Research Report

Lumbar Lordosis and Pelvic Inclination of Asymptomatic Adults

Background and Purpose. We examined the association between pelvic inclination and lumbar lordosis during relaxed standing and eight variables thought to contribute to lordosis. **Subjects.** Ninety subjects (45 men, 45 women) without back pain or a history of surgery were examined. The mean age was 54.8 years (SD=8.5) for male subjects and 58.9 years (SD=8.8) for female subjects. **Methods.** Multiple linear regression modeling was used to assess the association of pelvic inclination and size of lumbar lordosis in a standing position with age, gender, body mass index, physical activity level, back and one-joint hip flexor muscle length, and performance and length of abdominal muscles. **Results.** Abdominal muscle performance was associated with angle of pelvic inclination for women (R^2=.23), but not for men. Standing lumbar lordosis was associated with abdominal muscle length in women (R^2=.40), but it was multivariately associated with length of abdominal and one-joint hip flexor muscles and physical activity level in men (R^2=.38). No correlation was found between angle of pelvic inclination and depth of lumbar lordosis in a standing position. **Conclusion and Discussion.** Neither univariate nor multivariate regression models account for variability in the angle of pelvic inclination or size of lumbar lordosis in adults during upright stance; no correlation was found in standing between these two variables. The use of abdominal muscle strengthening exercises or stretching exercises of the back and one-joint hip flexor muscles to correct faulty standing posture should be questioned. [Youdas JW, Garrett TR, Harmsen S, et al. Lumbar lordosis and pelvic inclination of asymptomatic adults. *Phys Ther.* 1996;76:1066–1081.]

Key Words: *Kinesiology/biomechanics, Muscle length, Muscle performance, Muscles, Trunk mobility.*

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An assumption often made by physical therapists and others is that the size of the lumbar lordotic curve and the degree of pelvic inclination in a standing position are associated with the muscle lengths of the sagittal-plane pelvic rotators and the performance (strength) of the abdominal muscles.[1] Such assumed relationships are based on the anatomy of the muscles and their potential actions on the pelvis. The abdominal muscles tilt the pelvis posteriorly,[2,3] whereas the lumbar erector spinae muscles tilt it anteriorly.[2] When a person tilts the pelvis posteriorly in a standing position, lumbar lordosis decreases.[4] The lengths of the lumbar erector spinae and abdominal muscles also, in theory, should influence the size of the lumbar lordotic curve and degree of pelvic inclination in a standing position. For example, if the lumbar erector spinae muscles are shortened and the abdominal muscles are relatively lengthened, the degree of pelvic inclination and size of the lumbar lordosis would be expected to be greater than normal. Therefore, in a normal standing position, the degree of pelvic inclination is related to the lumbar curve, and both are related to the performance and length of the back and abdominal muscles.

Walker et al[5] made repeated measurements of lumbar lordosis, pelvic tilt, and abdominal muscle performance on 31 asymptomatic physical therapy students (23 female, 8 male) between 20 and 33 years of age. Lumbar lordosis was measured with a flexible curve, and the angle of pelvic tilt was measured with an inclinometer. Abdominal muscle performance was measured with the leg-lowering test originally described by Kendall et al.[1] All measurements were considered reliable. Spearman's rho correlation of abdominal muscle performance measurements with pelvic tilt and with lumbar lordosis yielded values of .18 and .06, respectively. The Pearson product-moment correlation of lordosis with pelvic tilt was .32. On the basis of these data, Walker et al[5] concluded that no relationship existed between lumbar lordosis and pelvic inclination in a standing position and the independent variable of abdominal muscle performance. The authors suggested that pelvic tilt and lumbar lordosis were likely influenced by a combination of

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This study was approved by the Mayo Institutional Review Board and was deemed minimal risk to all volunteers.

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several complex factors. Specifically, they stated that lumbar lordosis and pelvic inclination may be related to abdominal muscle length. Furthermore, Walker et al proposed that in addition to the abdominal muscles, other muscles could influence standing lumbar lordosis and pelvic tilt, although these muscles were not identified.

The findings of Walker et al[5] suggested that the clinical practice of using standing postural alignment to make predictions about the performance and length of abdominal and back muscles may not be justified. Furthermore, the prescription of muscle stretching or strengthening exercises to correct the size of lumbar lordosis and degree of pelvic inclination in patients in a standing position requires further justification. One limitation of the study by Walker et al is the narrow age range of their subjects. As aging occurs, perhaps there is a relationship between the muscle performance of the abdominal muscles and standing lumbar lordosis and pelvic inclination. This question can be answered by examining a group of asymptomatic older adults.

The primary aims of our study were to expand on the study by Walker et al[5] and to determine whether any association exists between pelvic inclination or lumbar lordosis during relaxed standing and the following factors: age, gender, body mass index (BMI), physical activity level, abdominal muscle performance, abdominal muscle length, back muscle length, and one-joint hip flexor muscle length.

Age, gender, BMI, and physical activity level can be justified as examples of complex factors that may be related to standing pelvic inclination and lumbar lordosis. Aging is associated with an increase in percentage of body fat and a decline in lean body mass (LBM).[6] Flynn et al[7] measured total body potassium (TBK) in 564 asymptomatic men and 61 asymptomatic women over 18 years of age as an indirect method for estimating LBM. They reported that each man and woman had less TBK and thus less LBM after age 40 years and that the loss of potassium increased at a greater rate in women than in men after age 60 years. These findings suggest a gender effect in the rate of change in body composition over time. Body mass index is the ratio of body weight to height squared.[8] It is calculated using a standard physician's scale and is considered a reliable indicator of obesity. Furthermore, physical inactivity is a risk factor for many conditions associated with aging, such as coronary artery disease, obesity, and osteoporosis. Harris et al[9] reported that 20% of Americans exercise at a level recommended for cardiorespiratory fitness, 40% are sedentary, and the remaining 40% exercise at a level below that recommended for fitness. On the basis of reports in the literature, we believe that with aging there is an increase in BMI and a decrease in physical activity, as measured by a physical activity questionnaire, and that these changes are associated with an increase in standing lumbar lordosis and pelvic inclination.

Decreasing muscle performance with aging is a common clinical observation. Murray et al examined the age-related differences in 72 asymptomatic men[10] and women[11] whose ages varied from 20 to 86 years. The torque generated by the extensor and flexor muscles of the right knee was measured with a Cybex® II dynamometer* during maximum isometric and isokinetic contraction. Decreases in torque were associated with age, with the highest values in the youngest group and the lowest values in the oldest group. Although Murray et al studied the performance of the knee flexors, we believe that the same relationship between age and muscle performance would be observed in the abdominal muscles. With increasing age, obesity, and decreased physical activity, we believe that abdominal muscle performance decreases, with an increase in anterior tilt of the pelvis associated with an increase in the standing lumbar lordosis and pelvic inclination.

Physical therapists frequently examine a patient's standing posture to determine whether a muscle imbalance exists. According to Kendall et al,[1] lordotic posture would be associated with anterior tilt of the pelvis and hip-joint flexion, resulting in an increase in standing lumbar lordosis and pelvic inclination. When a lordotic posture is present, Kendall et al[1] contended, the low back and hip flexor muscles are shortened, whereas the abdominal muscles are lengthened. If this is true, we contend that as aging occurs, abdominal muscle performance will decrease and muscle length will increase. With aging, the increase in standing lumbar lordosis and pelvic inclination should also be associated with shortness of the one-joint hip flexor and lumbar erector spinae muscles if Kendall and colleagues' contention is correct.

Method

Subjects

The subjects were 90 asymptomatic volunteers (45 men, 45 women) aged 40 to 69 years. These three decades were chosen because they include a broad range of asymptomatic men and women who have varied occupations and levels of physical activity. There were 30 subjects (15 men, 15 women) in each of three age groups (40–49 years, 50–59 years, and 60–69 years). The mean age of the male subjects was 54.8 years (SD=8.5), and the mean age of the female subjects was 58.9 years (SD=8.8). The mean height of the male

* Cybex, Div of Lumex Inc, 2100 Smithtown Ave, Ronkonkoma, NY 11779.

subjects was 175.3 cm (SD=7.4), and the mean height of the female subjects was 161.3 cm (SD=5.8). The mean weight of the male subjects was 82.1 kg (SD=13.7), and the mean weight of the female subjects was 67.8 kg (SD=13.4).

