Physiotherapy Research International
Physiother. Res. Int. 12(1) 29–38 (2007)
Published online in Wiley InterScience
(www.interscience.wiley.com) **DOI**: 10.1002/pri.351

Are differences in leg length predictive of lateral patello-femoral pain?

MARY CARLSON College of Health Sciences, University of Texas at El Paso, Texas, USA
JERRY WILKERSON School of Health, Physical Education and Recreation, Indiana University, Indiana, USA

ABSTRACT **Background and Purpose.** *Lateral patello-femoral pain can shorten an athletic career and generally decrease an individual's physical activity and functional level, such as preventing stair climbing and reducing the ability to rise from a chair. Leg length inequality is associated with patello-femoral pain. A leg length test that best distinguishes the difference between people who have lateral patello-femoral pain and those who do not would have clinical utility. The purpose of the present study was, first, to determine if unilateral, lateral patello-femoral pain was associated with the longer leg when inequality of leg lengths existed and, second, to determine if leg length direct measurement, indirect measurement or quadriceps angle (Q angle) could correctly classify participants according to the presence or absence of patello-femoral pain.* **Method.** *The study used an* ex post facto*, two-group quasi-experimental design. A volunteer sample of 52 participants (14 males, 38 females), ranged in age from 18 to 52 years. Three methods were used to measure leg lengths: palpation meter (PALM) on anterior superior iliac spines (ASIS) while participants maintained centred weight-bearing position on a high resolution pressure mat; tape measurement from ASIS to medial malleolus (supine); tape measurement from ASIS to lateral malleolus (supine). Additionally, Q angle was measured in supine position. Patellar grind test, medial retinacular and lateral patellar palpation screened for patello-femoral pain.* **Results.** *Logistic regression analysis determined correctness of membership in painful and non-painful patello-femoral groups. The PALM method of indirect measurement of leg length differences overall correctly classified approximately 83% of the participants. Tape measure to medial and lateral malleoli as well as Q angle did not yield significant results.* **Conclusion.** *The results suggested that the PALM method of measuring leg length differences may have clinical utility in differentiating between patients who are likely to sustain patello-femoral pain syndrome and those who will not. Copyright © 2006 John Wiley & Sons, Ltd.*

Key words: leg length, PALM, prediction, Q angle, tape measure

INTRODUCTION

Lateral patello-femoral pain occurs at the articulation between the lateral facet of the patella and the lateral femoral condyle. Powers (1998) found that lateral patello-femoral pain has an estimated prevalence of 25% of all knee injuries whether in the general population or in sports injuries. Patello-femoral pain occurs more frequently in women than men (Powers, 1998), possibly due to the increased lateral patellar forces from the wider female pelvis and increased incidence of femoral ante-version in women (Vigorita and Morgan, 1995) but men have more patello-femoral pain than women in the athletic population (Powers, 1998). Additionally, in a review of 2002 running injuries, patello-femoral pain was the most common injury, found in 38% of the men and 62% of the women (Taunton et al., 2002).

Both dynamic and static forces affect the medial or lateral orientation of the patella. The dynamic component is a complementary association between the vastus lateralis and vastus medialis muscles. Muscular pull of the larger vastus lateralis muscle is normally 12–15° lateral to the long axis of the femur, while the pull of the smaller vastus medialis muscle is 15–18° medial to the long axis of the femur (Lieb and Perry, 1968). The distal, medial portion of the vastus medialis muscle is called the vastus medialis oblique (VMO). The VMO (albeit small) is an extremely important portion of muscle because its line of pull is approximately 55° medial to the long axis of the femur. Weakness of the vastus medialis muscle, in particular the VMO, can allow increased lateral forces on the patella (Powers, 1998).

Increased lateral forces on the patella can be caused by factors other than muscular imbalance. Static forces that contribute to increased lateral orientation of the patella are structural anomalies such as external tibial torsion, femoral ante-version (internal femoral torsion) and genu valgus. Structural anomalies can cause increased lateral force on the patella by increasing the obliquity of the pull of the quadriceps muscle at the knee joint (Grelsamer and Klein, 1998). Also, activities that increase knee flexion, such as squatting (Dye, 2002; Wallace et al., 2002) and stair climbing (Salsich et al., 2002), increase patello-femoral joint force and symptomatic pain.

