# Impact of Pain Reported During Isometric Quadriceps Muscle Strength Testing in People With Knee Pain: Data From the Osteoarthritis Initiative

Daniel L. Riddle, Paul W. Stratford

D.L. Riddle, PT, PhD, FAPTA, Departments of Physical Therapy and Orthopaedic Surgery, Virginia Commonwealth University, Richmond, VA 23298-0224 (USA). Address all correspondence to Dr Riddle at: dlriddle@vcu.edu.

P.W. Stratford, PT, MSc, Department of Clinical Epidemiology and Biostatistics, School of Rehabilitation Science, McMaster University, Hamilton, Ontario, Canada, and Department of Surgery, Sunnybrook Health Sciences Centre, Toronto, Ontario, Canada.

[Riddle DL, Stratford PW. Impact of pain reported during isometric quadriceps muscle strength testing in people with knee pain: data from the Osteoarthritis Initiative. *Phys Ther.* 2011;91:1478–1489.]



Published Ahead of Print: August 11, 2011
Accepted: May 22, 2011
Submitted: February 3, 2011

**Background.** Muscle force testing is one of the more common categories of diagnostic tests used in clinical practice. Clinicians have little evidence to guide interpretations of muscle force tests when pain is elicited during testing.

**Objective.** The purpose of this study was to examine the construct validity of isometric quadriceps muscle strength tests by determining whether the relationship between maximal isometric quadriceps muscle strength and functional status was influenced by pain during isometric testing.

**Design.** A cross-sectional design was used.

**Methods.** Data from the Osteoarthritis Initiative were used to identify 1,344 people with unilateral knee pain and Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) pain subscale scores of 1 or higher on the involved side. Measurements of maximal isometric quadriceps strength and ratings of pain during isometric testing were collected. Outcome variables were WOMAC physical function subscale, 20-m walk test, 400-m walk test, and a repeated chair stand test. Multiple regression models were used to determine whether pain during testing modified or confounded the relationship between strength and functional status.

**Results.** Pearson *r* correlations among the isometric quadriceps strength measures and the 4 outcome measures ranged from −.36 (95% confidence interval=−.41, −.31) for repeated chair stands to .36 (95% confidence interval=.31, .41) for the 20-m walk test. In the final analyses, neither effect modification nor confounding was found for the repeated chair stand test, the 20-m walk test, the 400-m walk test, or the WOMAC physical function subscale. Moderate or severe pain during testing was weakly associated with reduced strength, but mild pain was not.

**Limitations.** The disease spectrum was skewed toward mild or moderate symptoms, and the pain measurement scale used during muscle force testing was not ideal.

**Conclusions.** Given that the spectrum of the sample was skewed toward mild or moderate symptoms and disease, the data suggest that isometric quadriceps muscle strength tests maintain their relationship with self-report or performance-based disability measures even when pain is elicited during testing.

Reductions in skeletal muscle strength are known to be associated with many disorders encountered in clinical practice.[1–3] To quantify the extent of weakness, muscle strength testing is commonly conducted. Muscle strength usually is assessed either manually or by use of a dynamometer. These data then may be used to plan an intervention that could include exercises designed to increase strength of the involved muscle or muscle group.[4,5]

One of the reasons why muscle strength testing is commonly done in clinical practice is the presumed association between muscle strength measurement, which is used to assess system- or organ-level impairment, and activity or participation restrictions, which are person-level limitations.[6] Correlations among muscle strength and higher-order measurements such as self-reported functional status or person-level performance vary depending on the disorder, but generally have been shown to be in the low to moderate range.[3,7–12] One factor that frequently has been suggested in textbooks as a potential contraindication to manual or dynamometer-based muscle strength testing is the patient's report of pain during the test.[13–15] For example, Daniels and Worthingham suggested that the patient "should be observed closely for any evidence of discomfort or pain, and resistance should be discontinued if either occurs."[15(p3)] Kendall and colleagues also suggested that pain during testing may compromise the utility of the test.[14] Although the exact intent of these statements is unclear, these commonly used textbooks seem to imply that therapists should consider disregarding the results of muscle strength tests if pain is provoked during testing. Although these textbooks focus primarily on manual muscle tests, the same validity concerns regarding pain during testing apply to muscle strength tests performed with a dynamometer.

We found 2 reports that examined the potential impact of pain during muscle strength testing. Stevens and colleagues[16] and Mizner et al[17] assessed the extent to which pain during testing influenced muscle activation during maximal isometric quadriceps muscle contractions obtained on patients prior to and following knee replacement surgery. In the first study (N=28),[16] the authors found that knee pain during strength testing had a small but statistically significant influence on quadriceps muscle activation, whereas no influence was found in the other study (N=20).[17]

A more extensive literature search has demonstrated that muscle strength is reduced in people with a variety of disorders.[1–3] Hall and colleagues,[18] for example, found that people with knee osteoarthritis (OA) and pain had weaker isometric quadriceps muscle strength and greater Western Ontario and McMaster Universities Osteoarthritis Index physical function subscale (WOMAC-PF) scores[19] than people with knee OA but no pain. However, the pain measurement was obtained at an unreported point in time prior to and not during the isometric muscle strength test. We found no other studies that examined whether pain during testing influenced the relationship between muscle strength and functional status.

