Comparison of Dynamic Posteroanterior Spinal Stiffness to Plain Film Radiographic Images of Lumbar Disk Height

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Abstract

Background: Assessments of spinal stiffness have become more popular in recent years as a noninvasive objective biomechanical means to evaluate the human spine. Studies investigating posteroanterior (PA) forces in spinal stiffness assessment have shown relationships to spinal level, body type, and lumbar extensor muscle activity. Such measures may be important determinants to discriminate between patients with low back pain (LBP) and asymptomatic subjects.

Objective: To determine the relationships between dynamic PA spinal stiffness and radiographic measures of lower lumbar disk height and disk degeneration.

Methods: L4 and L5 posterior disk height (PDH), vertebral body height (PVH), anterior disk height (ADH), and vertebral body height (AVH) were obtained from digitized plain film anteroposterior (AP) and lateral radiographs of 18 symptomatic LBP patients presenting to a chiropractic office (8 female patients and 10 male patients, aged 15-69 years, mean 44.3, SD 15.4 years). Disk degeneration (DD) and facet arthrosis (FA) were qualitatively assessed from the films by an independent examiner. Anterior disk height ratios (ADHR = ADH/AVH) and posterior disk height ratios (PDHR = PDH/PVH) were calculated from the disk height measurements and were compared to L4 and L5 posteroanterior spinal stiffness obtained using a previously validated mechanical impedance stiffness assessment procedure.

Results: One third of the subjects were found to have radiographic evidence of mild or moderate DD and approximately two thirds of the subjects showed signs of mild or moderate FA. The L4 and L5 anterior disk height and posterior disk height were approximately one half and one fifth of the respective vertebral body heights, and the PA stiffness was greater at L4 than at L5. Male subjects had a greater ADHR than female subjects, but female subjects had a greater L4 and L5 PA stiffness in comparison to male subjects; however, these differences were not statistically significant. Posteroanterior L5 vertebral stiffness was found to be significantly correlated to the L5 PDHR.

Conclusions: Computations of spinal input impedance are relatively simple to perform, can provide a noninvasive measure of the dynamic mechanical behavior of the spine, appear to have potential to discriminate pathologic changes to the spine, and warrant further study on a larger sample of normal subjects and patients. (J Manipulative Physiol Ther 2003;26:233-241)

Key Indexing Terms: *Biomechanics; Chiropractic; Degeneration; Intervertebral Disk; Mechanical Impedance; Radiography; Spine; Stiffness*

Introduction

Evaluation of patients with musculoskeletal disorders routinely includes the use of plain film radiography to assess the spine for alignment and/or pathology. Radiographic examination and static biomechanical evaluation of the radiographs are commonly used procedures in the chiropractic profession.[1] Although many chiropractors use radiographic examination as a general screening tool and for medicolegal protection,[1] excessive use of ionizing radiation and cost containment have led to new attitudes and practice patterns among clinicians.[2] This may be attributed to recent clinical guidelines that have called for a decrease in the utilization of plain film radiography in patients with low back pain (LBP).[3,4] In the ab-

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sence of "red-flags" (history and/or physical examination indicators of potential serious spinal or soft tissue pathology), radiographic examination of patients with acute low back pain has been deemed by some to be unwarranted in the first 4 to 7 weeks of treatment.[3]

Despite clinical guidelines, many chiropractors utilize radiographic examination to biomechanically assess the spine for misalignments.[1,5] Projection error largely influenced by the shape of the object and by the increasing obliquity of the rays of the x-ray beam have cast doubt on the validity of such assessments, as 3-dimensional (3-D) lateral translation projects as axial rotation on the anteroposterior (AP) radiograph.[6,7] Moreover, the use of millimetric measurement of the projected lamina offset on the AP radiograph is an inaccurate method for the assessment of the degree of 3-D axis vertebral rotation. Static radiographic assessments of spinal biomechanics have been further criticized for their failure to account for the variability, adaptability, and functional capability of the human musculoskeletal system.[8] Alternative noninvasive, inexpensive means to biomechanically assess the human spine is of growing interest to clinicians and researchers alike.