When the quadriceps muscle exerts force laterally on the patella, the lateral surface of the patella rubs against the medial portion of the lateral femoral condyle causing increased compression and friction between the articular surfaces. The articular cartilage lacks innervation so pain may not be perceived initially (Hungerford and Barry, 1979).

In contrast to articular cartilage, the subchondral bone is highly innervated. When articular cartilage is no longer able to spread force over an area larger than the contact area the concentration of force causes the subchondral bone to register pain (Goodfellow et al., 1976; Cox, 1985; Powers, 1998). With continued compression and friction, articular cartilage deteriorates until subchondral bone is exposed. When the bone is no longer protected by articular cartilage, exposed nerve endings in the bone produce pain (Goodfellow et al., 1976).

Additionally, an important biomechanical function of articular cartilage is its visco-elastic ability to spread force over an area larger than the contact area (Goodfellow et al., 1976). As increased lateral compression and friction cause the articular surface to deteriorate, the visco-elastic force-spreading property is compromised, then destroyed (Goodfellow et al., 1976).

DOI: 10.1002/pri

Leg length differences have been recognized as a source of musculoskeletal problems for decades (Gross, 1983; Cohen et al., 1996). Multiple techniques for measuring leg length differences have evolved secondary to the observed relationship between overt leg length inequalities and musculoskeletal dysfunction. Currently, it is believed that many physiotherapists continue to use the tape measure technique to measure leg length differences.

The tape measure technique is a form of direct measurement that obtains leg length by assessing the distance from the anterior superior iliac spine (ASIS) to the medial or lateral malleolus (McCaw, 1992; Cowen et al., 1996). Giles and Taylor (1981) reported the tape measure methods are the least accurate, whereas radiographic measurement is the most accurate and serves as the criterion standard for all other measures. However, radiography is expensive, involves exposure to radiation and is not readily accessible to most physiotherapists (McCaw, 1992).

Overt leg length inequalities often can be detected through observation by the experienced clinician. Other than radiographic measurement, the most accurate measurement technique is the indirect method of judging bilateral pelvic height by an experienced clinician (Gofton, 1985). The clinician places a hand on each iliac crest (or other pelvic landmarks) and determines height symmetry through observation. Clinicians may augment observation through use of a commercially available instrument that combines an inclinometer with calipers to quantify leg length difference. The PALM instrument (Performance Attainment Associates, Saint Paul, MN, USA) uses an inclinometer to determine degree difference in height of the iliac bones. A second part of the PALM is the caliper that measures the distance between bony landmarks, such as anterior superior iliac spines (ASIS). This device may allow more objective quantification of iliac bone height differences compared to the subjective method of visual determination.

Physiotherapists and other clinicians have observed anecdotally that with functional leg length inequality, the longer leg usually is the one that has lateral patello-femoral pain. Brady et al. (2003) defined functional length inequality as being a unilateral asymmetry of the lower extremity that did not include an osseous component. For the purpose of the present study, that definition was modified to include possible osseous component. If there is an association between leg length inequality and lateral patello-femoral pain, early intervention to correct leg length differences may prevent this common and painful disorder. The purpose of the present study was to determine if unilateral, lateral patello-femoral pain was associated with the longer leg when inequality of leg lengths existed, and to determine if leg length direct measurement, indirect measurement or Q angle could correctly classify participants according to the presence or absence of patello-femoral pain.

Hypotheses

The following hypotheses were investigated during the study.

- Participants with unilateral patello-femoral pain will have significantly greater functional leg length differences as measured by the PALM than those with no patello-femoral pain.
- In participants with functional leg length inequalities and unilateral, lateral patello-femoral pain, the pain will occur in the longer extremity.

DOI: 10.1002/pri

METHOD

Study design

The study used an *ex post facto*, quasi-experimental research design. Participants were assigned to two groups on the basis of presence or absence of lateral patello-femoral pain assessed in the final step in the experiment.

Participants

Fourteen males and 38 females between the ages of 18 and 52 years volunteered to participate in the study. Participants were excluded from the study if they had knee surgery less than six months prior to the study or if they had enough adipose tissue in the area of the ASIS to make palpation of that landmark unreliable. Each participant signed an informed consent form before participating in the study.

