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Abstract

The purpose of this study was to evaluate the reliability and variability of repeated measurements of isometric (IM) lumbar extension (LB EXT) strength made at different joint angles. Fifty-six men (age, 29.4 ± 10.7 years) and 80 women (age, 24.3 ± 9.1) completed IM LB EXT strength tests on 3 separate days (D1, D2, and D3). On D1 and D2, subjects completed two tests (T1 and T2) separated by a 20- to 30-minute rest interval. For each test, IM LB EXT strength was measured at 72, 60, 48, 36, 24, 12, and 0 degrees of lumbar extension. Mean IM strength values, within-day reliability coefficients, and test variability over the seven angles improved from D1 to D2 (D1: mean, 160.0 to 304.1 N · m, $r = 0.78$ to 0.96, SEE = 37.6 to 46.9 N · m; D2: mean, 176.3 to 329.1 N · m, $r = 0.94$ to 0.98, SEE = 29.0 to 34.4. N · m). The most reliable test results showed that the IM LB EXT strength curves were linear and descending from flexion to extension and ranged from 235.8 ± 85.2 to 464.9 ± 150.7 N · m for men (extension to flexion) and from 134.6 ± 53.2 to 237.3 ± 71.9 N · m for women. Lumbar extension strength was clearly greatest in full flexion, which is in contrast to previously reported results. One practice test was required to attain the most accurate and reliable results. These data indicate that repeated measures of IM LB EXT strength are highly reliable and can be used for the quantification of IM LB EXT strength through a range of motion. (Key words: lumbar extension, isometric strength, liability, variability)

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The purpose of this study was to evaluate the reliability and variability of repeated measurements of isometric (IM) lumbar extension (LB EXT) strength made at different joint angles. Fifty-six men (age, 29.4 ± 10.7 years) and 80 women (age, 24.3 ± 9.1 years) completed IM LB EXT strength tests on 3 separate days (D1, D2, and D3). On D1 and D2, subjects completed two tests (T1 and T2) separated by a 20- to 30-minute rest interval. For each test, IM LB EXT strength was measured at 72, 60, 48, 36, 24, 12, and 0° of lumbar extension. Mean IM strength values, within-day reliability coefficients, and test variability over the seven angles improved from D1 to D2 (D1: mean, 160.0 to 304.1 N · m, $r = 0.78$ to 0.96, SEE = 37.6 to 46.9 N · m; D2: mean, 176.3 to 329.1 N · m, $r = 0.94$ to 0.98, SEE = 29.0 to 34.4 N · m). Mean strength values leveled off by D3 (174.5 to 317.0 N · m). The most reliable test results showed that the IM LB EXT strength curves were linear and descending from flexion to extension and ranged from 235.8 ± 85.2 to 464.9 ± 150.7 N · m for men (extension to flexion) and from 134.6 ± 53.2 to 237.3 ± 71.9 N · m for women. Lumbar extension strength was clearly greatest in full flexion, which is in contrast to previously reported results. One practice test was required to attain the most accurate and reliable results. These data indicate that repeated measures of IM LB EXT strength are highly reliable and can be used for the quantification of IM LB EXT strength through a range of motion. [Key words: lumbar extension, isometric strength, reliability, variability]

LOW-BACK PAIN (LBP) is one of the most common and costly medical problems in modern industrialized societies. It has been estimated that eight of ten people will experience LBP sometime in their lives,[6] with aggregate annual costs of over 50 billion dollars.[3] Many lumbar problems are muscular in origin,[13] and patients suffering from LBP often have weak lumbar muscles.[12,18] Consequently, physicians, physical and occupational therapists, and exercise physiologists have taken great interest in programs to develop and maintain lumbar strength in LBP patients. The development and maintenance of lumbar strength also may play a vital role in protecting the spine from stress and may help prevent LBP.[18]

