ABSTRACT

Objective: To review new and advanced biomechanical assessment techniques for the lumbar spine and illustrate the differences in lumbar function in patients with low back pain and asymptomatic subjects.

Data Sources: The biomedical literature was searched for research and reviews on spinal kinematic differences between low back pain subjects and healthy controls. A data search for articles indexed on MEDLINE until April 2002 was performed.

Results: Kinematic measurements of lumbar function were categorized into 3 areas where low back patients may differ from normals: (1) end range of motion during simple movements; (2) higher order kinematics (displacement, velocity, and acceleration) during complex movement tasks; and (3) spinal proprioception. The assessment of higher order kinematics during complex movement tasks is the most highly researched and the most successful in describing differences between the populations. The use of simple end range of motion appears questionable, while assessing spinal proprioception is the least researched, yet shows potential in highlighting differences between low back sufferers and asymptomatics.

Conclusion: Current kinematic biomechanical assessment techniques are capable of identifying functional differences between low back pain populations and controls. The use and validity of the majority of these techniques as outcome measures are currently unknown, yet may be valuable in generating functional diagnoses, evaluating the mechanisms of current therapies, and prescribing specific rehabilitation programs. (J Manipulative Physiol Ther 2004; 27:57-62)

Key Indexing Terms: Biomechanics; Spine Kinematics; Chiropractic; Low Back Pain; Outcome Measures

INTRODUCTION

Assessing and identifying lumbar spine dysfunction in patients with low back pain (LBP) is necessary in the development of objective outcome measures of spinal function. If, as previously postulated, 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 may be fundamental in creating a diagnosis based on spinal function rather than aberrant anatomy. A diagnosis based on function via tools and techniques to quantify dysfunction provides a means to assess a patient’s current condition separate from their subjective perception of pain. Although presently unknown, biomechanical assessment techniques that categorize patients with different functional characteristics may help determine the patients which respond best to different therapies. It is possible that patients with low back pain may have completely different functional inadequacies and only the use of advanced assessments of spine function will describe and identify these dysfunctions. It is then possible that
patients with different functional inadequacies may respond better to treatment aimed at correcting their functional limitations. Currently, this is unknown and future research using these biomechanical assessment techniques can address these possibilities. Additionally, biomechanical assessment techniques may provide insight into the various physiological effects of commonly used chiropractic therapeutics that may currently lack an identified mechanism for their clinical effectiveness (ie, spinal manipulation, specific exercise programs, physical therapy modalities).

The aim of this review is to introduce the reader to new biomechanical assessment techniques for the lumbar spine. This article will not thoroughly review traditional outcome measures (end range of motion [ROM], trunk strength, simple measures of trunk muscle electromyographic [EMG] amplitude, pain scoring, and motion palpation). Rather, this article will review biomechanical assessment techniques that are currently used in spine biomechanics laboratories, yet have not been used as outcome measures in the clinical research investigating chiropractic therapy. The biomechanical differences that evidence themselves using these biomechanical assessment techniques between patients with low back pain and pain-free controls will be reviewed. I hope that with future research many of these assessment techniques could be incorporated into clinical research and practice to improve the assessment of spinal function and possibly improve or validate therapy. This review is limited to noninvasive biomechanical measurement procedures. For the most part, investigations using imaging techniques or needle electromyograms are not reviewed; nor will this review assess motion or static palpation of lumbar musculature or joints of the spine. It is the intent of this review to provide the clinician and researcher with an introduction to the current and latest techniques used to assess spinal function and the manner in which low back injury has been documented to influence the measurable function of the lumbar spine.

For this article, biomechanical assessment techniques will be split into 2 broad categories: kinematic measures of lumbar function and electromyographic measures of lumbar function (companion part II paper).

