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Revised protocol for the kinematic assessment of impairment

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Abstract

BACKGROUND CONTEXT: Marras et al. developed a functional motion performance tool that accurately identified impaired low back motion performance, with sensitivity of 90% and specificity of 94%. However, the protocol required testing of five controlled tasks and was relatively time consuming.

PURPOSE: To determine whether a more time-efficient low back motion functional performance evaluation tool with acceptably high sensitivity and specificity could be developed.

STUDY DESIGN/SETTING: Low back functional motion (kinematic) performance evaluations were completed on two groups, consisting of controls (no history of back pain) and low back pain patients. A second low back pain population was also evaluated prospectively to assess recovery.

PATIENT SAMPLE: The study population consisted of 335 patients and 374 controls. Thirty acute low back pain patients were monitored prospectively.

OUTCOME MEASURES: Kinematic low back functional performance measures.

METHODS: Low back motion functional performance was measured using the lumbar motion monitor. A revised discriminant function model was developed using data from only one of the five original functional motion performance control tasks. Prospective study data were used to track differences in recovery time between the revised and original discriminant function models.

RESULTS: The revised model using functional motion performance from the controlled sagittally symmetric task had a sensitivity of 90% and specificity of 92%. When comparing the revised and original model results, the time to recovery was the same in 90% of cases.

CONCLUSIONS: The revised (more time efficient) testing procedure yielded high sensitivity and specificity.

Keywords: Low back pain; Dynamic functional performance assessment; Kinematic

Introduction

Despite decades of research on prevention and treatment, low back disorder is one of the fastest growing reasons for work loss and health-care visits [1]. The National Research Council [2] quantified the magnitude of the problem and indicated that there are 20 million physician visits annually for low back disorders. However, few tools are available to quantify the extent of functional loss resulting from a low back disorder.

Objective quantitative assessment of low back functional motion performance is a critical aspect of understanding low back disorders for several reasons. First, it may provide a quantitative measure of the severity of the disorder. In the absence of such a measure, we rely solely on the subjective interpretation of the patient's symptoms or health-care provider's impression of severity. Second, quantitative assessment provides a measure of improvement and in the case of a recurrence may serve as an indicator of relapse. Finally, a quantitative functional motion performance measure may provide a method for determining safe return to work.

The rising cost of health care has obviated the need for objective functional motion performance evaluations in order to quantify impairment. "Impairment is medically determined loss of structure or function of part of the body" [1]. The American Medical Association (AMA) [3] has published guidelines, but these are rather subjective for nonspecific low back pain. More recent guidelines use goniometers to measure ranges of motion. However, according to Waddell

FDA device/drug status: investigational/not approved (lumbar motion monitor).

Nothing of value received from a commercial entity related to this research.

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[1], these methods have little scientific basis. Spieler et al. [4] criticize the low back impairment guideline for focusing too much on structural rather than functional loss. Spieler [4] states that the guide fails to provide a comprehensive, valid, reliable, unbiased and evidence-based system for the rating of impairment. These criticisms of the current system suggest that the system is subjective and does not provide repeatable measures of impairment. Thus, a quantitative functional motion performance measure with good scientific basis may provide an objective rather than subjective assessment of impairment.

During the past decade, Marras et al. [5–8] have developed and validated a dynamic low back functional assessment technique. The complete testing protocol required the subject to flex and extend the trunk at five transverse plane-twisting positions. The theory underlying this protocol was that each task required the recruitment of a different set of muscles or different sequencing of muscle activation patterns. It was hypothesized that the healthy subjects would be using well-developed motor control programs, whereas low back pain patients would be constantly adjusting their motor control programs in order to avoid pain resulting from their injury. Theoretically, the motion profiles observed from the evaluation may provide a window into the trunk's musculoskeletal control program [5] or "central set" [9]. There is a theoretical basis for the five task protocols. However, it may require too much time to administer routinely.