Common physical examination procedures in patients with low back pain include the application of posteroanterior (PA) forces to the spine to assess presumed mobility and pain provocation.[9] While manual palpation procedures have been shown to be reliable for pain provocation,[10,11] biomechanical assessments of the spine using motion palpation procedures for the presence of "fixation" (increased stiffness or restricted mobility) have not been shown to be reliable.[12-15] This may be attributed to the qualitative nature of such assessments. In favor of more reliable means of objectively assessing the spine's stiffness on examination, new instruments have been developed and tested for their reliability and validity with promising results.[16-20]

Studies investigating posteroanterior forces in spinal stiffness assessment have shown relationships to spinal level, body type, and lumbar extensor muscle activity.[21-24] Such measures may be important determinants to discriminate between patients with low back pain and asymptomatic subjects.[25-27] However, little objective evidence is available for discerning variations in PA spinal stiffness and its clinical significance.

In previous work, Nathan and Keller[28] quantified the intersegmental motion response and dynamic PA stiffness of 3 human subjects (1 normal subject and 2 surgical patients). These authors observed that decreased intervertebral motion and an increased dynamic PA stiffness were associated with the presence of disk degeneration.[28] The objective of the current study was to examine the relationship between lumbar PA dynamic stiffness and disk height in a larger population of low back pain subjects.

Methods

Subjects

Eighteen patients with low back pain (8 female patients and 10 male patients, aged 15-69 years, mean 44.3, SD 15.4 years) were included in the study if they had not consulted a physician or therapist for low back or leg pain in the past 6 months or previously underwent spinal manipulative therapy. Patients were excluded if they were pregnant, had previous history of lumbar spinal surgery, or presented any contraindication to spinal manipulative therapy (eg, malignancy, inflammatory or infective processes involving the spine, significant osteoporosis, or spinal disorders including spondylolisthesis, ankylosing spondylitis, spinal fusion, previous spine surgery, or neurologic deficit). Patients were also excluded if they complained of significant symptoms unrelated to lumbar complaints. Patients with combined low back and referred or radicular buttock, thigh, or leg pain were included in the study. Following written and verbal explanation of the protocol for the study, patients signed a written informed consent form acknowledging their participation in the study.

Patient Assessment Procedure

Patients completed history and health status questionnaires (visual analog score [VAS], LBP history, LBP symptom frequency, and Oswestry Low Back Disability Index) and were gowned and underwent a physical examination consisting of orthopedic and neurologic examinations, lumbar range of motion, and plain film radiographic examination of the lumbar spine (anteroposterior and lateral views) taken at 40-inch tube-film distance. The review of history, physical, and radiographic examinations was used to rule out neurologic deficit or spinal pathology and was performed by a licensed doctor of chiropractic in accordance with standard clinical practice. Based on these findings, patient symptomatology and physical status were used for inclusion criteria in the study.

Each subject was placed in the prone position by use of a motorized vertical/horizontal table (Softec/Tri-W-G, Valley City, ND). An Activator Adjusting Instrument (AAI) (Activator Methods International, Ltd., Phoenix, Ariz) equipped with a preload control frame and impedance head (load cell and accelerometer) was then used to deliver PA manipulative thrusts to several common spinal landmarks, including the posterior superior iliac spine (PSIS) (left and right); sacral base (left and right); and S1, L5, L4, L2, T12, and T8 spinous and transverse processes. The AAI is a hand-held, manually activated, and adjustable-force chiropractic instrument that produces a loading history approximately 5 milliseconds in duration and 150 N in peak amplitude.[16] PA thrusts imparted to the spine were consistent with those delivered in routine clinical practice for which forces were directed perpendicular to the body surface curvature. A

