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Quantification and Classification of Low Back Disorders Based on Trunk Motion

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Summary: One of the more difficult tasks associated with the treatment of low back disorders (LBDs) is the clinical assessment of the disorder. Proper diagnoses and assessments are imperative for the successful treatment and tracking of the disorder. Unfortunately, current techniques are only able to quantitatively diagnose a small percentage of LBDs. In this study we have studied the trunk motion characteristics of 339 normal subjects and 171 subjects suffering from 1 of 10 categories of LBDs. We have found that traditional parameters such as range of motion do not distinguish well between the normal and LBD groups. However, by considering range of motion in addition to higher order trunk motion characteristics such as trunk velocity and acceleration we have found that we can quantitatively describe the degree of a LBD. In addition, based upon these motion characteristics we were able to correctly classify over 80% of our 510 subjects into 1 of 11 classifications (normal plus 10 LBD groups). These motion related parameters may relate to biomechanical sensitivities to spinal loading. These results indicate that trunk motion characteristics hold great promise for the quantitative documentation and classification of LBDs. These motion parameters also hold promise for the quantification of recovery.

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Introduction

Low back pain (LBP) and low back disorders (LBDs) have been shown to be one of the most common and significant musculoskeletal conditions facing society today (1). It has been estimated that up to 80% of the population will experience a LBD at some time during their working career (2). At any one point in time 15 to 17% of the population will suffer from a LBD (3). These disorders strike during the prime working years. LBD is the primary reason for activity limitation for those under 45 years of age (4). This situation has resulted in a financial cost of over 4 billion dollars in lost wages per year and a total cost to society of between 25 and 95 billion dollars per year in the United States alone (5).

The assessment of LBD

One of the more difficult tasks associated with the treatment of LBD is the clinical assessment of the disorder. An accurate assessment is required for several reasons. First, an accurate diagnosis is necessary so that appropriate treatments can be administered. Second, an accurate assessment permits one to quantify the extent of a disorder. This information is useful so that one could judge the rehabilitative progress as well as for workers' compensation purposes. Third, assessments permit one to take the appropriate precautions so that the patient is not placed in situations where the disability would be exacerbated. For example, one can match ergonomic trunk motion descriptions of a job (job demands) with clinical functional evaluations of a worker to ensure a return to work does not over tax the worker's abilities. Fourth, erroneous pathologic diagnoses may perpetuate patients' self perception of illness, thus, prolonging disability. This may also lead to unnecessary and expensive diagnostic studies which have a finite risk of medical complication and false positive results, potentially leading to inappropriate and unsuccessful surgery. Finally, the evaluation of efficacy of treatment modalities is confounded by the inability to document the heterogeneity of the patient groups. Thus, an accurate assessment is important to facilitate proper individual treatment.

It has been estimated that the precise diagnosis is unknown in 80 to 90% of patients with disabling LBDs (6). Thus, misdiagnoses can precipitate iatrogenic problems.

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There are currently several methods by which LBDs are classified. Anatomically based assessments may be used to classify patients according to the presumed structure which is injured or otherwise painful. However, more than 25% of healthy asymptomatic individuals may have MRI, CT, or myelogram evidence of disk herniation. In addition, a pathoanatomic diagnosis is available in fewer than 15% of patients with LBD (7). Thus, the clinical examination and anatomic imaging may be unable to identify or may incorrectly identify the source of the structural problem in those suffering from a LBD.

More recently the Quebec Study classification system has been developed (8). This system accounts for: 1) the fact that many patients suffering from LBD do not have a clearly identifiable causative structural abnormality, and 2) recognizes that LBD are time limited. This classification scheme, thus, permits one to incorporate the patient history and symptom reports into the classification of the LBD. It is not necessary to make a major pathoanatomic diagnosis for most patients early during the course of a LBD. However, this classification system does not permit one to immediately diagnose the source of the problem and may suffer from confounding from differing structural problems. Thus, under certain circumstances this classification scheme might not permit the prescription of the most optimal treatment or may not permit one to take appropriate precautions to avoid reinjury since such treatment or precautions depend on knowledge of the pathoanatomic diagnosis.

Functional assessments of LBD have increased in popularity over the past several years. These assessments are based upon the premise that the trunk's musculature both support as well as load the spine during a trunk exertion. Therefore, one could document the amount of trunk force (strength) a LBD patient is willing to generate before pain increases and this measure can be compared to a normative data base to serve as an indicator of the extent of the disorder. Historically, trunk force has been documented by employing isometric, isokinetic, concentric and eccentric loadings upon the trunk. These techniques have yielded a large amount of data that describe the capacity of the trunk musculature to support loads imposed on the body (9, 10). *Parnianpour* et al (11) have demonstrated that such techniques could document the changes in the motor control of the trunk during repetitive fatiguing movements. However, strength measurement protocols usually require the maximal exertions that may be limited by the pain tolerance (which varies greatly between people) rather than the strength deficit (12). In addition, some have voiced concern over safety associated with strength testing (13).

Recently functional assessments have incorporated free dynamic motions of the trunk without external loading the trunk (14). Our previous studies have shown that trunk motion characteristics, independent of trunk torque production, are a feasible means to document the existence of a LBD. The concepts of trunk motion characteristics, patterns of the movement profiles, and "movement signature" have been used to objectively document the large amount of information about the status of the trunk's musculoskeletal control system (15-22). Preferred motions have also been found to be highly repeatable. Still, there is much controversy as to the value of trunk motion as a measure of the musculoskeletal system status.

Trunk motions may be affected by factors other than LBD. The existing literature is limited in its description of the motion patterns of normal and LBD patients. The effects of age and gender on dynamic parameters of motions have not been evaluated. Case studies are not sufficient evidence for identification of the LBD disorder based on the motion characteristics (16). Proponents of this untested hypothesis argue that one could characterize quantitatively the extent of a LBD by comparing the trunk functional motion characteristics of a patient suffering from LBD with the motion characteristics of a normative group of subjects (adjusted for age and gender). It is also believed that different sources of LBD would be manifested by different musculoskeletal system compensations that would be identifiable via the trunk motion signature. Based on this theory, when the trunk is voluntarily and dynamically loaded in different lines of action the various pathologies would be identifiable by a reduction in the acceptable motion at different points throughout the motion. Therefore, one should be able to classify LBD patients via observation of the trunk motion characteristics under different asymmetric conditions.

Objective

The objective of this study was four fold: 1) to establish the reliability of motion assessment using an exoskeletal goniometer; 2) to determine the effect of the age, gender and asymmetry on the motion variables of normal and LBD patients; 3) to develop a method to quantify the extent of a disorder; and 4) to test the hypothesis of whether one could use trunk motion signature to classify LBD patients into the appropriate LBD diagnosis categories.

Methods

This study assumed that by observing motion characteristics as a function of various asymmetric bends of the trunk a composite measure of the trunk musculoskeletal control system can be established. It has been shown that during symmetric lifting motions, dynamic motion characteristics are controlled primarily with the large, well developed muscles such as the erector spinae (23). However, during asymmetric exertions, motor control becomes more complex and one would expect that a combination of the smaller less developed muscles (such as the internal and external oblique groups) would be synchronously recruited to control a precision bending motion of the trunk (24). This change in the primary control muscles would result in a reduced range of motion as well as a reduction of the dynamic motion characteristics as the bending task becomes more asymmetric. Our previous studies (25) have shown that this is indeed the case for normal subjects. Hence, such a protocol permits one to describe the status of the trunk's musculoskeletal control system. The current study will extend this concept to those suffering from various categories of LBD to determine whether sensitivities to various pathoanatomic conditions and symptoms could be quantitatively identified via this motion signature.

Experimental protocol

An experiment has been developed to solicit the trunk motion characteristics or motion signature response to asymmetric bending. In this experiment a group of normal subjects as well as a group of subjects suffering from various (well documented) LBDs were asked to flex and extend their trunks repeatedly in various symmetric and asymmetric planes of movement while the three-dimensional motion characteristics of the trunk were monitored. No trunk resistance or external load was applied to the trunk during these tests. During the testing session the subjects viewed a screen that indicated the instantaneous twisting (asymmetric) position of the trunk. A twisting position target (± 2 degrees) was also identified on the screen. The subjects were asked to repeatedly flex and extend their trunk at their preferred speed while maintaining their twisting position within the target. If the twisting position fell outside the target during the trial a tone was automatically sounded and the trial was repeated. In this manner it was possible to monitor the free dynamic natural motion characteristics of the trunk without physically restricting or interfering with the trunk motion.

Table 1. The number of normal subjects tested shown as a function of gender and age.

	Normal Subjects					
Sex	All age groups	20's	30's	40's	50's	60's
Male	193	67	38	38	25	25
Female	146	45	25	26	24	26
Total	339	112	63	64	49	51

Subjects

The normal subject population consisted of 339 males and females between the ages of 20 and 70 who claim to have never experienced a significant back pain. The number of subjects of each gender as well as the number of subjects within each decade of age are shown in Table 1. 171 patients suffering from various LBDs were recruited from the practices of two of the authors (RRC and SRS), which are secondary and tertiary referral practices for LBDs. Consequently, symptoms had generally been present for more than 7 weeks at the time of evaluation. Of these subjects, 96 were males and 75 were female. Only patients with a well diagnosed LBD were included in this study. Anthropometric characteristics of both the normal as well as the LBD groups are shown in Table 2. Of the anthropometric characteristics, only standing height was similar between the 2 groups. Trunk dimensions were generally larger for the LBD group, except for spine length, which was shorter for the LBD group.