Subjects were recruited through personal contact by one of the authors or through advertisements placed on bulletin boards at the Mayo Clinic (Rochester, Minn) or in a local newspaper. All subjects were queried by one of the authors to confirm that they fulfilled each admission criterion. For admission into the study, subjects (1) had no low back pain, (2) were free from pain medications, (3) were free from major illness, (4) had no previous back surgery, (5) had no history of back trauma that required hospitalization, and (6) had no scoliosis greater than 15 degrees, as determined by visual examination. Informed written consent was obtained from all subjects.

To allow us to describe the sample more completely, each subject was asked to complete two brief questionnaires. In the first questionnaire, the Lipid Research Clinics Physical Activity Questionnaire,[12] subjects were asked to rate their level of physical activity relative to peers at work and at leisure and to indicate whether they regularly performed (ie, at least three times a week) strenuous exercise or hard physical labor (Appendix). Based on their answers on the questionnaire, subjects were classified as "very active" if they answered "yes" to questions 3 and 4, "moderately active" if they answered "yes" to question 3 and "no" to question 4, "low active" if they answered "no" to question 3 and rated themselves as active as their peers for questions 1 and 2, and "very low active" if they rated themselves as less active than their peers at work and outside of work and answered "no" to question 3. Ainsworth et al[12] reported that the Lipid Research Clinics Physical Activity Questionnaire was reliable and valid for predicting cardiorespiratory fitness and body fat.

Fifty-one percent of the women and 65% of the men reported engaging in strenuous exercise or hard physical labor at least once a week. We designed the second questionnaire, the Low Back Pain and Functional Limitations Questionnaire, to obtain general descriptive information about the history of low back pain and its influence on the vocational and leisure time activities of a subject. Eighty-two percent of the women and 76% of the men reported having two or fewer episodes of low back pain during the 12 months prior to our study. Ninety-eight percent of the men and women reported no absences from work because of back pain during the 12 months before our study. Only 9% of the women and 16% of the men were prevented from engaging in their normal leisure-time activities because of low back pain during the 12 months prior to our study.

Examiners

Measurements were made by two of the authors (JWY and TRG), who each had at least 20 years of teaching and clinical experience in physical therapy. Some measurements required the combined effort of both examiners. In such cases, one examiner was referred to as the "examiner" and the other examiner was referred to as the "instructor."

Procedure

Part 1. Before collecting data from the 90 subjects, the two testers conducted a pilot study to investigate the intratester reliability for measurements of lumbar lordosis; pelvic inclination; performance of abdominal muscles; and length of abdominal, low back, and one-joint hip flexor muscles. Making these measurements required that physical therapists work as a team, one as an "examiner" and the other as an "instructor." The subjects were 10 volunteers (5 men, 5 women) between the ages of 23 and 37 years (mean age=24.9, SD=4.4). Each subject met the previously described inclusion criteria. Informed oral consent was obtained from all subjects before any measurements were taken. All subjects changed from their daily street attire into shorts (men) and shorts and a gown (women) to provide adequate exposure of the low back and abdomen.

The spinous processes of S-2 and L-4 were located with palpation techniques described by Hoppenfeld.[13] The spinous process of T-12 was estimated by identifying the inferior margins of ribs T-12 bilaterally and simultaneously palpating these rib margins while moving superiorly and medially with the distal tips of the thumbs until they disappeared deep to the soft tissue. The examiner estimated the location of spinous process T-12 by bisecting a straight line joining the tips of the thumbs. Removable red adhesive dots, 6 mm in diameter, were placed on the skin overlying the center of each spinous process. These dots were removed after the first examination and replaced by fresh dots before the second examination, using the previously described palpation techniques. The order of measurement was identical for each subject: (1) angle of pelvic inclination in a standing position, (2) contour of lumbar curve in a standing position, (3) length of low back muscles in a sitting position, (4) length of abdominal muscles in a prone position, (5) performance of abdominal muscles in a supine position, and (6) length of anterior hip-joint soft tissues in a supine position.

Measurement of pelvic inclination. The procedure for measuring pelvic inclination began with the subject in a standing position (Fig. 1). First, the examiner palpated and marked the spinous processes of T-12, L-4, and S-2 with adhesive dots. Each subject stood barefoot on the

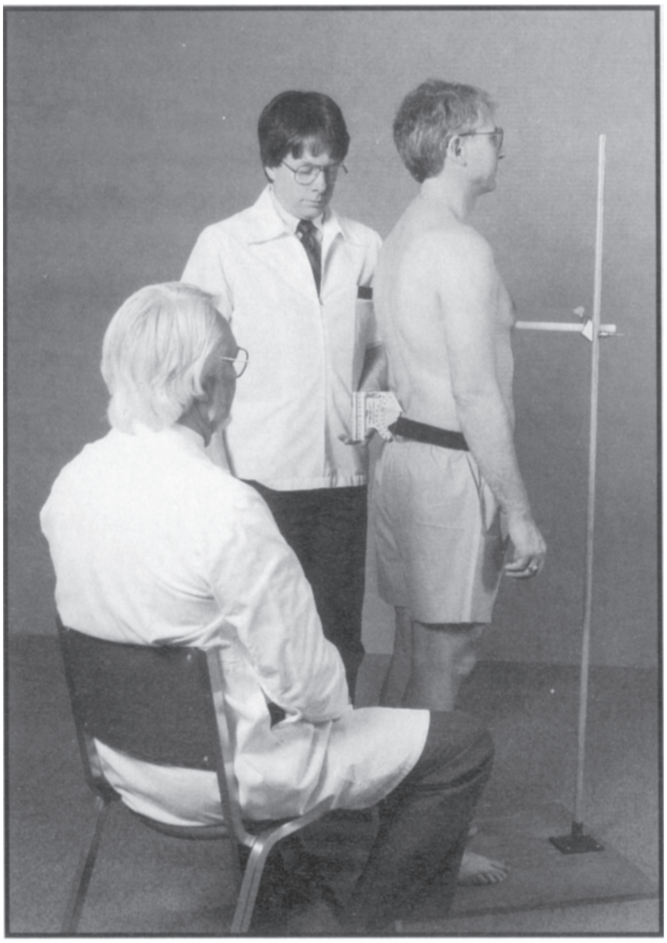

Figure 1.
Procedure for measuring the angle of pelvic inclination. Subject stands on wooden platform. An adjustable dowel mounted to a vertical rod is positioned to lightly touch subject's xiphoid process. The Back Range of Motion (BROM™) II unit is mounted on the subject so that the upper contact of the unit is positioned over the S-1 spinous process. The protractor of the BROM™ II is moved until the bubble in the vial is centered between the black lines.

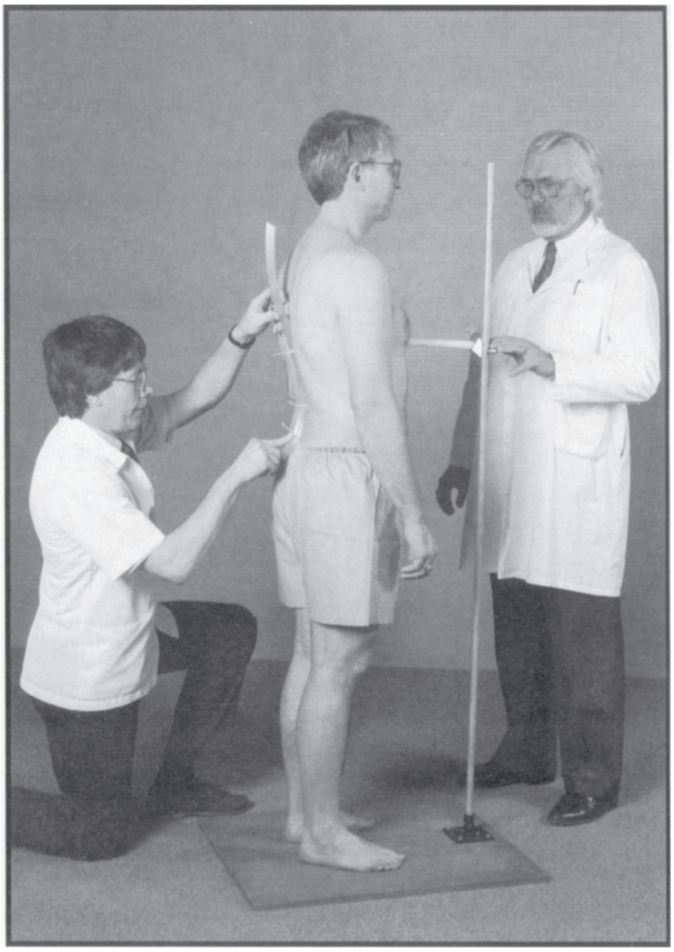

Figure 2.
Procedure for measuring size of lumbar lordosis. Subject stands on wooden platform. An adjustable dowel mounted to a vertical rod is positioned to lightly touch subject's xiphoid process. The flexible curve is molded to the midline contour of subject's lumbar spine. Twist-ties attached to the curve mark the location of spinous processes of T-12, L-4, and S-2.

base of the platform and assumed a comfortable, erect posture, with body weight evenly distributed between both feet. The instructor positioned a dowel horizontally mounted on an adjustable stand until it lightly touched the xiphoid process of the subject's sternum. This device, which has been described previously,[5] was designed to control postural sway while subsequent measurements are made with the subject in a standing position. The instructor traced an outline of the subject's feet on a piece of paper so that subsequent measurements could be made with the subject in the same position.