The importance of strengthening the lumbar area to prevent and rehabilitate LBP necessitates the development of a reliable and accurate test for lumbar strength to evaluate the effectiveness of training techniques. Accurate and reliable testing also is required for screening individuals with weak lumbar muscles who may be predisposed to lumbar problems. Accurate assessment of lumbar strength requires 1) stabilization of the pelvis to isolate the lumbar extensor muscles and minimize the contribution from the hip and leg muscles, 2) measurement through a range-of-motion (ROM), and 3) standardization of the testing position and correction for the influence of gravitational forces (body weight) during testing.[5]

If the pelvis is free to move during lumbar extension, the pelvis will rotate as the hamstring, gluteal, and adductor muscles contract.[2] The effect of pelvic rotation during lumbar testing was observed as early as 1942 by Mayer and Greenberg,[11] who noted that leg and buttock muscles could contribute significantly to lumbar extension strength measures. More recently, Smidt et al[17] demonstrated the importance of stabilizing the pelvis and lower extremities to eliminate pelvic movement and isolate the lumbar area during lumbar testing. Unfortunately, clinical assessment of lumbar strength often fails to isolate the lumbar area before lumbar extension strength testing.

Because of acceleration at the beginning and deceleration at the end of the movement, and the fact that dynamic strength is influenced by the speed of movement,[15] dynamic strength tests are not appropriate for the quantification of strength through a ROM. Weakness in a specific area of lumbar extension may go undetected using a dynamic test if the weakness is at the beginning or end of the ROM. Also, if dynamic movement is done at fast speed (>120°/sec), kinetic forces may be recorded that give an inaccurate measure of true strength and influence the shape of the strength curve.[1,14] Isometric strength tests can accurately quantify strength through a ROM if multiple joint angles are measured.[4,9] Few investigations, however, have measured isometric lumbar extension strength at more than one joint angle. Exceptions are Smidt et al[17] and Marras et al,[10] who examined lumbar strength at four angles and three angles, respectively. Thus, accurate and reliable data on lumbar extension strength through a ROM are limited.

During lumbar extension strength testing in a standing or sitting position, gravitational forces on the torso can influence the measurement. Although there is some controversy concerning the need for correction of the influence of gravitational forces during testing, because most bodily activities are not "corrected" for gravity, the actual force generated by the lumbar muscles in the sitting and standing positions is influenced by the mass of the torso. Thus, although one can not neglect the fact that in normal daily activities the lumbar muscles are influenced by torso mass, standardization of the testing position and correction for gravitational forces on the torso mass are required for accurate quantification of lumbar extension strength.

The purpose of the present study was to evaluate the reliability and variability of a specific multiposition test protocol to quantify isometric lumbar extension strength through a 72° ROM. The testing protocol involved isolation of the lumbar musculature through pelvic stabilization and correction for gravitational forces on the torso. An additional

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Table 1. Characteristics of the Subjects (n = 136)

	Men (n = 56)		Women (n = 80)	
Variable	Mean ± SD	Range	Mean ± SD	Range
Age (yr)	29.4 ± 10.7	18-58	24.3 ± 9.1*	17-52
Height (cm)	178.0 ± 6.7	166.2-193.8	165.6 ± 8.1*	152.0-185.5
Weight (kg)	77.9 ± 11.2	57.0-102.5	60.8 ± 9.6*	42.2-84.9

*$P \leq 0.01$ between men and women.

purpose of the study was to describe isometric lumbar extension strength through a 72° ROM for a sample of healthy men and women.

METHODS

Subjects. One hundred thirty-six subjects (56 men, 80 women) participated in this study. Characteristics of the subjects are presented in Table 1. All subjects were healthy and had no orthopedic problems or other medical conditions that would contraindicate lumbar extension exercise. Documented informed consent was obtained from each subject.