LBD Classification

Classification of LBP syndromes is hampered by the lack of clear and consistently applicable pathologic diagnoses for perhaps the majority of LBP patients seen in the typical clinical setting. Different physicians may assign the same patient differing diagnoses, based on differing pathophysiologic hypotheses (e.g. disk degeneration, facet syndrome, disk bulge, myofacial pain syndrome). Recognition of this clinical uncertainty led the Quebec Task Force on Spinal Disorders to develop a classification scheme which does not presume a specific pathologic diagnosis, but rather categorizes patients according to more consistently identifiable clinical characteristics. This categorization scheme is based on the location of pain (local back pain without radiation of pain to the extremity, with proximal radiation, or with distal radiation), on the presence of neurologic signs, and whether there has been local root compression or spinal stenosis seen on specific imaging techniques, such as myelography, computerized tomography or magnetic resonance imaging. Pain location categories were also subdivided according to pain duration. In addition, categories for postoperative patients (with or without pain) and chronic pain syndrome patients were established. Although this classification does not establish the structural lesion responsible for observed clinical phenomena, this does permit rational clinical decisions for further diagnostic studies and treatment,

Table 2. Anthropometric characteristics of the normal and LBD subjects populations (mean [SD]).

Anthropometric Var.	Sex	Normal Subjects	LBD Patients
Weight(lb)	Male	178.8(31.2)	187.5(29.8)**
	Female	148.4(35.0)	156.3(42.6)*
Standing height(cm)	Male	177.7(7.2)	177.6(8.6)
	Female	163.6(6.6)	163.2(6.8)
Spine Length(cm)[1]	Male	53.4(3.7)	52.4(3.0)**
	Female	47.9(3.3)	46.3(3.4)**
Trunk Breadth(cm)[2]	Male	30.3(3.2)	32.3(3.4)**
	Female	27.5(4.5)	29.6(4.8)**
Trunk Depth(cm)[2]	Male	23.2(4.0)	25.3(4.4)**
	Female	21.5(5.3)	23.6(5.9)**
Trunk Circ.(cm)[2]	Male	90.1(11.1)	96.7(11.4)**
	Female	82.1(15.5)	88.5(18.2)**
Leg Length[3]	Male	95.9(6.2)	92.9(11.4)**
	Female	89.3(5.1)	85.6(7.9)**
R. Illiac. height(cm)[4]	Male	108.8(5.6)	107.2(5.4)*
	Female	100.6(4.8)	100.2(4.8)
L. Iliac. height(cm)[4]	Male	108.8(5.6)	107.2(5.4)*
	Female	100.5(4.8)	100.3(4.9)

[1] The distance from the lumbar-sacral joint (L5/S1) to the top of the first cervical vertebrae (C1).

[2] The dimensions were measured at the level of the umbilicus.

[3] The height of top of the greater trochanter.

[4] The height of the top of the ilium in the mid-axillary plane on the right (left) side.

** Significant at $p < 0.001$ from t-test between the normal and patients

* Significant at $p < 0.01$ from t-test between the normal and patients

Table 3. LBD classification showing the number of patients and percentage of total LBD patients in each category.

Category	Number of Patients	Percentage of Total
Quebec 1	16	9.4%
Quebec 2	17	10%
Quebec 3	17	10%
Spondylolisthesis	16	9.4%
Herniated Disc Pain > 3	30	18%
Herniated Disc Pain <= 3	12	7%
Stenosis	26	15%
Quebec 9.2	11	6%
Non-organic	17	10%
Quebec 11	9	5.2%
Total	171	100%

and allows a higher degree of inter-observer reliability.

The presence of potential non-organic components to individual patients' pain syndromes, which could affect volitional movement, was recognized. For most patients, signs for non-organicity were recorded in 5 categories: superficial tenderness, overreaction, regionalization of symptoms, variation of exam with distraction, and simulation maneuvers (26). Patients were considered to have a probable significant non-organic pain component if signs in more than 3 categories were present or if elevation of the Hs or Hy scale was seen on MMPI testing.

In this study we analyzed trunk motion differences among 10 patient categories that included both anatomic and pain location categories generally corresponding to those of the Quebec Task Force. The following categories were evaluated: LBP with proximal radiation (Quebec Class 2), LBP with distal radiation (Quebec Class 3), localized LBP (Quebec Class 1), isthmic spondylolisthesis, herniated lumbar disk with minimal or no pain (3 or less on a 10 point analog visual scale (HNP ≤ 3)), herniated lumbar disk with moderate or worse pain (HNP > 3), spinal stenosis, post-operative patients with pain (Quebec 9.2), patients with evidence for significant non-organic pain components, and other diagnoses, predominately idiopathic scoliosis (Quebec 11). The number of subjects associated with each LBD classification group is shown in Table 3. The list of categories were finalized after considerable analysis of the clinical and practical issues.

This set of categories discriminates between those herniated disk patients who have minimal or no pain, and those who have more severe pain. Patients were seen with varying degrees of relief after non-surgical management of lumbar disk herniation, and we speculated that the lumbar motion might vary greatly with pain severity. Patients with isthmic spondylolisthesis are evaluated as a distinct category. Although no specific category exists for this diagnosis within the scheme of the Quebec Task Force, we believe that isthmic spondylolisthesis is a sufficiently distinct structural anomaly to warrant evaluation for specific motion characteristics. There were too few patients with degenerative spondylolisthesis to permit evaluation.

The patients with LBP, with and without varying radiating pain (Quebec 1, 2, and 3) comprised both patients who (at various points through their treatments) underwent specific imaging tests which were negative for any significant neural compression, and patients who had never been subjected to such imaging. Because those with distal radicular pain without prior imaging may represent patients who are afflicted with lumbar disk herniation, they were excluded from this analysis. In addition, patients who could not be classified, due to insufficient clinical information, were excluded, as were those with overlapping diagnoses, such as spondylolisthesis and disk herniation.

Experimental design

Five asymmetric positions of the trunk were tested in this study. Asymmetry was defined as the amount of trunk twist in the transverse plane of the body. Asymmetry was set at 5 levels consisting of a sagittally symmetric position (0), 15 degrees of twist to the right (15 right), 15 degrees of twist to the left (15 left), 30 degrees of twist to the right (30 right), and 30 degrees of twist to the left (30 left). These asymmetric lines of action are illustrated graphically in Figure 1. The initial testing position for each subject consisted of the 0 condition followed by the two 15-degree conditions, followed by the two 30-degree conditions. The order of the right and left conditions were counterbalanced in the experimental design. Subjects were not always able to perform all conditions.

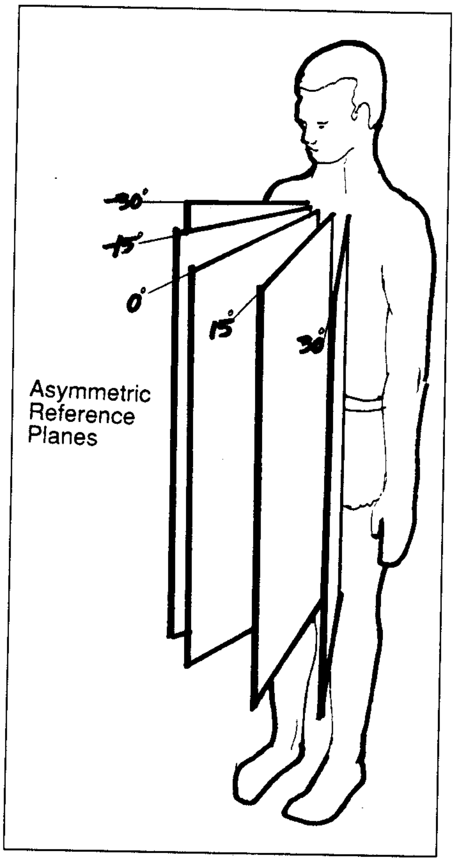

Fig. 1. Asymmetric planes defining the testing conditions.

Twenty-seven dependent variables were observed from in this experiment as a function of each asymmetric condition. One variable (ability) simply described the capability of the subject to complete the various experimental conditions. The second variable consisted of twisting ROM capability (not part of experimental conditions). 15 trunk motion characteristics or features were observed as a function of the experimental conditions. These characteristics consisted of: 1) the range of motion (ROM) (difference between maximum and minimum position) in the sagittal plane, 2) ROM in the frontal plane, 3) ROM in the transverse plane*, 4) peak flexion velocity in the sagittal plane, 5) peak extension velocity in the sagittal plane, 6) peak flexion acceleration in the sagittal plane, 7) peak extension acceleration in the sagittal plane, 8) peak right lateral (frontal) bending velocity, 9) peak left lateral bending velocity, 10) peak right lateral bending acceleration, 11) peak left lateral acceleration, 12) peak right axial velocities in the transverse plane*, 13) peak left axial velocity in the transverse plane*, 14) peak right axial acceleration in the transverse plane*, and 15) peak left axial acceleration in the transverse plane*. Finally, 10 weighting coefficients were used to characterize the continuous nature of each of the angular position, velocity and acceleration profiles in the sagittal plane. These coefficients were computed based on the optimal feature extraction procedure that enabled to accurately reconstruct the continuous profiles while reducing the dimensions of the original data (17).

Apparatus

Many researchers have documented trunk positions using electrogoniometers (27-31). However, many of these studies were unable to document trunk position in three-dimensional space and none have focused upon the evaluation of dynamic trunk motion characteristics. The trunk's three-dimensional dynamic trunk motion characteristics were monitored in this study with a tri-axial electrogoniometer. This device was developed in our laboratory and is referred to as the lumbar motion monitor (LMM). This device has been used previously to document trunk motions used by workers in industry (32). The LMM is essentially an exoskeleton of the spine that has been instrumented with a series of potentiometers to document the three-dimensional position in space of the thoraco-lumbar spine. The LMM is attached via a harness system to the thorax and the pelvis with a pre-molded semi-rigid plastic material (Orthoplast). This provides two stable "anchors", at

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* Note: These motion characteristics were limited by the experimental conditions.

the mid-spine (thorax) and at the pelvis. Thus, the LMM measures the difference in trunk position of primarily the lumbar spine (as a unit) relative to the pelvis. The LMM is shown on a subject in Figure 2.