Materials

The testing equipment included a Tekscan high-resolution pressure mat (HRMat by Tekscan, Inc.), a standard large goniometer, a standard tape measure, a carpenter's level and a palpation meter (PALM, Performance Attainment Associates, 3550 LaBore Road, Suite 8, Saint Paul, MN 55110-5126, USA). Petrone et al. (2003) concluded that the PALM was a valid, reliable tool for measuring pelvic crest height differences. Prior to the current study, intra-rater and validity testing (unpublished data) was conducted on the PALM by the researcher with relative errors of 1% for validity of inclinometer and intra-rater reliability and 4% for caliper measures.

The pressure mat provided feedback for participants to balance weight equally on each foot, preventing the creation of an artificial leg length discrepancy through centre of gravity displacement. The standing participant watched the computer monitor and moved an icon on the screen by shifting their weight from side to side. By maintaining the icon position centred in a designated circle on the monitor, the participant maintained centre of pressure at body midline.

Procedure

The university's Institutional Review Board approved the research before data collection. Prior to measurement, participants changed into a hospital gown to allow access to anatomical pelvic landmarks, and for measuring leg lengths.

Measurement of leg length differences was performed using three methods:

- the palpation meter (PALM)
- tape measure to medial malleolus
- tape measure to lateral malleolus.

Additionally, quadriceps angle (Q angle) was measured and clinical testing determined the presence or absence of patello-femoral pain.

Each participant was measured three times using each measuring technique. The mean of the three measurements was calculated and recorded to increase accuracy of the measurement (Beattie et al., 1990). After all measurements were completed, each participant was evaluated for lateral patello-femoral pain bilaterally. The researcher performed all tests with the participant in supine position while the researcher stood on the tested side. The researcher alternated direct measurements of the right and left legs to decrease likelihood of memory biasing the measurements. The lateral patello-femoral pain testing was performed

DOI: 10.1002/pri

last to prevent expectation bias during leg length measurements.

Indirect measurement with PALM

A standard carpenter's level was used to ascertain that the floor was level before the high-resolution mat was placed on the floor. The same level was used to assure calibration of the PALM prior to each data collection session. Anterior/posterior lines were placed on the mat 7.6 cm to the right and left sides of the mid-point for placement of the medial border of the foot. This line placed the feet approximately in line with the shoulders for most of the participants, and foot placement was adjusted outward for the participants with broader shoulders to obtain good alignment (Gross et al., 1998). A medial/lateral line was placed four inches from the cord end of the mat to be the forward border for the tip of the great toes.

Participants stood on the pressure mat, placing bare feet on the designated spaces. The participants maintained a balanced stance by observing the computer screen and making weight-bearing adjustments as needed. The researcher marked the ASIS on each side with washable ink, then placed the caliper tips of the palpation meter on the right and left ASIS (Gross et al., 1998). The width of the pelvis between the right and left ASIS was measured in centimetres and the angle of incline was noted in degrees with appropriate right or left designation. Sine trigonometric function (Sine θ = opposite/hypotenuse) determined the difference in height between the right and left ASIS. The width of the pelvis in centimetres served as the hypotenuse of the triangle. The angle of incline served as the angle θ. The trigonometric function was solved to find the side of the right triangle opposite to the angle θ as the leg length difference in centimetres.

Quadriceps angle measurement

The second phase of the experiment was Q angle measurement. With the participant in supine position with legs extended and relaxed, the researcher palpated, marked and verified the ASIS. The procedure was repeated to mark the centre of the patella and the tibial tuberosity. A standard large goniometer was used to measure the Q angle three times on each leg with the average of the three measures used for calculations.

Direct measurement of leg length

The third and fourth tests were the direct measurements of leg length using a standard tape measure from the ASIS to the medial and lateral malleoli, respectively. The participant was in supine position, with legs extended and relaxed. The mark for the location of the ASIS was used for the proximal point of measurement. Then the centres (most prominent point) of the medial and lateral malleoli were palpated and marked with a washable ink marker (Gross et al., 1998). Finally, a tape measure was extended from the ASIS to the medial malleolus on each lower extremity to determine the leg length. The measure was also taken from the ASIS to the lateral malleolus in the same manner. The average of the three measures was used in the calculations.