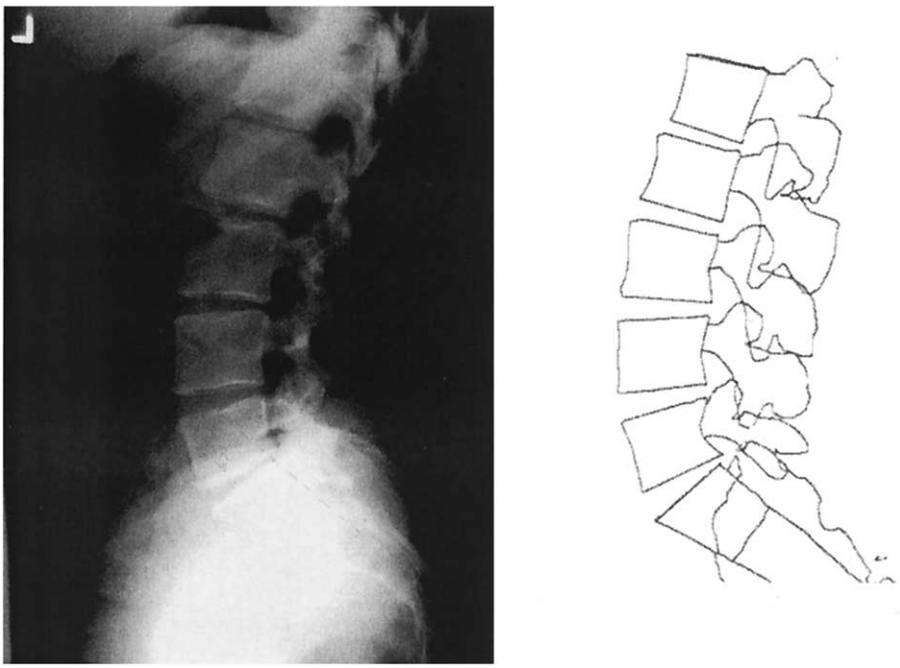

Fig 1. *Lateral lumbar radiograph (left) of a patient with moderate (grade 2) degenerative disk disease and corresponding digitized image (right).*

total of 20 PA thrusts were delivered to each patient. PA dynamic effective stiffness was obtained from segmental contact points applied to the L4 and L5 spinous processes using a validated in vivo mechanical impedance assessment procedure.[16,29] The mechanical impedance (Zmin1, Ns/m) and effective stiffness (Kmin1, kN/m) at the PA natural frequency (fmin1) are reported here. Effective stiffness was calculated by multiplying the dynamic mechanical impedance (Z, Force/Velocity, Ns/m) times the circular frequency ($\omega = 2\pi f$, rad/sec), where f is the frequency in Hz.

Radiographic Assessment

Anteroposterior and lateral lumbar radiographs were assessed by an independent licensed doctor of chiropractic (TKP). Pencil markings were used to identify the anterior-superior, posterior-superior, anterior-inferior, and posterior-inferior corners of each vertebral body from L4 to L5 and the anterior-superior and posterior-superior aspects of the sacral base from the lateral lumbar radiographs (Fig 1). A computerized digitizing system (Spinal Digital Imaging, Inc., Dallas, Tex) captured each of the 4 vertebral body marked points. From these measurements, the L4 and L5 posterior disk height (PDH), posterior vertebral body height (PVH), anterior disk height (ADH), and anterior vertebral body height (AVH) were calculated. Anterior and posterior disk height ratios were calculated as PDHR = PDH/PVH and ADHR = ADH/AVH, respectively. Normalization of the disk height data in this manner produces a dimensionless parameter that takes into account differences in body stature (height, trunk girth) between the subjects. Facet arthrosis (FA) and disk degeneration ([DD] = osteophyte formation) were also qualitatively assessed from the radiographs using a simple 0 to 3 grading scheme depicted in Tables 1 and 2. This methodology, adapted from Kellgren,[30] has demonstrated acceptable reliability for grading spinal degeneration in the cervical[31] and lumbar spine.[32]

Descriptive statistics were performed on all variables grouped according to gender. The disk parameters and mechanical impedance data were also examined on the basis of the data grouped according to disk degeneration, facet arthrosis, VAS score, and Oswestry Low Back Disability Index score. A Kruskal-Wallis 1-way analysis of variance by ranks test was performed to test for independence among the group means. Following the Kruskal-Wallis test, a post hoc analysis was performed using Scheffé test to determine if the group means were significantly different at the $P = .05$ significance level. A linear regression analysis was also performed to compare L4-5 and L5-S1 PDHR and ADHR to the corresponding L4 and L5 posterior-anterior dynamic effective stiffness.