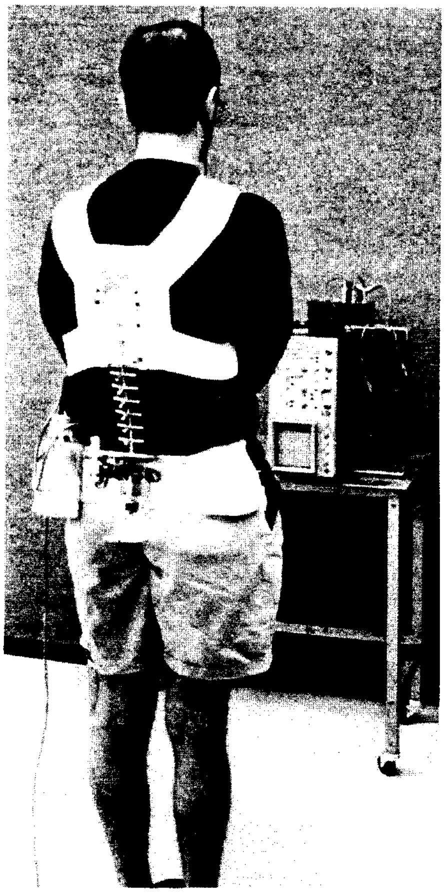

Fig. 2. Subject wearing LMM during experimental testing.

The LMM signals were sampled at 60 Hz via an analog-to-digital converter and a portable 386-based microcomputer. After the data were collected, the signals were processed in the laboratory to determine position, velocity, and acceleration of the trunk as a function of time in the sagittal, frontal (lateral), and transverse (axial twisting) planes of the body. Voltage readings from the potentiometers are converted into angular position in the cardinal planes using a regression (calibration) model ($R^2 = 0.978$ sagittal, 0.976 lateral, 0.983 twisting). The angular velocity and acceleration were obtained through numerical differentiation. Filtering (to eliminate noise) was also performed prior to differentiation of the signal. Our validation study (33) indicated that the LMM's ability to measure trunk position velocity and acceleration in three-dimensional space is more consistent than video-based systems. The transverse plane position signal from each back monitor was controlled with a comparator circuit. The comparator circuit was used as a feedback mechanism to the subject so they could control the transverse plane motion and, thus, control the asymmetric experimental conditions.

Measurement reliability

In order to assess the repeatability and reliability of the LMM testing protocol an initial study was performed. 20 normal subjects performed the experimental protocol on 5 separate testing occasions with a 1-week period separating each testing session. The trunk motion characteristics in the sagittal and frontal planes were compared over the 5 testing periods. There were no statistically significant differences among the trunk motion characteristics between the 5 testing sessions (MANOVA, $p > 0.05$). Sagittal plane trunk motion characteristic intraclass correlation coefficients (ICCs) among the males averaged 0.82 and ranged from 0.81 to 0.83. The ICCs for females subjects averaged 0.64 and ranged from 0.58 to 0.73 for the various trunk motion characteristics in the primary (sagittal) plane of motion. These results indicates that the vast majority of trunk motions were a function of the experimental protocol and not due to normal variations of the subjects from day to day. The ICCs were less acceptable for the parameters in the accessory planes of motion.

Procedure

Subjects were permitted to become familiar with the visual display representing the transverse plane trunk position. The subject was instructed to twist so their transverse plane position dot moved within the target zone. Subjects were given 6 instructions. These consisted of: 1) cross their arms in front of their chest, 2) stand with their feet shoulder width apart, and keep them in the same location for all conditions, 3) flex and extend their trunks repeatedly in the sagittal plane as fast as they can comfortably while keeping the transverse plane position dot between the target zone dots, 4) watch the dots at all times during testing, 5) if their transverse plane position fell outside the target zone a tone would sound and the trial would be repeated, and 6) move continuously until instructed to "relax". Data were collected up to 14 seconds for each experimental run.

Data analysis

Custom software developed in the Biodynamics Laboratory converted the electrical signal from each back monitor into trunk position, velocity and acceleration. The software program graphically displays trunk positions in each plane of the body separately and permits one to analyze each motion component independently throughout the exertion. The first entire motion (flexion and extension) during each trial was considered a warm-up motion and was discarded for analysis purposes. The following 4 flexions were analyzed and averaged. Then the 4 matching extensions were analyzed and averaged. This process was completed for each plane of the body. The analysis program computed the trunk motion characteristic variables discussed earlier.

The feature extraction from the continuous movement patterns required the following data processing. The middle 3 cycle of movements were interpolated and averaged into 128 data points, thus the data were normalized with respect to cycle time and allowed between individual comparison. Data matrices consisted of the 170 columns (number of patients) and 128 rows (number of data points for each patient's continuous profile; i.e. position, velocity and acceleration). The eigenvalue and eigenvectors of the correlation matrix of the patient data matrices were computed by singular value decomposition (SVD) algorithm using MATLAB (Math Works Inc., Natick, MA 01760, USA). The eigenvectors represent the principal patterns (bases) and the eigenvalues reflect the amount of explained variability of the original data matrix. Using the original data matrices and the eigenvectors, the weighting coefficient matrices were computed. Inspection of eigenvalues indicated that the first 5 eigenvectors explained more than 97% of variability of the original data. The first 10 weighting coefficients were used to reconstruct the original movement profiles. Using the eigenvectors extracted from the patients' data matrices, the weighting coefficients for normal subjects were also computed. Thus, both normal and patients coefficients having the same bases allowed the representation of the continuous patterns of motion with a significant reduction in the dimension of the original data (from 128 data points to 10 coefficients). A more detailed description of the method is provided in *Parnianpour* et al. (17).

Table 4. Mean (SD) of sagittal trunk motion characteristics as a function of the asymmetric condition for all classification categories. The right and left 15-degree and 30-degree conditions are combined.

	SAGITTAL PLANE				
	ROM (degrees)	FLEX VEL (deg/sec)	EXT VEL (deg/sec)	FLEX ACC (deg/sec**2)	EXT ACC (deg/sec**2)
Normal					
Zero [100%]	36 (15)	92 (49)	96 (48)	404 (245)	414 (254)
Fifteen [100%]	22 (11)	50 (32)	51 (32)	202 (162)	208 (165)
Thirty [86%]	17 (9)	42 (27)	41 (26)	180 (143)	175 (141)
Quebec 1					
Zero [100%]	37 (15)	60 (38)	61 (36)	208 (167)	208 (141)
Fifteen [91%]	20 (9)	31 (18)	33 (21)	108 (76)	126 (103)
Thirty [18%]	22 (4)	40 (11)	45 (14)	167 (89)	177 (97)
Quebec 2					
Zero [100%]	29 (16)	42 (25)	47 (29)	139 (92)	149 (97)
Fifteen [68%]	20 (8)	23 (15)	25 (16)	68 (51)	72 (49)
Thirty [12%]	13 (9)	21 (16)	24 (16)	75 (57)	81 (65)
Quebec 3					
Zero [100%]	30 (13)	34 (21)	33 (19)	106 (71)	100 (65)
Fifteen [65%]	21 (11)	19 (9)	20 (10)	55 (35)	58 (39)
Thirty [6%]	7 (0.9)	16 (0.5)	18 (0.3)	82 (12)	94 (4)
Spondylolisthesis					
Zero [100%]	40 (12)	39 (38)	70 (34)	281 (232)	292 (203)
Fifteen [94%]	25 (11)	34 (17)	35 (17)	124 (89)	138 (97)
Thirty [53%]	16 (11)	27 (16)	25 (14)	107 (65)	105 (75)
Herniated Disc Pain > 3					
Zero [100%]	30 (11)	40 (30)	45 (32)	135 (131)	138 (109)
Fifteen [60%]	20 (16)	27 (24)	28 (26)	96 (81)	99 (81)
Thirty [13%]	15 (13)	32 (23)	32 (24)	129 (71)	137 (86)
Herniated Disc Pain <=3					
Zero [100%]	29 (11)	52 (30)	55 (30)	189 (116)	185 (112)
Fifteen [77%]	22 (7)	35 (17)	34 (17)	135 (95)	131(96)
Thirty [45%]	17 (8)	24 (14)	25 (14)	88 (73)	95 (67)
Stenosis					
Zero [100%]	27 (11)	33 (19)	35 (19)	111 (92)	116 (127)
Fifteen [31%]	14 (6)	15 (7)	17 (9)	42 (22)	51 (27)
Thirty [0%]	***	***	***	***	***
Quebec 9.2					
Zero [100%]	27 (13)	28 (20)	30 (15)	82 (50)	90 (54)
Fifteen [22%]	10 (5)	8 (2)	10 (3)	28 (11)	29 (11)
Thirty [9%]	6 (6)	4 (2)	4 (3)	14 (8)	17 (9)
Non-organic					
Zero [100%]	28 (14)	31 (19)	32 (22)	85 (54)	99 (79)
Fifteen [29%]	21 (9)	24 (18)	26 (18)	65 (50)	87 (71)
Thirty [0%]	***	***	***	***	***
Quebec 11					
Zero [100%]	33 (17)	68 (41)	66 (40)	269 (183)	257 (187)
Fifteen [78%]	24 (16)	34 (21)	33 (18)	114 (68)	99 (64)
Thirty [61%]	15 (7)	21 (15)	21 (14)	79 (71)	90 (78)

[ ] percentage of subjects performing at that asymmetric condition

*** No subjects were able to complete these conditions

The trunk motion characteristics of both the normative and LBD groups were characterized through descriptive statistics. Next, each of the trunk motion variables measured by the LMM were normalized with respect to the gender and age values from the normal data base. In order to facilitate subject classification, several models were created utilizing various combinations of the dependent measures. The models were tested via quadratic discriminant function analyses. In order to account for the different group sample sizes, this method uses individual within-category covariance matrices in calculating distances for discriminating the 11 different categories. The trunk motion based models were used to determine how well the various categories of LBD patients and normal subjects could be classified. Both the sensitivity and specificity were computed to assess the performance of the discriminant function.

