Quantifying passive resistance to motion in the straight-leg-raising test on asymptomatic subjects

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The clinician needs an objective way to measure limb motion in the straight-leg-raising test. A biomechanical algorithm was used to quantify resistance to motion in 15 asymptomatic subjects. Measurements from a pendulum electrogoniometer and hand-held load cell were used to calculate a moment representing passive resistance to motion. After three measurement trials, significant increases in range of motion (4.7%) and moment (8.4%) occurred. Then, an isometric contraction-relaxation of the hip extensors produced a highly significant increase in motion (8.8%) but decrease in moment (<14.3%). A third order polynomial fit of moment per angle stratified the sample into two groups according to their change in moment. Motion in group 1 increased 8.0%, and in group 2, 9.5%. However, group 1 had no change in moment whereas group 2 had a highly significant decrease in moment (22.9%). The measured change in resistance demonstrated that a simple biomechanical algorithm quantified properties in a clinical test that were not observed in range of motion alone.

(Key words: Musculoskeletal system, biomechanics, motion, hip joint)

The clinical practice of palpating joint motion to evaluate joint function[1] has been developed to detect pathologic, physiologic, and anatomic barriers.[2] In the straight-leg-raising test, the clinical assessment of motion restriction is used in the differential diagnosis of lumbar nerve root compression[3] and hamstring muscle length.[4,5] When short hamstring muscles are treated, however, the test should reveal an increase in motion and decrease in resistance to motion. In the clinical test, the observer's assessment of resistance in a complex motion is subjective. As a result, an objective biomechanical measure of limb motion is needed for diagnosis and evaluation of treatment.

Limb motion is passively resisted by segment weight and passive factors such as muscle length and ligament stiffness. Wright and Johns[6] demonstrated the use of a mechanical model for rheumatologic evaluation of joint function. A similar application of a mechanical model in manual medicine is the assessment of motion restrictions that may arise from muscle, ligament, or joint mechanisms.[7]

Biomechanical models have been used to evaluate passive resistance to joint motion in the laboratory.[8-11] That is, when a force is applied at the heel to rotate the straight leg at the hip joint, the rotation is resisted by (1) the weight of the leg and (2) soft tissues surrounding the hip joint. The most important soft tissues resisting this rotation are the hip extensors, that is, muscles and tendons. The

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This study was supported by a Biomedical Research Support Grant from the College of Osteopathic Medicine, Michigan State University.

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resistance to motion around the joint may be described by a mechanical moment, that is, a force at the heel multiplied by the distance from the point of force application at the heel to the center of rotation at the hip joint.

The purpose of the present investigation is to measure a mechanical change in the resistance to motion during straight-leg-raising. To produce this change in resistance, we used an isometric contraction-relaxation technique developed by Mitchell and coworkers.[12] Thus, a simple biomechanical algorithm to calculate resistance to motion has been applied to the straight-leg-raising test before and after a manual treatment of hip extensors.

Methods

Data are reported for 15 asymptomatic, volunteer subjects. All subjects were fully functional without any symptoms or disabilities despite some with musculoskeletal injuries within the past 10 years. All data in *Table 1* but leg length were obtained by the subjects' responses to a written questionnaire. Leg length was measured with an anthropometer as the distance from the most lateral projection of the greater trochanter to the heel.

Two observers collected the range-of-motion and resistance-to-motion data. They were blinded to measured results that were calculated and stored on a microcomputer during the leg-raising trials. The experimental protocol consisted of the following sets of trials:

- In trials 1 through 3, the observer (H.M.R.) measured range of motion and resistance to motion.
- In trials 4 through 6, the observer (M.C.B.) measured range of motion and isometric-contraction of hip extensors.
- In trials 7 through 9, the observer (H.M.R.) measured range of motion and resistance to motion.

