects, range of motion did not reach acceptable levels of reliability (ICCs 0-0.70).

Validity

Regarding the validity of the B-200 to measure range of motion of the trunk, no content validity studies were available at this time. In the reliability study by Dillard et al,⁶¹ validity of the B-200 to measure trunk range of motion was assumed to be impacted since the B-200 instrument prevents extension beyond approximately 38 degrees. Cross-validity between three inclinometry methods relative to the B-200 measure of lumbar function was examined by Rondinelli et al.⁵⁰ The results of the study showed the cross-validity between

the B-200 and all three inclinometry methods to be uniformly low (ICC of -0.28, -0.33, -0.27). The three inclinometry methods included the single inclinometry, double inclinometry, and back range of motion (BROM) methods. It is worth mentioning that lumbar range of motion is the only determinant considered for the reliability and validity of the B-200 in this literature review and, therefore, reliability and validity of the trunk measurements of torque and velocity are not included.

Spinoscope

The Spinoscope (Spinex Medical Technologies Inc., Montreal, Canada) (fig. 5) is a device used to measure spinal coordination. It works through the use of an advanced imaging system that tracks the motion of tiny infrared light emitting diodes (LED) which are taped to the surface of the skin overlying the spinal column. High tracking accuracy and resolution can be achieved with this method. Therefore, measurements are obtained non-invasively.⁶⁵

The spine is a series of joints and, in a spinal pathology, a pattern of spinal mobility is altered. This altered pattern in spinal mobility can be due to pain or mechanical damage to the structures. The Spinoscope was designed to measure spinal coordination and to detect altered patterns.⁶⁵ Other measurements that can be obtained with the Spinoscope include spine motion, pelvic motion, change in lordosis, modified Schober test, muscle relaxation phenomenon, intersegmental mobility, and gross range of motion. The measurements can all be accomplished simultaneously.⁶⁵

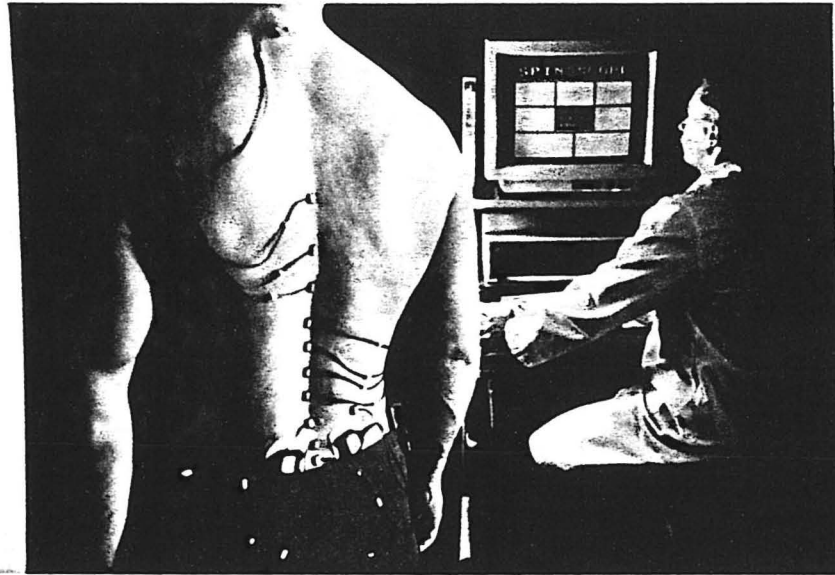


Fig 5.--Spinoscope

To conduct a Spinoscope test, the patient must first be prepared by placing markers (LEDs) at anatomical landmarks and also placing the EMG surface electrodes above the iliac crest. The LEDs are placed along the spinal column with the LED 1 over the spinous process of C₇ and LED 9 over the spinous process of L₄ specifically. The patient then stands at a designated space in the testing room, which is a 15' x 15' windowless room lighted with fluorescent fixtures.⁶⁶