Results

Table 3 summarizes the demographic and clinical status of the patients. Although the male subjects were about 10

Table 1. *Radiographic criteria for the grading of facet joint arthrosis as obtained from the lumbar anteroposterior radiograph*

Grade	Severity	Radiographic appearance
0	None	Absence of facet joint degeneration
1	Mild	Questionable osteophytic margins of the facet joints
2	Moderate	Definite osteophytes; subchondral sclerosis in the facet joints
3	Severe	Moderate-severe osteophytes; moderate-severe subchondral sclerosis; irregularity of the facet joints

Table 2. *Radiographic criteria for the grading of degenerative disk disease from the lateral lumbar radiograph*

Grade	Severity	Radiographic appearance
0	None	Absence of disk degeneration
1	Mild	Minimal anterior osteophytes
2	Moderate	Definite anterior osteophytes; mild-moderate disk space narrowing; mild-moderate sclerosis of the vertebral end plates
3	Severe	Osteophytes; moderate-severe narrowing of the disk space; moderate- severe sclerosis of the vertebral end plates

years older on average than the female subjects, the female subjects in this patient population tended to have greater VAS and disability scores than the male subjects.

A greater number of the male subjects were found to exhibit radiographic evidence of degeneration (facet arthrosis and disk degeneration) in comparison to female subjects (Table 4). Overall, approximately one third of the subjects were found to have radiographic evidence of mild or moderate DD, and approximately two thirds of the subjects showed signs of mild or moderate FA. Only 3 of the subjects showed severe DD or FA at 1 lumbar level. Evidence of DD and FA was most prevalent at the L4 level and was slightly more prevalent in the male subjects. Examination of the disk height ratios for the combined male and female population indicated that the L4 anterior disk height and posterior disk height were 46.4% and 18.9% of the respective vertebral body heights. Similar results were found for the L5 vertebrae. Male subjects tended to have greater ADHR in comparison to female subjects at the L4 and L5 levels. An increased ADHR indicates a greater amount of lumbar lordosis. The opposite trend was seen for the PDHR. From a statistical standpoint, there were no gender-specific differences in disk height ratio or dynamic stiffness. Nor were there any differences in these measurements on the basis of the subjects grouped according to disk degeneration, facet arthrosis, VAS score, or Oswestry Low Back Disability Index score. Figure 2 summarizes the anterior and posterior intervertebral disk height geometry (ADH, PDH) and vertebral body height geometry (AVH, PVH) obtained for the L4 and L5 segments of the 18 subjects. The L5 PDH, AVH, and PVH were significantly different (2-tailed, paired t test, $P < .05$) from the L4 values.

The dynamic mechanical characteristics of the L4 and L5 segments are also summarized in Table 4. In this group of patients, the PA natural frequency or frequency associated with the greatest spinal mobility was approximately 43 Hz. At this frequency, the L4 segment tended to have a greater impedance and dynamic stiffness in comparison to the L5 segment. Female subjects had a greater L4 and L5 stiffness in comparison to male subjects, but these differences were not statistically significant. A positive, linear correlation between Kmin1 and PDHR was found for the L5 vertebral segment (Kmin1 = 47.5 × PDHR + 6.5, $r = 0.76$, $P < .001$) (Fig 3). Significant positive, linear correlations between Kmin1 and PDH ($r = 0.69$, $P < 0.002$) and Zmin1 and PDH ($r = 0.60$, $P < .01$) were also noted.

Discussion

In this study, we aimed to investigate the relationships between dynamic PA spinal stiffness and correlations of lumbar intervertebral disk height and degeneration. Although no correlation was found between anterior disk height at L4-5 or L5-S1 or posterior disk height at L4-5, the correlation between increased dynamic effective stiffness (min1) and decreased posterior lumbosacral disk height at L5-S1 is of interest. Decreased radiographic disk height has been found to be associated with fissure formation in the disk,[33] and stress profilometry testing has revealed that the mechanical behavior of disk tissue to be highly dependent on the severity of degenerative changes.[34] Thus, increased spinal stiffness among disks with decreased height may be expected.