Results

Trunk motion characteristics

The sagittal plane trunk motion characteristics of the 339 normal subjects in response to the various experimental conditions are shown at the top of Table 4. Note that in this table the right and left asymmetries were combined at each asymmetric conditions since no statistically significant differences were found between the right and left sides. This table presents summary statistics of the unimpaired subjects to perform the experimental conditions in terms of trunk position, velocity, and acceleration characteristics. In general, this normal group exhibited the greatest position, velocity, and acceleration characteristics under the sagittally symmetric (0) condition. As the testing condition became more asymmetric, the magnitude of the trunk motion characteristics decreased monotonically.

The descriptive characteristics that portray the sagittal plane trunk motion characteristics of the various LBD categories are also shown in Table 4. This table indicates that compared to the normative group, the ability to perform the various asymmetric conditions as well as the magnitude of the performance measures were significantly reduced in the LBD group. All subjects were able to perform the 0 test condition. All subjects within the normal group were also able to perform the 15-degree asymmetry condition, whereas, in none of the LBD classifications were all the subjects able to perform the 15-degree asymmetric condition. This trend was also true for the 30-degree asymmetric conditions, however, only 86% of the normal group and far fewer LBD patients were able to successfully complete these conditions. Significant decreases in the magnitude of the motion characteristic were also observed as the test condition became more asymmetric. The greatest differences between the normal and LBD categories relate to measures of the higher order derivatives of motion (i.e., velocity and acceleration). For example, the mean sagittal plane ROM between the normal and LBD groups under the 0 asymmetry condition differs by only 5 degrees. However, when the peak extension velocity and acceleration measures were compared mean differences of 49 degrees/s and 251 degrees/s^2, respectively, were found.

Table 5. Statistical summary showing effect of LBD, sex, and age on motion variables. Each individual plane was evaluated via ANOVA.

PLANE	DIRECTION	MOTION VAR.	TYPE[1]	SEX	AGE	TYPE by SEX	TYPE by AGE	SEX by AGE
		ALL VAR'S (MANOVA)	**	**	**		**	*
SAGITTAL		RANGE (degree)		**	**			**
	FLEX.	VELOCITY (deg/sec)	**	*	**			*
	EXTEN.	VELOCITY (deg/sec)	**	*	**			*
	FLEX.	ACC. (deg/sec^2)	**	*	**		*	
	EXTEN.	ACC. (deg/sec^2)	**	*	**		*	
LATERAL		RANGE (degree)						
	RIGHT	VELOCITY (deg/sec)	**		**			
	LEFT	VELOCITY (deg/sec)	**		**			
	RIGHT	ACC. (deg/sec^2)	**		**			
	LEFT	ACC. (deg/sec^2)	**		**			
TRANSVERSE		RANGE[2] (degree)	*					
	CW	VELOCITY (deg/sec)	**		**			
	CCW	VELOCITY (deg/sec)	**		**			
	CW	ACC. (deg/sec^2)	**		**		*	
	CCW	ACC. (deg/sec^2)	**		**		*	

** Significant effect ($p < 0.001$)
* Significant effect ($p < 0.01$)

[1] Normal subjects vs. LBD patients
[2] Controlled range of motion

Characterization of LBDs

The subject's motion characteristics in the 3 planes of the body were tested for statistically significant differences as a function of LBD (normal vs. LBD), age, and gender. Several significant trends can be derived from the statistical summary in Table 5. First, many of the motion characteristics can distinguish between normal and LBD subjects. In both the sagittal and lateral planes of the body it was found that the range of motion was not significantly different between the normal and LBD group. (There was a significant difference in range of motion in the transverse plane of the body, but this range of motion was controlled by the experimental conditions.) However, the velocity and acceleration characteristics differed significantly between the 2 groups. Second, the table also indicates that gender and age both influenced the motion characteristics of the subjects with age decreasing the magnitude of the measures. Few statistically significant interactions between any of these variables were observed. These findings suggest that one need only adjust the measured motion characteristics of a subject for the influences of the age and gender in order to quantify performance relative to the normative group. This normalization of the motion characteristics were performed to allow for the determination of their differences as a function of the LBD status (normal vs. LBD). The mean values (and the associated standard deviations) necessary to normalize

Table 6. Mean (SD) trunk motion characteristics of the normal subjects shown as a function of gender and age. Any motion characteristics of LBD patients can be normalized by dividing the measured value by the age and gender matched mean value reported in this table.

PLANE	DIRECTION	MOTION VAR.	AGE									
			MALE					FEMALE				
			20's	30's	40's	50's	60's	20's	30's	40's	50's	60's
SAGITTAL		RANGE (degree)	38.71 (14.41)	41.47 (13.57)	42.75 (14.35)	42.76 (16.58)	37.60 (15.54)	38.64 (17.04)	31.41 (12.82)	29.28 (10.61)	26.47 (7.72)	23.88 (9.46)
	FLEXION	VELOCITY (deg/sec)	104.12 (51.98)	113.88 (49.86)	107.53 (47.15)	101.75 (49.38)	80.25 (45.51)	100.02 (53.74)	82.34 (37.71)	72.45 (28.73)	61.62 (19.54)	47.91 (15.87)
	EXTENSION	VELOCITY (deg/sec)	106.54 (48.09)	120.94 (53.82)	114.84 (44.01)	105.16 (46.26)	81.99 (42.88)	104.50 (53.43)	90.95 (39.96)	78.31 (29.35)	67.79 (22.14)	49.64 (18.38)
	FLEXION	ACC. (deg/sec^2)	475.49 (250.44)	541.90 (287.85)	473.56 (248.38)	425.40 (222.40)	299.02 (181.32)	435.59 (270.85)	354.86 (175.65)	335.70 (144.80)	257.09 (117.98)	194.71 (72.27)
	EXTENSION	ACC. (deg/sec^2)	490.93 (269.25)	552.06 (302.13)	493.27 (248.04)	417.55 (206.49)	322.76 (264.20)	445.10 (248.90)	373.01 (187.90)	318.66 (163.54)	291.78 (146.52)	188.36 (90.72)
LATERAL		RANGE (degree)	3.72 (3.22)	4.25 (3.70)	3.14 (2.55)	3.74 (2.77)	2.69 (1.59)	2.95 (2.05)	3.22 (3.56)	2.69 (1.46)	2.87 (1.61)	2.67 (1.86)
	RIGHT	VELOCITY (deg/sec)	13.27 (9.32)	14.18 (12.08)	10.86 (8.49)	12.48 (8.33)	9.50 (8.47)	10.58 (6.04)	12.65 (13.83)	10.65 (8.02)	9.95 (5.93)	7.62 (3.85)
	LEFT	VELOCITY (deg/sec)	13.29 (10.61)	15.49 (13.66)	10.72 (7.95)	12.73 (8.02)	9.44 (8.22)	12.72 (12.37)	11.53 (11.58)	10.96 (7.07)	9.83 (4.83)	8.20 (4.57)
	RIGHT	ACC. (deg/sec^2)	79.57 (48.73)	68.57 (48.62)	56.18 (35.87)	63.94 (48.83)	54.92 (55.15)	89.78 (58.14)	67.29 (72.35)	57.51 (68.08)	50.39 (31.70)	45.24 (22.42)
	LEFT	ACC. (deg/sec^2)	81.76 (54.89)	72.33 (43.55)	52.03 (32.36)	59.61 (39.99)	49.03 (40.13)	96.51 (74.03)	60.32 (58.75)	60.38 (57.21)	52.26 (25.98)	46.31 (28.48)
TRANSVERSE		RANGE (degree)	1.79 (0.80)	1.50 (0.72)	1.73 (0.94)	1.96 (0.86)	1.81 (0.83)	1.73 (0.71)	1.45 (0.66)	1.51 (0.56)	1.41 (0.70)	1.80 (0.73)
	CW	VELOCITY (deg/sec)	7.87 (3.82)	6.90 (3.85)	6.37 (2.96)	7.03 (3.37)	6.08 (2.66)	6.74 (2.41)	6.04 (2.79)	5.83 (1.94)	5.38 (3.27)	6.06 (3.05)
	CCW	VELOCITY (deg/sec)	7.71 (5.44)	6.91 (3.56)	6.71 (3.28)	6.63 (3.64)	6.06 (3.19)	6.66 (2.53)	6.03 (3.33)	5.94 (2.38)	5.02 (2.82)	6.01 (4.36)
	CW	ACC. (deg/sec^2)	57.44 (35.20)	47.66 (35.91)	36.26 (18.35)	36.44 (16.04)	31.85 (14.45)	60.74 (41.72)	51.85 (41.53)	33.06 (14.15)	25.84 (11.64)	37.12 (25.97)
	CCW	ACC. (deg/sec^2)	61.36 (48.40)	46.55 (36.90)	38.03 (20.78)	33.38 (16.55)	36.74 (22.27)	59.62 (41.95)	38.78 (19.91)	34.00 (13.41)	24.34 (10.34)	35.78 (29.91)

the zero asymmetry condition for age and gender are shown in Table 6 for the 3 planes of the body. Furthermore, this normalization process permits one to quantitatively describe the extent of a LBD by characterizing the patient's trunk motion characteristics relative to the expected trunk motion characteristics of the normal group. Thus, LBDs can be described in terms of the percent of the normative group's motion characteristics and is shown in Table 7. For example, patients in the stenosis classification had 81% of the range of motion of the normal group in the zero condition once matched for age and gender relative to the normal group. Whereas the extension velocity and acceleration were 48% and 38% of the normal groups' age and gender adjusted values, respectively.