All motion tests began with the relaxed, supine subject's hip in external rotation. This leg-lifting protocol differs from the standard straight-leg-raising test in which the hip is usually held in neutral rotation because the present study sought to obtain maximal relaxation of each subject. Consequently, the hip externally rotated as the leg was raised through the loose-packed position of the hip described by Walmsley.[13]

The right leg was raised at 0.15 to 0.20 radian/s until the contralateral leg was observed to move. A pendulum electrogoniometer,[14] calibrated to an accuracy of ±0.48 degree, was strapped to the thigh just proximal to the knee. The heel rested in a shallow plastic cup (5.7 cm diameter) attached to a 23-kg-capacity load cell. The operator held the load cell, calibrated to an accuracy of ±0.35 kg, in the hand raising the leg. All transducer output was sampled at 10 Hz, digitized[15] by an Apple II+ computer, and stored on floppy disk after each trial.

The force to raise the leg was measured perpendicularly to the leg's long axis. The algorithm for the resisting moment was developed from a biomechanical model of the leg (*Figure 1*) in static equilibrium and described in the following equation:

$$M_R = FL_1 - WL_2 \cos \Theta \qquad \text{(equation 1)}$$

where M_R is the moment representing the resistance to motion at the hip joint; F is the force that is applied at the heel; L_1 is the length of the leg (*Table 1*) from the hip joint to the heel; W is the weight of the leg; L_2 is the distance from the hip joint to the leg's center of gravity; and Θ is the angle between the leg and horizontal. The moment at the hip joint represents the passive resistance to motion of the resting leg at the beginning of the test. Thus, when $\Theta = 0$ degree, the moments at the center of gravity (WL_2) and at the heel (FL_1) are assumed to be equal.

The moment per angle relationship was modeled with the following third order polynomial by use of Microsoft CHART, version 3.0 (Microsoft Corp, Bellevue, Wash):

$$y = a_1x + a_2x^2 + a_3x^2 \qquad \text{(equation 2)}$$

The y-intercept was forced to 0. *Figure 2* illustrates the fit between raw data and model. The maximum moment in Newton-meters (N-m) at the endpoint of motion was calculated for all trials. The estimated moment in trial 7 was calculated with the polynomial at the angle of maximum moment in trial 3. Thus, the change in resistance to motion was computed at the same position of the leg in subsequent trials.

In trials 4 through 6, the location of the motion restriction and range of motion were measured by the clinician. The first isometric contraction began at the position of motion restriction. *Table 2* reports the positions of the isometric contractions normalized to the total range of motion. The duration of the contractions is given in seconds.

Three submaximal isometric contractions of the hip extensors were made during one movement of the leg. After each contraction, the subject was instructed to relax while the physician raised the leg to the next contraction position.

Results

The range of motion in straight-leg-raising was measured in six trials before treatment and three trials after treatment. Repeatability in the measurements was evaluated with a univariate repeated measures F test, and later comparisons between trials used a paired Student's t test with the level of significance at .05.[16]

The range of motion for the total sample increased significantly from trial 1 to trial 3 (*Table 3*). Trials 4 through 6 and 7 through 9 were statistically repeatable within each series. The range of motion in trial 3 did not differ significantly from the average of trials 4 through 6. As a result, trial 1 measured initial conditions, and trial 3 mea-

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Table 1
Anthropometry and Injury History of All Persons in the Sample

Subject No., sex, and age, y*	Leg length, cm†	Injury			Treatment	Time lapse since injury, y
		Location	Type	Cause		
Subject 1 M, 24.2	87.0	Head, chest, leg	Sprain, cuts bruises	Auto accident, fall, sports	Brace, sutures	5-10
Subject 2 M, 24.9	94.0	Back	Pulled muscle	Twisting	None	1-5
Subject 3 M, 36.4	92.0	Back, shoulder, knee	Torn ligament	Auto accident, sports	Medication, exercise	1-5 and >10
Subject 4 F, 20.9	83.0	Back	?	Weightlifting	Exercise, heat rest	<1
Subject 5 F, 24.5	91.0	Back, hand	Broken bone, sprain	Sports	Rest, cast	5-10
Subject 6 M, 23.6	97.0	No injury				
Subject 7 M, 18.3	90.0	Wrist, foot	Broken bone	Sports	Surgery, cast	1-5
Subject 8 M, 29.7	82.0	Head, arm	Broken bone	Work accident	Cast and surgery	5-10
Subject 9 M, 63.3	95.0	Back, leg	Sprain, pulled muscle	Fall	Manipulation	5-10
Subject 10 M, 60.0	92.0	Back	Sprain	Hiking, backpacking	Manipulation	>10
Subject 11 F, 22.6	86.0	Neck, back, elbow	Broken bone, sprain	Auto accident, fall	Manipulation, rest, cast	1-5
Subject 12 F, 24.5	84.0	Back, ankle, foot	Sprain, pulled muscle	Sports	Manipulation, rest, heat	5-10
Subject 13 M, 30.5	93.0	Neck, shoulder, hand, leg, knee, ankle, foot	Broken bone, sprain, pulled muscle, cuts, bruises, torn ligament	Sports (football)	Surgery, cast, physical therapy, manipulation, crutches, etc	1-15
Subject 14 F, 22.7	89.0	Leg	Broken bone	Fall	Cast	>10
Subject 15 M, 35.0	98.0	?	Broken bone	Skiing	Physical therapy, cast, heel lift	>10