Little research which investigates the relationship between degenerative disk disease and spinal stiffness is available. However, the current study corroborates findings of two studies. In 1994, Nathan and Keller[28] reported decreased posteroanterior spinal motion and increased posteroanterior spinal stiffness in a subject with degenerative disk disease when compared to a normal subject. In 1998, Kaigle et al[35] reported a significant increase in spine stiffness in degenerated disks as compared to normal disks in an in vivo porcine model. An increase in stiffness can mean a reduction in the amount of allowable motion within the motion segment or a potentially harmful increase in force to obtain the desired motion. This may locally result in greater stresses due to an altered ability of the disk to distribute loads.[35]

In addition to the intervertebral disk, the spinal musculature also contributes to spinal stiffness. Persistent muscle

Table 3. *Patient demographics and clinical status*

Subjects	n	Age (years)	Weight (kg)	Height (cm)	VAS (0-10)	Oswestry * (0-50)
All	18	44.3 (15.4)	75.4 (12.9)	172 (10.1)	2.8 (2.3)	9.0 (6.4)
Males	10	49.3 (14.4)	83.1 (10.3)	178 (6.74)	2.1 (2.4)	7.3 (5.8)
Females	8	38.1 (15.2)	65.8 (9.1)	165 (9.73)	3.6 (2.0)	11.1 (6.8)

n = number of subjects.
Standard deviation in parentheses.
*Oswestry Low Back Disability Index.
VAS, Visual analog score.

Table 4. *Summary of L4 and L5 segment mechanical and radiographic results grouped by gender (10 male subjects and 8 female subjects)*

Subjects	Level	ADHR ( )	PDHR ( )	Zmin1 (Ns/m)	Kmin1 (kN/m)	Fmin1 (Hz)	DD (n)	FA (n)
All	L4	0.46	0.19	70.1	18.5	42.7	6	11
		(0.12)	(0.06)	(17.5)	(3.8)	(5.4)		
	L5	0.45	0.16	52.9	14.1	42.6	7	10
		(0.14)	(0.06)	(13.1)	(3.6)	(5.1)		
Males	L4	0.50	0.18	63.1	17.0	43.5	5	7
		(0.13)	(0.07)	(15.8)	(3.9)	(4.8)		
	L5	0.50	0.15	49.0	13.7	44.2	4	6
		(0.14)	(0.06)	(11.4)	(4.0)	(5.5)		
Females	L4	0.42	0.20	78.8	20.3	41.8	1	4
		(0.10)	(0.05)	(16.3)	(3.0)	(6.3)		
	L5	0.39	0.17	57.6	14.5	40.6	3	4
		(0.12)	(0.05)	(14.3)	(3.11)	(4.1)		

n = number of subjects with mild, moderate, or severe degeneration.
Mean and (SD).
ADHR, Anterior disk height ratio; *DD*, disk degeneration; *FA*, facet arthrosis; *PDHR*, posterior disk height ratio.

activation, which restricts intervertebral motion, is a means by which the neuromuscular system provides stability to help protect diseased passive spinal structures from movements that may cause pain.[36] Mechanoreceptors and mechanosensitive nociceptive afferents in the lumbar spinal tissues signal sensory signals on excessive stress or strain, which, in turn, causes contraction of the paraspinal muscles to act to prevent possible tissue damage while maintaining stability.[37] Research by Solomonow et al[38] has documented this relationship, confirming that the stiffening of the motion segment via muscular activity acts to increase its resistance to mechanical disturbances to the natural alignment of the vertebrae. Lumbar extensor muscle activity has been found to result in an increase in lumbar PA stiffness even at low levels of activity.[24] Such interactions of the neuromuscular system can contribute to a loss of mobility and sustained excessive loading of the intervertebral disk, creep deformation, and subsequently decreased disk height.[39,40]

Disk degeneration involves biochemical alterations in disk cell metabolism,[41] cell-mediated changes in matrix composition[42] leading to gross structural disruption.[33] Such changes may occur as a feature of aging or be accelerated by loading history or trauma.[39] In this manner, it is reasonable to expect postural faults or spinal injury to be associated with decreases in lumbosacral disk height and increases in spinal stiffness. The relationship between spinal stiffness and overall spinal flexibility is unknown. Despite the fact that lumbar flexibility is known to reduce with advancing age, it is uncertain whether intervertebral disk degeneration is associated with reduced or increased flexibility.[43,44] Further studies are needed to clarify whether the lumbar degenerative process differs among gender and age and how such changes affect the stability of the functional spinal unit.