Pelvic inclination was measured with an inclinometer (the Back Range of Motion [BROM™] II[†]). The inclinometer consisted of a protractor to which was attached a fluid-filled chamber that contained an air bubble, similar to a carpenter's level. The inclinometer was mounted on the subject using Velcro® straps[‡] according to the procedure suggested by the manufacturer. The upper contact of the unit was positioned over the spinous process of S-1. The examiner moved the protractor until the bubble in the vial was centered between the black lines. The examiner was blinded to the reading of the inclinometer; the instructor sat in a chair and recorded the angle of pelvic inclination from the scale on the inclinometer, which was marked in 1-degree units. The inclinometer was removed, and the subject remained in a standing position while retaining his or her habitual lumbar curve.

[†] Performance Attainment Associates, 958 Lydia Dr, Roseville, MN 55113.

[‡] Velcro USA Inc, 406 Brown Ave, Manchester, NH 03103.

Measurement of lumbar lordosis. Lumbar lordosis was measured with a flexible curve,[§] 61 cm long and 2 cm wide, that bends in one plane only and that can maintain a fixed shape that can be transferred to paper. The examiner molded the flexible curve to the midline contour of the subject's lumbosacral spine; the sites of the curve that intersected with the adhesive dots over the spinous processes of T-12, L-4, and S-2 were marked with twist-ties attached to the flexible curve (Fig. 2). The examiner lifted the flexible curve from the subject's spine and, without altering the configuration of the curve, placed it on a piece of poster board. While the examiner held the flexible curve, the instructor traced the convex side of the curve's outline on a piece of poster board. Marks corresponding to spinous processes T-12, L-4, and S-2 also were made along the curve's contour. Next, the subject was instructed to step off the platform, and the instructor removed the red dots from the subject.

After a 1-minute rest, the subject remounted the platform and stood so that both feet were within the previously traced outlines of the feet. The subject's spinous processes were again palpated and marked with red adhesive dots. The measurement procedure was repeated for both the angle of pelvic inclination and the size of lumbar lordosis. The second tracing of the lumbar curve was placed on the reverse side of the poster board so that its contour would not influence the examiner while calculating the curvature of the first tracing. Quantification of the curves (in degrees) was done with a previously described technique that involved drawing three different straight lines on each tracing tangent to the marks previously made at the position of spinous processes of T-12, L-4, and S-2.[14–16] The intersections of these three tangent lines were measured with a clear plastic protractor marked in 1-degree units. The sum of the two angles was the estimate of the degree of curvature of the lumbar spine. The criterion-related validity of the flexible curve was assessed by comparing values of lumbar lordosis obtained with the curve and those obtained radiographically.[17] Hart and Rose[17] reported a linear association (r) of .87 between the two measurements. Similarly, Burton[14] reported that measurements of standing lumbar flexion and extension obtained with the flexible curve were 1 degree higher than those obtained with radiographs.

Measurement of peak lumbar flexion. The procedure for measuring maximum lumbar spine flexion has been described by others[14–16]; it served to provide an indirect measurement of the length of the subject's low back muscles. This maneuver is in accordance with that of Kendall et al,[1] because the low back muscles are elongated in a direction opposite to their action. The subject sat on the front edge of a chair (Fig. 3) with both feet flat on the floor. The subject was instructed to bend forward and to try to place his or her head between the knees while keeping both arms lateral to the knees. Each subject performed three repetitions of trunk flexion, with a 15-second hold at the end of the range to increase compliance of the soft tissues of the low back. With the subject's trunk in maximum forward flexion, the examiner palpated and marked the spinous processes according to the palpation techniques described.

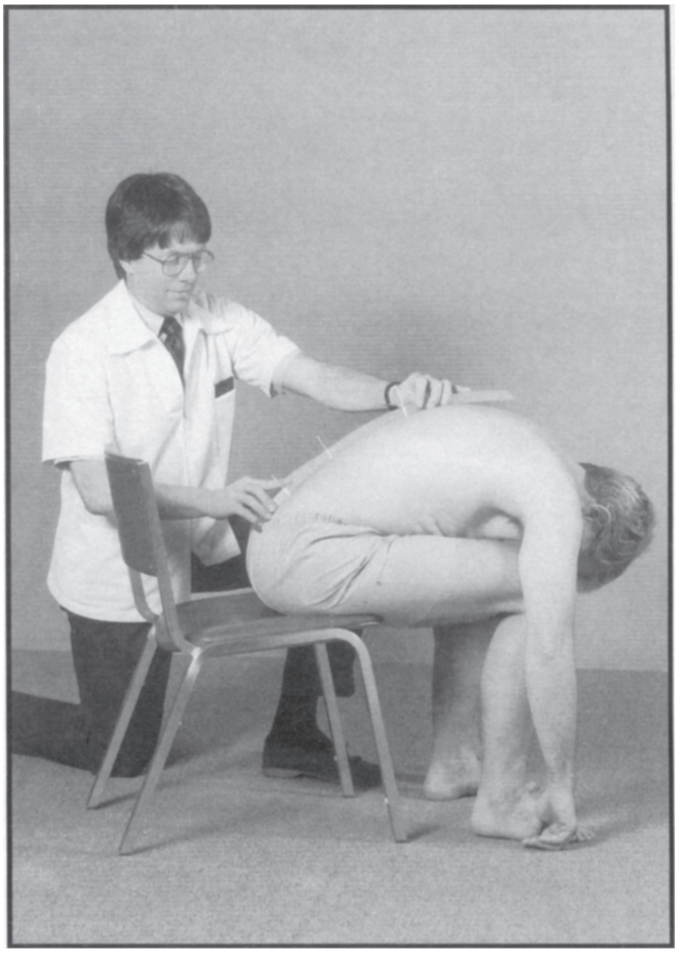

Figure 3.
Procedure for measuring maximum sagittal mobility of lumbar spine with subject sitting on the edge of a standard chair, with feet flat on floor and spread to shoulder width. Subject bends trunk forward, attempting to place the head between knees, with arms hanging vertically on the side of each knee. The flexible curve is molded to the midline contour of subject's lumbar spine. Twist-ties attached to the curve mark location of spinous processes of T-12, L-4, and S-2.

Next, the subject was instructed to resume a sitting position, with the trunk vertical to the chair's seat. The instructor asked the subject to "bend forward at your waist and try to place your head between your knees." At the endpoint of trunk flexion, the examiner molded the flexible curve to the contour of the subject's spine and

[§] Acu-Arc Adjustable Curve, Hoyle Products Inc, Fillmore, CA 93015.