Procedures. The subjects reported to the laboratory for testing on 3 separate days (D1, D2, and D3). These test days were separated by at least 72 hours to allow the subjects time to recover from any residual fatigue or soreness that might have been associated with the testing. On D1 and D2, subjects completed two isometric lumbar extension strength tests (T1 and T2). Tests T1 and T2 were separated by a 20- to 30-minute rest interval. On D3, subjects completed only the T1 part of the isometric lumbar extension strength test. During each test, maximum voluntary isometric lumbar extension strength was measured in the sitting position through a 72° arc of lumbar motion (at 72, 60, 48, 36, 24, 12, and 0° of trunk flexion) with a MedX (Ocala, FL) lumbar extension machine. The movement arm of this testing device is attached to a load cell that is interfaced to an IBM microcomputer.

The subjects were seated in the lumbar extension machine (Figure 1), and their knees were positioned so that the thighs were parallel to the seat. A lap belt (thigh restraint) was secured in place over the top of the thighs, just below the waist. This thigh restraint was tightened to prevent any vertical movement of the thighs or pelvis. Two pads (femur restraints) mounted on an adjustable crank then were placed against the anterior side of the tibia just below the tibial tuberosity. The femur restraints were cranked forward to drive the femurs up and back toward the pelvis. With the thigh restraint acting as a fulcrum as the femurs were pushed up and back, the pelvis was forced back and against a specially designed lumbar pad (pelvic restraint). In this manner the femurs were used to anchor the pelvis against the pelvic restraint for stabilization. A headrest was adjusted to the level of the occipital bone for comfort, support, and positional standardization. Standardized positioning of the arms was achieved by two handle bars attached to and extending 43 cm from the movement arm. Subjects were instructed to maintain a light grasp on the handles during the positioning and testing procedures.

After the pelvis was stabilized and the testing position standardized, the subjects were moved into a neutral, upright posture (18 to 36° of flexion) to establish the center-line of their torso mass (torso, head, and arms). A counterweight was locked into place at this position and the subject was moved to 0° of lumbar flexion (full extension). The counterweight was adjusted while the subject rested against the upper back pad (movement arm of machine) at 0° of lumbar flexion to neutralize the gravitational force on the head, torso, and upper extremities. Subjects then were checked for any limitations in their range of lumbar motion between 0 and 72° of flexion.

To begin each test, the movement arm was locked into place at 72° of flexion and the subjects were instructed to extend their back against the upper back pad by gradually building tension over a 2- to 3-second period. Isometric torque generated was displayed to the subjects as concurrent visual feedback on a video display terminal. Once maximal tension had been achieved, the subjects were instructed to maintain the contraction for an additional 1 second before relaxing. After each isometric contraction, a 10-second rest period was provided while the next testing angle was set. To insure pelvic stabilization, the femur and thigh restraints were tightened if lumbar-pelvic movement was noted during the test. This was easily checked by noticing any rotation of the pelvic restraint.

Data Analysis. Maximal voluntary isometric torque was measured in Newton meters (N · m). Descriptive statistics (means and standard deviations) were calculated for each angle of each test. A reliability analysis of the isometric lumbar extension strength measures was completed by calculating the 1) mean difference, 2) Pearson product-moment correlation coefficient (r), 3) standard error of the estimate (SEE), and 4) total error (E) at each angle for various combinations of tests completed on D1 through D3. The significance of the calculated mean differences was evaluated using paired t tests. Standard error of the estimate and E were calculated using the following formulas:

$$\mathrm{SEE} = \mathrm{Sy}_{12}\sqrt{1 - r^2}$$

$$\mathrm{E} = \sqrt{\Sigma\,(\mathrm{y}_1 - \mathrm{y}_2)2/\mathrm{N}}$$

$$\text{Where } \mathrm{Sy}_{12} = \text{pooled deviation of } \mathrm{Y}_1 \text{ and } \mathrm{Y}_2\ (\mathrm{Sy}_{12} = \sqrt{(\mathrm{Sy}_1{}^2 + \mathrm{Sy}_2{}^2)/2}).$$