The subject then performs a series of motions. The patient starts the testing by standing still for two seconds. This allows the machine to verify correct marker placement. If the markers are correctly placed, the patient bends down and returns to erect standing. This motion tests the ability of each joint to sustain a moderate increase in compression. The patient then laterally bends to both sides from the standing position. This motion introduces axial torque and tests the joint response under torsion. This completes the minimum recommended protocol with no load.⁶⁶

If it is appropriate, the subject can be tested while lifting weights to test the spine's ability to sustain loads. The patient's spine may be normal when it moves unloaded and, therefore, the subject's coordination will also be normal. The patient's normal response may become abnormal as the load lifted increases.⁶⁶ Results from the Spinoscope test can help determine a patient's "safe" lifting ability by measuring spinal coordination with increasing loads and increasing range of motion. It can also specify the vertebral level at which an

abnormal response appears and if the limitation is at the anterior or posterior part of the joint. The results can be used as a method to monitor a patient's recovery through therapy and to determine return to work level.⁶⁶

According to the manufacturers of the Spinoscope, the Spinoscope was designed to be simple to operate. Placement of the LEDs and surface electrodes on the patient requires no special skills and no knowledge of computers is required to operate the Spinoscope. Measurements can be taken dynamically with the patient unrestricted. It is a non-invasive technique so subjects can be evaluated as often as necessary without harm.⁶⁶

Another advantage of the Spinoscope is that it is highly resistant to malingers. The way the patient moves is examined versus the spinal range of motion available. In the case of malingers, range of motion is under voluntary control, but the way the subject bends is not under conscious control. More specifically, the malingerer would be unable to control the division of labor between spine and pelvis, the unfolding of lordosis, muscle relation, and the motion at each intervertebral joint.⁶⁵ According to Gracovetsky et al,⁶⁷ the detection of pathology is done by monitoring the coordination of the spine during loaded/unloaded exercises and comparing the patient coordination with that of the normal.

One of the biggest disadvantages of the Spinoscope is its high cost. The price of the Spinoscope is well over \$100,000 and a single test runs for \$400+ Other disadvantages are the largest amount of space (special room)

required for the equipment and time for set-up. According to Spinex Medical Technologies, the Spinoscope is designed to accommodate a patient flow of up to four patients/hour. At this time, reliability studies on the Spinoscope are not available. Regarding validity, the Spinoscope differs from the currently established spinal range of motion measurement device used in the AMA Guide to Permanent Impairment⁹ and is actually a skin surface measurement. A final point to remember is that the Spinoscope is designed and used to measure spinal coordination and not to measure trunk range of motion.

CHAPTER III

DISCUSSION AND CONCLUSION

Incidence of low back syndrome has increased to epidemic proportions¹ and despite its high prevalence, the process of spinal disability evaluation is in disarray.¹² To effectively evaluate the low back pain patient, tools with adequate measurement characteristics are required. These include the important characteristics of reliability and validity and also cost-effectiveness and time-effectiveness.

Measurements are fundamental to the practice of physical therapy. Meaningful and useful measurements in physical therapy are vital if physical therapists are to be recognized as credible health care providers. One function of measurements is to establish patient status so that appropriate interventions can be applied. However, if measurements are not meaningful and useful, then is the selection of appropriate interventions possible? Addressing these concerns should be a high priority to the physical therapy profession by analyzing the objectivity of spinal range of motion measurement tools.

Spinal range of motion measurement tools were evaluated for these measurement characteristics in the sagittal plane motions of extension and flexion. Tools such as goniometers, flexible rulers, inclinometers, motion

analysis systems, B-200, and Spinoscope were evaluated and the advantages and disadvantages of each were revealed.