The functional motion performance developed by Marras et al. [5–8] may be used as a screening tool to provide an objective continuous measure of dynamic functional impairment resulting from low back pain. According to Andersson [10] a screening tool should be valid and easy to administer. Validity is the tool's ability to accurately identify those with disease, in this case low back pain (sensitivity), and those without disease, in this case without low back pain (specificity). Thus, assessing the validity of the tool dichotomizes the measure. The value of the functional motion performance tool is its ability to objectively quantify the extent of impairment as well as functional recovery. The criticism of the current AMA guidelines by Spieler et al. [4] indicates a need to develop objective quantitative impairment measures that are valid. Thus, a continuous functional motion performance tool that objectively measures impairment would fill a void in the current impairment rating system.

The drawback of the Marras et al. [5–8] testing protocol is that it has five control tasks requiring approximately 30 minutes to administer, which might be impractical for routine use. Therefore, the goal of this investigation was to revise the original statistical model so that a more time-efficient testing protocol could be used yet maintain the high sensitivity and specificity (validity). The second goal was to evaluate the revised model sensitivity to recovery time as compared with the original model.

Methods

Approach

The functional motion performance results from the Marras et al. [5] protocol have been developed into two measures. First, a status measure (impaired or normal based on probability of normal) is used to assess the validity of the functional motion performance. The original model status measure has reported a sensitivity of 90% and specificity of 94% using discriminant function analysis [5]. The second measure is severity (extent of impairment) quantified by comparing the range of motion (ROM), velocity and acceleration for each of the five tasks to a normative database, as shown in Fig. 1. The severity chart shown in Fig. 1 provides a graphical illustration of the extent of impairment. The percentage of normal measure uses the current patient's performance data compared with a performance database of controls normalized for age and gender. A performance measure of 100% is equal to the average performance given that patient's age and gender group. The current study attempted to quantify both status and severity using data from only one functional control task. This would allow a 5- to 10-minute testing procedure that would be easier to administer than the original 30-minute testing procedure.

Previous studies have compared the functional motion performance results with symptoms and disability questionnaire results [11,12]. This is not the objective of the current study. The goal of the current study is to determine whether a more time-efficient protocol requiring only one functional control task yields valid results based on sensitivity and specificity.

Subjects

Two groups of subjects were recruited for the original study. First, 374 healthy subjects with no history of low back pain were recruited. Healthy subjects ranging in age from 20 to 70 years were used to compile a database with

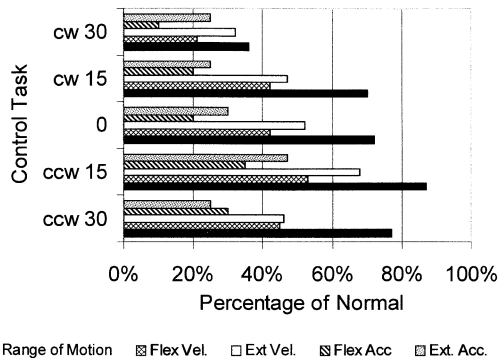

Fig. 1. Severity of impairment for each motion parameter at all control tasks. acc=acceleration; cw=clockwise; ccw=counterclockwise; ext=extension; flex=flexion; vel=velocity.

at least 25 men and women represented in each decade of age. The large number of controls allows the data to be normalized by age and gender. Second, low back pain patients were recruited from a secondary referral practice. A total of 335 low back pain patients were evaluated. The patients all had chronic low back pain (more than 6 months of symptoms) and were categorized into 1 of 10 symptom or diagnostic categories, as listed in Table 1. The symptoms categories are based on the Quebec Task Force study [13]. Approximately 10% of the patients were in each diagnostic category.

A second data set of 30 patients was collected and used as a comparative measure of recovery. These patients all had local low back pain symptoms and no radicular symptoms (Quebec task force category 1 [13]). These 30 patients were recruited during the first month of their symptoms and were evaluated every 2 weeks for 3 months. Thus, a total of six functional motion performance evaluations were completed. The status outcome measure will be assessed to validate the accuracy of "time to recovery" predictions between the two models.