A large-scale study is needed to quantify the potential influence of pain during muscle strength testing on the relationship between muscle strength and functional status. The study would require a large sample to account for potential covariates and a well-defined and reliable method of obtaining strength measurements. The study also would require the inclusion of people with a full spectrum of disease from mild to severe in order to be generalizable to clinical settings.

The Osteoarthritis Initiative (OAI) is a 4-year National Institutes of Health–funded longitudinal cohort study of 4,796 people with knee OA or at high risk of knee OA. The OAI investigators collected data on maximal isometric quadriceps muscle strength from all participants. In addition, they determined the extent of pain during isometric strength testing. Pain during testing could act to modify the quadriceps muscle strength and functional status relationship via an interaction with quadriceps muscle strength. Alternatively, pain could be a confounder of the quadriceps muscle strength and functional status relationship by being both a significant independent predictor of functional status and by causing a shift in the magnitude of the quadriceps muscle strength coefficient when added to a regression model predicting functional status.[20]

The consistent finding of low to moderate correlations between muscle strength and functional status supports the premise that muscle strength affects functional status. If the presence of pain during testing alters the relationship between muscle strength and function, the clinical usefulness of these muscle strength tests may be compromised.

The overall aim of our study was to use OAI data to determine whether the relationship between person-level functional status and maximal isometric quadriceps muscle strength was influenced by pain during strength testing. Specifically, our primary aim was to estimate the extent to which pain severity during isometric knee extension strength testing affected the relationship between measured torque values and the 20-m walk test, 400-m walk test, chair stand test, and WOMAC-PF

scores. For these tests, we were interested in whether pain during testing acted as an effect modifier or confounding variable. A secondary purpose was to estimate the extent to which pain severity during knee extension strength testing directly affected the measured knee extension torque and 20-m walk test, 400-m walk test, chair stand test, and WOMAC-PF scores. That is, our primary aim determined whether the relationship between isometric knee extension strength and function was affected by pain during testing. The secondary aim determined whether pain during testing, examined independently from the isometric knee extensor strength measure, was associated with either reduced function or reduced isometric knee extension strength, with these latter variables treated as the dependent variables.

## Method

### The OAI

A total of 3 subcohorts (ie, control, incidence, and progression) were defined and are being followed for 4 years. Each subcohort has racially and ethnically diverse mixes of people between the ages of 45 and 79 years at baseline. Only baseline data and 2-year data were used in the present study. The baseline data for the control subcohort of 122 people without OA and who are not believed to be at risk for OA were excluded from the current study. The incidence subcohort comprises 3,285 people who either have knee pain or OA or are at risk for developing knee OA. The progression subcohort has 1,389 people with symptomatic OA in one or both knees. *Symptomatic knee OA* is defined as the presence of definite osteophytes on radiographic images and self-reported pain on most days of a month in the previous 12 months. The incidence cohort could have either radiographic evidence of definite osteophytes or self-reported pain on most days in their involved knee, but not both.

Participants were recruited from 4 clinic sites for the OAI study using a variety of approaches, including mailings to clinical populations in the 4 recruitment sites, advertisements in local newspapers, presentations to churches and community and civic organizations, and via a Web site. Participants were recruited from: (1) the University of Maryland School of Medicine in Baltimore, Maryland; (2) the Ohio State University in Columbus, Ohio; (3) the University of Pittsburgh in Pittsburgh, Pennsylvania; and (4) Memorial Hospital of Rhode Island, in Pawtucket, Rhode Island.

### OAI Study Sample

Exclusion criteria for OAI participation were the presence of rheumatoid arthritis, bilateral knee arthroplasty or pre-existing plans to undergo bilateral (not unilateral) knee arthroplasty in the next 3 years, bilateral Osteoarthritis Research Society International (OARSI) stage 3 (severe) knee OA,[21] a positive pregnancy test, inability to provide a blood sample, use of ambulatory aids other than a single straight cane for more than 50% of the time, comorbid conditions that might interfere with 4-year participation, being unlikely to reside in clinic area for at least 3 years, current participation in a double-blind randomized controlled trial, and being unwilling to sign an informed consent statement. In addition, because of magnetic resonance imaging (MRI) requirements, men weighing more than 130 kg and women weighing more than 114 kg were excluded because they were unable to undergo 3.0-tesla MRI. In total, 27% (n=4,796) of those screened (N=17,457) were admitted to the study. Common reasons for nonparticipation were dropping out after the initial telephone screen (n=3,321) and admission quotas being met for certain age and sex categories (n=2,954). See the study design protocol[22] for more detail.