Tests were compared using analysis of variance (ANOVA) with repeated measures. Post-hoc tests were completed when appropriate using single degree of freedom contrasts. A lumbar extension strength

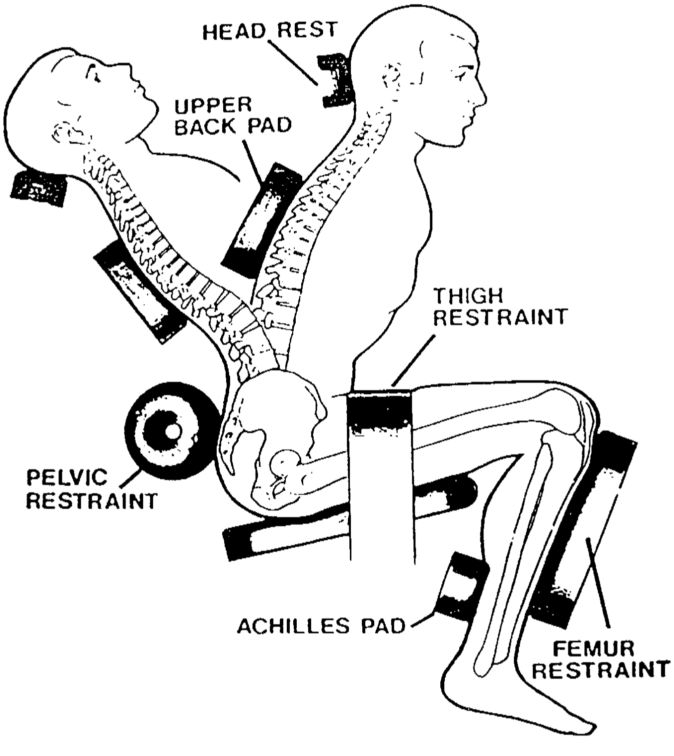

Fig 1. Restraining mechanisms of the MedX lumbar extension machine.

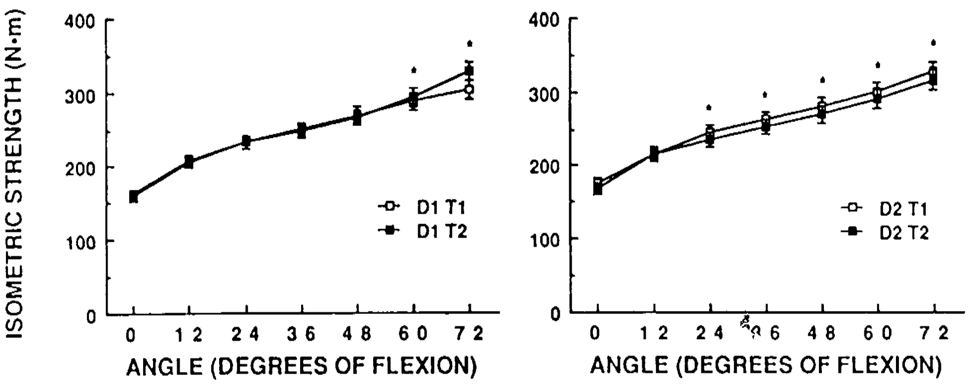

Fig 2. Isometric strength measures for tests completed on day 1 and day 2 (N = 136). D1 T1 = day 1 test 1; D1 T2 = day 1 test 2; D2 T1 = day 2 test 1; D2 T2 = day 2 test 2. $^*P \leq 0.05$.

curve was developed for men and women using the mean values of the most reliable test. A repeated measures ANOVA was used to compare the strength curves between males and females. All statistical computations were performed using the SAS[16] statistical package. An alpha level of $P < 0.05$ was required for statistical significance.

RESULTS

Intra-Day Analysis

Isometric torque noted at each angle of measurement for T1 and T2 completed on D1 and D2 are presented in Figure 2. On D1, observed torques were significantly greater ($P \leq 0.05$) during T2 at 72 and 60° of lumbar flexion. On D2, T1 torques were significantly greater ($p \leq 0.05$) than those noted for T2 at 72, 60, 48, 36, and 24° of flexion.