**Discussion**

**Kinematic Measures of Lumbar Function**

Kinematic assessments of lumbar function require the measurement of the position of the lumbar spine in space. This is typically done through 2 means: video analysis and electrogoniometer techniques. Both methods can provide 3-dimensional dynamic tracking of spinal movements. These measures of spinal movement are that of spinal regions, ie, the lumbar spine, rather than individual motion segment movement. In addition to simple end range of motion, these techniques can provide a movement profile in all 3 planes about each axis of motion. The displacement data generated from the film or electrogoniometer signal can be mathematically 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. These include:

1. Assessment of end range of motion measures.
2. Assessment of higher order kinematics during complex and simple movements.
3. Assessment of spinal proprioception.

This review will thoroughly review the last 2 kinematic measures and briefly review the literature evaluating the utility of end range of motion in describing lumbar dysfunction and discriminating low back pain patients from pain-free controls.

**Assessing End Range of Motion**

Assessment of end range of motion is a ubiquitous practice in any physical exam. Range of motion is commonly used with other techniques and clinical wisdom to generate a working diagnosis. Assessing range of motion provides clinicians with insight into what postures relieve pain and what postures aggravate pain. However, the discriminant validity of end range of motion and its utility as an outcome measure over the course of a rehabilitation program are questionable.2,3

Discriminant validity indicates whether test scores are able to distinguish between subjects with low back pain and subjects with no pain. In a review of the literature, Zubierer et al2 concluded that end range of motion values have poor discriminant validity. Their review demonstrates the huge subject-to-subject variability in range of motion values. On average, low back pain subjects do not have a decreased mobility compared with pain-free controls. While a patient may have a decreased mobility relative to their normal mobility, this decreased value may be well within the large range of normal population values. Without knowing a patient’s normal/pain-free range of motion value, identifying a deficit in range of motion function appears objectively impossible. This finding was mirrored in reviews and studies of numerous authors.4-6 However, there have been studies that have shown statistical differences between the 2 populations.7-9 These discrepancies between studies and the uncertainty thus engendered of the utility of end range of motion as an outcome measure lend support to the idea that other spinal assessments should be developed and researched to function as outcome measures of spinal dysfunction.

The relationship between end range of motion and other outcome measures has also been investigated. Nattras et al6 compared lumbar ROM with the Waddell Physical Impairment Scale, Waddell Disability Index, and the Oswestry Low Back Pain Disability Index and concluded that ROM measurements do not show a consistent relationship to the
level of physical impairment in subjects with low back pain. Flexion-extension ROM and the velocity during this movement have also shown little relationship to Oswestry scores and work status over a 1-year period. This poor relationship between change in ROM scores, pain, and other measures of function have also been demonstrated over the course of a rehabilitation program.

Assessing Higher Order Kinematics During Various Tasks

While the research is mixed, simple ROM assessments appear to have poor discriminant validity and little relation to other measures of spinal function. In an effort to improve the assessment of spinal function and develop objective and valid outcome measures, researchers have recently attempted more complicated assessments of spinal function to delineate the differences between low back pain sufferers and normals.

One method developed by Marras et al. assesses spinal ROM, velocity, and acceleration (higher order kinematics) in all 3 planes during complex flexion-extension tasks. This protocol requires subjects to maximally flex and extend their trunk at 5 different positions of trunk rotation (0° of rotation, 15° clockwise and counter clockwise, and 30° clockwise and counter clockwise). Lumbar kinematics are measured with a specially designed electrogoniometer that provides a dynamic assessment of the position of the lumbar spine in space. From this assessment, 6 measures of displacement, velocity, and acceleration data are extracted and used to create a model that evaluates the functional performance of the spine. In addition, 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 sensitivity of the functional performance model is 86% and the specificity is 94%. By using a more complex movement task and more complex yet simply calculated descriptors of motion, a more detailed assessment of the functional performance of the lumbar spine can be arrived at to elucidate deficiencies in function which would be ignored by simple measures of range of motion.

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 an 85% accuracy in identifying patients with low back pain. A neural network is a computer process that 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 low back pain and control groups, 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. Again, suggesting a complex task and more complex analysis are necessary for 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.