### Sample for Current Study

To be included in the study, participants had to have all of the following findings: (1) a verbal pain rating of 3 or higher on a scale that read in the following way: "Please rate the pain that you've had in your right (or left) knee during the past 30 days that best describes the pain at its worst. '0' means 'No pain' and '10' means 'Pain as bad as you can imagine'"; (2) a verbal pain rating of 0 on the uninvolved side; and (3) a WOMAC pain subscale score of 1 or higher on the involved knee. We used these criteria because we wanted a sample that had unilateral knee pain that was sufficient to affect daily function. The OAI investigators required participants to complete WOMAC scales for each knee. For people with bilateral knee problems, we would be unable to judge the potential influence of the isometric quadriceps muscle test on whole person function because of the potential influences of 2 involved knees on WOMAC scores. By eliminating people with bilateral knee problems, we were able to judge the effects of quadriceps muscle tests for the involved side without concern for potential influences by a contralateral knee problem. Because the OAI study is longitudinal, we also recruited people from the 2-year follow-up who met the inclusion criteria but were not included in the baseline data set. Therefore, the study sample comprised 1,344 people with unilateral knee problems, 875 of whom were selected from the baseline data set and 469 of whom were recruited from the 2-year follow-up data set. Data from release versions 0.2.2 and 3.2.1 were used in our study.

## Outcome Variables of Interest

For the outcome measures, we chose the WOMAC-PF subscale; the 5-repetition chair stand test, measured in stands per second; the 20-m walk test, measured in meters per second; and the 400-m walk test, measured in seconds. The performance-based tests were chosen because they represent daily activities commonly performed by people with knee OA and require differing amounts of endurance, strength, and balance. The WOMAC-PF was chosen because it is a commonly used and validated scale for patients with knee OA. The WOMAC pain subscale is scored from 0 to 20, with higher scores indicating more severe pain, and the WOMAC-PF subscale is scored from 0 to 68, with higher scores indicating worse disability.[19,23–25] All measures are thoroughly described in the operations manuals.[26]

## Independent Variables

**Key independent variables of interest.** The key predictor variables of interest were: (1) maximal isometric quadriceps femoris muscle strength for the symptomatic knee of each participant, normalized to body weight, and (2) patient rating of the extent of pain during muscle testing for the symptomatic knee, rated as "none," "mild," "moderate," or "severe," or "don't know." The OAI investigators reported no evidence of reliability for pain intensity measurement using this scale. Pautex and colleagues[27] examined people with primarily arthritic pain and various levels of dementia and reported high reliability (intraclass correlation coefficient=.97) and strong associations (Spearman rho=.85–.91) between a verbal rating scale similar to that used in the OAI study and more traditional visual analog scales of pain measurement. Jensen,[28] in a systematic review of pain measures used for cancer pain, found strong associations between scales very similar to that used in the OAI study and more traditional pain intensity scales, as well as responsiveness to changes following treatment.

The Good Strength Chair (Metitur Oy, Jyvaskyla, Finland) was used to obtain isometric quadriceps muscle strength measurements. A strain gauge transducer was used to measure the force applied to the resistance pad affixed with a strap and positioned 2 cm above the individual's calcaneus. The strain gauge was calibrated with known weights once a week during the course of the study.

Participants were positioned on the chair with their back supported and arms comfortably on armrests with knees hanging over the edge of the seat. Straps were used around each participant's waist, thigh, and ankle for stabilization during testing. The knee joint line was palpated and marked with a pen. The knee to be tested was positioned at 60 degrees of flexion using a goniometer. The distance from the joint line to the transducer was measured and recorded. After the participant was correctly positioned, the examiner conducted 2 practice sessions while instructing the participant to exert 50% effort. The examiner then conducted three 100% effort trials on each knee using the following instructions:

> OK, now we will do the real test. As soon as I say "push," I want you to push as hard and as fast as you can against the pad. You're going to give a 100% effort. Hold on to the arms of the chair. Try to keep your upper body still. Just use your leg. The test will take just a few seconds. We will do 3 trials. Please don't hold your breath as you push. Just relax and exhale slowly. 3, 2, 1, ready . . . push, push, push, push, push, OK relax.

Participants were given a 30-second rest between trials, and the torque (force [in newtons] multiplied by level arm length [in centimeters]) measurements were adjusted for effects of gravity due to leg weight. All testers collecting data were trained in the use of the instrument and were required to complete a training session and a competency test prior to the study. The maximum torque produced during the 3 trials was recorded as the strength for each limb. All strength measurements were normalized by dividing by body weight. Curb and colleagues[29] used the Good Strength Chair and reported the reliability (Pearson *r*) of isometric quadriceps strength measurements obtained on 203 people aged 35 to 71 years to be .92.

Immediately following the completion of the third trial for each limb, each participant was asked the following question, "Did you have any pain during this test?" and the participant responded with "none," "mild," "moderate," "severe," or "don't know."