Correlation coefficients, SEEs and Es for T1 and T2 on D1 and D2 are presented in Table 2. On D1, correlations ranged from $r = 0.78$ to $r = 0.96$ going from 0° flexion to 72° flexion. On D2, correlation coefficients from 0° to 72° of flexion ranged from $r = 0.94$ to $r = 0.98$. Standard errors of estimate between T1 and T2 on D1, ranged from 37.6 to 46.9 N · m. On D2, SEEs were considerably less, ranging from 28.7 to 34.4 N · m. Total error values between T1 and T2 on both D1 and D2 were similar to values noted for the SEEs.

Interday Analysis

Isometric torque values for T1 completed on D1, D2, and D3 are presented in Figure 3. Seventeen subjects did not complete the D3 test and, therefore, data were analyzed on a sample of n = 119. At each angle of measurement, torques were significantly greater ($p < 0.05$) on D2 and D3 when compared with D1. When D2 torques were compared with D3, torque values were similar except at 12° flexion. At 12° of flexion, the observed torque on D3 was significantly greater ($p < 0.05$) than that of D2.

Correlation coefficients, SEEs, and Es between D1 T1, D2 T1, and D3 T1 are presented in Table 3. Correlation coefficients between D1 T1 and D2 T1 ranged from $r = 0.70$ to $r = 0.95$, from 0 to 72° of flexion. Between D2 T1 and the test completed on D3 T1, correlations ranged from $r = 0.81$ to $r = 0.97$ from 0 to 72° of flexion. Standard errors of estimate for D1 T1 versus D2 T1 ranged from 40.2 to 54.1 N · m. For D2 T1 versus D3 T1, standard errors ranged from 32.8 to 46.3 N · m. Total errors were noticeably greater than SEEs at 72° of lumbar flexion for both sets of comparisons and at 0° of lumbar flexion for D1 T1 versus D2 T1.

Normal Curves

Based on the findings of the intraday and interday analyses, isometric lumbar extension strength curves were constructed for men and women from the D2 T1 test data (Figure 4). These data showed the highest reliability coefficients without further increase in mean torque values (from D2 to D3). The curves are linear and descending from flexion to extension. At each angle, men were significantly stronger than the women. This also was the case when isometric torque was expressed per unit body weight (Table 4).

The variability of the single test used to define the normal curves (D2 T1) was calculated by dividing the SEE between D2 T1 by 2. This variability then was expressed as a percentage of the mean torque observed at each angle. Absolute and relative values for test variability of the normal curves are presented in Table 5. Single test variability for isometric lumbar extension strength measured at multiple joint angles

Table 2. Pearson Product-Moment Correlation Coefficients (r),* Standard Errors of Estimate (SEE),† and Total Errors (E)‡ for Tests Completed on Day 1 and Day 2 (n = 136)

		Angle (degrees of lumbar flexion)						
		0°	*12°*	*24°*	*36°*	*48°*	*60°*	*72°*
D1 T1	*r*	0.78	0.87	0.93	0.94	0.95	0.96	0.95
versus	SEE	46.9	45.2	37.6	38.0	39.1	38.9	46.0
D1 T2	E	48.6	46.7	37.0	39.1	39.7	40.1	48.3
D2 T1	*r*	0.94	0.94	0.95	0.97	0.97	0.98	0.98
versus	SEE	29.0	34.0	34.4	29.5	32.6	28.7	30.9
D2 T2	E	30.6	33.6	36.6	31.3	33.0	30.5	33.7

*All zero-order correlation coefficients significant at $P \leq 0.01$.

†SEE – $Sy \sqrt{1 - r^2}$; $Sy = \sqrt{(Sy_1{}^2 + Sy_2{}^2)/2}$.

‡$E = \sqrt{\Sigma(y_1 - y_2)^2/N}$.