Classification

The normalized trunk motion characteristics were used as a basis to classify the 510 subjects that participated in this experiment into the various normal and LBD groups. Several models employing combinations of trunk motion features as well as continuous motion indices were tested to determine which combination of motion indices best distinguished between LBD groupings. A model was constructed utilizing the summed values of each of the four motion characteristics (ability, position, velocity, and acceleration) over all 5 experimental conditions. Specifically, an 8 variable model consisting of: 1) ability (the number of asymmetric conditions the subject was able to complete, 2) sagittal extension velocity, 3) twisting range, 4) sagittal range, 5) right lateral velocity, 6) first coefficient of sagittal position, 7) first coefficient of sagittal velocity, and 8) fourth coefficient of sagittal acceleration were used in a discriminant function model to classify the data. When identifying normal vs. LBD subjects as a group the model correctly classified 93.5% of normal subjects and 80% of LBD patients. When the model was used to classify the subjects into the specific LBD group the model correctly classified the subjects over 80% of the time (error rate = 0.196). The results of this classification model are shown in Table 8. The success rate of the classification varied from 16% to 100%. Table 9 indicates the specificity and sensitivity statistics for the model. This table indicates that the model specificity is particularly good with an average specificity value of over 97%. The sensitivity of the model is perfect for the Non-organic and Quebec Category 9.2 groups.

Discussion

Reliability of trunk motion measures

This study has shown that trunk motion characteristics, independent of trunk strength, serve as a sensitive and repeatable measure of trunk musculoskeletal status. Our previous study has established the accuracy of the LMM as a measurement tool. The current study has documented the reproducibility of the motion characteristics derived from the LMM on

Table 7. Patient performance shown as a function of LBD classification and as a percentage of the normal group's sagittal plane performance under each asymmetric condition. The right and left 15-degree and 30-degree conditions are combined.

Note: All values are expressed as percentage of mean normal normalized performance

[ ] percentage of subjects performing at that asymmetric condition

*** No subjects were able to complete these conditions

	PERCENTAGE OF NORMAL SAGITTAL PLANE PERFORMANCE				
	ROM	FLEX VEL	EXT VEL	FLEX ACC	EXT ACC
Quebec 1					
Zero [100%]	100%	65%	65%	51%	52%
Fifteen [91%]	91%	62%	66%	54%	62%
Thirty [18%]	146%	100%	100%	90%	97%
Quebec 2					
Zero [100%]	80%	44%	46%	33%	34%
Fifteen [68%]	87%	45%	46%	33%	34%
Thirty [12%]	81%	52%	59%	44%	47%
Quebec 3					
Zero [100%]	82%	38%	34%	27%	24%
Fifteen [65%]	93%	39%	37%	28%	28%
Thirty [6%]	40%	37%	43%	43%	51%
Spondylolisthesis					
Zero [100%]	100%	70%	67%	65%	64%
Fifteen [94%]	100%	65%	65%	59%	64%
Thirty [53%]	93%	61%	58%	55%	56%
Herniated Disc Pain>3					
Zero [100%]	78%	41%	43%	31%	31%
Fifteen [60%]	85%	50%	52%	44%	45%
Thirty [13%]	83%	66%	68%	61%	66%
Herniated Disc Pain<=3					
Zero [100%]	81%	53%	52%	43%	40%
Fifteen [77%]	97%	61%	58%	56%	54%
Thirty [45%]	100%	47%	49%	37%	41%
Stenosis					
Zero [100%]	85%	46%	48%	39%	38%
Fifteen [31%]	81%	44%	50%	35%	41%
Thirty [0%]	***	***	***	***	***
Quebec 9.2					
Zero [100%]	74%	30%	31%	20%	22%
Fifteen [22%]	47%	17%	20%	14%	14%
Thirty [9%]	35%	9%	9%	6%	8%
Non-organic					
Zero [100%]	72%	32%	31%	19%	21%
Fifteen [29%]	89%	43%	45%	28%	36%
Thirty [0%]	***	***	***	***	***
Quebec 11					
Zero [100%]	92%	72%	66%	65%	60%
Fifteen [78%]	100%	68%	63%	58%	49%
Thirty [61%]	92%	52%	53%	46%	53%

Table 8. Quadratic discriminant function results summary showing the number of subjects and percentage of the subject population classified into each category. Bold numbers along the diagonal indicate correct classification.

Note: The percentage classified is rounded to the neared whole number and may not sum to 100.

		Predicted Group Membership											
	Categories	Normal	Quebec 1	Quebec 2	Quebec 3	Spondy-lolisthesis	HNP >3	HNP <=3	Stenosis	Quebec 9.2	Non-organic	Quebec 11	Totals
Actual Group Membership	Normal	**317** **94%**	5 2%	1 1%	1 1%	7 2%	2 1%	3 1%	0 0	0 0	0 0	3 1%	339
	Quebec 1	6 38%	**4** **25%**	3 19%	0 0	1 6%	1 6%	1 6%	0 0	0 0	0 0	0 0	16
	Quebec 2	2 12%	0 0	**8** **47%**	2 12%	0 0	0 0	0 0	4 23%	0 0	2 12%	0 0	17
	Quebec 3	0 0	0 0	0 0	**11** **65%**	0 0	0 0	0 0	4 23	0 0	2 12	0 0	17
	Spondy-lolistheis	4 25%	1 6%	1 6%	2 12%	**5** **44%**	0 0	0 0	0 0	0 0	1 6%	0 0	16
	HNP >3	3 10%	0 0	5 16%	3 10%	2 6%	**5** **16%**	1 3%	10 33%	0 0	1 3%	0 0	30
	HNP <=3	3 25%	0 0	1 8%	0 0	1 8%	0 0	**5** **42%**	0 0	1 8%	1 8%	0 0	12
	Stensosis	0 0	0 0	1 4%	2 8%	0 0	1 4%	0 0	**20** **77%**	0 0	2 8%	0 0	26
	Quebec 9.2	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	**11** **100%**	0 0	0 0	11
	Non-organic	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	**17** **100%**	0 0	17
	Quebec 11	2 22%	0 0	1 11%	0 0	0 0	0 0	0 0	0 0	0 0	1 11%	**5** **55%**	9
													510

Table 9. Specificity and sensitivity of quadratic discriminant function analysis results.

Category	Specificity (%)	Sensitivity (%)
Normals	88	94
Quebec 1	98	25
Quebec 2	97	47
Quebec 3	98	65
Spondylolisthesis	98	44
Herniated Disc Pain > 3	99	16
Herniated Disc Pain <=3	99	42
Stensosis	96	77
Quebec 9.2	99	100
Non-organic	98	100
Quebec 11	99	55

different testing occasions. As expected, higher reliability measures were found for the motion characteristics in the sagittal plane. Based upon MANOVA results, no statistically significant differences were detected over the 5 different testing sessions. The motion characteristics associated with the accessory plane were less organized and less reproducible (18, 19,34). This is most likely due to the inexperience associated with precise lateral trunk control. The subjects that participated in the LMM reliability test were normal. Future work should consider the reliability and repeatability of trunk motions produced by the LBD patients. However, since LBDs are often transient in nature it would be more difficult to separate motion characteristic repeatability compared to a change in the status of the LBD patient. We believe, therefore, that the assessment of motion characteristics provides a measure of the trunk's musculoskeletal status that is feasible to use with a LBD patient and does not contain the inherent risk associated with traditional trunk strength based measures.

Quantification of LBD

The quantification of trunk motion can facilitate the consistency of disability ratings. *Clark* et al. (35) have shown that disability ratings among medical examiners can vary by as much as 70%. The 2 major impairment evaluation systems are those developed by the American Medical Association (AMA) (36, 37) and the American Academy of Orthopaedic Surgeons (AAOS) (38). They are used by 60% and 30% of clinicians in the United States, respectively, and are based primarily on pathological and radiological diagnoses (39, 40). These schemes are highly problematic with respect to the nonspecific LBDs. Strength and motion analyses are considered as "upcoming tools" in the evaluation of the lumbar spine (41). The AMA recently included static ROM in their system. However, we believe that it has not resulted in much improvement. The current study questions the logic in relying on ROM as an assessment tool as it did not discriminate well among the normal and LBD patients. Large ROM variations within normal subjects and among the LBDs categories makes ROM the least sensitive mobility measure for impairment evaluation. The National Institute for Occupational Safety and Health (42, 43) has spent considerable resources to identify the reliable clinical tools for evaluation of the spine. The 19 tests that passed the criteria for reliability became so dominated by pelvic tilt and lumbar lordosis measures that it raises questions regarding its clinical validity and utility (40). The present study strongly suggest the inclusion of the dynamic motion parameters in the disability assessment protocol given their proven validity and high reliability.

The quantification of trunk motions has been suggested as a means to assess potentially effective treatment of a LBD. The surgical treatment for LBDs is indeed warranted for only a small minority of patients and does require an anatomically based diagnosis. However, the anatomical based diagnosis of the majority of mechanical LBD does not augment the treatment path of the patients since very little can be done to reverse the degradation of the bone or the discs themselves. A positive imaging study showing such degeneration, does not predict the presence of pain or its future recurrence. We can restore the functional deficit with exercise programs and aggressive conservative treatments (44-47). In particular, it has been recognized that functional restoration of the mechanical LBP patient is necessary and is far more important in the management of the condition than is an anatomically based diagnosis. Thus, a quantitative measure of performance is desirable.

We have shown that trunk motion measures must be adjusted or normalized for factors that may affect motion. The significant effects of age and gender on the performance parameters warranted the normalization procedure used here (Tables 5 and 7). It was noted that a reduction in the motion characteristics were evident only in the latter decades of life. Males were significantly faster and exhibited greater sagittal mobility.