**Covariates.** We adjusted for age,[30] sex,[31] comorbidity,[32,33] and the presence or absence of symptomatic knee OA status.[34,35] The modified Charlson Comorbidity Index asks patients a series of questions regarding the presence and impact of 13 diseases such as heart attack, diabetes, and cancer. Scores in the OAI ranged from 0 to 10, with 70% of the sample scoring 0. We, therefore, dichotomized the score to either 0 or ≥1. The covariates were chosen because they have been shown to be related to quadriceps muscle strength and functional status in people with knee pain and arthritis.[36–43]

## Data Analysis

We calculated descriptive statistics, and they are summarized in Table 1. For our primary purpose, we gener-

ated multiple regression models for each of the following dependent variables: (1) repeated chair stand test; (2) 20-m walk test; (3) 400-m walk test; and (4) based on a subsequently described residual analysis, the square root of the WOMAC-PF subscale score. Three models were considered for each functional status measure. With the functional status measure as the dependent variable, the initial model specified quadriceps muscle strength as the independent variable and age in years, sex, baseline OA symptoms (yes, no), and comorbidity (dichotomized as 0 or ≥1) as covariates. We chose not to include a more traditional 0 to 10 verbal pain rating scale in our models for 2 reasons: (1) the focus of our study was on the relationship between pain during isometric strength tests and functional status, and (2) we were concerned about potential colinearity between the verbal pain rating and pain during isometric testing.

The intent of our first model was to estimate the relationship between torque—as portrayed by its regression coefficient—and the functional status measures without considering pain. Our second (full) model added pain severity during isometric strength testing (trichotomized as no pain, mild pain, and moderate and severe pain combined) and pain severity-by-strength interaction terms. We needed to collapse the categorical responses of "moderate" and "severe" pain during isometric strength testing because only 12 people reported severe pain during testing. Dummy variables coded 0 and 1 were applied to identify the pain severity in the isometric strength groups. The "no pain" severity group served as the reference group.

We also examined whether models generated from baseline data differed from models generated from follow-up data. This examination was accomplished by including the following 4 additional terms into the full model mentioned above: source (baseline and follow-up samples), source-by-strength interaction, source-by-pain interactions, and source-by-pain-strength interaction.

We considered effect modification as present if the 95% confidence intervals (CIs) of either of the pain severity-by-strength interaction terms excluded zero. Conceptually, an interaction exists if the modeled regression lines for a functional status measure and torque are not

**Table 1.**
Characteristics of the Sample (N=1,344)

| Variable | Mean (SD, Range) or N (%) | Missing Data (n) |
|---|---|---|
| Demographics | | |
| Age (y) | 62.3 (9.22, 45–81) | 0 |
| Female | 770 (57.3) | 0 |
| Race | | 0 |
| Other nonwhite | 28 (2.1) | |
| White or Caucasian | 1,097 (81.6) | |
| Black or African American | 207 (15.4) | |
| Asian | 12 (0.9) | |
| Comorbidity score | 0.47 (0.95, 0–7) | 32 |
| BMI (kg/m$^2$) | 28.82 (4.69, 16.9–44.6) | 37 |
| Subcohort at baseline | | 0 |
| Control[a] | 3 (0.2) | |
| Incidence | 917 (68.2) | |
| Progression | 424 (31.5) | |
| Symptom duration | | 0 |
| ≤1 y | 301 (22.4) | |
| 2–5 y | 470 (35.0) | |
| >5 y | 573 (42.6) | |
| History of traumatic knee injury | 543 (40.4) | 12 |
| Muscle tests | | |
| Isometric quadriceps muscle torque (N-cm/kg) | 121.88 (45.53, 19–339) | 170 |
| Pain during isometric testing | | 170 |
| None | 916 (77.9) | |
| Mild | 184 (15.6) | |
| Moderate/severe | 74 (6.4) | |
| Functional and performance measures | | |
| WOMAC[b] pain subscale score | 4.44 (3.20, 1–20) | 0 |
| WOMAC physical function subscale score | 12.29 (11.08, 0–68) | 12 |
| 20-m walk test (m/s) | 1.31 (0.21, 0.44–1.99) | 47 |
| 400-m walk test (s) | 309.9 (59.09, 42.09–898.13) | 100 |
| Repeated chair stand test (stands/s) | 0.50 (0.15, 0.17–1.51) | 98 |

[a] The 3 participants from the baseline control subcohort became symptomatic during follow-up and met the criteria for inclusion in the study during 2-year follow-up.
[b] WOMAC=Western Ontario and McMaster Universities Osteoarthritis Index.

parallel for the pain groups (ie, the regression lines have different slopes). In the absence of effect modification, we constructed a third model to assess whether pain severity during isometric testing was a confounding variable. Confounding exists if the modeled regression lines for a functional status measure and torque have the same slope but different y-intercepts (ie, the regression lines are parallel but not coincident). This model was similar to the second model; however, the interaction terms were removed. We considered pain severity during isometric testing to be a confounding variable if 2 conditions were met: (1) either of the 95% CIs of the regression coefficients for pain severity during isometric testing excluded zero, and (2) the isometric quadriceps muscle strength regression coefficient differed significantly from that of the first model. Our intent was to equate a significant difference in extension strength regression coefficients to literature-based estimates of an important within-patient change for the function measures. For example, Kwon and colleagues[44] reported a 50- to 60-second change in 400-m walk time to represent a substantial change for sedentary older adults. Also, from the work of Kennedy et al,[45] it is possible to estimate the minimal detectable change to be approximately 54 seconds for 400 m. Thus, if we consider 55 seconds in the 400-m walk test to be a significant difference and we apply the mean extension strength for our sample (121.9 N-cm/kg units), the extension strength regression coefficients would have to differ by 0.45. Pua et al[46] reported an important WOMAC-PF subscale score difference to be approximately 9 points.