Units for SEE and E are N · m.

D1 T1 = day 1, test 2; D1 T2 = day 1, test 2; D2 T1 = day 2, test 1; D2 T2 = day 2, test 2.

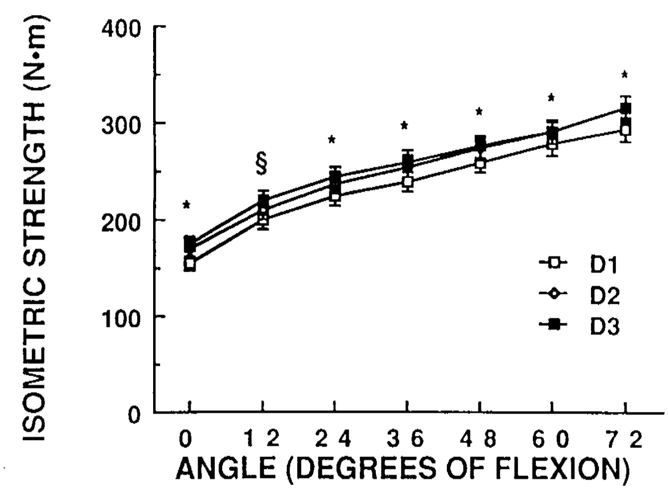

Fig 3. Isometric strength measures for test 1 completed on days 1, 2 and 3 (N = 119). D1 = day 1; D2 = day 2; D3 = day 3. * = D2, D3 > D1, $P < 0.05$; = D3 > D2 > D1, $P < 0.05$.

through a 72° ROM ranged from 20.5 to 24.3 N · m and represented 6.7 to 11.6% of the mean torque values.

DISCUSSION

Results of the intraday and interday analyses indicate that there was a significant learning effect associated with the first test completed on D1. Such an effect has been reported for isometric testing of other muscle groups[7,8] and has been attributed to either a physiologic response, a motor learning effect, or a combination of these factors. The greater torques noted for D1 T2 at 72° and 60° of lumbar flexion when compared with D1 T1 suggest that subjects were not giving their best effort at these angles during T1. On D2 the subjects were stronger during T1 at five of the seven angles tested when compared with T2. It is likely that a small amount of fatigue associated with the maximal effort required at each of the seven test positions was present after the 20- to 30-minute rest interval provided between the two tests completed on D2. The fact that this difference between tests was not present on D1, in addition to the fact that the torque values noted for D2 T1 were significantly greater than those for both tests on D1 at each angle,

Table 3. Pearson Product-Moment Correlation Coefficients (r),* Standard Errors of Estimate (SEE),† and Total Errors (E)‡ between Test 1 Completed on Day 1, Day 2, and Day 3 (n = 119)

		Angle (degrees of lumbar flexion)						
		0°	*12°*	*24°*	*36°*	*48°*	*60°*	*72°*
D1 T1	*r*	0.70	0.83	0.90	0.92	0.95	0.94	0.95
versus	SEE	54.1	50.9	45.2	44.9	40.2	47.1	45.2
D2 T1	E	60.5	55.0	48.3	49.4	44.8	48.2	65.8
D2 T1	*r*	0.81	0.92	0.94	0.96	0.95	0.94	0.97
versus	SEE	46.3	36.6	36.1	32.8	40.5	45.4	35.5
D3 T1	E	49.1	37.6	38.0	36.1	43.2	48.2	49.7

*All zero-order correlation coefficients significant with $P \leq 0.01$.

†SEE = $Sy\sqrt{1 - r^2}$; $Sy = \sqrt{(Sy_1^2 + Sy_2^2)/2}$.

‡E = $\sqrt{\Sigma(y_1 - y_2)^2/N}$.

Units for SEE and E are N · m.

D1 T1 = day 1, test 1; D2 T1 = day 2, test 1; D3 T1 = day 3, test 1.