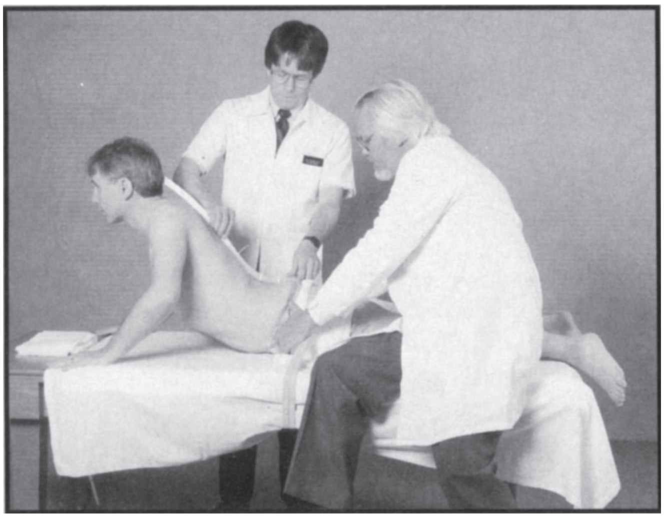

Figure 4.
Procedure for measuring maximum sagittal mobility of the lumbar spine. Subject lies prone on table covered with 1-cm-thick felt pad. A belt fastened so that it passes underneath the table and above subject's buttocks stabilizes pelvis during backward bending maneuver. Subject places palms of the hands at shoulder width, pushes against table, and passively extends lumbar spine. Examiner grasps subject's pelvis with both hands so the thumbs are placed over subject's iliac crests and the distal tips of second and third fingers are positioned between tabletop and subject's anterior superior iliac spines. The endpoint of passive lumbar extension occurs when the subject's anterior superior iliac spines begin to move away from the examiner's fingertips. The flexible curve is molded to the midline contour of subject's lumbar spine. Twist-ties attached to the curve mark the location of spinous processes of T-12, L-4, and S-2.

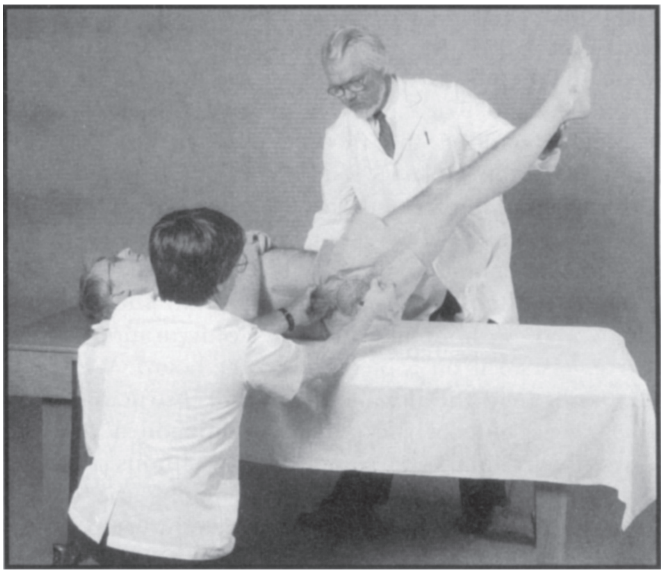

Figure 5.
Measurement of abdominal muscle performance with subject (without shoes) positioned supine on padded (1-cm-thick felt) wooden treatment table. Examiner elevates subject's fully extended legs to a point not to exceed 90 degrees of hip flexion. Subject lowers legs to tabletop at start of a 10-second count. During leg lowering, subject attempts to keep the lumbar spinous processes pressed tightly against tabletop. The axis of a plastic, 360-degree universal goniometer (UG) is positioned at the subject's greater trochanter. The stationary arm of the UG is held parallel to the longitudinal axis of the subject's trunk, and the movable arm of the UG is aligned parallel to the longitudinal axis of the subject's femur. Examiner places the fingertips of his left hand between the surface of the tabletop and the subject's lower back. The endpoint of the test is when the subject's lower back begins to move away from the examiner's fingertips. Abdominal muscle performance is recorded (in degrees) at the angle formed between the horizontal and longitudinal axes of the lower legs at the point where the lower back begins to extend and the lumbar spinous processes no longer contact the examiner's fingertips.

marked the position of the spinous processes of T-12, L-4, and S-2 on the curve with twist-ties. The examiner then removed the curve from the subject's back and instructed the subject to resume an erect sitting posture. While the examiner held the flexible curve, the instructor traced the outline of the curve on the poster board using the convex side of the flexible curve. The adhesive dots were removed from the subject and reapplied after a 1-minute rest. Without any warm-up, the procedure was repeated for a second measurement, and this tracing of the curve was put on the reverse side of the poster board. Quantification of the curves (in degrees) has been described by others.[14–16]

Indirect measurement of abdominal muscle length. A measurement of passive lumbar spine extension identical to the McKenzie[18] prone press-up maneuver was used to estimate indirectly the length of the abdominal muscles. This maneuver is consistent with that of Kendall et al,[1] because the abdominal muscles are lengthened in a direction opposite to their action. This technique has been described previously.[14,15] With the subject positioned prone on a wooden table with the horizontal surface covered with a 1-cm-thick felt pad (Fig. 4), the ends of a webbed belt were fastened so that the belt was positioned about 5 cm inferior to the subject's posterior superior iliac spines. This served to stabilize the pelvis during the backward bending maneuver. The examiner then palpated and marked the spinous processes of T-12, L-4, and S-2 with red adhesive dots. Next, the instructor asked the subject to complete a prone push-up: "Place the palms of both hands even with your shoulder joints, push down against the tabletop with your hands, and try to arch your back as far as you can by straightening your elbows. I will tell you when to stop pushing." The instructor grasped the subject's pelvis with both hands so that the thumbs were placed over the subject's iliac crests, and the distal tips of the second and third fingers were positioned between the tabletop and the subject's anterior superior iliac spines. The instructor determined the endpoint of the back movement when the subject's anterior superior iliac spines began to move away from the instructor's fingertips. This position of each passive lumbar extension movement was maintained for 15 seconds.

Each subject completed three warm-ups, and the curvature of the lumbar spine was measured during the fourth movement. After the flexible curve was removed from the subject's spine, the subject resumed a prone resting position with arms at the side. As before, while the examiner held the flexible curve, the instructor traced the outline on the poster board with the convex side of the curve. The calculated angle reflects the ability of the muscle to be lengthened. The adhesive dots were removed from the subject and reapplied after a rest period of 60 seconds. This measurement procedure was completed a second time, without the warm-ups. As before, the second tracing of prone extension was put on the reverse side of the poster board. This technique for assessing the length of the abdominal muscles is consistent with that of Kendall et al.[1] Passive lumbar extension increased the distance between the origin and insertion of the abdominal muscles, thereby elongating the muscles in a direction opposite to their action.

Measurement of abdominal muscle performance. The leg-lowering test has been described by others.[1,5,19] This test is widely used in clinical practice[1] to assess the ability of the abdominal muscles to flex the lumbar spine by flattening the low back against the table and keeping it flat, despite increasing resistance produced by the double leg-lowering movement and the tendency of the lumbar spine to extend. While the subject lay supine on the wooden treatment table with arms folded across the chest (Fig. 5), the instructor raised the subject's fully extended legs to a point that did not exceed 90 degrees of hip flexion. For some subjects with tight hamstring muscles, this angle was less than 90 degrees. The instructor repeated a series of standardized instructions to the subjects, emphasizing the need for keeping the lower back pressed tightly against the tabletop while they lowered their fully extended legs to the table over a period of 10 seconds. The examiner counted aloud, "one thousand one, one thousand two...one thousand ten," and the subject was instructed to begin lowering the legs toward the tabletop at the start of the count and to complete the test at the count of "one thousand ten."

The examiner positioned the axis of a large, plastic, 360-degree universal goniometer (UG) with 30.5-cm (12-in) movable arms and a sturdy pivot joint[||] over the subject's left hip. Before the study, one of the two testers assessed instrumentation accuracy of the UG by measuring 23 different randomly selected known angles generated by a computer graphics plotter. The mean difference between the observed and known angles was 0.2 degree, with a standard deviation of 0.4 degree. On the basis of these results, we considered the UG to be accurate. The measurement scale of the UG was blinded

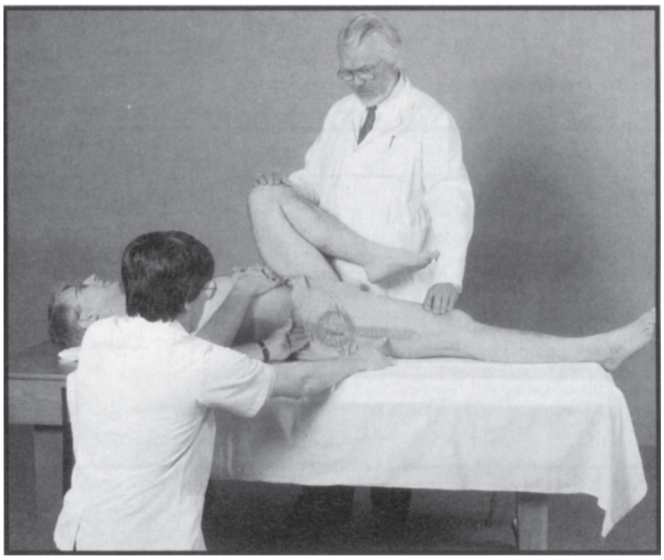

Figure 6.
Procedure for measuring length of the right one-joint hip flexors with subject positioned supine on padded (1-cm-thick felt) table with left hip joint flexed so that lumbar lordotic curve is eliminated and lumbar spine is pressed lightly against tabletop. Subject's left knee is flexed passively so that the calf rests against the posterior thigh. Right trunk-thigh angle is measured (in degrees) with a 360-degree, hand-held universal goniometer (UG). Stationary arm of the UG is parallel with the longitudinal axis of the subject's trunk and the tabletop; axis of the UG is centered at the subject's greater trochanter. Movable arm of the UG is aligned with the longitudinal axis of the subject's right thigh. After the measurement is obtained, the UG is removed from the subject, with care not to move the arm of the UG.