We could not find literature-based estimates of important change for the 20-m walk test or the repeated chair stand test. However, we observed that our estimates for the 400-m walk test and the WOMAC-PF subscale were reasonably similar to the standard deviations reported for our study sample. Accordingly, we equated a significant difference in extension strength regression coefficients to be 1 standard deviation divided by the mean extension strength for our sample. Applying this approach, the requisite changes in extension strength regression coefficients were as follows: repeated chair stand test=0.001, 20-m walk test=0.002, 400-m walk test=0.484, and square root of the WOMAC-PF subscale score=0.027.

We performed analyses of covariance to estimate the effect of pain severity during isometric quadriceps muscle strength testing on function measures and isometric quadriceps muscle strength. Function measures and isometric quadriceps muscle strength were the dependent variables; pain severity during isometric testing trichotomized as no pain, mild pain, and moderate and severe pain combined was the independent variable; and sex, age, baseline OA, and comorbidity were the covariates.

Prior to conducting all analyses, we examined the distribution of continuous variable scores. Following each regression analysis, we calculated and examined jackknife residuals and leverages. Diagnostic plots included histograms of residuals, jackknife residuals versus predicted values, and jackknife residuals versus leverage values. We calculated 95% CIs for all regression coefficients. Only participants with complete data were included in the analysis. Data were analyzed using STATA 10.1 software (StataCorp LP, College Station, Texas).

## Results

The sample characteristics are summarized in Table 1. Our regression diagnostic analyses revealed that the residuals associated with WOMAC-PF subscale scores demonstrated a positive skew. The application of a square-root transformation resulted in a distribution of residuals that was consistent with a normal distribution.

Bivariate Pearson *r* correlations between the quadriceps muscle strength measures and the 4 outcome measures were as follows: square-root–transformed WOMAC-PF subscale score=−.27 (95% CI=−.32, −.21), 20-m walk test=.36 (95% CI=.31, .41), 400-m walk test=23.35 (95% CI=−.40, −.30), and repeated chair stand test=−.36 (95% CI=−.31, −.41). Tables 2, 3, 4, and 5 display regression analyses pertaining to our primary purpose. Shown in these tables are the regression coefficients and their 95% CIs.

The analyses that included sample source (baseline or 2-year follow-up) and its interactions did not provide evidence that the models differed for baseline and follow-up samples. Accordingly, our subsequent results are for the entire group.

For the repeated chair stand test, the full model analysis displayed an extension strength-by-pain during testing interaction for the moderate/severe pain group ($\beta$=0.002, 95% CI=0.001, 0.002), suggesting that effect modification was present (Tab. 2). The residual analysis revealed that 2 cases in the moderate/severe pain group displayed characteristics consistent with potential outliers. Specifically, they exerted a strong influence on the regression line.[47] When these cases were removed, neither effect modification nor confounding was evident (Tab. 2). Neither effect modification nor confounding was evident for the 20-m walk test (Tab. 3), 400-m walk test (Tab. 4), or square root of the WOMAC-PF subscale score (Tab. 5).

## Table 2.

Regression Model for Repeated Chair Stand Test (Stands/s)[a]

| | Model | | | |
|---|---|---|---|---|
| | Initial (n=1,095) | Full (n=1,093) | Two High-Influence Cases Removed (n=1,091) | Two High-Influence Cases and Interaction Removed (n=1,091) |
| Regression Term | β Coefficient (95% CI) | β Coefficient (95% CI) | β Coefficient (95% CI) | β Coefficient (95% CI) |
| Constant | 0.483 (0.414, 0.551) | 0.485 (0.414, 0.556) | 0.490 (0.420, 0.559) | 0.49 (0.419, 0.555) |
| Sex (if male)[b] | 0.006 (−0.025, 0.012) | −0.005 (−0.023, 0.013) | −0.003 (−0.020, 0.015) | −0.003 (−0.020, 0.015) |
| Age | −0.002 (−0.003, −0.001) | −0.002 (−0.003, −0.001) | −0.003 (−0.003, −0.001) | −0.002 (−0.003, −0.001) |
| Baseline OA (if no)[b] | 0.031 (0.014, 0.049) | 0.032 (0.015, 0.050) | 0.033 (0.017, 0.050) | 0.034 (0.017, 0.050) |
| Comorbidity (if none)[b] | 0.016 (−0.002, 0.035) | 0.020 (0.002, 0.038) | 0.020 (0.002, 0.038) | 0.019 (0.002, 0.037) |
| Isometric quadriceps muscle torque | 0.001 (0.001, 0.001) | 0.003 (0.002, 0.003) | 0.001 (0.001, 0.002) | 0.001 (0.0007, 0.001) |
| Pain during isometric testing[b] | | | | |
| Mild | | 0.009 (−0.050, 0.068) | 0.008 (−0.049, 0.066) | 0.002 (−0.019, 0.023) |
| Moderate/severe | | −0.169 (−0.256, −0.082) | −0.065 (−0.156, 0.25) | 0.002 (−0.030, 0.035) |
| Torque × pain interaction[b] | | | | |
| Torque × mild pain | | −0.000 (−0.001, 0.000) | −0.000 (−0.000, 0.000) | |
| Torque × moderate/severe pain | | 0.002 (0.001, 0.002) | 0.001 (−0.000, 0.001) | |
| $R^2$ | 0.166 | 0.186 | 0.166 | 0.163 |