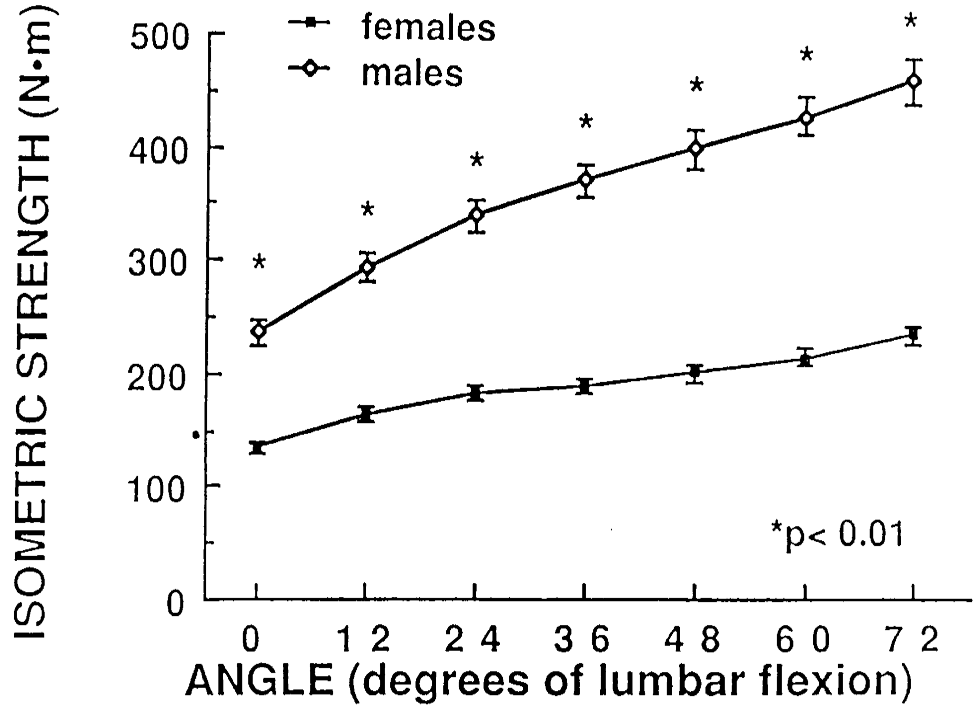

Fig 4. Isometric lumbar extension strength curves for men (n = 56) and women (n = 80). *$P \leqslant 0.05$.

Table 4. Relative Strength of Men and Women for Isometric Lumbar Extension (N · m/kg body wt)*

	Angle (degrees of lumbar flexion)						
	0°	*12°*	*24°*	*36°*	*48°*	*60°*	*72°*
Men (n = 56)	3.0 ± 1.1	3.8 ± 1.2	4.4 ± 1.3	4.8 ± 1.4	5.2 ± 1.6	5.5 ± 1.8	6.0 ± 1.9
Women (n = 80)	2.2 ± 0.9†	2.7 ± 0.9†	3.0 ± 0.9†	3.1 ± 1.0†	3.3 ± 1.0†	3.5 ± 1.2†	3.9 ± 1.2†

*Values are means ± SD.
†$P \leq 0.05$.

suggests that the subjects may have been initially hesitant to perform maximal isometric contractions. By D3 T1, isometric strength values had leveled off, with the exception of the value noted at 12° of flexion.

Standard errors of estimate were considerably less for all comparisons involving tests completed on D2 than noted for comparisons with tests completed on D1. In addition, the correlation coefficients for 0° and 12° of lumbar flexion were significantly greater for the D2 test comparison then for D1 (Table 3). These findings are indicative of high reliability and low variability following the D1 testing. Because the mean torques improved initially and then leveled off after the D2 T1 test and the r and SEE values improved after the D1 tests, a single practice test is recommended for best results with the protocol used in the present study. From a practical standpoint, however, the improvements after the D1 testing were relatively small, and a single test may be sufficient for routine clinical evaluation.