The inclusion of the asymmetric planes of motion were necessary to quantify functional motion characteristics. The asymmetric conditions increase the stress level of the test such that the subtle differences amongst various categories could be detected. During purposeful work or leisure time activities of daily living complex motions involving asymmetries are present and identifying the limiting or symptom provoking planes of motion in patients is extremely important. 2 groups of patients, Non-organic and Spinal Stenosis, were unable to perform the 30-degree asymmetric condition. Only 86% of normal subjects were able to complete this task.

LBD classification

A considerable body of knowledge has evolved recently that utilizes different technologies to document the importance of dynamic parameters in differentiating LBD patients and normal subjects (10, 14, 48, 49, 50). Examination of the continuous profiles of movement can provide insight as to the discriminatory capability of dynamic measures in differentiating between LBD groups. The group mean profiles of the sagittal angular position, velocity and acceleration are depicted with respect to normalized cycle time in Figures 3 a, b, and c, respectively. Due to the large amount of data presented we have not included measures of variability in these figures. We have replotted the sagittal angular velocity and acceleration of the LBD patients in the 10 categories in Figure 4, hence making the separation among the groups clearer. This graphical representation is useful in explaining the results of discriminate analysis. There are certain distinct features separating some groups from each other, while other groups are indistinguishable from each other given the within group variability. To illustrate these points, we will provide a few examples and leave a more comprehensive biomechanical and clinical discussion to another communication. The angular position profiles separate into the following 5 grouping with the descending order in their sagittal flexion: Quebec 1 and HNP < 3; Quebec 2, HNP ≤ 3; Stenosis and Quebec 11; Non-organic and Quebec 3; and Quebec 9.2 and Spondylolisthesis. The logic in this grouping is clearly evident in the Stenosis group which exhibited the least lumbar lordosis and extension range. This finding correlates well with the clinical and biomechanical literature that reports extension as a symptom provoking maneuver that is often

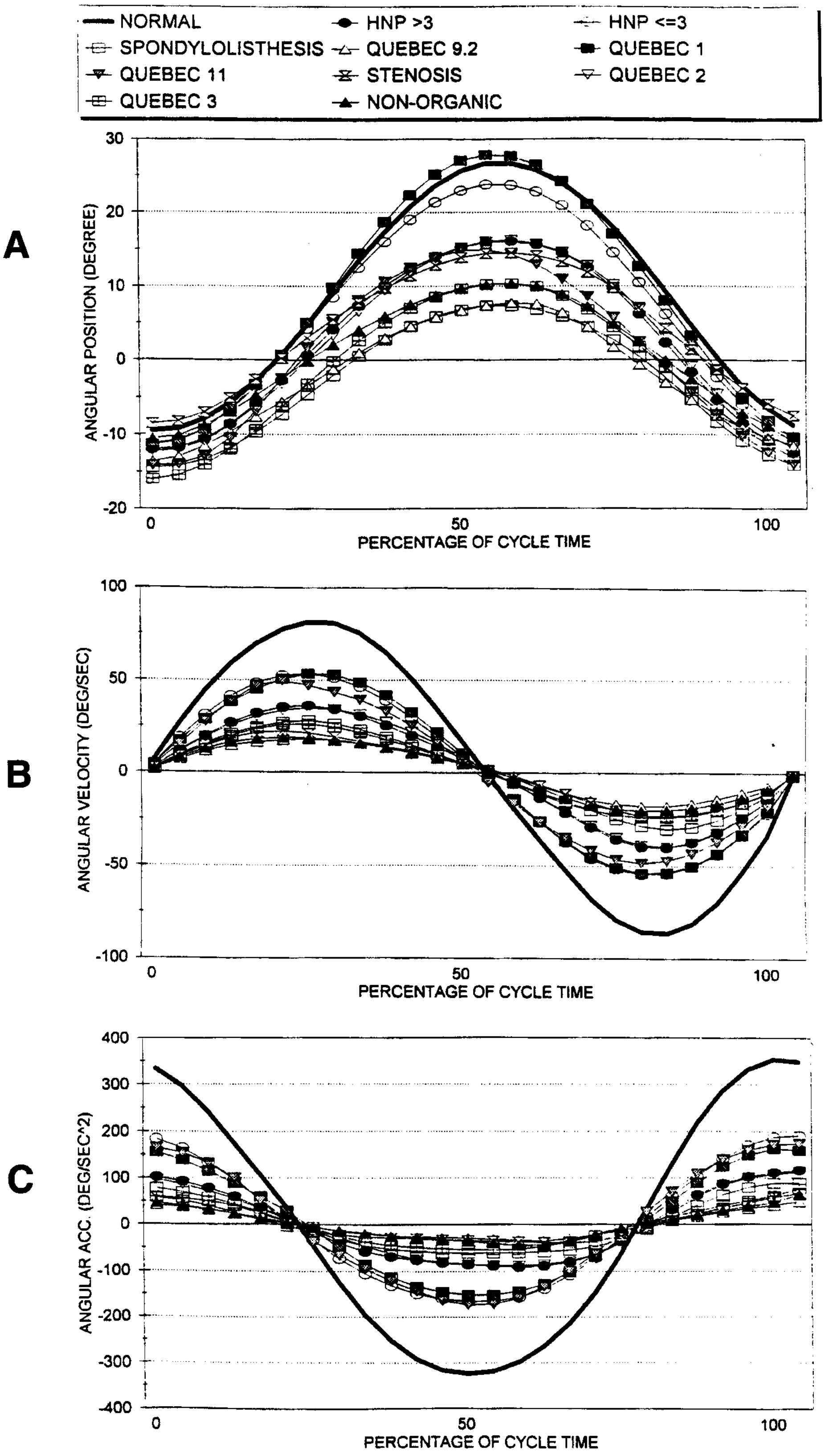

Fig. 3. The mean profiles of the sagittal angular position, velocity, and acceleration for the normal subjects and patients in the 10 LBD categories.

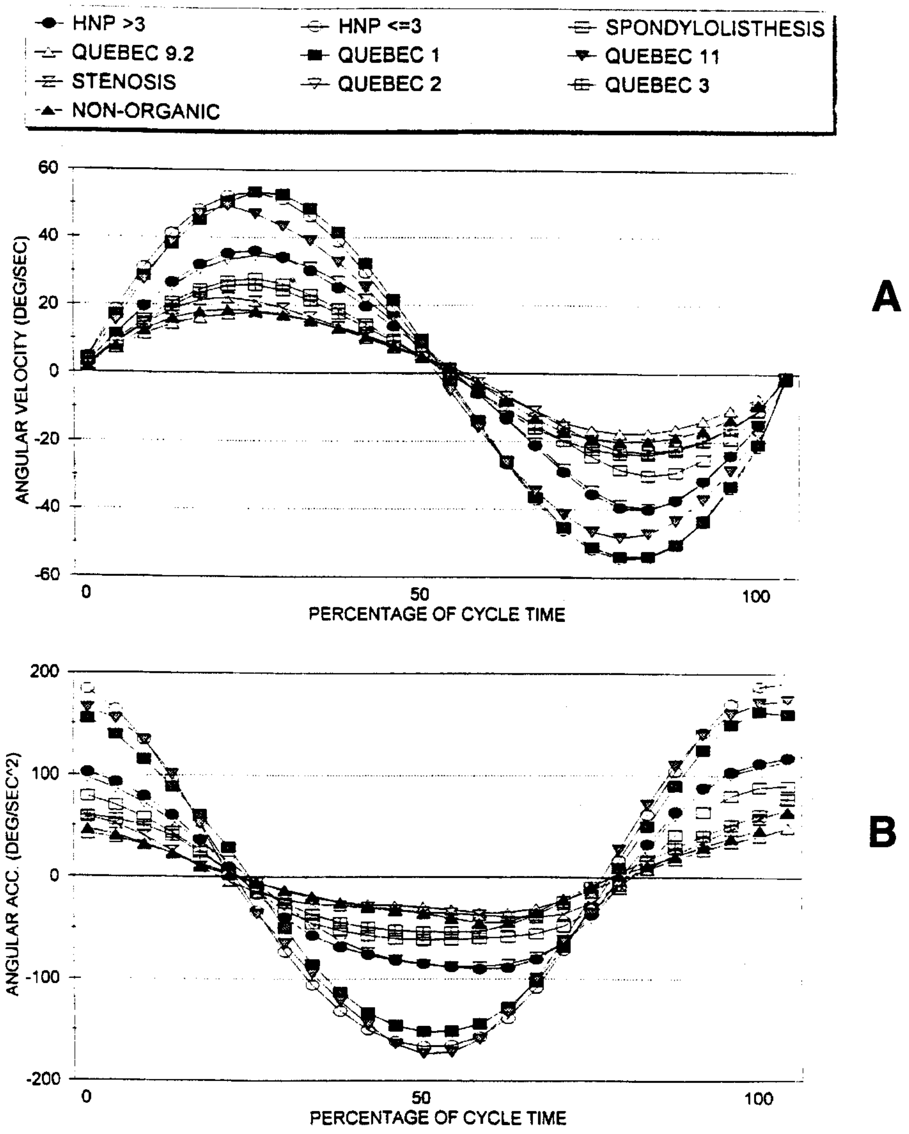

Fig. 4. The mean profiles of the sagittal angular position, velocity, and acceleration for the patients in the 10 LBD categories.

restricted in this group (51). Another example can be seen in the restricted sagittal flexion seen in the spondylolisthesis group. This limitation has also been reported in the literature (18,5 1). However, the large variability within the normal and LBDs makes this the least discriminating motion parameter.