[a] CI=confidence interval, OA=osteoarthritis.
[b] Variable coding: 1 if male, 0 if female; 1 if baseline OA no, 0 if yes; 1 if no comorbidities, 0 if 1 or more comorbidities; 1 if pain severity mild, 0 if otherwise; 1 if pain severity moderate/severe, 0 if otherwise.

## Table 3.

Regression Model for 20-m Walk Test (m/s)[a]

| | Model | | |
|---|---|---|---|
| | Initial (n=1,148) | Full (n=1,146) | Interaction Removed (n=1,146) |
| Regression Term | β Coefficient (95% CI) | β Coefficient (95% CI) | β Coefficient (95% CI) |
| Constant | 1.345 (1.252, 1.438) | 1.34 (1.246, 1.440) | 1.34 (1.240, 1.430) |
| Sex (if male)[b] | 0.018 (−0.006, 0.043) | 0.018 (−0.007, 0.043) | 0.18 (−0.007, 0.043) |
| Age | −0.004 (−0.005, −0.002) | −0.004 (−0.005, −0.003) | −0.004 (−0.005, −0.003) |
| Baseline OA (if no)[b] | 0.039 (0.015, 0.062) | 0.039 (0.016, 0.063) | 0.040 (0.016, 0.063) |
| Comorbidity (if none)[b] | 0.051 (0.026, 0.76) | 0.053 (0.028, 0.078) | 0.052 (0.027, 0.077) |
| Isometric quadriceps muscle torque | 0.001 (0.001, 0.002) | 0.002 (0.001, 0.003) | 0.001 (0.001, 0.002) |
| Pain during isometric testing[b] | | | |
| Mild | | −0.015 (−0.096, 0.065) | 0.003 (−0.027, 0.033) |
| Moderate/severe | | −0.037 (−0.154, 0.080) | 0.017 (−0.028, 0.063) |
| Torque × pain interaction[b] | | | |
| Torque × mild pain | | 0.000 (−0.00, 0.001) | |
| Torque × moderate/severe pain | | 0.000 (−0.000, 0.001) | |
| $R^2$ | 0.187 | 0.188 | 0.187 |

[a] CI=confidence interval, OA=osteoarthritis.
[b] Variable coding: 1 if male, 0 if female; 1 if baseline OA no, 0 if yes; 1 if no comorbidities, 0 if 1 or more comorbidities; 1 if pain severity mild, 0 if otherwise; 1 if pain severity moderate/severe, 0 if otherwise.

## Table 4.

Regression Model for 400-m Walk Test (s)[a]

| | Model | | |
|---|---|---|---|
| | Initial (n=1,103) | Full (n=1,101) | Interaction Removed (n=1,101) |
| Regression Term | β Coefficient (95% CI) | β Coefficient (95% CI) | β Coefficient (95% CI) |
| Constant | 299.50 (27.0, 326.92) | 294.11 (265.80, 322.43) | 297.81 (270.19, 325.43) |
| Sex (if male)[b] | −10.38 (−17.73, −3.03) | −10.42 (−17.69, −3.15) | −10.31 (−17.57, −3.04) |
| Age | 1.14 (0.78, 1.50) | 1.19 (0.83, 1.55) | 1.18 (0.82, 1.54) |
| Baseline OA (if no)[b] | −10.82 (−17.68, −3.95) | −10.33 (−17.14, −3.51) | −10.47 (−17.28, −3.66) |
| Comorbidity (if none)[b] | −11.66 (−19.06, −4.25) | −11.28 (−18.61, −3.94) | −11.10 (−18.42, −3.77) |
| Isometric quadriceps muscle torque | −0.32 (−0.41, −0.24) | −0.46 (−0.74, −0.18) | −0.33 (−0.41, −0.25) |
| Pain during isometric testing[b] | | | |
| Mild | | 9.02 (−14.40, 32.44) | −1.05 (−9.83, 7.73) |
| Moderate/severe | | 19.51 (−14.94, 53.97) | 1.78 (−11.44, 15.00) |
| Torque × pain interaction[b] | | | |
| Torque × mild pain | | −0.08 (−0.26, 0.09) | |
| Torque × moderate/severe pain | | −0.16 (−0.45, 0.13) | |
| $R^2$ | 0.171 | 0.181 | 0.179 |

[a] CI=confidence interval, OA=osteoarthritis.
[b] Variable coding: 1 if male, 0 if female; 1 if baseline OA no, 0 if yes; 1 if no comorbidities, 0 if 1 or more comorbidities; 1 if pain severity mild, 0 if otherwise; 1 if pain severity moderate/severe, 0 if otherwise.