*Average (± SD) = 30.7 (±13.5).
†Average (± SD) = 90.2 (±5.0).

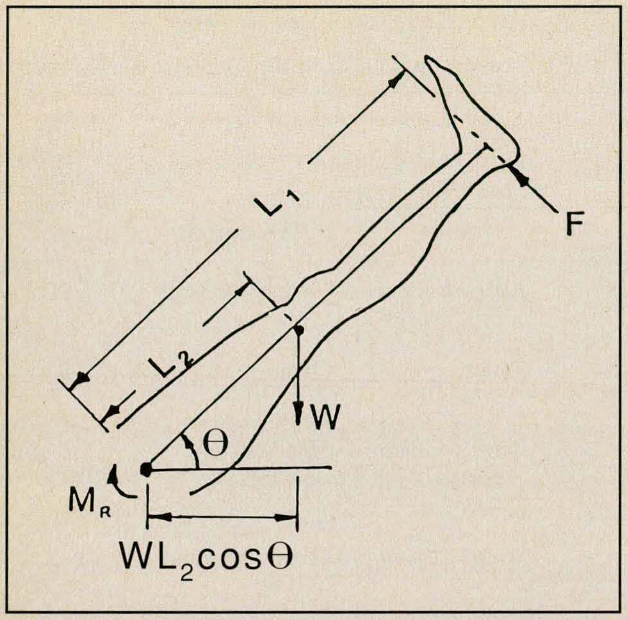

Figure 1. *Free body diagram illustrating biomechanical model described in equation 1.* M_R *= resistive moment about hip joint;* F *= force applied at heel;* L_1 *= distance from hip joint to heel;* W *= weight of leg;* L_2 *= distance between hip joint and leg's center of gravity, and* θ *= angle of leg to horizon.*

sured the effects of three consecutive straight-leg-raising trials.

Trial 7 measured the effects of the isometric contraction-relaxation treatment. The results are reported in *Table 3.* The maximum moment was measured in trial 3 at maximum range of motion. The moment estimated by the polynomial fit of the moment per angle results in trial 7 was calculated at the same leg position as the maximum moment in trial 3.

Multiple correlation coefficients of the polynomials had average values of 0.96 ($\pm$0.03) for trial 1, 0.96 ($\pm$0.02) for trial 3, and 0.96 ($\pm$0.01) for trial 7. These three trials had minimum correlation coefficients of 0.87, 0.88, and 0.91, respectively. These coefficients indicate that the polynomial fitting procedure was reliable.

In the total sample, multiple trials (1 through 3) produced significant increases in motion (4.7%) and maximum moments (8.4%). The isometric contraction-relaxation treatment between trial 3 and trial 7 produced a highly significant (P<.001) increase in motion (8.8%) with a small (4.0%) increase in maximum moments. However, the 14.3% decrease in the estimated moment in trial 7 was significantly different (P<.001) from the maximum moment in trial 3 at the same leg position.

The change in resistance from maximum moment in trial 3 to estimated moment in trial 7 stratified the sample into two groups according to the following criteria:

Group 1 (subjects 9 through 15 in *Table 1*) = trial 7 estimated moment + (2×SE of the prediction) ⩾ trial 3 maximum moment − (2×SE of the prediction).

Group 2 (subjects 1 through 8 in *Table 1*) = trial 7 estimated moment + (2×SE of the prediction) < trial 3 maximum moment − (2×SE of the prediction).