The higher order derivative dynamic motion characteristics discriminated much better amongst the LBD groups. The following groupings listed in the descending order of peak angular velocity is evident: HNP < 3, Quebec 1 and Quebec 11; Quebec 2 and HNP > 3; Spondylolisthesis and Quebec 3; Stenosis; Non-organic and Quebec 9.2. A similar grouping emerges for sagittal angular acceleration. The quadratic discriminant function is the result of a multivariate analysis that considers the within group variances of all the 8 dependent parameters in the model. Hence, it is more rigorous than our visual univariate inspection of these plots. Nevertheless, the clinical insight and the visual feedback that these figures could provide cannot be overestimated. Figure 3 includes the normal motion profiles to the ones of the patient groups to provide a relative guide for goal setting in the rehabilitation phase, emphasizing the extent of functional deficit of each LBD category along each of the dimensions of performance.

We believe that the motion parameter changes associated with a LBD are related to biomechanical factors. It is crucial from a biomechanical stand point to determine the mechanisms of load transmission through the passive and active components of the spine. Finite element models as well as experimentally based models have made significant contributions towards the understanding of the load sharing of the passive tissues during the various activities of the trunk (51-54). Based on these rationales one can hypothesize that certain movements will load specific structures of the spine and this situation may result in injury (either by a single high load; or more likely by repetitive loading at much smaller magnitudes). The same framework has been used to predict the motion patterns that would avoid the pain of an injured or strained tissue, (i.e., the avoidance of rotation to the side that further pushes out the bulging of the disc).

We anticipated that various low back conditions would exhibit specific patterns of motion. The motion characteristic changes observed as a function of the LBD classification may reflect increased trunk guarding, an attempt to minimize impulse loading due to acceleration, or an altered control strategy which minimizes pain sensation. Particular pain patterns occur with particular musculoskeletal conditions throughout the body. We speculated that similar lumbar pain patterns, generally correlated with a similar set of painful lumbar structures, would show similar variations in motion due to similar losses of structural integrity, barriers to motion, motor weakness, or direction and rates of motion that are painful. Likewise, patients with strong psychological factors contributing to their pain expression might be expected to show much different motion patterns, with specific organic range of motion, velocity and acceleration patterns being probably difficult to learn, either at a conscious or subconscious level. The existence of the secondary gains or psychological overlay's have shown to influence the physical performance (8, 46, 55, 56, 57).

The overall results of the discrimination function analysis are encouraging and present a marked improvement over the previously available techniques. The model was constructed so that both motion characteristics as well as continuous motion parameters could capture the unique characteristics of the subject's movement as a function of the various asymmetries. When the model was used to identify normal vs. LBD subjects, as a group, it correctly classified 93.5% of normal subjects and 80% of LBD patients. When the model was used to classify the subjects into the **specific** LBD groups the model correctly classified the subjects over 80% of the time (Table 8). The model sensitivity for each category ranged from 16 to 100%, while the specificity varied from 88% to 99% (Table 9). The results of the discriminant function analysis are more optimistic because the same database was used to develop the model. Additional research is required to replicate the study and further validate the model.

The comparison of the results of this study with other studies in the literature is difficult due to differences in the patient categories. The most comprehensive model by *Waddell* et al. (40) that included total flexion, total extension, average lateral flexion, average straight leg raising (SLR), spinal tenderness, bilateral active SLR, and situp correctly classified 78% of the chronic LBP patients (n = 120) and asymptomatic normal (n = 70) subjects. The specificity and sensitivity of this model was 86% and 76%, respectively. The original 23 parameter candidates were reduced to the aforementioned 7 after a comprehensive analysis. However, no dynamic motion parameters were considered in the original list of candidate parameters. Our model does markedly better despite the large variability among our patient groups. This should encourage others to include dynamic motion characteristics in their clinical research and practice.

The discriminant function correctly identify 16% of painful herniated lumbar disks (HNP > 3). Even when painful, 10% demonstrated motion characteristics which classify as normal, however a majority demonstrated motion characterized as herniated lumbar disk (16%), spinal stenosis (40%), or proximal (16%) and distal (10%) radiation pain syndromes. This seems to demonstrate a marked heterogeneity of abnormal motion in herniated disk patients, with pain inhibition potentially occurring from various factors common to other lumbar conditions. The results of this study could also be interpreted that based on motion parameters, the behavioral performance of these groups are overlapping. Inspection of Figure 4, indicates the overlap in the motion characteristics of these groups.

Patients with LBP pain without radiation also frequently exhibited motion patterns similar to some other categories, particularly normal patients (37%), and those with proximal radicular pain (18%). Localized spinal pain patients also appeared similar to herniated disk patients in some cases, but were never classified as spinal stenosis, post-operative pain or non-organic patients.

Spinal stenosis patients exhibited very identifiable motion patterns. 77% could be correctly classified on the basis of the motion analysis. Some were classified as painful herniated disks and radicular pain syndromes, and 2 appeared with non-organic motion patterns.

Patients with continued post-operative pain (Quebec 9.2) were also readily identified by this analysis. In no case was either diagnosis misclassified as some other particular structural lesion. The Non-organic patient group had scored 3 or higher in the Waddel symptom magnification test. They represented only 17% of our patient population and were classified correctly 100% of the time by the model. Other patients occasionally classified as non-organic may represent failure of the model, or truly represent the predominant prevailing condition. There remains some subjectivity in the scoring of Waddell's signs, and patients evaluated after referral with a known structural diagnosis, may have been judged differently than those without such a diagnosis. Repeat evaluations with assessment of non-organic signs in a blinded fashion, or more uniform evaluation by MMPI, may decrease this incidence of misclassification. We are confident that the motion characteristics of the other patient classes are representative of the pathology since we isolated the symptom magnifiers into a distinct class.

Even though the ability of this procedure to correctly classify a LBD patient is less than perfect one must judge the classification potential of this technique relative to other tools used to classify patients. Chance would dictate that in this study 9% of the subjects should be correctly classified. Currently medical technology allows us to determine a pathoanatomic diagnosis in only 12% to 15% of individuals (58). Our least successful classification (HNP > 3) was in line with these traditional pathoanatomically based success rates. However, overall, our success rate was much better. On average, we were able to correctly classify subjects in over 80% of the cases. The functional motion assessment used in this study correctly categorizes almost all normal subjects. Therefore, the classification rates observed in this study can be considered a significant increase from previous methods such as anatomic classification where structural evidence of herniated disc is found in as many as 27% of healthy individuals (59).

Our classification success rate is also a function of the quality of our clinical data and the ability of current clinical techniques to correctly classify LBD patients. In other words, the motion measures may be more accurate a predictor than the techniques used to clinically classify subjects in this study. The motion characteristics used in this study are not to replace the existing methods of patient evaluation, taking good history and using other valid and reliable clinical tests, but to add to their discriminating power. It is hoped that these evaluation tools will be used to better reinvent the diagnostic categories, as the present categories reveal the considerable overlap amongst them based on motion characteristics.

Limitations

The presented evidence supporting the efficacy of trunk motions as a quantitative measure of disability is still in its infancy and requires more experimental research such as that presented here to evolve. One major complication, is the tremendous complexity of the spine. The large number of degrees of freedoms in the passive spine in addition to numerous muscles that span each motion segment allow the central nervous system numerous possible motions. Thus, both the kinematic and kinetic redundancies of the spine may limit the ability to correctly specify the insulted tissue via motion analysis. However, it can accurately quantify the functional trunk performance and functional deficit as compared to the normative database provided here (Table 5).

Several limitations must also be considered when evaluating the usefulness of this study. For example, it is unclear how well this motion based classification would work with patients from a typical practice that have not been prescreened for psychological factors. In addition, it is not known how well this motion based classification system would work with acute LBD patients. During the acute phase of LBP the symptom generation and the state of stress and strain in the anatomical tissues are much better related than in its chronic phase when illness behavior could become an issue. We would expect that it may work even better than with the chronic LBD patients used in this study because acute injury motion patterns would show less symptom magnification and less generalized trunk muscle deconditioning. We would hypothesize that this situation would increase the likelihood that the motion characteristics would be related to specific pain locations in the trunk. Recent imaging investigations (60-63) suggest that specific patterns of movement among the motion segments in the cervical and lumbar spine of the patients are present. However, at present there are no non-invasive techniques that would permit intersegmental motion to be analyzed triaxially during the dynamic complex (asymmetrical) conditions tested here. Therefore, although our motion variables are more global, reflecting mostly the lumbar motion, the correct classification over 80% suggests that it may also reflect partially the specific patterns distinguishing between LBDs. In addition, similar dynamic motion parameters were able to predict the risk associated with industrial jobs (32). We are presently merging these 2 databases to address the utilization of the ergonomics studies (quantification of the task demands) and clinical functional capacity evaluation.

Trunk motion and recovery

It is suggested that functional quantification of the patients is crucial to optimization of conservative treatment. Such quantification can sharpen the clinicians understanding of the functional deficits and help identify the appropriate dimensions of performance that need the greatest attention (i.e. a patient that is unable to perform the test in a 15-degree asymmetric condition, or has adequate range of motion but has only 50% of normative extension velocity). The functional deficits are time dependent and should be updated over the course of the rehabilitation. It must be realized that the strength and motion parameters are psychophysical measures and as such represent the patient's behavior in terms of what the patient is able to perform given the associated pain and/or disuse. The outcome of these performances will depend on pain-inhibition, fear-avoidance (40), psychological distress (64), and illness behavior (40, 65) in addition to physical or sensory disorder. Thus, dynamic motion characteristics may prove to be sensitive outcome measures in recovery of patients in a multidisciplinary rehabilitation program (46).