Patello-femoral pain test

The participant remained in supine position on the plinth with legs extended and relaxed. The researcher performed a lateral patellar grind test, pushing the lateral facet of the patella against the lateral condyle of the femur in a grinding manner (Powers, 1998). Then the lateral border of the patella was palpated for tenderness. In the final test

DOI: 10.1002/pri

(Bassett Sign), the researcher palpated the medial retinaculum for tenderness (Powers, 1998). If both knees tested positive to lateral patello-femoral pain but the pain was unequal, the leg with greater pain was considered to be the painful side.

Analysis

Logistic regression analysis (Cohen et al., 2003) was performed to determine if the participants with unilateral, lateral patello-femoral pain also had leg length differences significantly greater than those participants without patello-femoral pain. Logistic regression predicts group membership based on values of a set of predictor variables and will indicate the best predictor of the set of variables (Tabachnik and Fidell, 1989; Cohen et al., 2003). The dichotomous grouping (dependent) variable was patello-femoral pain with two levels (presence and absence of pain). The predictor variables were four measurements:

- PALM measurement
- tape measure from ASIS to medial malleolus
- tape measure from ASIS to lateral malleolus
- Q angle.

The data were examined to determine if the longer leg had the patello-femoral pain, using a binomial test.

Since the first run of logistic regression revealed a correlation matrix with a correlation of −0.604 between the two direct measures to the medial and lateral malleoli, the direct measure to the medial malleolus (p = 0.126) was dropped. The research literature supported the direct technique of tape measure to the lateral malleolus as the more accurate of the two direct measures (Giles and Taylor, 1981) so that measure was retained for the next iteration.

RESULTS

Participants were separated into 'painful' (n = 14) and 'non-painful' (n = 38) groups based on the patello-femoral pain testing results. Since the interest of the study was a comparison between unilateral pain and no pain, data from the three participants with equal bilateral pain were discarded, reducing the number of participants from 55 to 52.

Leg length differences

Logistic regression analysis showed significant (p = 0.002) prediction value with PALM only (Table 1). Overall correct prediction was 82.7% with correct prediction of 97.4% for no patello-femoral pain and 42.0% correct prediction for patello-femoral pain. The odds ratio was 17.893 for PALM, 0.508 for direct measure to lateral malleolus and 1.017 for Q angle, showing the PALM method to be nearly 36 times as effective a predictor as direct measure and nearly 18 times as effective a predictor as Q angle. Nagelkerke R^2 was 0.260.

TABLE 1: Logistic regression analysis descriptive statistics

	Wald	*p value*	*Exp (B)*
PALMdiff	6.719	0.010†	17.893
Tapelatdiff	1.214	0.271	0.508
Qangle	0.013	0.909	1.017
Constant	5.387	0.020†	0.192

PALMdiff = difference score measured with PALM; Tapelatdiff = difference score measured by tape to the lateral malleoli; Qangle = difference score of quadriceps angle; Constant = computer-generated model.
† Significance.

In 79% (11/14) of the participants with unilateral, lateral patello-femoral pain, the pain was in the longer leg, showing a positive connection between unilateral, lateral patello-femoral pain and the longer leg when leg length inequalities exist. The binomial test approached significance ($p = 0.057$) in separation of the groups.

DISCUSSION

The research literature (Brady et al., 2003) supports measure of leg length differences through determining levelness of the pelvis. Additionally, the current research found clinical application in this indirect measure of leg length differences with leg length differences measured by the PALM method successfully predicting the presence or absence of patello-femoral pain approximately 83% of the time. It is also possible that the people 'incorrectly' classified into the pain group may eventually have patello-femoral pain because of the effect of leg length disparity over time.

The current research assessed three leg length measures and Q angle, and determined which were predictors of patello-femoral pain. The researcher conducted the testing in a way to eliminate expectation bias by testing for patello-femoral pain after all other measures were completed. Testing for the aetiology of leg length differences was beyond the scope of the present study. Additionally, the researcher identified sources of potential error in using the PALM device for measuring leg length inequalities. The discussion addresses Q angle, physiological adaptations of the longer leg and potential sources of error for the measurement device.