The natural course of low back pain has also been assessed using the functional performance model designed by Marras et al. and 3 other outcome measures (symptoms, activities of daily living, and work status) for 3 months. Assessments were made every 2 weeks. This study found that all 4 measures improved with time, functional performance was the most sensitive measure for visit-to-visit improvement, and functional performance was the only measurement to show changes in the last 2 weeks. It should also be noted that the functional performance model is able to detect impairment magnification, making it possible to detect insincere efforts during the performance of the functional performance protocol.

Differences in Spinal Kinematics During Gait Between LBP Sufferers and Controls

While differences in various measures of gait kinematics (comfortable walking speed, step length, swing time, and maximal endurance) exist between low back pain sufferers and controls, less research has investigated differences in spinal kinematics during gait. Nonetheless, differences between the populations have been documented. Lamoth et al. investigated the rotational relationship between the thorax and the pelvis at varying degrees of walking velocity in 39 low back pain sufferers and 19 healthy individuals. The influence of increases in walking velocity on individual pelvic and thoracic rotations was not significantly different between groups. The difference between the low back pain group and the controls was most noticeable in the pelvic-thorax coordination during gait. In normal healthy gait subjects, there was a shift from an inphase rotational coupling between the pelvis and thorax at low velocity to an antiphase coupling at higher velocities. Subjects with low back pain did not make this shift from inphase rotational coupling at low velocities to antiphase coupling at higher velocities.

Vogt et al. compared lumbar kinematics in low back pain sufferers and controls during gait. The study examined pelvic and thoracic (T12) angular displacement in all 3 planes during standard velocity treadmill walking. No differences in angular displacement magnitudes were found between groups; however, a significantly increased intrasubject variability was noted for pelvic and thoracic angular displacements in the low back pain group. The phasic relationship between the thorax and pelvis was not studied. The authors suggest that this higher stride-to-stride variability in
angular displacement may be due to deficits in motor control and spinal proprioception.

How spinal kinematics during gait may change with rehabilitation, their relationship to other outcome measures, and the discriminant validity of this spinal assessment protocol are unknown.

Lumbar Proprioception

Much like other joints following injury, the proprioceptive sense of the spine may be impaired. Lumbar 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 can be monitored, 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 patient’s attempted spine repositioning is termed the repositioning error (RE).

Repositioning Error Differences Between LBP Sufferers and Asymptomatics

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 research is growing and differences in repositioning error between low back pain patients have been demonstrated.

Newcomer et al investigated whether differences in spinal repositioning error existed between 20 LBP sufferers and 20 controls during flexion/extension and lateral bend. Spinal position was measured using a 3Space Tracker System (Polhemus, Inc., Colchester, VT). The 3Space Tracker is an electromagnetic tracking device consisting of 1 source box (emits an 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 xyz coordinate position in space of the 2 sensors can now be tracked. The difference between the sensors can be calculated, providing dynamic angles of flexion, lateral bend, and rotation of the spine. In this study, the sensors were placed on T1 and S1, resulting in a global measure of the position of the entire spine. 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. Newcomer et al 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. RE in the low back pain group was greatest during flexion compared with all other movements. The authors suggest the seemingly paradoxical finding of patients having a smaller RE in extension and a greater RE in flexion to be clinically significant and a result of the complex nature of the flexion task. They postulate that flexion is a more complex and motor control demanding task than the other movements, so deficits in proprioception will be amplified and more noticeable. It should be noted that in a previous investigation by the same authors, no difference in RE was found between the 2 groups. This null finding is explained by the lack of immobilization of the pelvis and legs in the previous study, allowing for proprioceptive information to come from these body segments that are not impaired.

Gill and Callaghan demonstrated a difference in the repositioning error between subjects with low back pain and controls in both a standing and four-point kneeling (FKP) posture. Participants were required to reproduce a position of 20° 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 intraclass correlation coefficient (ICC) > .85 for both tasks.