The present study has also collected preliminary observations on some LBD patients longitudinally through the course of the LBD so that we could explore the prognosis value of the dynamic parameters of motion. Figure 5 depicts the recovery trends of 13 LBD patients during 3 visits to their physician. The performance parameters of normalized sagittal ROM, extension velocity and accelerations are shown. 38% of patients had ROM within the normal range (above the threshold defined as the mean ± 1 SD) in the initial visit, while only 15% and 7% of patients had their velocity and acceleration within the normal range, respectively. We observed that patient recovery (whether due to surgery and/or conservative therapy) can be assessed by the improvement in the performance parameters during the second and third visit. For example, by the third visit 85% of the patients ROM had returned to the normal range, whereas, 77% and 69% of the velocity and acceleration measures, respectively, were within normal range by the third office visit. Thus, we observed that the rate of improvement can be characterized more via a return to a normal range of the dynamic pa-

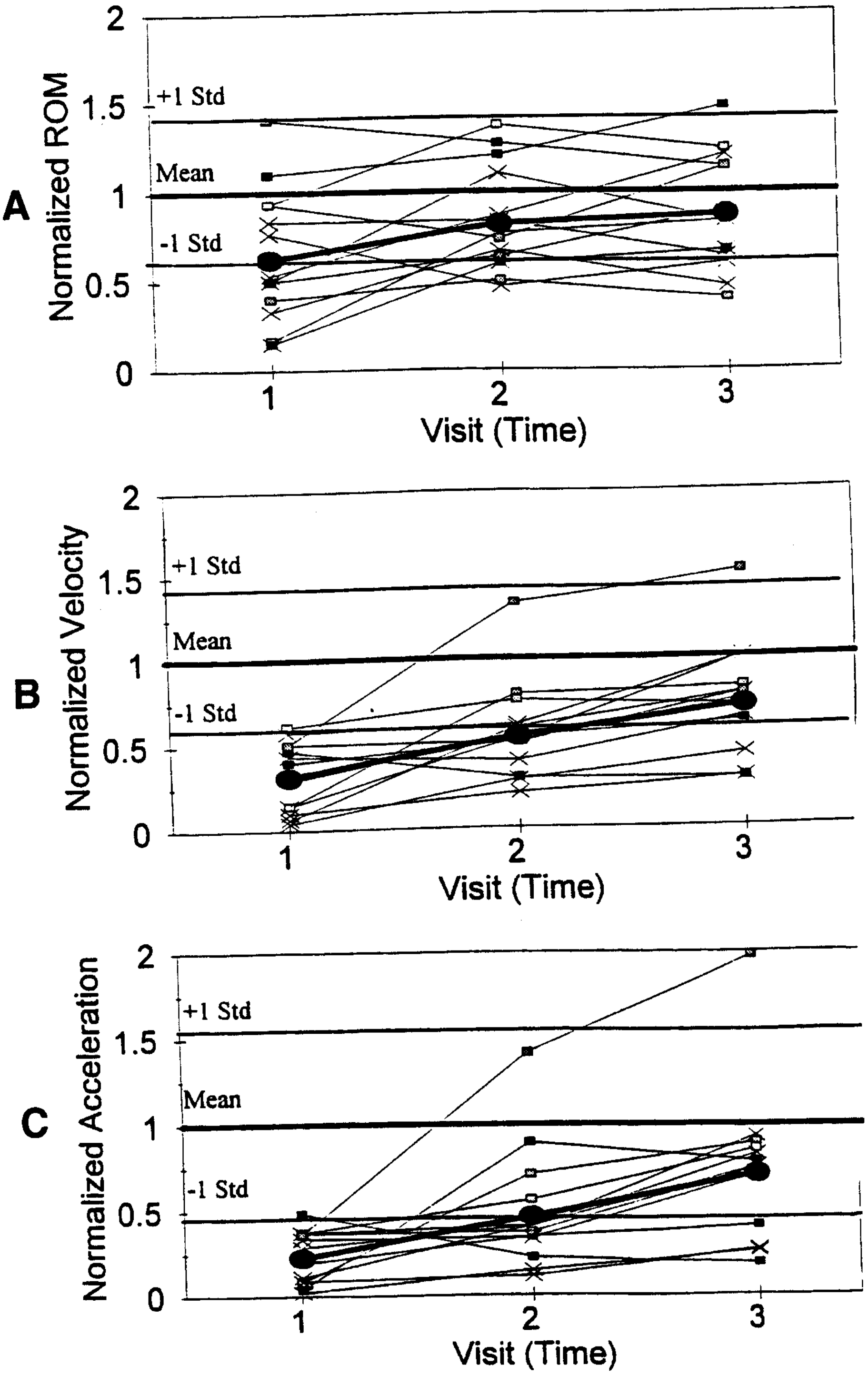

Fig. 5. Shows the improvement of 13 individuals and the mean (heavy dot and line) as a function of visits to the physician for A) the normalized sum of ROM, B) the normalized sum of velocity, and C) the normalized sum of acceleration.

rameters compared to ROM. The functional restoration may be a function of reduction in the inhibitory afferent and/or efferent signals that influence the control strategies of trunk movements. In addition, it can be argued that the dynamic parameters are more sensitive in portraying the changes in the functional state of LBD patients.

Conclusions

In the presence of limited resources, clinicians and policy makers must increase the quality of the health care delivery while maintaining the cost since the present rapid growth in health care cost can not be sustained. In the past decade the need for quantification of trunk performance was realized and the technological innovations introduced many novel instruments (8, 32, 66). The needs of the present decade will include quantification of the rehabilitation processes. *Mooney* (67) presented a historical account of the dose-response relationship of the therapeutic exercise in realization of the appeal for the "credibility". If health care costs are to be curtailed, clinicians must have sensitive and reliable tools so that they could scientifically and critically evaluate the activities of the multidisciplinary rehabilitation team and their patients. We envision that the task of LBD management will consist of several stages consisting of objectively measuring the present state of the trunk performance, making a diagnosis, quantifying the functional deficits, planning a definite goal (target), selecting the optimal proven effective treatment (conservative or surgical); prescribing a quantifiable dose of therapeutic exercise, and providing the biofeedback for positive reinforcement of progress and functional restoration with an operant conditioning behavioral approach (55, 68). The present study contributes toward the first 3 stages of the rehabilitation process, and future clinical studies should address their full integration.

The need for objective evaluation of trunk muscle performance has been universally accepted, since the current diagnostic technology cannot relate the experience of LBP to the impairment of specific spinal structures. However, reliable and quantifiable trunk performance measures has been a subject of intense research. The functional-based impairment evaluation schemes have traditionally used spinal mobility. Given the poor reliability of ROM, its large variability among individuals, and the static psychometric nature of ROM, the use of dynamic motion characteristics of motion with the higher order derivatives has been presented for documentation of the degree of a LBD. In addition, based upon these motion characteristics we were able to correctly classify over 80% of our 510 subjects into 1 of 11 classifications (normal plus 10 LBD groups). These motion related parameters may relate biomechanical sensitivities spinal loading. These results indicate that trunk motion characteristics hold great promise for the quantitative documentation and classification of LBDs. These motion parameters also hold promise for the quantification of recovery.

Acknowledgements

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Literature Review

Brief literature extracts

This section is a regular feature of our journal. Its aim is to report on studies in physical medicine and rehabilitation (PMR) which recently appeared in accepted journals which are not specialized in PMR. This is meant to be of service to those of our readers who have no regular access to medical libraries and thus might have missed what was printed in the N Engl J Med, Lancet, Ann Int Med, JAMA, Br Med J, etc.

We invite all our readers to contribute to these columns. All contributions should be short (max. 2 typed pages) and contain the main findings of the study followed by a brief comment on the importance, relevance, strength or shortcomings of the particular study.

Massage contra anxiety

The effects of back massage on anxiety levels of elderly residents in a long-term care institution were measured. 21 residents, 17 females and 4 males, participated in the study. Subjects were randomly assigned to 3 groups which received back massage with normal conversation, conversation only and no intervention respectively. The dependent variable, anxiety, was measured prior to back massage, immediately following, and 10 min later, on 4 consecutive evenings. The Spielberger Self-Evaluation Questionnaire (STAI), electromyographic recordings, systolic blood pressure, diastolic blood pressure (DBP) and heart rate were used as measures of anxiety. Analysis of variance was used to examine differences in group mean scores over the pre-test to post-test, post-test to delayed time interval, and pre-test to delayed time intervals, Scheffe comparisons being made where indicated. With the exception of mean DBP which showed no change from pre-test to post-test and HR which increased from post-test to delayed time interval, there was a statistically insignificant decrease in mean scores on all variables in the back massage group from pre-test to post-test and from post-test to delayed time interval, there was a statistically insignificant decrease in mean scores on all variables in the back massage group from pre-test to post-test and from post-test to delayed time interval. There was a statistically significant difference in the mean anxiety (STAI) score between the back massage group and the no intervention group. The difference between the back massage group and the conversation only group approached statistical significance. Verbal reports from subjects indicated that they perceived back massage as relaxing. Back massage may be an effective, non-invasive technique for promoting relaxation and improving communication with patients.

Fraser J, Ross Kerr J: Psychophysiological effects of back massage on elderly institutionalized patients. J Adv Nurs 1993;18:238-245.

Comment: Classical muscle massages firmly belong to the physical therapeutic repertoire in Europe but have little importance, for instance, in the US. One of the reasons for this discrepancy is the lack of hard data showing clinical benefit. Very few controlled clinical trials do exist that demonstrate that massages help in a given condition. Surprisingly perhaps it is the psychological aspect that has been studied most thoroughly in terms of controlled trials. The present study is but one of several such studies confirming the clinical impression that anxiety can be effectively reduced by massage therapy. The question arises whether this is a true massage effect or the "therapeutic touch". Results like this should, in my mind, stimulate all of us who prescribe massages for musculoskeletal problems to conduct similarly rigorous trials to prove that what we do is scientifically sound.

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