Experimental design

The experimental protocol required subjects to flex and extend their trunk repeatedly in each of the five symmetric and asymmetric positions in the transverse plane while the motion components of the torso were measured. The method used to assess low back motion functional performance was the same as described by Marras et al. [5,6]. Trunk motion components included ROM, flexion and extension velocity and acceleration. The database contained over 700 controls and patients and was split into a training and test set. Discriminant function analysis was used to classify the two groups using two different classification models. The original 1999 model used subject data from all testing conditions. The revised 2002 model used data from the sagittally symmetric test condition.

Table 1
Low back disorder diagnostic categories

1. Local low back pain (Quebec task force category 1)
2. Local low back pain with proximal radicular pain (Quebec task force category 2)
3. Local low back pain with distal radicular pain (Quebec task force category 3)
4. Isthmic spondylolisthesis
5. Lumbar disc with herniated nucleus pulposus with minimal pain (3 or less on a 10-point visual analog scale)
6. Lumbar disc with herniated nucleus pulposus with pain (greater than 3 on a 10-point visual analog scale)
7. Spinal stenosis
8. Postoperative patients with pain (Quebec task force category 9.2)
9. Patients with nonorganic pain components
10. Other diagnoses, mainly idiopathic scoliosis

The prospective study group data of 30 patients was used to compare differences between the original "recovery time" model and the revised "recovery time" model. These 30 patients were observed six times during a 3-month recovery period. This evaluation of data will ensure that assessing only one functional task accurately quantifies functional motion performance recovery.

The lumbar motion monitor (LMM), a triaxial electrogoniometer, was used to quantify functional motion performance [14]. Fig. 2 shows the LMM, an instrumented exoskeleton of the spine, on a person. The LMM signal is collected at 60 Hz and transmitted to a laptop computer for storage and further analysis. The LMM has been validated quantifying position, velocity and acceleration in all three planes of the body [14].

The experimental protocol required subjects to flex and extend at maximum speed while maintaining the twisting position within a ±2-degree tolerance of the desired position. There were five transverse plane control positions, including 0 (symmetric), 15 degrees clockwise (cw) and counterclockwise (ccw), as well as 30 degrees cw and ccw. The twisting position signal from the LMM was displayed for the subject in order to provide visual feedback. The twisting signal was also sent to a comparator circuit to provide auditory feedback to the subject. If the subject went outside the twisting

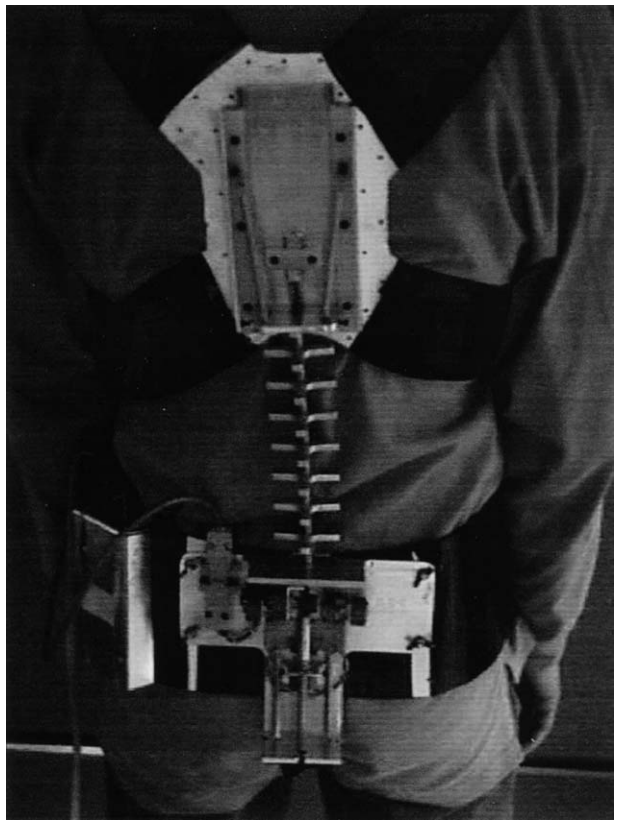

Fig. 2. Lumbar motion monitor on a participant.

boundary, an auditory signal would sound and the trial was repeated.