Group 1 had an 8.4% increase in maximum moments from trial 1 to trial 3 and a 6.5% increase in motion. The 8.0% increase in motion following the isometric contrac-

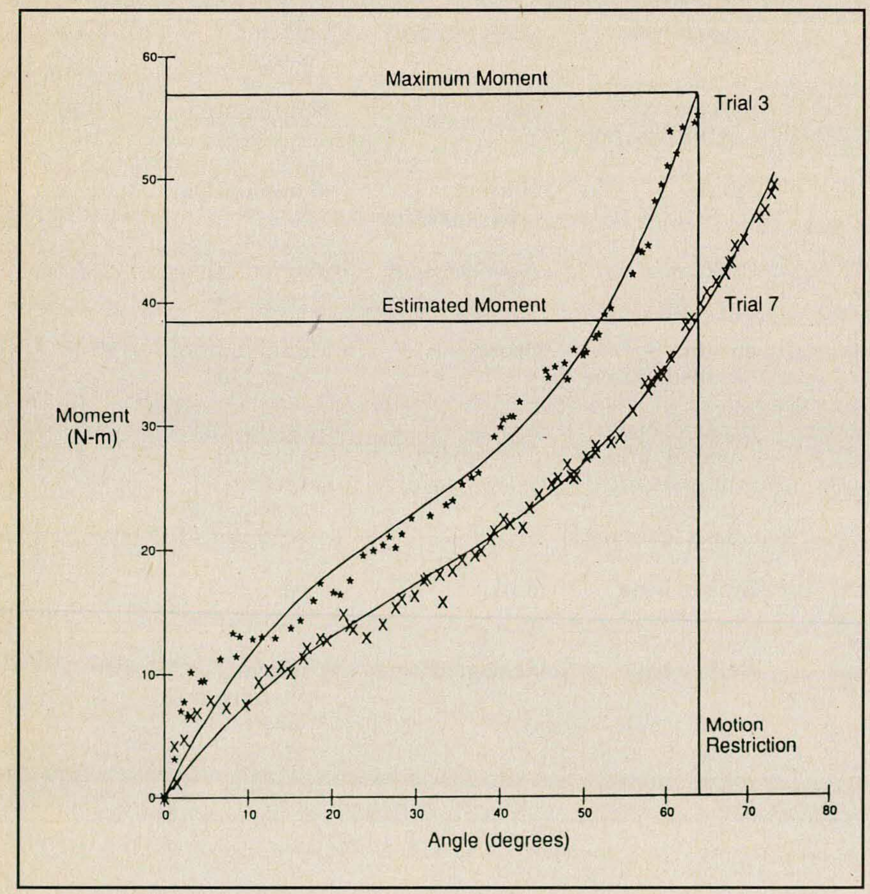

Figure 2. *Example of raw data fit by third order polynomial to show definition of maximum and estimated moments at the motion restriction.*

tion, was accompanied by a 13.7% increase in maximum moment ($P=.059$). However, when the estimated moment in trial 7 was compared with the maximum moment in trial 3, there was a small decrease of 3.8% in the moments.

Group 2, on the contrary, did not significantly change motion or maximum moment from trial 1 to trial 3. The isometric contraction significantly ($P<.001$) increased motion (9.5%) and slightly decreased the maximum moment (2.8%). However, the 22.9% decrease in trial 3 maximum moment to trial 7 estimated moment was highly significant ($P<.001$).

Table 2
Relative Angular Position and Length of Time for Three Isometric Contractions of the Manual Medicine Treatment

Treatment sequence	Features of isometric contractions: Relative position (ratio to range of motion)		Contraction time, s	
	Average	SD	Average	SD
First	0.85	±0.09	3.73	±0.57
Second	1.00	±0.07	3.31	±0.88
Third	1.16	±0.10	2.53	±0.60

Discussion

Motion restrictions are described by the endpoint to motion that is defined by either the patient or clinician. In the former case, the endpoint to motion is identified by a painful response of the patient. When the clinician identifies the endpoint to motion, palpatory characteristics of pelvic motion or an increased resistance to leg motion are used by the clinician. For the latter case, a biomechanical algorithm was developed[17] to quantify the resistance to motion at the hip joint during passive straight-leg-raising. This algorithm has been used to measure the change in resistance produced by an isometric contraction-relaxation[12] of the hip extensors.