Brumagne et al investigated spinal proprioception in low back pain sufferers and controls and found differences in accuracy between the 2 groups during a sacral tilting procedure. An electrogoniometer was placed on the sacrum, which measured the 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 movement occurred during sitting and resulted in no movement of the upper torso, only of the lumbar spine and pelvis, similar to the four-point kneeling protocol. Similar to the other studies, a significant difference was found between the low back pain group and the control group. The low back pain group showed a larger repositioning error during lumbar flexion. Extension was not evaluated. Previous work with this technique showed an intraclass correlation coefficient of .51.

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.

Other Measures of Spinal Proprioception

Other techniques in addition to repositioning error have been used to assess spinal proprioception. These involve measurement of postural sway 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. Postural sway is measured using a force plate which 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 concomitant center of pressure occurs. It should be noted this measure of postural sway may not be a sole indication of aberrant low back function. Other factors are involved which influence sway, including lower limb joint receptors, lower limb stiffness, and vestibular controls. This increase in sway or movement of the center of pressure during stance of patients with low back pain has also been demonstrated during sitting on varying levels of unstable surfaces. This technique has been used to attempt to remove the lower limb contribution of controlling postural sway. Patients were required to sit on wobble boards of varying stability with their lower body fixed to ensure all movement control occurred via the spinal system. The wobble boards were on top of a force plate that calculated the movement of the center of pressure. This increased sway was also correlated with an increased erector spinae latency response time during sudden loading.

The last protocol that assesses lumbar proprioception requires participants to determine when their spine has been moved. Participants are seated in a jig, which controls rotational trunk movement. Participants’ spines are rotated 1° per second. Participants are required to release a button when they perceive spinal movement. Taimela et al demonstrated a decreased ability in low back pain patients to sense spinal rotational movement compared with healthy controls. This same decrease in sensing movement has been documented in patients with lumbar stenosis. Between-trial repeatability of this procedure had an ICC of .77 for low back pain patients and .84 for controls.

Summary of Kinematic Assessments of Lumbar Function: Applicability to Practice and Future Research Consideration

The most equipment intensive and least researched kinematic outcome measure appears to be the assessment of trunk kinematics during gait. This assessment requires no less than 2 video cameras, ample walking space, digitizing equipment (often expensive and time consuming), and customized software. The insufficient research, equipment strains, and a long preparation time to conduct these types of assessments suggest it has the least application to the clinical environment. Conversely, assessing lumbar kinematics during complex tasks (The Functional Performance Model by Marras et al) or lumbar proprioception require only a dynamic electrogoniometer and associated software. The costs are less prohibitive (approximately $10,000 for a dynamic electrogoniometer), and the time to fix the equipment to the patient is relatively short (less than 5 minutes).

Assessing the higher order kinematics of patients before and during rehabilitation may provide a better means of documenting patients’ progress compared with simple pain measures. It may also be an excellent means of elucidating the mechanisms of individual treatments. Assessing lumbar proprioception is exceedingly simple and combined with an assessment of the higher order kinematics of the lumbar spine it may provide great insight into a patient’s functioning. Testing the influence of therapy on lumbar proprioception has never been done; yet, many therapeutic interventions are hypothesized to improve motor control and lumbar function. For example, proprio-neuromuscular facilitation (PNF) protocols and spinal manipulation are both touted by their users to influence motor control and hence proprioception. However, little or no research exists to support such claims. The use of these outcome assessments is ideal to evaluate these claims.

Conclusion

By documenting the spinal higher order kinematics and proprioception, patients may be able to be categorized based on these functional parameters. Rehabilitation programs may be designed to specifically target these dysfunctions once it is determined which type of rehabilitation interventions best influence specific characteristics of spinal function. Perhaps a patient only has proprioceptive deficits but no higher order kinematic deficits. Treatment can be appropriately tailored. Or, with further research, it may be shown that patients with certain functional characteristics respond best to spinal manipulation, while others may respond to other treatment protocols. By exploring these biomechanical assessments of lumbar function, clinicians and researchers may attain a better understanding of lumbar dysfunction and subsequently improve patient care.

References

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