Procedure

Upon arrival, consent to participate was acquired with a document approved by the university internal review board. The appropriate size LMM was placed on the subject's back. Subjects were instructed to cross their arms in front of them, stand with their feet approximately shoulder width apart and flex and extend their trunk as fast as they could comfortably while maintaining the twisting position in the control zone on the display. If the twisting position moved outside the control zone, the trial was repeated. Patients were allowed to rest or stop the testing session at anytime.

Data analysis

Custom software was developed to convert the LMM signal into trunk position, velocity and acceleration. The flexion and extension velocity and acceleration were evaluated separately. ROM was calculated from the position data. The "percentage of normal" measures were calculated by comparing the data with a database of controls for that person's age and gender. Fig. 1 illustrates the "severity of impairment" expressed as "percentage of normal" measure for a typical patient. Two performance measures were derived. First, all 25 percentage of normal measures (ROM, flexion velocity, extension velocity, flexion acceleration, extension acceleration at each condition) were averaged into one combined score. Second, a cw/ccw difference measure was created with all 25 measures as well as the average cw/ccw differences.

Statistical analysis

Discriminant function analysis was used to calculate "probability of normal," determine classification error, sensitivity and specificity. The "probability of normal" is a continuous measure (0 to 1), indicating the low back status of the person. To validate the screening tool, specificity and sensitivity must be calculated, which requires dichotomizing the continuous measure. The default cutoff value in the Statistical Analysis System (SAS) is 0.5 for discriminant function procedures [15]. In this particular case, a probability of less than 0.5 indicates impaired low back status and a probability above 0.5 indicates normal low back status. The entire database of 709 subjects was randomly split into training and test data sets to best evaluate model results. The training set had 228 controls and 171 patients, and the test set had 146 controls and 164 patients. Once a revised model was chosen, the recovery data set of 30 subjects was analyzed with both discriminant function models to evaluate differences in time to recovery.

In order to evaluate the revised model, five "severity of impairment" measures were created: 1) average ROM severity, which was the average of five ROM percentage of normal scores, 2) the average velocity severity was an average of both the flexion and extension velocity percentage of normal scores for each task, 3) the average acceleration severity was also from both flexion and extension acceleration percentage of normal scores, 4) an overall average, which included 25 measures (ROM, velocity and acceleration), was calculated, and 5) an overall average that included differences between cw and ccw side was calculated. This overall average measure included the 25 measures in the previous average as well as 10 measures that used the absolute value of the difference between the cw and ccw side for ROM, velocity and acceleration. Five linear regression models were developed to predict the average performance of the five control tasks from the performance at the symmetric task. For these regression models, the log transformation of the data was taken, which is a standard statistical method [16].

Results

The functional motion performance screening tool provides an objective quantitative assessment of a patient's low back kinematic function. The probability of normal is a continuous measure. However, to validate the screening tool using sensitivity and specificity, the measure must be dichotomized, which provides more of a status measure.

Low back status

Table 2 lists the model variables for both the original (1999) and revised (simplified 2002) models. As indicated, the ability to perform the task and lateral ROM during the symmetric control task were removed from the model. Classification performance for the revised model was very similar to the original model (Table 3). This table lists the sensitivity, specificity and overall error for the training and test data sets for each model. The test set error rate in the original model was 7.9%, whereas it is 8.3% using the revised model. Sensitivity remained the same at 90%. However, specificity decreased from 94% to 92%. Thus, the revised model is slightly more likely to misclassify normal performance as impaired performance than the original model. The overall model

Table 2
List of variables in discriminant function model

Original 1999 model	Revised 2002 model
Ability to perform tasks	Twisting range
Twisting range	Sagittal ROM at zero
Sagittal ROM at zero	Sagittal extension velocity at zero
Sagittal extension velocity at zero	Sagittal extension acceleration at zero
Sagittal extension acceleration at zero	
Lateral ROM at zero	

ROM=range of motion.