Q angle

Q angles of males in this study varied from 10° to 15° in the longer leg, with a mean of 13°. The findings were within the normal range for males, which is generally considered to be between 10° and 15° (Horton and Hall, 1989).

The Q angles of females in this study varied from 14° to 20° in the longer leg, with a mean of 15.9°. Since the normal range for females is generally considered to be in the 15° to 20° range (Ando et al., 1993; Guerra et al., 1994; Schulthies et al., 1995; Cowan et al., 1996; Papagelopoulos and Sim, 1997) the findings were within the normal range.

Physiological adaptations of the longer leg

There are several ways that the longer leg will functionally shorten itself when leg length inequalities exist, and many of them may increase the pressure on the lateral patello-femoral articulation (Greenfield, 1990). The pelvis can unilaterally rotate in the sagittal plane. One way that the longer leg functionally shortens itself in standing position is through posterior, unilateral rotation on the longer side (Blustein and D'Amico, 1985; Blake and Ferguson, 1992; Brady et al., 2003). Sometimes the unilateral rotation is combined with hip-hiking of the longer leg, which, in turn, is responsible for scoliotic curvature (Subotnick, 1981; Woerman and Binder-Macleod, 1984; Blustein and D'Amico, 1985; Blake and Ferguson, 1992; McCaw, 1992). At the hip joint, external rotation of the lower extremity can functionally shorten the longer leg by minimizing the toe-off function during gait (Greenfield, 1990).

At the knee, two functional adjustments are possible to effectively shorten the longer leg. Knee hyperextension and valgus deformity will each decrease the distance from the hip to the foot. Furthermore, pronation at the ankle–foot complex functionally

DOI: 10.1002/pri

decreases the length of the longer leg (Greenfield, 1990). Therefore, leg length differences left undiscovered and unmediated may cause a plethora of somatic pathology due to the body's efforts to correct the inequality. Although the adaptations seem intuitively to be a source of patello-femoral pain, research is needed to determine if these various adaptations truly lead to patello-femoral pain syndrome.

Potential error sources for PALM

While conducting the PALM measures, the researcher noted difficulty in confidently marking the ASIS on a person with a large amount of subcutaneous fat in the area of the ASIS. In this research, the data from that one person was not accepted for analysis because of the researcher's lack of confidence in securing correct placement of the tool. In a clinical setting, the PALM may not accurately assess patients with subcutaneous fat over the ASIS for this same reason, thereby limiting its use with the full range of patients.

A second source of error could come from the tester. Even though the marks placed on the skin for the ASIS probably increase the accuracy of caliper placement, the tester can move the caliper tips or skin quite easily while reading the instrument. The researcher discovered this while practising with the PALM prior to data collection. The researcher practised several times to be consistent in placement and avoid moving the skin. In a clinical setting where time is constrained, due care would need to be observed to avoid tester error.

A third source of identified error is uneven weight distribution. If the centre of gravity is skewed to one side, a false leg length difference can occur with the leg bearing the heavier weight appearing to be longer than the unloaded leg. The unloaded leg may also allow its side of the pelvis to drop, thereby increasing the error. Since the researcher wanted to promote greatest accuracy in a research setting, a pressure mat was used to maintain the centre of gravity equidistantly between the participant's feet. In the clinic, the practitioner may not have a pressure mat. In that case, the clinician should critically evaluate the patient's right–left weight distribution from the frontal plane before using the instrument to avoid this potential error.

In the present study, Q angle and the direct measurement from the ASIS to the medial malleolus or lateral malleolus were non-significant ($p = 0.936$ and 0.668, respectively) as predictors of patello-femoral pain. The Q angle method is generally supported in the research literature (Messier et al., 1990; Woodland and Francis, 1992; Caylor et al., 1993; Guerra et al., 1994; Cohen et al., 1996), but was not supported by the results of the current study.

Physiotherapists include multiple tests and measures when evaluating patients and commonly use tape measures to assess leg lengths. Although the direct tape measurement techniques are the most commonly used clinical method of measuring anatomical leg length differences, they are considered by most researchers to be very inaccurate (Heilig, 1978; Giles and Taylor, 1981; Danbert, 1988; Blake & Ferguson, 1992; Smith, 1996) and may account for the poor utility in predicting patello-femoral pain in the present study.