The stiffness values reported in the current study corroborate previous work in asymptomatic subjects where effective stiffness was found to range from 18 to 21 kN/m depending on the age of the subjects.[16] As compared with values reported herein, the lower stiffness values may indicate a difference in the age, clinical status, or spinal level tested in the subjects. There are numerous reasons why the lumbosacral joint may be stiffer. Whereas the lumbosacral joint allows the majority of flexion-extension of the trunk,[45,46] passive stabilizers of the lumbosacral spine, in-

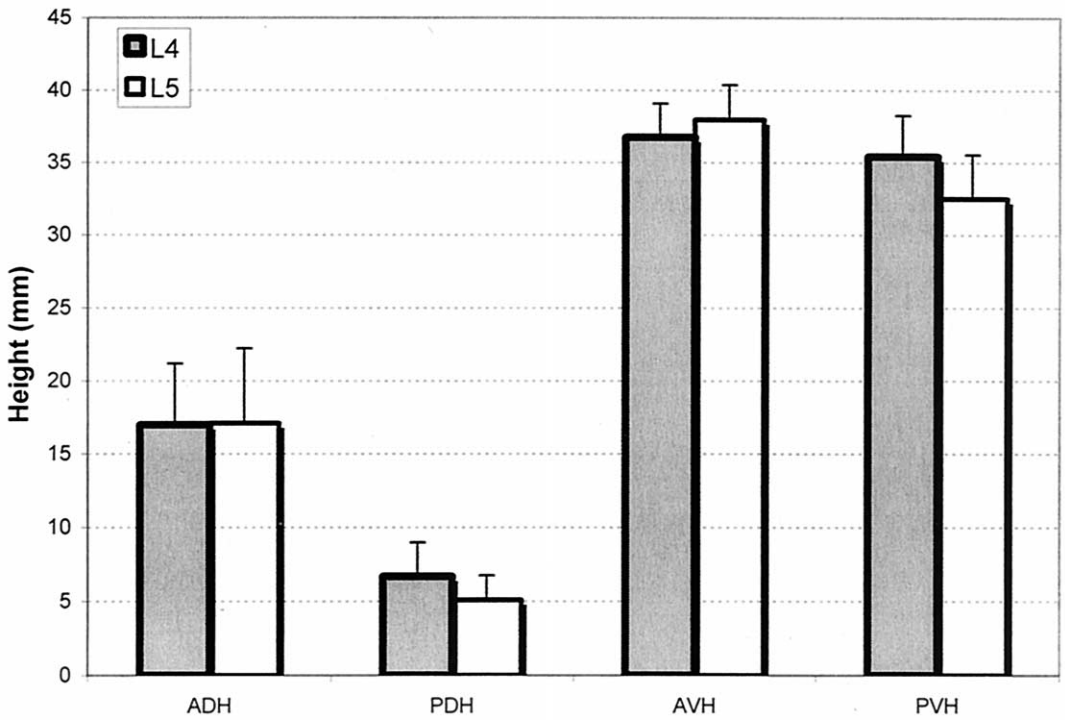

Fig 2. *Intervertebral disk dimensions (ADH, PDH) and vertebral body dimensions (AVH, PVH) obtained from the radiograph measurements of the L4 and L5 segments. Results (mean and SD) for all 18 subjects are shown.*

cluding the iliolumbar ligaments that originate from the L5 transverse process and insert into the iliac crest,[47] act to restrain flexion, extension, axial rotation, and lateral bending of L5 on S1.[48]

Study Limitations

Sources of error in the current study include the subjective nature of qualitatively evaluating radiographic images for the presence of degeneration. As suggested by Espeland et al,[49] we attempted to improve diagnostic consistency by reducing variation caused by different thresholds for abnormality. We used methodology similar to Kellgren et al[30] to assess the lumbar radiographs for the presence of degenerative changes. This radiographic evaluation criteria has demonstrated acceptable reliability for grading spinal degeneration in the cervical[31] and lumbar spine.[32] Although the use of computer-aided radiographic digitization has been found to be concurrently valid and reliable,[50] an additional source of error lies within the radiographic digitization process where variations of pencil markings and/or capturing data points could be variable.