The first spinal range of motion measurement tool analyzed was the goniometer. Goniometers were found to be a reliable method for measuring joint range of motion in extremities.^{5,14} It is a simple to use, inexpensive, and time-saving measurement tool. However, it was found to be unacceptable to measure lumbar spine mobility since the goniometer is a uniaxial measurement tool and the spine is a multiaxial joint. The measurement of these small joints of the spine are also compounded by motions above and below the measurement points. Its questionable reliability to measure spinal range of motion is another limitation. Other variations of goniometers, such as the electrogoniometer, have been shown to be reliable, but it is a relatively expensive piece of equipment.

The flexible ruler is another inexpensive tool to assess spinal mobility. However, the method used to measure lumbar curve is laborious, time-consuming, and a secondary source of error is introduced. Repeatable measures can be obtained with the flexible ruler but under certain conditions, such as a patient's obesity, inaccurate measurements may be produced. Its validity was also found to be questionable.

The third tool analyzed, inclinometers, was found to be a simple, practical, and inexpensive method for obtaining accurate and reproducible measurements of the spine's mobility. Currently, the inclinometer is the only

recognized non-invasive measurement method to be valid for measuring spinal range of motion.⁹ Its reliability for both intrarater and interrater reliability is generally good; however, some studies revealed questionable reliability.⁴⁸ The EDI-320, at a cost of approximately \$625, is a particularly easy to use device and, according to the American Medical Association Guide to Permanent Impairment,⁹ electrogoniometers have greater precision than mechanical inclinometers.

Motion analysis systems allow for dynamic and unrestricted spinal range of motion measurement and also for accurate and reproducible measurements of spinal range of motion. However, it requires time for set-up and is a relatively expensive clinical tool. Another limitation of motion analysis systems is that it differs from the currently established validated tool.⁹

The B-200 is a useful tool for the evaluation of the low back. It has the capability to dynamically measure motion, velocity, and torque in the low back. Regarding its reliability to measure motion of the lumbar spine, the B-200 resulted in poor reproducibility.⁶¹ Due to its poor reproducibility, high cost (approximately \$64,000), time for set-up, and large size of the instrument, it is not recommended to measure spinal range of motion since less expensive and more accessible tools are available.

Finally, the Spinoscope is not appropriate to measure trunk range of motion since it is specifically designed to measure spinal coordination. It is an expensive piece of equipment and should only be used when warranted. For

specific situations, such as the detection of spinal pathology, the Spinoscope has been found to be a useful clinical tool.⁶⁷

In order for a clinical technique to be accepted by medical practitioners, it should be easy to administer, reliable, and valid.¹⁶ Radiographic measures would be most objective, but measurement tools should also not put the patient's safety at risk, either by necessitating radiographic exposure or invasive procedures. As this review illustrates, each technique for measuring spinal motion has disadvantages, such as cost, questionable reliability and/or validity, and time factors. If all these factors are considered, the inclinometer appears to be the tool of choice for measuring spinal range of motion.

Currently, the inclinometer is the only non-invasive method considered valid for measuring spinal range of motion.⁹ Its reliability, ease of application, low cost, and time for application are also advantages for general clinical use. The EDI 320, in particular, allows for quick and easy lumbar range of motion for a relatively low cost.

Although a tool meets the criteria of acceptable reliability and validity, procedures for its use should be standardized in a clinic. According to Wilks,⁶⁸ a third major requirement for scientific measurements, besides reliability and validity, is an operational definition to guide the process. This allows measurement error to be accounted for when test results are interpreted.

It is important to continually assess the measurement tools in physical therapy. Continued research is recommended on existing clinical measurement

tools and also on future technological advances. This continual assessment will assist physical therapists to make wiser, more knowledgeable, and “scientific” choices in spinal range of motion measurement tools.