Eichler (1977) used 10 physicians and seven medical students to examine 25 participants. The testers recorded the values in writing and were asked not to communicate with each other. The same tape measure was used by all testers from the ASIS to the lateral malleolus but the recorded values

DOI: 10.1002/pri

showed a large variability. In accordance with Blake and Ferguson (1992), Eichler concluded that there were six reasons for error in tape measure methodology: unilateral difference in thigh circumference, unilateral log axis deviation (i.e. genu varus), inability to accurately locate the ASIS, use of the most lateral part of the lateral malleolus instead of the most distal tip, unilateral rotation of the pelvis and joint contractures.

IMPLICATIONS

The data from the present study suggest that the PALM method is promising in terms of predicting the presence or absence of patello-femoral pain. The predictive validity of this method may be linked to the greater accuracy of this and similar methods in documenting leg length differences shown previously. The PALM or a similar tool may have clinical utility for physical therapists.

ACKNOWLEDGEMENT

The palpation meter was used without charge from the manufacturer.

REFERENCES

Ando T, Hirose H, Inoue M, Shino K, Doi T. A new method using computed tomographic scan to measure the rectus femoris–patellar tendon q-angle comparison with conventional method. Clinical Orthopaedics and Related Research 1993; 289: 213–219.

Beattie P, Isaacson K, Riddle DL, Rothstein JM. Validity of derived measurements of leg-length differences obtained by use of a tape measure. Physical Therapy 1990; 70: 150–157.

Blake RL, Ferguson H. Limb length discrepancies. Journal of the American Podiatric Medical Association 1992; 82: 33–38.

Blustein SM, D'Amico JC. Limb length discrepancy. Journal of the American Podiatric Medical Association 1985; 75: 200–206.

Brady RJ, Dean JB, Skinner TM, Gross MT. Limb length inequality: clinical implications for assessment and intervention. Journal of Orthopaedic and Sports Physical Therapy 2003: 33; 221–234.

Caylor D, Fites R, Worrell TW. The relationship between quadriceps angle and anterior knee pain syndrome. Journal of Orthopaedic and Sports Physical Therapy 1993; 17: 11–16.

Cohen J, Cohen P, West SG, Aiken LS. Applied Multiple Regression/Correlation Analysis for the Behavioral Sciences (third edition). Mahwah, NJ: Lawrence Erbaum Associates, 2003.

Cowan DN, Jones BH, Frykman PN, Polly DW, Harman EA, Rosenstein RM, Rosenstein MT. Lower limb morphology and risk of overuse injury among male infantry trainees. Medical Science in Sports and Exercise 1996; 28: 945–952.

Cox JS. Patellofemoral problems in runners. Clinical Sports Medicine 1985; 4: 699–710.

Danbert RJ. Clinical assessment and treatment of leg length inequalities. Journal of Manipulative and Physiological Therapeutics 1988; 11: 290–295.

Dye SF. Patellofemoral pain: a current prospective. Journal of Musculoskeletal Medicine 2001; 18: 440. Available at: http://infotrac.galegr. . ./purl=rc1_HRCA_0_A79351726&dyn=41!ar_fmt?sw_aep=txshracd260 (accessed 5 July 2002).

Eichler J. Methodological errors in documenting leg length and leg length discrepancies. In: Hungerford DS (Ed.), Leg Length Discrepancy: The Injured Knee. New York, NY: Springer-Verlag, 1977; 29–35.

Giles LGF, Taylor JR. Low-back pain associated with leg length inequality. Spine 1981; 6: 510–521.

Gofton JP. Persistent low back pain and leg length disparity. Journal of Rheumatology 1985; 12: 747–750.

Goodfellow J, Hungerford DS, Woods C. Patellofemoral joint mechanics and pathology. Journal of Bone and Joint Surgery 1976; 58-B: 291–299.

Greenfield B. Evaluation of overuse syndromes. In: Donatelli R (Ed.), Biomechanics of the Foot and Ankle. New York, NY: FA Davis, 1990; 153–177.

Grelsamer RP, Klein JR. The biomechanics of the patellofemoral joint. Journal of Orthopedic and Sports Physical Therapy 1998; 28: 286–298.