from the examiner with white adhesive paper. The right hand of the examiner kept the stationary arm of the UG parallel to the longitudinal axis of the subject's trunk, and the movable arm of the goniometer was aligned with the longitudinal axis of the subject's femur. The instructor placed the fingers of his left hand between the tabletop and the subject's spinous processes of L-3 and L-4, and his right upper extremity was used to passively elevate the subject's lower extremities before the start of the test and to prevent them from suddenly falling to the tabletop during the test. The endpoint of the test was determined by the instructor when the subject's lower back began to lift away from his fingers. The instructor signaled this event to the examiner by making a clicking sound with his tongue.

At the instructor's signal, the examiner stopped moving the movable arm of the UG, although the subject continued to lower his or her fully extended legs to the surface of the table; however, the examiner kept counting until the 10-second interval was completed. The subjects were not aware of when the UG was stopped. Each subject had two practice trials, and the first measurement was taken on the third trial. A 60-second rest period separated the three trials. The UG was handed to a recorder, who read the UG and recorded the angle.

[||] Fred Sammons Inc, 145 Tower Dr, Burr Ridge, IL 60521.

Table 1.
Intratester Reliability for Measurements of Pelvic Inclination, Lumbar Lordosis, Abdominal Muscle Performance, and Lengths of Abdominal, Back, and One-Joint Hip Flexor Muscles

Variable	ICC (1,1)[a]
Pelvic inclination	.91
Standing lumbar lordosis	.82
Lumbar extension in prone position	.96
Abdominal muscle performance	.93
Lumbar flexion in sitting position	.90
Length of one-joint hip flexor muscles	
Right	.50
Left	.29

[a] ICC=intraclass correlation coefficient; ICC (1,1) estimates the reliability of a single measurement made by the tester.

Table 2.
Descriptive Statistics for Asymptomatic Men and Women Regarding Their Self-Reports of Levels of Physical Activity and Frequency of Low Back Pain and Functional Limitations

		Men (n=45)		Women (n=45)	
Question	Response	No.	%	No.	%
Rate your level of physical activity	Very low active	2	4.4	7	15.6
	Low active	14	31.1	15	33.3
	Moderately active	2	4.4	3	6.7
	Very active	27	60.1	20	44.4
Did you experience low back pain during the last year?	No	28	62.2	29	64.4
	Yes	17	37.8	16	35.6
How many episodes of low back pain did you experience during the last year?	0	28	62.2	29	64.4
	1–2	6	13.3	8	17.8
	3–4	3	6.7	4	8.9
	5–6	5	11.1	2	4.4
	≥7	3	6.7	2	4.4
Were you absent from work due to low back pain during the last year?	No	44	97.8	44	97.8
	Yes	1	2.2	1	2.2
Did the presence of low back pain prevent you from engaging in your normal leisure-time activities during the last year?	No	38	84.4	41	91.1
	Yes	7	15.6	4	8.9

The recorder then folded the arms of the UG so that it read 0 degree and returned it to the examiner. After a 60-second rest, the leg-lowering test was repeated a second time without the two practice trials. Abdominal muscle performance scores could vary from 0 to 90 degrees; the smaller the angle, the better the muscle performance, because the abdominal muscles could hold the low back snugly against the instructor's fingertips, despite the increasing demands of the double-leg lowering.

Indirect measurement of one-joint hip flexor length. This clinical procedure was described previously by Kendall et al[1] and was used to estimate indirectly the length of the one-joint hip flexors. Kendall et al argued that the one-joint hip flexors have normal length if, when the low back and sacrum are flat on a table, the posterior thigh touches the table when the knee joint is in full extension. The subject was instructed to lie supine on the treatment table with the hips and knees straight and arms folded across the chest (Fig. 6). The right lower limb was measured first for all subjects. First, the instructor grasped the subject's left lower extremity and slowly moved the knee joint passively toward the subject's chest, with resulting hip and knee flexion. This movement continued until the subject's spinous processes L-4 and L-5 were flat against the tabletop, as determined with palpation by the instructor. The examiner then measured the right trunk-thigh angle (in degrees) with the UG.

The stationary arm of the UG was aligned with the longitudinal axis of the subject's trunk and parallel to the tabletop, and the axis of the UG was centered at the subject's greater trochanter. The movable arm of the UG was aligned with the longitudinal axis of the subject's right thigh. After obtaining the measurement, the UG was removed, with care taken not to move its arms, and the measurement recorded. The UG was then folded in preparation for the second measurement. The subject's left lower extremity was returned to the starting position, and after a 60-second rest the procedure was repeated for a second measurement of the right trunk-thigh angle. This procedure was subsequently performed in an identical fashion on the left lower extremity to obtain two measurements of the left trunk-thigh angle. This angle reflects the ability of the muscle to be lengthened.

Part 2. We collected data from 90 asymptomatic subjects who were different from those who participated in the pilot study. After obtaining written consent, each subject was asked to complete two brief questionnaires. After the questionnaires were completed, the body height (in inches) and weight (in pounds) of each subject were measured with a standard clinical scale.[#] The accuracy of this device was checked on a weekly basis. Next, the two examiners made the six measurements in the order described in part 1. The measurement procedures were identical to those outlined in part 1, except only one measurement was obtained for each procedure because good intratester reliability was established in the pilot study.

Data Analysis

Part 1. Intraclass correlation coefficients (ICCs) were used to assess the intratester reliability of the six measurements obtained from each of the 10 volunteers in the pilot study.[20] For each measurement, we calculated the ICC (1,1).

No universally acceptable levels have been adopted for ICCs for the purpose of describing the reliability of the measurements. We used a previously reported scheme for defining the amount of reliability based on ICC values: .75 and greater is excellent reliability, .40 to .75 is fair to good reliability, and less than .40 is poor reliability.[21]

Part 2. The Quetelet or BMI was used to assess whether the subject was overweight, with *overweight* defined as an excess of body weight relative to a specified standard for height.[22] The BMI was derived by converting the measurements of both height (in inches) and weight (in pounds) to metric system units and then obtaining the ratio of weight (in kilograms) divided by height squared (in square meters). Subjects were classified as underweight if the BMI was less than or equal to 20, as having normal weight if the BMI was greater than 20 but less than or equal to 25, as overweight if the BMI was greater than 25 but less than or equal to 30, and as obese if the BMI was greater than 30. This classification scheme was used in a British report of adults' heights and weights.[23] Because two subjects were classified as underweight, the categories of underweight and normal were collapsed.

The physical activity status is a categorical variable with four levels (very low, low active, moderate, and highly active). Because two subjects rated themselves as very low active and two subjects rated themselves as moderately active, the stability of any model containing categorical variables for levels would be questionable. Thus, the physical activity status was collapsed to two levels. Subjects were classified as either low active (very low to low active on the original scale) or active (moderately to highly active). Only the right trunk-thigh angle for estimating the lengths of the one-joint hip flexor muscles was used in the modeling, because the values for

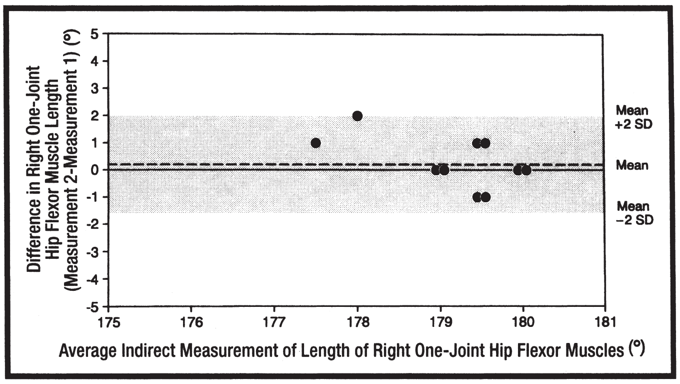

Figure 7.
Difference between first and second measurements of length of right one-joint hip flexor muscles as a function of the mean value of each pair of readings (n=10).

both sides were highly correlated. Gender was the strongest predictor of both lumbar lordosis and pelvic inclination and was highly correlated with the other independent variables. For these reasons, assessment of what other variables might be significantly associated with sizes of lumbar lordosis and pelvic inclination was performed separately for male and female subjects. The Pearson product-moment correlation coefficient (r) was used to assess the association between the lumbar lordosis and degree of pelvic inclination for both men and women.