In general, resistance to motion increases nonlinearly with increasing leg angle. Wright and Johns,[6] Yoon and Mansour,[8] and Vrahas and coauthors[9] concluded that passive connective tissues resist motion slightly in the range of daily activities and contribute a much higher resistance at the endpoints of motion. Fisk,[10] however, found a decrease in the resisting moment at approximately 45-degree leg elevation. Resistance continually increases because the weight of the pelvis is added as the leg is raised.[18,19] In 1991, Göeken and Hof[11] observed an increase in electrical activity of thigh and back muscles as well as a reduction in lordosis during straight-leg-raising. Thus, movements in the pelvis and low back are coupled with leg motion to continually increase resistance to motion.

Table 3
Average Range of Motion, Maximum Moment, and Estimated Moment of the Leg Lift

	Total (N=15)		Group 1* (N=7)		Group 2* (N=8)	
	Average	SD	Average	SD	Average	SD
• Trial 1						
Range of motion, degrees	76.0	±15.3	69.7	±10.9	81.6†	±17.0
Maximum moment, N-m	41.89	± 8.11	36.59	± 7.69	46.53	± 5.30
• Trial 3						
Range of motion, degrees	79.6†	±15.3	74.2	±14.1	84.3†	±15.5
Maximum moment, N-m	45.39†	± 7.61	39.65	± 5.09	50.42	± 5.62
• Trial 7						
Range of motion, degrees	86.6‡	±16.8	80.1†	±15.2	92.3‡	±16.8
Maximum moment, N-m	47.19	± 8.53	45.09	± 9.90	49.04	± 7.30
Estimated moment, N-m	39.72‡	± 5.51	38.21	± 6.22	41.04‡	± 4.83

*Grouping based on change in resistance from maximum moment in trial 1 to estimated moment in trial 3.
†$P > .05$.
‡$P < .001$.

Repeatedly measuring the range of leg motion for three trials produced a preconditioning effect[20] that remained constant during the subsequent three clinical trials. The preconditioning effect was an increase in range of motion. Connective tissues retain a memory of past activity (including injury and trauma), which in studies of the mechanical response of connective tissue to cyclical loading is referred to as preconditioning. In this instance, preconditioning in trials 1 and 3 did not reduce resistance to motion accompanying the increase in range of motion.

In trial 7, after the isometric contraction-relaxation of the hip extensors, leg motion and the resistance to motion increased from those in trial 3 at the maximum range of motion. When resistance to motion was compared at the same angular position of the leg in trials 3 and 7, the total sample showed a significant decrease in resistance. In the analysis, however, two groups of responses emerged from the data. Group 1 increased range of motion without a corresponding change in resistance to motion following the treatment. Group 2, however, increased range of motion with a corresponding decrease in resistance to motion. The decrease in resistance to motion in Group 2 after treatment was proportionately equal to the resistance measured in Group 1 immediately before and after treatment. Thus, the change in resistance in Group 2 produced a mechanical response at the hip joint that overall is similar to the response observed in Group 1.

The change following the isometric contraction-relaxation procedure may be explained by either a neuromuscular response or a mechanical change in the motion properties of the passive connective tissues surrounding the hip joint. In the former case, the hypothesis of Mitchell and associates[12] that isometric contractions modify the feedback loop through reciprocal innervation may explain the decrease in resistance. Or, the change may be explained by a mechanical change in the passive connective tissues that are structurally in series with the contracting muscles. In either case, the mechanism is not clear, but the resulting consequence of reducing the resistance has functional significance. That is, if the force required to move the leg is reduced by the isometric contraction-relaxation, a corresponding reduction in the energy needed to move the limb also occurs. Thus, the physiologic effect is an improvement in mechanical function at the hip joint that is more energy-efficient for motor activities.

Conclusion

The present study measured the mechanical response of soft tissues to an isometric contraction-relaxation treatment of the hip extensors. The biomechanical algorithm quantified properties of motion restriction that were not observed in range of motion alone. Thus, the clinical significance of resistance to motion and physiologic mechanisms causing changes in such resistance during straight-leg-raising may be investigated with a simple model.

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