REFERENCES

1. American Academy of Orthopaedic Surgeons. Joint motion-method of measuring and recording. 1965:46-49.
2. Webster BS, Snook SH. The cost of compensable low back pain. *Journ Occ Med.* 1990;32:13-15.
3. Saunders HD. Evaluation, Treatment and Prevention of Musculoskeletal Disorders. Minneapolis, Minn: Viking Press, Inc; 1985.
4. Delitto A. Are measures of function and disability important in low back care? *Phys Ther.* 1994;74(5):452-459.
5. Rothstein JM. Measurement and clinical practice: theory and application. In: Rothstein JM, ed. *Measurement in Physical Therapy: Clinics in Physical Therapy.* New York, NY: Churchill Livingstone, Inc; 1985:1-46.
6. Miller LJ, ed. *Developing Norm-Referenced Standardized Tests.* New York, NY: Haworth Press; 1989:1-10.
7. Keeley J, Mayer TG, Cox R, Gatchel RJ, Smith J, Mooney V. Quantification of lumbar function. Part 5: reliability of range of motion measures in the sagittal plane and in vivo torso rotation measurement technique. *Spine.* 1986;11(1):31-35.
8. Hayes KW. The effect of awareness of measurement error on physical therapists' confidence in their decisions. *Phys Ther.* 1992;72(7):515-525.
9. American Medical Association: *Guides to the Evaluation of Permanent Impairment.* 4th ed. Chicago, Ill: American Medical Association; 1993:112-130.
10. Deyo RA. Measuring the functional status of patients with low back pain. *Arch Phys Med Rehabil.* 1988;9(2):106-119.

11. Gajdosik RL, Bohannon RW. Clinical measurement of range of motion. Review of goniometry emphasizing reliability and validity. *Phys Ther.* 1987;67:1867-1872.
12. Mayer TG. Assessment of lumbar function. *Clin Orthop.* 1987;221:99-109.
13. Dopf CA, Mandel SS, Geiger DF, Mayer PJ. Analysis of spine motion variability using a computerized goniometer compared to physical examination. A prospective clinical study. *Spine.* 1994;19(5):586-595.
14. Miller PJ. Assessment of joint motion. In: Rothstein JM, ed. *Measurement in Physical Therapy: Clinics in Physical Therapy.* New York, NY: Churchill Livingstone, Inc; 1985:103-136.
15. Moore ML. The measurement of joint motion. Part I - introductory review of the literature. *Phys Ther Rev.* 1949;29:195.
16. Beattie P, Rothstein JM, Lamb RL. Reliability of the attraction method for measuring lumbar spine backward bending. *Phys Ther.* 1987;67:364-369.
17. Mayer TG, Catchel RJ. *Functional Restoration for Spinal Disorders: The Sports Medicine Approach.* Philadelphia, Pa: Lea & Febiger; 1988:124-138.
18. Paquet N, Malouin F, Richards CL, Dionne JP, Comeau F. Validity and reliability of a new electrogoniometer for the measurement of sagittal dorsolumbar movements. *Spine.* 1991;16(5):516-519.
19. Stratford P, Agostino V, Brazeau C, Gowitzke BA. Reliability of joint angle measurements: a discussion of methodology issues. *Physiotherapy Can.* 1984;36(1):5-9.
20. Mayerson NH, Milano RA. Goniometric measurement reliability in physical medicine. *Arch Phys Med Rehabil.* 1984;65:92-94.
21. Salisbury PJ, Porter RW. Measurement of lumbar sagittal mobility. A comparison of methods. *Spine.* 1987;12(2):190-193.
22. Hellebrandt FA, Duvall EN, Moore ML. The measurement of joint motion: part III. reliability of goniometry. *Phys Ther Rev.* 1949:302-307.
23. Boone DC, Azen SP, Lin CM, Spence C, Baron C, Lee L. Reliability of goniometric measurements. *Phys Ther.* 1978;58:1355-1360.