For both men and women, each dependent variable was plotted against each independent variable, and their Spearman rank-order correlation coefficient (r) was calculated. A linear regression model[24] was also fit to the data, and a two-tailed t test with a significance level of .05 was used to assess whether the true slope of the regression line was different from zero. When at least two variables were found to be univariately associated with a dependent variable for a given gender, both forward-selection and backward-elimination modeling building techniques were used to obtain a subset of variables associated with the dependent variable for that gender. The power of a two-tailed t test (α=.05) with 88 degrees of freedom to detect that a slope that is 2.8 times its standard error is different from zero is approximately .80. All data analyses were performed using the SAS version 6.08 statistical package.[**]

Results

Part 1

The ICCs for each of the seven measurements taken in the pilot study are listed in Table 1. Except for the indirect measurement of length of the right and left one-joint hip flexors, all ICCs were greater than .80. The

[#] Continental Scale Corp, Bridgeview, IL 60455.

[**] SAS Institute Inc, PO Box 8000, Cary, NC 27511.

ICCs for the right and left one-joint hip flexors were .50 and .29, respectively.

Bland and Altman proposed a graphic technique[25,26] to express the agreement between repeated measurements of a continuous variable. Estimates of the ICC are dependent on the heterogeneity of the individuals (the range of potential values).[27] The greater the degree of heterogeneity, the higher the ICC. In our pilot study, the range of potential values for hip flexor muscle length was quite narrow. We used the approach proposed by Bland and Altman to assess agreement. For each of the 10 subjects in the pilot study, we plotted the algebraic difference between the value of the first and second measurements of hip flexor muscle length (y-axis) versus the mean value (x-axis) for the two measurements for right extremities (Fig. 7). For the right leg, the reflection of the length of the one-joint hip flexors obtained on the second measurement varied from 2 degrees above to 1 degree below that of the first measurement. For the left leg, the second measurement varied from 1 degree above to 4 degrees below the value of the first measurement.

Part 2

Descriptive data for both men and women about their responses to the two questionnaires are given in Table 2. Descriptive statistics of the measurements of standing lumbar lordosis and angle of pelvic inclination and the associated measurements of the length and performance of abdominal and hip muscles and length of back muscles for men and women are given in Table 3. Figure 8 illustrates the plot of standing pelvic inclination versus each independent variable for both male and female subjects. The male subjects' Spearman rank-order correlation coefficients varied from .05 for hip flexor muscle difference to −.24 for age, whereas the female subjects' correlation coefficients varied from .01 for right trunk-thigh angle to .37 for abdominal muscle performance. There was no observable relationship for both male and female subjects between standing pelvic inclination and physical activity level. Figure 9 illustrates the plot of standing lumbar lordosis versus each independent variable. The male subjects' Spearman rank-order correlation coefficients varied from −.06 for hip flexor muscle difference to .49 for abdominal muscle length. The female subjects' correlation coefficients varied from −.05 for abdominal muscle performance to .64 for the indirect measurement of abdominal muscle length. No relationship between standing lumbar lordosis and physical activity level could be seen. Abdominal muscle performance and the indirect measurement of back muscle length were found in women to be associated with pelvic inclination (Tab. 4). The search for a subset of independent variables associated with pelvic inclination in women revealed that once abdominal muscle performance was accounted for, no other factor under consideration contributed to the variability in pelvic inclination among women. Among men, there was no evidence to suggest that any of the independent variables under consideration were associated with pelvic inclination.

Among women, both age and abdominal muscle length were associated with standing lumbar lordosis (Tab. 4). Once abdominal muscle performance was accounted for, no evidence suggested that any of the other factors under consideration contributed to the variability of standing lumbar lordosis in women. Among men, both the indirect measurement of abdominal muscle length and physical activity level were associated with standing lumbar lordosis (Tab. 5). The search for a subset of independent variables associated with standing lumbar lordosis in men revealed that once abdominal muscle length and physical activity level were accounted for, the right trunk-thigh angle contributed to the variability in standing lumbar lordosis in the male subjects (Tab. 5).

For both men and women, the Pearson product-moment correlation coefficient was calculated to express the linear association between the angle of pelvic inclination and the standing lumbar lordotic curve (r=.06 for women, r=−.08 for men) (Fig. 10).

Discussion

Part 1

The ICCs (1,1) demonstrated that intratester reliability was excellent for measurements of pelvic inclination (ICC=.91), lumbar extension in the prone position (ICC=.96), abdominal muscle performance (ICC=.93), lumbar flexion in the sitting position (ICC=.90), and standing lumbar lordosis (ICC=.82). Intratester reliability was fair for right one-joint hip flexor muscle length (ICC=.50) and poor for left one-joint hip flexor muscle length (ICC=.29). The low ICCs for estimates of the intratester reliability of measurements of the length of one-joint hip flexor muscles may be explained by low between-subject variability.

The ICC is basically a ratio of the variability among subjects to the total variability; therefore, equivalent measurements among subjects can result in low reliability coefficients, even if individual measurements are consistent, which is an inherent limitation of the ICC.[26] According to the graphic technique, we would expect two measurements to differ from one another by ±2 degrees for the right side and by ±4 degrees for the left side. Furthermore, these plots indicated that the differences among the subjects were narrow, generally ranging between 177 and 181 degrees, thus accounting for the low ICC values. The results of the pilot study verified