Reliability coefficients for single angle isometric strength measures are generally high, ranging above $R = 0.90$.[7,8] This also is true for the reliability of repeated measurements of isometric strength made at multiple joint angles.[4] Smidt et al[17] reported intraclass correlations for isometric lumbar extension ranging from $R = 0.43$ to $R = 0.97$ and noted that reliability was best when subjects were in the neutral sitting position. Reliability coefficients were considerably lower when subjects were in full flexion ($R = 0.43$) and extension ($R = 0.79$). Reliability coefficients in the present study were greatest in the fully flexed position and decreased slightly toward extension. The high reliability coefficients noted at all angles following D1 testing in the present study suggest that when the testing position is carefully standardized, repeatable measures are possible. The low reliability coefficients noted for isometric lumbar extension strength measures in other studies may be due to a lack of positional standardization during testing.

Variability of muscular strength measurement is rarely reported. One early report of individual variation in muscular strength indicated that strength may vary from 1.5 to 11.6% for women and 5.3 to 9.3% for men when variability was calculated as the standard deviation from the mean of repeated measurements.[19] The variability associated with multiple joint angle measurements for isometric knee extension strength range from approximately 10 to 20% when reported standard errors of the estimate are expressed as a percentage of the observed mean torques.[4] Smidt et al[17] reported an average percent change in maximum isometric lumbar extension of 17%. Single test variability for the normal isometric lumbar extension strength curves in the present study (6.7 to 11.6%) are well within the expected range of individual variation for muscular strength.

Table 5. Single Test Variability for the Normal Isometric Lumbar Extension Strength Curves for Men and Women

	Angle (degrees of lumbar flexion)						
	0°	*12°*	*24°*	*36°*	*48°*	*60°*	*72°*
SEE/$\sqrt{2}$*	20.5	24.0	24.3	20.9	23.1	20.3	23.8
Percent†	11.6	11.1	9.9	7.9	8.2	6.7	7.2

*Values are N · m.
†Values are [(SEE/$\sqrt{2}$)/mean torque] × 100.

Our data describing the normal isometric strength curve for men and women are in partial agreement with data reported by Smidt et al[17] and Marras et al,[10] who found that lumbar extension strength is greater in the flexed then the extended position. Smidt et al[17] reported that isometric torque for lumbar extension ranges from approximately 250 to 450 N · m for men and approximately 125 to 225 N · m for women. Both Smidt et al[17] and Marras et al[10] found that lumbar extension strength leveled off or decreased toward the fully flexed position (72° of flexion). Our data clearly show that lumbar extension strength is highest in full flexion in normal men and women who have a 72° ROM capability. A possible explanation for the discrepancy between the results of the present study and those of Smidt et al[17] and Marras et al[10] is lack of correction for the gravitational effects on torso mass. As the trunk moves toward full flexion from the sitting position (as in Smidt et al[17]) or the standing position (as in Marras et al[10]), the influence of gravitational forces on the torso mass become progressively greater. If these gravitational forces are not accounted for, they will reduce observed strength values. The magnitude of this reduction will be greatest in the fully flexed position.

In summary, a new lumbar extension testing device that stabilizes the pelvis and counterbalances torso mass allowed us to evaluate the reliability and variability associated with measuring isometric lumbar extension strength at multiple joint angles through a 72° ROM. Following an initial practice session, reliability coefficients at all testing levels were high ($r = 0.94$ to $r = 0.98$), and SEEs represented from 7 to 12% of the mean torque values. These findings are consistent with the reliability and variability reported for assessing the strength of other muscle groups. A mean isometric lumbar extension strength curve was developed for men and women. Both curves were linear and descending from flexion to extension. Peak isometric strength was noted at 72° of flexion, which is in contrast to previously published reports. It is concluded that the MedX lumbar extension machine is highly reliable and specific for the quantification of isometric lumbar extension strength through a 72° arc of lumbar extension.

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