24. Low JL. The reliability of joint measurement. *Physiotherapy*. 1976;62:227-229.
25. Fitzgerald GK, Wynveen KJ, Rheault W, Rothschild B. Objective assessment with establishment of normal values for lumbar spinal range of motion. *Phys Ther*. 1983;63:1776-1781.
26. Task Force on Standards for Measurement in Physical Therapy. Standards for tests and measurements in physical therapy practice. *Phys Ther*. 1991;71:589-622.
27. Currier DP. *Elements of Research in Physical Therapy*. 2nd ed. Baltimore, Md: Williams and Wilkins; 1984:166-167.
28. Dunn WW. In: Miller LJ, ed. *Developing Norm-Referenced Standardized tests*. New York, NY: Haworth Press; 1989:1-10.
29. Smidt GL. Biomechanical analysis of knee flexion and extension. *J Biomech*. 1973;6:79-92.
30. Russell JG. How dangerous are diagnostic x-rays? *Clin Radiol*. 1984;35:347-351.
31. Burdett RG, Brown K., Fall MP. Reliability and validity of four instruments for measuring lumbar spine and pelvic positions. *Phys Ther*. 1986;66(5):677-684.
32. Hart DL, Rose S.J. Reliability of a noninvasive method for measuring the lumbar curve. *JOSPT*. 1986;8:180-184.
33. Newton M, Waddle G. Reliability and validity of clinical measurement of the lumbar spine in patients with chronic low back pain. *Physiotherapy*. 1991;7(12):796-800.
34. Walker ML, Rothstein JM, Finucane SD, Lamb RL. Relationships between lumbar lordosis, pelvic tilt and abdominal muscle performance. *Phys Ther*. 1987;67:512-516.
35. Bryan Jm, Mosner EA, Shipee R, Stull MA. Investigation of the flexible ruler as a noninvasive measure of lumbar lordosis in black and white adult female sample populations. *JOSPT*. 1989;11:3-7.

36. Lovely FEW, Rothstein JM, Parsons WE. Reliability of clinical measurements of lumbar lordosis taken with a flexible rule. *Phys Ther.* 1989;69(2):96-102.
37. Hazard R., Williams MM, McKenzie RA. Reliability of three methods for measuring prone lumbar extension. *NZ Jour Physiotherapy.* 1994;22(1):11-13.
38. Israel M. A quantitative method of estimating flexion and extension of the spine--a preliminary report. *Milit Med.* 1959;124(3):181-186.
39. Frey JK, Tecklin JS. Comparison of lumbar curves when sitting on the Westnofa Balans multi-chair, sitting on a conventional chair and standing. *Phys Ther.* 1986;66:1365-1369.
40. Burton AK. Measurement of "regional" lumbar sagittal mobility. *JOSPT.* 1987;9(4):166-169.
41. Anderson JHD, Sweetman BJ. A combined flexirule/hydrogoniometer for measurement of lumbar spine and its sagittal movement. *Rheumatol Rehabil.* 1975;14:173-179.
42. Flint MM. Lumbar posture: a study of roentgenographic measurement and the influence of flexibility and strength. *Res Q.* 1963;34:15-20.
43. Portek I, Pearcy MJ, Reader GP, Mowat AG. Correlation between radiographic and clinical measurement of lumbar spine movement. *Br J Rheumatol.* 1983;22:197-205.
44. Wilner S. Spinal pantograph: a non-invasive technique for describing kyphosis and lordosis in the thoracolumbar spine. *Acta Orthop Scand.* 1981;52:525-529.
45. Chiarello CM, Savidge R. Interrater reliability of the Cybex EDI-320 and fluid goniometer in normals and patients with low back pain. *Arch Phys Med Rehabil.* 1993;74:32-37.
46. Mellin G. Measurement of thoracolumbar posture and mobility with a myrin inclinometer. *Spine.* 1986;11:759-762.
47. Gill K, Krag MH, Johnson GB, et al. Repeatability of four clinical methods for assessment of lumbar spinal motion. *Spine.* 1988;13:50-53.