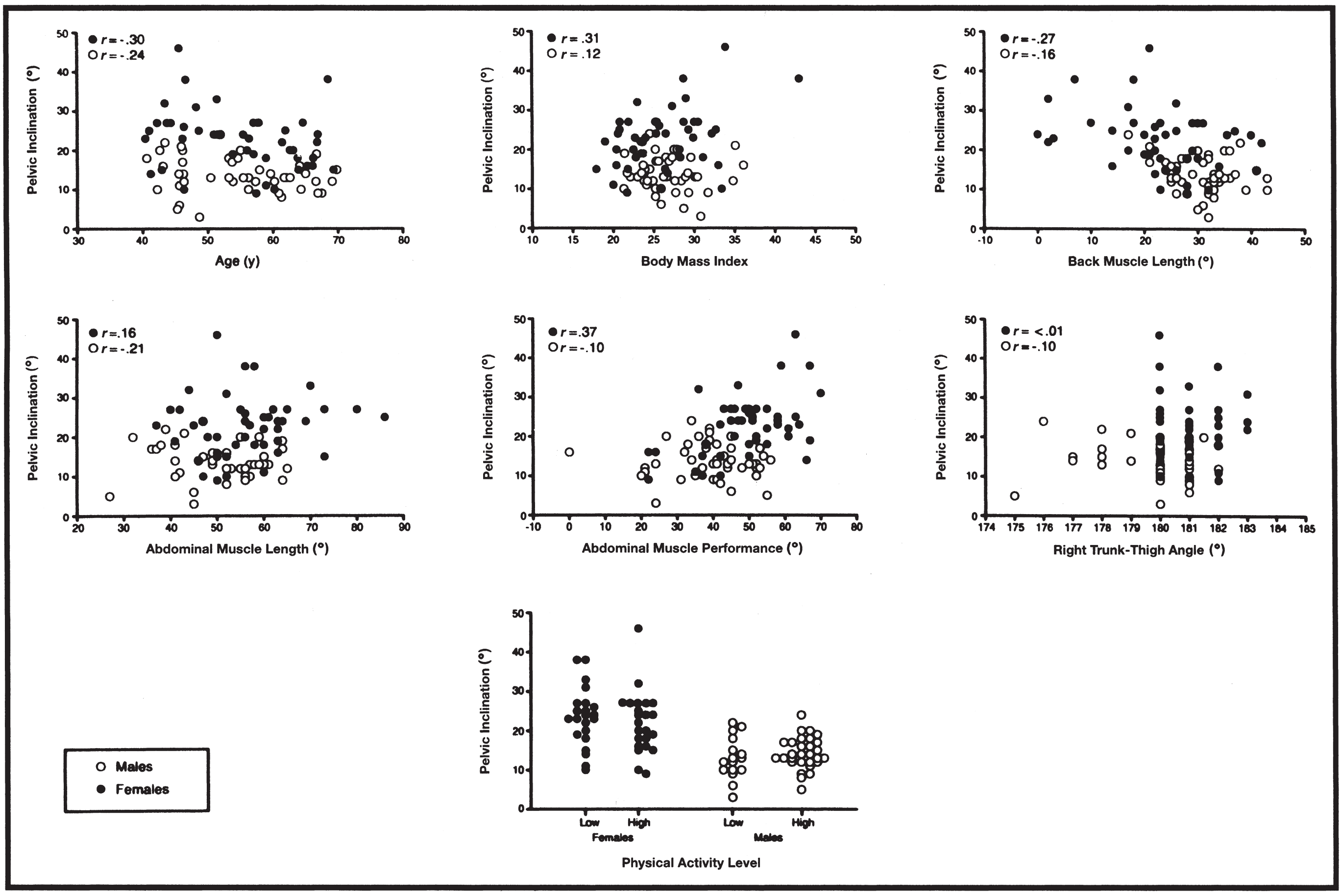

Figure 8.
Plot of standing pelvic inclination versus the eight independent variables for both men and women. Except for physical activity level, the Spearman rank-order correlation coefficient estimates the relationship between standing pelvic inclination and each independent variable.

Table 3.
Descriptive Statistics for Asymptomatic Men and Women Regarding the Angle of Pelvic Inclination and Size of Lumbar Lordosis in Standing and Selected Explanatory Variables

	Men (n=45)			Women (n=45)		
Variable[a]	**$\overline{X}$**	**SD**	**Range**	**$\overline{X}$**	**SD**	**Range**
Age (y)	54.8	8.5	40.6–69.8	54.9	8.8	40.4–69.3
Height (cm)	175.3	7.4	163.8–192.4	161.3	5.8	146.1–172.7
Weight (kg)	82.1	13.7	60.5–114.1	67.8	13.4	46.8–100
Body mass index (kg/m^2)	26.6	3.5	21.3–36.1	26.1	5.0	17.9–43
Pelvic inclination (°)	13.8	4.5	3–24	22.8	7.6	9–46
Lumbar curve (°)						
Standing	37.5	11.0	14–58	52.7	15.3	22–81
Sitting	31.0	5.7	17–43	22.9	10.1	0–42
Prone	50.1	9.2	27–65	56.5	10.4	37–86
Supine trunk-thigh angle(°)						
Left	180.4	1.8	175–183	181.6	1.4	177–184
Right	179.9	1.5	175–182	180.1	1.0	180–183
Abdominal muscle performance (°)	39.4	11.3	0–56	49.6	11.5	22–70

[a] For each variable, the overall value was found by dividing the sum of the individual values over the three decades by 45.

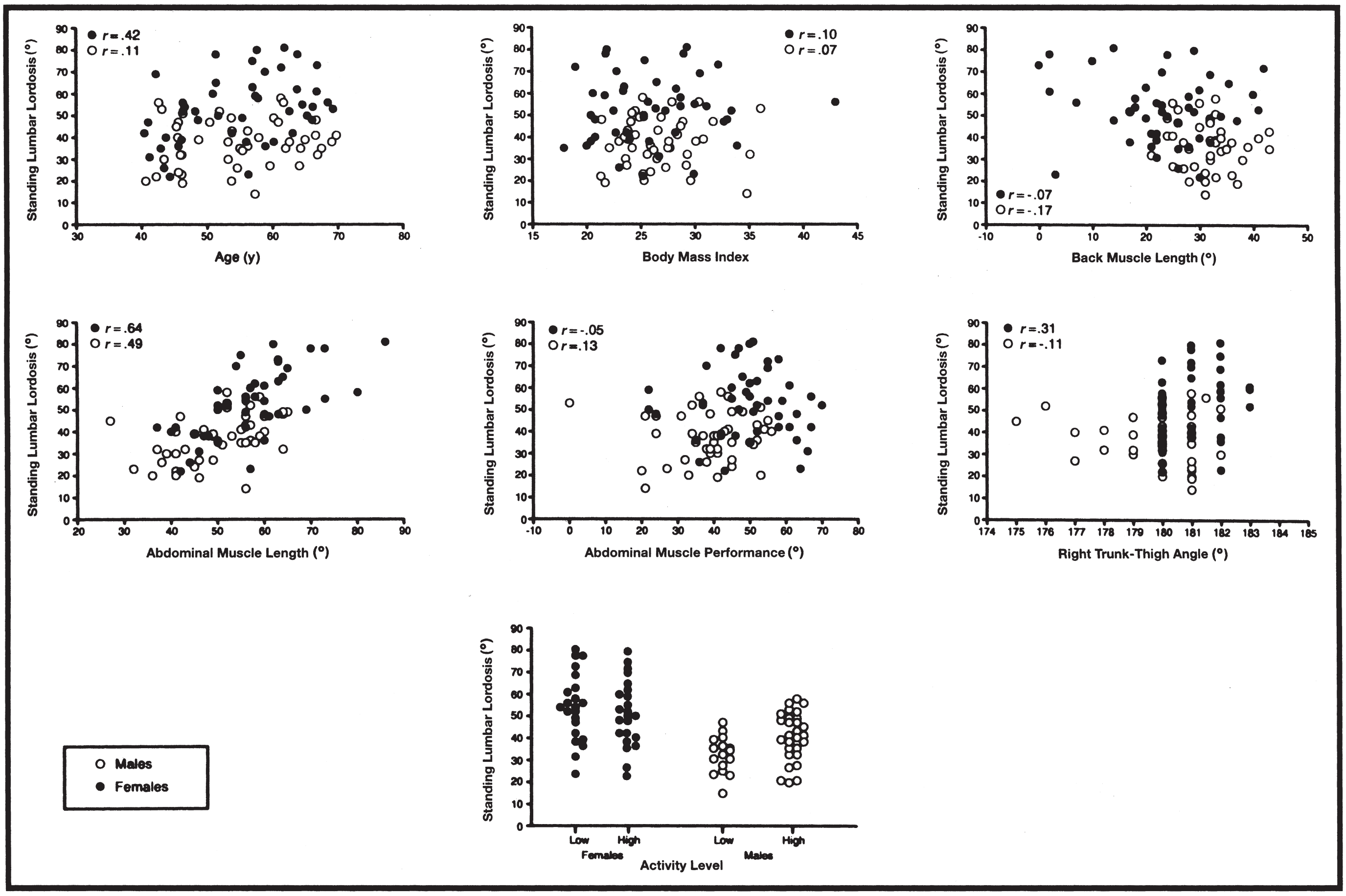

Figure 9.
Plot of standing lumbar lordosis versus the eight independent variables for both men and women. Except for physical activity level, the Spearman rank-order correlation coefficient estimates the relationship between standing lumbar lordosis and each independent variable.

that the methods used to obtain estimates (1) of pelvic inclination and size of the lumbar lordosis in the standing position, (2) of the performance of the abdominal muscles, and (3) of the lengths of the abdominal, back, and hip flexor muscles in asymptomatic adults were reliable.

Part 2

We believe that the subjects in our study are typical of asymptomatic adults between 40 and 69 years of age in terms of the frequency of heavy physical exertion habits and complaints of low back pain. Ainsworth et al[12] studied 78 asymptomatic subjects (50 women, 28 men; age range=21–59 years) who used the Lipid Research Clinics Physical Activity Questionnaire to provide a global self-assessment of their usual physical activity. Of these 78 subjects, 34 (43.6%) exercised strenuously at least three times weekly, 4 (5.1%) exercised strenuously less than three times weekly, and 40 (51.2%) did not exercise strenuously. Our results are similar to those of Ainsworth et al; 47 (52.2%) of our 90 subjects exercised strenuously at least three times weekly, 5 (5.6%) exercised strenuously less than three times weekly, and 38 (42.2%) did not exercise strenuously. Only 1 man and 1 woman (2.2% of the subjects) reported that low back pain caused them to miss work during the last year; only 7 men (15.6%) and 4 women (8.9%) reported that low back pain had prevented them from engaging in their customary leisure-time activities during the last year.