## Table 5.

Regression Model for Square-Root–Transformed Western Ontario and McMaster Universities Osteoarthritis Index Physical Function Subscale Scores[a]

| | Model | | |
|---|---|---|---|
| | Initial (n=1,147) | Full (n=1,145) | Interaction Removed (n=1,145) |
| Regression Term | β Coefficient (95% CI) | β Coefficient (95% CI) | β Coefficient (95% CI) |
| Constant | 5.55 (4.78, 6.31) | 5.13 (4.33, 5.92) | 5.21 (4.44, 5.98) |
| Sex (if male)[b] | 0.08 (−0.13, 0.28) | 0.07 (−0.13, 0.27) | 0.07 (−0.13, 0.27) |
| Age | −0.01 (−0.02, 0.00) | −0.01 (−0.02, 0.01) | −0.01 (−0.02, 0.01) |
| Baseline OA (if no)[b] | −0.85 (−1.04, −0.66) | −0.81 (−1.00, −0.62) | −0.81 (−1.00, −0.62) |
| Comorbidity (if none)[b] | −0.29 (−0.50, −0.09) | −0.26 (−0.47, −0.06) | −0.27 (−0.47, −0.06) |
| Isometric quadriceps muscle torque | −0.01 (−0.01, −0.01) | −0.01 (−0.01, −0.01) | −0.01 (−0.12, 0.01) |
| Pain during isometric testing[b] | | | |
| Mild | | 0.69 (0.04, 1.34) | 0.30 (0.05, 0.54) |
| Moderate/severe | | 0.71 (−0.24, 1.66) | 0.96 (0.60, 1.33) |
| Torque × pain interaction[b] | | | |
| Torque × mild pain | | −0.00 (−0.01, 0.00) | |
| Torque × moderate/severe pain | | 0.00 (−0.01, 0.01) | |
| $R^2$ | 0.142 | 0.166 | 0.164 |

[a] CI=confidence interval, OA=osteoarthritis.
[b] Variable coding: 1 if male, 0 if female; 1 if baseline OA no, 0 if yes; 1 if no comorbidities, 0 if 1 or more comorbidities; 1 if pain severity mild, 0 if otherwise; 1 if pain severity moderate/severe, 0 if otherwise.

**Table 6.**
Effect of Pain During Isometric Testing on Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) Physical Function Subscale Scores and Extension Torque[a]

| | Regression Coefficients | |
|---|---|---|
| | $\sqrt{\text{WOMAC Disability}}$ (n=1,152) | Isometric Quadriceps Muscle Torque (n=1,150) |
| Regression Term | $\beta$ Coefficient (95% CI) | $\beta$ Coefficient (95% CI) |
| Constant | 3.79 (3.08, 4.50) | 148.06 (130.45, 165.65) |
| Sex (if male)[b] | −0.33 (−0.51, −0.15) | 42.90 (38.38, 47.42) |
| Age | 0.001 (−0.009, 0.11) | −0.86 (−1.11, −0.61) |
| Baseline OA (if no)[b] | −0.86 (−1.06, −0.67) | 4.83 (−0.01, 9.67) |
| Comorbidity (if none)[b] | −0.35 (−0.55, −0.14) | 9.41 (4.30, 14.53) |
| Pain during isometric testing[b] | | |
| Mild | 0.35 (0.10, 0.60) | −6.00 (−12.23, 0.23) |
| Moderate/severe | 1.10 (0.73, 1.47) | −12.46 (−21.77, −3.16) |
| $R^2$ | 0.11 | 0.28 |

[a] CI=confidence interval, OA=osteoarthritis.
[b] Variable coding: 1 if male, 0 if female; 1 if baseline OA no, 0 if yes; 1 if no comorbidities, 0 if 1 or more comorbidities; 1 if pain severity mild, 0 if otherwise; 1 if pain severity moderate/severe, 0 if otherwise.