48. Williams R, Binkley J, Bloch R, Goldsmith CH, Mink T. Reliability of modified-modified Schober and double inclinometer methods for measuring lumbar flexion and extension. *Phys Ther.* 1993;73(1):26-36.
49. Richman J, Mackrides L, Prince B. Research methodology and applied statistics, part 3: measurement procedures in research. *Physiotherapy Can.* 1980;32:253-257.
50. Rondinelli R, Murphy J, Esler A, Marciano T, Cholmakjuan C. Estimation of normal lumbar flexion with surface inclinometry: a comparison of three methods. *Am J Phys Med Rehabil.* 1992;71(4):219-224.
51. Dayhuff J, Clark C, Davis C, et al. Intertester and intertrial reliability of the BROM (Back Range of Motion) Device. University of Health Sciences. The Chicago Medical School. Department of Physical Therapy. January 1994.
52. Mayer T, Tencer A, Kristoferson S, Mooney V. Use of noninvasive techniques for quantification of spinal range of motion in normal subjects and chronic low back dysfunction patients. *Spine.* 1984;9:588.
53. Shirley FR, O'Connor PD, Robinson ME, MacMillan MM. Comparison of lumbar range of motion using three measurement devices in patients with chronic low back pain. *Spine.* 1994;19(7):779-783.
54. VanderLinden DW, Carlson S.J., Hubbard RL. Reproducibility and accuracy of angle measurements obtained under static conditions with the Motion Analysis Video System. *Phys Ther.* 1992;72(4):300-305.
55. Robinson ME, O'Connor PD, Shirley FR, MacMillan MM. Intrasubject reliability of spinal range of motion and velocity determined by Video Motion Analysis. *Phys Ther.* 1993;73:626-631.
56. Smidt GI, McQuade KJ, Wei SH. Evaluation of the Metrecom and its use in quantifying skeletal landmark locations. *JOSPT.* 1992;16(4):182-188.
57. Scholz JP, Millford JP. Accuracy and precision of the Peak Performance Technologies Motion Measurement System. *J Motor Behavior* (in press).
58. Scholz JP. Reliability and validity of the WATSMART three-dimensional optoelectric motion analysis system. *Phys Ther.* 1989;69(8):679-689.
59. B-200 Back Evaluation System User Manual. Isotechnologies, Inc., Hillsborough, NC. 1989.

60. Gomez T, Beach G, Cooke C, Hrudey W, Goyert P. Normative database for trunk range of motion, strength, velocity, and endurance with the Isostation B-200 Lumbar Dynamometer. *Spine*. 1991;16(1):15-21.
61. Dillard J, Trafimow J, Andersson GB, Cronin K. Motion of the lumbar spine. Reliability of two measurement techniques. *Spine*. 1991;16(3):321-324.
62. Parnianpour M, Li F, Nordin M, Frankel VH. Reproducibility of trunk isoinertial performances in the sagittal, coronal and transverse planes. *Bull Hosp Jt Dis Orthop Inst*. 1989;49:148-154.
63. Szpalski M, Federspiel CF, Poty S, Hayez JP, Debaize JP. Reproducibility of trunk isoinertial dynamic performance in patients with low back pain. *J Spinal Disorders*. 1992;5:78-85.
64. Szpalski M, Hayez JP. Intertester and intermachine reliability of the Isostation B-200 back testing dynamometer. *JOSPT* (in press).
65. Gracovetsky S, Kary M. The Spinoscope: a tool allowing the physician to objectively assess impairment, disability, and capacity of the spine. *J Insurance Med*. 1988;20(3):23-29.
66. Gracovetsky S, Newman N. Non-invasive assessment of the spine. Spinex Medical Technologies, Inc.; Montreal, Canada.
67. Gracovetsky S, Kary M, Levy S, Ben Said R, Pitchen I, Helie J. Analysis of spinal and muscular activity during flexion/extension and free lifts. *Spine*. 1990;15(12):1333-1339.
68. Wilks SS. Some aspects of quantification in science. In: Woolf H, ed. *Quantification*. New York, NY: Bobbs Merrill; 1961:5.