Table 3
Control versus patient sensitivities, specificity and error rates by model

Data set	1999 model	2002 model
Training		
Sensitivity	83%	85%
Specificity	93%	90%
Error rate	0.1180	0.1190
Test		
Sensitivity	90%	90%
Specificity	94%	92%
Error rate	0.0790	0.0830

performance, sensitivity and specificity is excellent for the revised model and has the added benefit of requiring fewer tasks than the original protocol.

Recovery status

The 206 evaluations representing the recovery status data [11,12] were evaluated with the original (1999) model as well as the revised (2002) model. The average difference in the "probability of normal" between the two models was 0.089 with a standard deviation of 0.09. Using a standard 0.5 cutoff point [15], the revised and original models agreed on time to recovery in 90% of cases. In 7% of cases, the original model indicated the performance was impaired, whereas the revised model indicated the performance was normal or recovered. Thus, in 7% of cases, the revised model may indicate an injured person is recovered earlier than the original model. In 3% of cases, the revised model would indicate the patient remained injured when the original (1999) model would have indicated recovery.

Severity

The original protocol had a severity measure for each of the five tasks for ROM, flexion velocity, extension velocity, flexion acceleration and extension acceleration, as shown in Fig. 1. Regression models predicting the average severity of impairment were developed. Table 4 lists the average severity of impairment measure, model variables, parameter estimates, standard error, p-values and r^2 for each model. ROM had the lowest r^2 value with 0.81. The velocity and acceleration models both had r^2 values of 0.88. The grand average of all 25 measures had an r^2 of 0.86. Finally, the grand average that included cw/ccw difference had an r^2 of 0.83. These regression models illustrate that we can predict performance at all five control tasks with the data from one symmetric control task and twisting ROM.

Discussion

The revised discriminant function model requires data from only one flexion extension control task as well as a maximum twisting position from the cw and ccw sides. This combination of tasks would require 5 to 10 minutes or one-third the time of the original protocol yet maintains a high sensitivity and specificity. The 10-minute protocol could be used by practitioners on a routine basis to benchmark low back motion functional performance and quantify recovery. Given the need for quantitative low back disorder measures, this quick functional motion performance evaluation may be used as a preplacement screening tool for those employees who will be exposed to jobs that might place them at risk for low back disorder. In addition, it can be used by physicians to quantify and track the extent of a low back disorder as part of the patient's medical record.

The results of this study show that this functional motion performance evaluation has a sensitivity of 90% and specificity of 92%, indicating excellent diagnostic capability. The ability of the functional motion performance screening tool to correctly identify functional status provided a validation of the tool. This tool may provide an objective quantitative assessment of low back functional impairment, which may provide an answer to the criticisms of Spieler et al [4]. Cherniack et al. [17] showed that the probability of normal score was not significantly correlated to the Short Form (SF)-36 score but was a good indicator of the patient's history. Using a combination of objective and subjective screening tools may allow for greater understanding of the extent of an injury as well as the recovery process. The revised functional motion performance evaluation tool would provide a more time-efficient method for evaluating functional impairment and still glean the same information as the full evaluation.

The time to recovery evaluation showed that in 90% of cases the time to recovery index matched between the revised model and the original model. Thus, in quantifying impairment, the amount of time the patient would be impaired would be the same in 90% of cases. It is noteworthy that the patient population used had their functional motion performance evaluated every 2 weeks during the first 3 months of recovery and 1-month intervals from 3 to 6 months of recovery. Changing the evaluation intervals may influence the comparison of time to recovery between the two models.