Limitations exist in attempting to correlate plain film radiographic images of lumbar disk height or pathology to spinal stiffness. For one, whereas radiographic images provide the morphological characteristics of the spinal structures, the 2-dimensional radiograph represents a static image. Inasmuch, because the spine is a dynamic structure, little can be interpreted regarding spinal function from a single static radiographic image. Moreover, intervertebral disk degeneration may be associated with segmental instability,[51] decreased mobility,[44] or be of little or no functional consequence. Conversely, other studies have demonstrated relationships between lumbar disk degeneration, pain, and disability.[52-54]

We did not identify any differences in the radiographic and mechanical impedance parameters grouped according to gender, function and disability, and degeneration, but this most likely reflects the relatively small number of patients examined in this study. Moreover, the patients involved in the current study had a relatively minor low back disability. Future work not only aims to increase the sample size but to compare dynamic spinal stiffness assessments among more discriminant and severe clinical presentations and to other diagnostic imaging modalities.

Conclusion

Computations of spinal input impedance are relatively simple to perform, can provide a noninvasive measure of the dynamic mechanical behavior of the spine, appear to have potential to discriminate pathologic changes to the spine, and warrant further study on a larger sample of normal subjects and patients. Ultimately, chiropractic

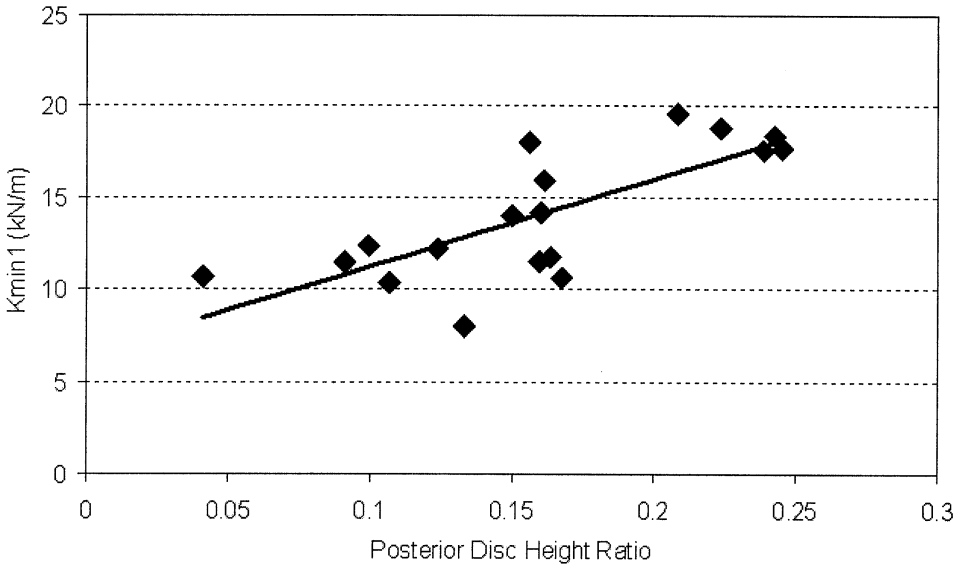

Fig 3. *Linear relationship between the L5 dynamic effective stiffness (Kmin1) and the L5-S1 posterior disk height ratio (PDHR). The L5 dynamic effective stiffness was obtained from a mechanical impedance analysis of the L5 spinous process in 18 patients with low back pain.*

clinicians may be able to use low force, impact type spinal manipulation together with dynamic impedance analysis procedures to quantify the mechanical response of the normal and abnormal spine, to perform spinal diagnosis, and subsequently to prescribe therapeutic treatment to patients.

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