Contrary to often-expressed opinions of some clinicians and authors, our data did not suggest an association between muscle performance of abdominal muscles and the angle of pelvic inclination in a normal standing posture in asymptomatic men. Such an association, however, was seen in women. According to Kendall et al,[1] increased pelvic inclination would be associated with tightness of the one-joint hip flexor muscles or the back extensor muscles, or both. Our data did not demonstrate any relationship between pelvic inclination and indirect measurement of the lengths of the one-joint hip flexor muscles (right trunk-thigh angle). We found an association between pelvic inclination and back muscle length (P=.048), although this association was not significant in the multivariate model.

The lumbar curve was not associated with abdominal muscle performance for either men or women. This finding seems counterintuitive to the idea that abdomi-

Table 4.
Univariate and Multivariate Regression Modeling Output for the Association of the Variables of Interest and Pelvic Inclination and Lumbar Lordosis in a Standing Position in Asymptomatic Women

Variable	Pelvic Inclination Univariate Model *P*	Pelvic Inclination Multivariate Model *P*	Standing Lumbar Lordosis Univariate Model *P*	Standing Lumbar Lordosis Multivariate Model *P*
Age	.070		.006	
Body mass index	.170		.930	
Back muscle length	.048		.510	
Abdominal muscle length	.486		<.001	<.001
Abdominal muscle performance	<.001	<.001	.703	
Trunk-thigh angle, right	.997		.085	
Physical activity level	.553		.548	

[a] R^2 of model=.23.
[b] R^2 of model=.40.

nal muscles, through pulling upward on the pelvis anteriorly, should have a major effect on the lumbar curve.[2] Our findings, however, agree with those of Walker et al,[5] who also reported that there was no evidence of an association between the lumbar curve and the performance of the abdominal muscles. Both studies used the same basic methods to obtain measurements of standing lumbar lordosis and abdominal muscle performance.

Some investigators[28,29] reported minimal electromyographic activity in the back and abdominal muscles during the standing posture in naive subjects who had not been trained to voluntarily activate their abdominal or back muscles. Other investigators[30] have shown that the abdominal muscles show minimal electromyographic activity during level walking. Despite these data about the activity of the back and abdominal muscles, some people have assumed that the lumbar lordosis and inclination of the pelvis in a standing position are inextricably linked to the length and performance of these two muscle groups. On the basis of our data and those of Walker et al,[5] we suggest that the active tension-generating capacity of a muscle may not sufficiently account for the variability of these muscles in posture to be clinically useful.

Furthermore, we and Walker et al[5] have observed a weak association between the inclination of the pelvis and the lumbar lordosis in asymptomatic standing subjects (Fig. 10). This result was unexpected, because some people contend that any increase or decrease in the amount of pelvic inclination during standing would likewise be related to an increase or decrease in the lumbar lordosis.

Walker et al[5] attempted to account for the variability in the angle of pelvic inclination and the lumbar lordosis by abdominal muscle performance in a group of young asymptomatic adults during standing. In contrast, we sought to account for the variability in the two dependent variables from among a broader age group of asymptomatic men and women by using several variables. On the basis of these two studies, it appears that the active tension-generating capacity of the abdominal muscles accounts for little of the variability in the lumbar curve in asymptomatic men and women who are naive about the role of these muscles during standing posture. Neither our study nor that of Walker et al,[5] however, considered the active tension-generating capacity of the abdominal, back, and hip flexor muscles and their influence on lumbar lordosis and angle of pelvic inclination in subjects with adaptive shortening of the one-joint hip flexors because of various disease states.

Further study is indicated in patients with chronic low back pain to determine whether the angle of pelvic inclination and lumbar lordosis are related to the length and performance of the abdominal, back, and hip flexor muscles. We would have postulated a relationship among BMI, physical activity level, and the angle of pelvic inclination and lumbar lordosis. For example, we reasoned that subjects with a large BMI might have low levels of physical activity. Such factors could be associated with the decreased tension-generating capacity of the lower abdominal muscles and, hence, an increased angle of pelvic inclination and lumbar lordosis. Our data indicate that BMI was not associated with standing pelvic inclination and lumbar lordosis in either men or women. Physical activity level was statistically associated in both the univariate and multivariate models with lumbar lordosis in men with no complaint of low back pain. Similar to the data of Walker et al,[5] our data do not support the current practice of teaching patients abdominal strengthening exercises in an effort to change standing posture. Furthermore, our data do not confirm a strong relationship between the lengths of the abdominal or one-joint hip flexor muscles and standing posture. These findings question the current practice of

Table 5.
Univariate and Multivariate Regression Modelling Output for the Association of the Variables of Interest and Standing Lumbar Lordosis in Asymptomatic Men

Variable	Univariate Model P	Multivariate Model[a] P
Age	.384	
Body mass index	.611	
Back muscle length	.256	
Abdominal muscle length	.002	<.001
Abdominal muscle performance	.729	
Trunk-thigh angle, right	.396	.045
Physical activity level	.010	.009

[a] R^2 of model=.38.

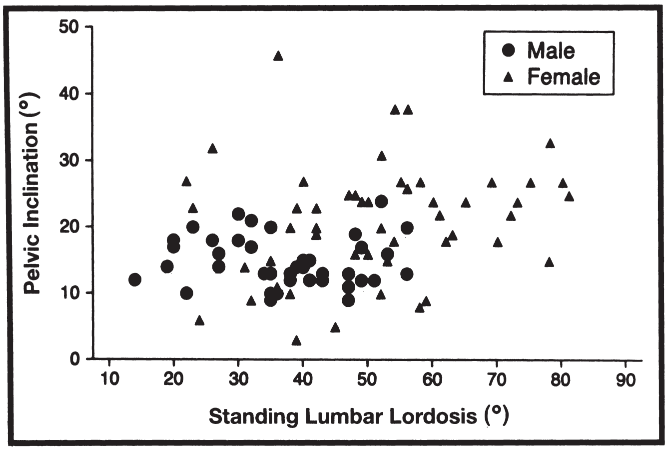

Figure 10.
Relationship between the measurements of pelvic inclination and the size of lumbar lordosis during standing in asymptomatic women and men (n=90).

teaching strengthening and stretching exercises to patients with mechanical low back pain to correct standing posture. Because our data and those of Walker et al[5] were obtained from asymptomatic subjects, we suggest that the next logical step involves examining the relationship between the angle of pelvic inclination and size of lumbar lordosis in a standing position and the explanatory variables we examined for a group of men and women who complain of chronic low back pain.

Conclusions

From the data in part 1 on asymptomatic subjects who participated in the pilot study, we concluded that repeated measurements of pelvic inclination; lumbar lordosis, abdominal muscle performance; and lengths of the abdominal, one-joint hip flexor, and back muscles made by the same physical therapist using well-defined measurement procedures have excellent reliability. From the data in part 2, we concluded that none of the linear regression models account for much of the variability in the angle of pelvic inclination or lumbar lordosis in a standing position. In standing subjects, we found a weak association between lumbar lordosis and pelvic inclination. Abdominal muscle strengthening exercises or stretching exercises to the back and one-joint hip flexor muscles are commonly used in an effort to correct faulty standing posture in patients with chronic low back pain. These practices do not appear to be valid on the basis of our data obtained from asymptomatic adults. Additional research will be necessary to confirm that a strong relationship exists between the size of lumbar lordosis and pelvic inclination and the length and performance of the abdominal, back, and one-joint hip flexor muscles during standing in patients with chronic low back pain.

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Appendix.

Lipid Research Clinics Physical Activity Questionnaire[12]

1. Thinking about the things you do at work, how would you rate yourself as to the amount of physical activity you get compared with others of your age and gender?
   a. Much more active
   b. Somewhat more active
   c. About the same
   d. Somewhat less active
   e. Much less active
   f. Not applicable
2. Now, thinking about the things you do outside of work, how would you rate yourself as to the amount of physical activity you get compared with others of your age and gender?
   a. Much more active
   b. Somewhat more active
   c. About the same
   d. Somewhat less active
   e. Much less active
3. Do you regularly engage in strenuous exercise or hard physical labor?
   a. Yes (answer question #4)
   b. No (stop)
4. Do you exercise or labor at least three times a week?
   a. Yes
   b. No