The original protocol generated percentage of normal information for each task allowing researchers and practitioners to evaluate severity of impairment on both the cw and ccw sides. The regression model predicting the overall average severity as well as cw/ccw difference with the symmetric task data accounted for 83% of the variance. The revised protocol would not allow for the evaluation of cw/ccw differences. The tradeoff for speed of evaluation is that we could no longer evaluate cw/ccw differences. This tradeoff is favorable because the revised protocol is much more time efficient. The revised protocol may be used during early rehabilitation phases and the full five-task protocol may be used during later phases of rehabilitation.

Finally, functional motion performance evaluations including the evaluation using the LMM are useful only

Table 4
Regression model results predicting performance on all five control tasks from the symmetric control task

Average severity of impairment	Model variables	Parameter estimate	Standard error	p-values	r^2
ROM (average of five)	Intercept	−0.85	0.03	.0001	0.81
	Twisting range	1.09	0.04	.0001	
	Sagittal ROM at zero	0.51	0.05	.0001	
	Sagittal flexion velocity at zero	0.13	0.04	.0001	
Velocity (average of 10 measures)	Intercept	−0.91	0.03	.0001	0.88
	Twisting range	1.18	0.04	.0001	
	Sagittal ROM at zero	−0.38	0.05	.0001	
	Sagittal extension velocity at zero	1.01	0.04	.0001	
Acceleration (average of 10 measures)	Intercept	−0.963	0.04	.0001	0.88
	Twisting range	1.24	0.04	.0001	
	Sagittal extension acceleration at zero	0.83	0.02	.0001	
Grand average (all 25 measures)	Intercept	−0.88	0.03	.0001	0.86
	Twisting range	1.15	0.04	.0001	
	Sagittal extension velocity at zero	0.39	0.06	.0001	
	Sagittal extension acceleration at zero	0.21	0.05	.0001	
Grand average 2 (all 25 measures and 10 left right differences)	Intercept	−1.61	0.04	.0001	0.83
	Twisting range	1.42	0.05	.0001	
	Sagittal extension velocity at zero	0.31	0.07	.0001	
	Sagittal flexion acceleration at zero	0.27	0.06	.0001	

when the subject is performing the test with a sincere effort. Studies have been published quantifying the sincerity of effort during these dynamic functional assessments [18,19]. The studies indicate that the sincerity of effort should be used in conjunction with the functional motion performance outcome to quantify both function and sincerity to ensure high quality of functional motion performance information.

Impairment ratings should be based on objective criteria [4]. This functional motion performance evaluation is one of the few tools that may be used to objectively quantify low back functional impairment. However, this tool does not quantify disability, which is defined as "a loss in the capacity to engage in gainful employment" [20]. Future studies are needed to quantitatively assess not only impairment but also disability. These studies should evaluate functional motion performance of the person as well as functional demand of the job, in order to objectively quantify the amount of disability for a specific job.

Conclusions

1. The revised model has acceptably high sensitivity and specificity for classifying low back functional status as either impaired or normal similar to the original model (within 2%).
2. Prospective evaluation of patient recovery showed that the revised model agreed with the original model in 90% of cases.
3. The regression model using functional motion performance measures from the zero control task explained 83% of the variance from all five tasks.

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Thirty Years Ago in Spine

Based on a case report in 1912, the names of Klippel and Feil became associated with the syndrome of short neck, low hairline, restricted neck motion and anomalous cervical vertebrae [1]. In 1974, Hensinger, Lang and MacEwen reviewed the 30-year experience of 50 Klippel-Feil patients treated at the Alfred I. duPont Institute [2]. Their work documented that patients with this syndrome were at risk for scoliosis (30), urinary tract anomalies (15 of 45 studied), Sprengel deformity (21), hearing impairment (15), synkinesia (9) and congenital heart disease (7). They also noted that findings of the classic triad of short neck, low hairline and restricted cervical motion are not always present and may be subtle in their presentations. In 1984, Winter, Moe and Lonstein reported that their review of 1,215 patients with congenital kyphosis and scoliosis showed 298 of them (25%) to have segmentation defects of the cervical spine [3].

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