Gross MT, Burns CB, Chapman SW, Hudson CJ, Curtis HS, Lehman JR et al. Reliability and valid-

DOI: 10.1002/pri

ity of rigid lift and pelvic leveling device method in assessing functional leg length inequality. Journal of Orthopedic and Sports Physical Therapy 1998; 27: 285–294.

Gross RH. Leg length discrepancy in marathon runners. American Journal of Sports Medicine 1983; 11: 121–124.

Guerra JP, Arnold MJ, Gajdosik RL. Q angle: effects of isometric quadriceps contraction and body position. Journal of Orthopedic and Sports Physical Therapy 1994; 19: 200–204.

Heilig D. Principles of lift therapy. Journal of the American Orthopedic Association 1978; 77: 466–472.

Horton MG, Hall TL. Quadriceps femoris muscle angle: normal values and relationships with gender and selected skeletal measures. Physical Therapy 1989; 69: 897–901.

Hungerford DS, Barry M. Biomechanics of the patellofemoral joint. Clinical Orthopaedics and Related Research 1979; 144: 9–15.

Lieb FJ, Perry J. Quadriceps function: an anatomical and mechanical study using amputated limbs. Journal of Bone and Joint Surgery 1968; 50-A: 1535–1548.

McCaw ST. Leg length inequality. Sports Medicine 1992; 14: 422–429.

Messier SP, Davis SE, Curl WW, Lowery RB, Pack RJ. Etiological factors associated with patellofemoral pain in runners. Medical Science in Sports and Exercise 1990; 23: 1008–1015.

Papagelopoulos PJ, Sim FH. Patellofemoral pain syndrome: diagnosis and management. Orthopedics 1997; 20: 148–157.

Petrone MR, Guinn J, Reddin A, Sutlive TG, Flynn TW, Garber MP. The accuracy of the palpation meter (PALM) for measuring pelvic crest height difference and leg length discrepancy. Journal of Orthopedic and Sports Physical Therapy 2003; 33: 319–325.

Powers CM. Rehabilitation of patellofemoral joint disorders: a critical review. Journal of Orthopedic and Sports Physical Therapy 1998; 28: 345–354.

Salsich GB, Brechter JH, Farwell D, Powers CM. The effects of patellar taping on knee kinetics, kinematics, and vastus lateralis muscle activity during stair ambulation in individuals with patellofemoral pain. Journal of Orthopedic and Sports Physical Therapy 2002; 32: 3–10.

Schulthies SS, Francis RS, Fisher AG, Van De Graaff KM. Does the Q angle reflect the force on the patella in the frontal plane? Physical Therapy 1995; 75: 24–30.

Smith CF. Instantaneous leg length discrepancy determination by 'thigh-leg' technique. Orthopedics 1996; 19: 955–956.

Subotnick SI. Limb length discrepancies of the lower extremity (the short leg syndrome). Journal of Orthopedic and Sports Physical Therapy 1981; 3: 11–16.

Tabachnick BG, Fidell LS. Using Multivariate Statistics (second edition). New York, NY: HarperCollins, 1989; 505–596.

Taunton JE, Ryan MB, Clement DB, McKenzie DC, Lloyd-Smith DR, Zumbo BD. A retrospective case-control analysis of 2002 running injuries. British Journal of Sports Medicine 2002; 36: 95–101.

Vigorita VJ, Morgan D. Pathology of the patella. In: Scuderi GR (Ed.), The Patella. New York, NY: Springer-Verlag, 1995; 56–67.

Wallace DA, Salem GJ, Salinas R, Powers CM. Patellofemoral joint kinetics while squatting with and without an external load. Journal of Orthopedic and Sports Physical Therapy 2002; 32: 141–148.

Woerman AL, Binder-Macleod SA. Leg length discrepancy assessment: accuracy and precision in five clinical methods of evaluation. Journal of Orthopedic and Sports Physical Therapy 1984; 5: 230–239.

Woodland LH, Francis RS. Parameters and comparisons of the quadriceps angle of college-aged men and women in the supine and standing positions. American Journal of Sports Medicine 1992; 20: 208–211.

Address correspondence to: Mary Carlson PT, PhD, College of Health Sciences, 1101 N Campbell, El Paso, Texas TX 79902, USA (E-mail: mcarlson@utep.edu).

(Submitted 26 July 2005; accepted 18 May 2006)