Table 6 reports the effects of pain severity during isometric testing on function and isometric quadriceps muscle strength adjusted for sex, age, baseline OA, and comorbidity. The key difference between the regression models reported in Tables 2, 3, 4, and 5, which examined for effect modification and confounding, and the models in Table 6 is that the models in this table did not include the isometric knee strength variable as a covariate. Rather, the models in Table 6 examined the independent effect of pain during testing without including isometric strength measure as a covariate. Regression models for the repeated chair stand test, 20-m walk test, and 400-m walk test are not shown because pain during testing was not related to these dependent measures. Pain severity during isometric testing was associated with WOMAC-PF subscale scores and isometric quadriceps muscle strength values. For the WOMAC-PF subscale, the regression coefficients for participants who reported mild and moderate/severe pain during testing were statistically greater than those for participants who reported no pain. The regression coefficients for mild and moderate/severe pain during testing were 0.35 and 1.10, respectively. These coefficient values correspond to an increase in WOMAC-PF subscale scores of 0.12 ($0.35^2$) for mild pain during testing and 1.21 ($1.10^2$) for moderate/severe pain during testing relative to the no-pain group, after adjustment for the other variables in the model. Pain severity during isometric testing also influenced isometric quadriceps muscle strength such that for participants who reported moderate/severe pain, the regression coefficient was −12.46 N-cm/kg relative to that of the no-pain group. The extension strength 95% CI for participants who reported mild pain during testing included zero.

## Discussion

We found that pain experienced during maximal isometric quadriceps strength tests did not affect the construct validity of the tests, as defined in this study. The relationships between strength measures and the 3 performance measures as well as self-reported disability were unaffected by pain reports during isometric testing. These findings have implications for clinicians examining patients with knee problems. Muscle strength tests are among the more commonly conducted tests in clinical practice. Traditional wisdom has suggested that muscle strength tests may not provide clinically useful information when patients complain of pain during testing. Our study provides evidence to suggest that the isometric quadriceps muscle strength/functional status relationship is unaffected by reports of increased pain during testing. Correlations between quadriceps muscle strength and function, although in the low to moderate range, indicate that even in the presence of pain, muscle strength tests are associated with measures that are highly important to patients (ie, measures of self-reported function and performance of daily tasks). Our study is the first, to our knowledge, that has examined the potential impact of pain during testing on the strength and functional status relationship.

The magnitudes of the bivariate correlations between quadriceps muscle strength and self-report and performance measures were in the range of −.36 to .36 and are consistent with other evidence on similar samples of people with knee pain and knee OA. For example, Wood and colleagues[11] examined the relationship between quadriceps muscle strength and WOMAC-PF subscale scores among 819 community-dwelling older adults with knee pain and found a correlation of −.37. Other studies have shown higher correlations between WOMAC scores and quadriceps muscle strength measures. For example, van der Esch and colleagues[48] found a correlation (Pearson $r$) of −.55 between

WOMAC-PF subscale scores and quadriceps muscle strength measures. The sample in their study comprised people with a disease spectrum that was approximately equivalent to those scheduled for knee arthroplasty.[49] We suspect this more serious disease spectrum may have led to the higher correlation. Participants in the OAI study generally have milder disease and associated higher function, which the WOMAC is not as adept at measuring.[50]

The finding of a slightly higher correlation between quadriceps muscle strength and the 3 performance measures (repeated chair stand test, 20-m walk test, and 400-m walk test) (Pearson $r=.35$ or $\pm.36$) versus the correlation between quadriceps muscle strength and WOMAC-PF subscale scores (Pearson $r=.28$) is not surprising. The WOMAC-PF subscale captures a large variety of 17 activities and, therefore, would be expected to demonstrate a lower correlation with quadriceps muscle strength compared with more specific individual performance tests. The explained variance in our models ranged from 17% to 19% and is consistent with other work using multivariable approaches to predict performance in patients with knee pain.[51]

Pain during testing examined separately from isometric quadriceps muscle strength was not associated with the performance-based tests but was found to be associated with WOMAC-PF subscale and extension torque measures (Tab. 6). Participants with moderate or severe pain during testing had WOMAC-PF subscale scores that were 1.21 points higher than those of participants with no pain during testing, a small difference that is not clinically important at an individual patient level.[46] Participants with moderate or severe pain during testing had approximately 10% lower strength scores than the average for the entire sample, but participants with mild pain had strength scores that were not significantly different from those of participants with no pain. Pain during testing had a weak influence on strength and self-reported disability but only for people with moderate or severe pain.

An incidental finding of our study was the role that age played in the different full models depicted in Tables 2, 3, 4, and 5. Age was not a significant predictor ($P=.17$) in the model predicting WOMAC-PF subscale scores but was consistently a highly significant predictor ($P<.001$) in the 3 performance-based models. These data suggest that self-report measures may not account for age-related differences that exist when individuals actually perform daily tasks. Self-report measures such as the WOMAC may be limited in that they do not appear to account for known age-related differences in actual performance. Other evidence has shown additional limitations of self-report measures such as the WOMAC.[52]

## Limitations

We did not examine the criterion-related validity of isometric quadriceps muscle strength measures for inferring a person's true maximal strength. Rather, we examined the construct validity of isometric quadriceps muscle strength tests when pain is elicited during testing. Our sample was somewhat limited in that the spectrum of disease represented in the OAI data set favors milder disease. As a result, we had a relatively small number of people who reported moderate or severe pain during testing (n=76). Despite this relatively small number, our findings were robust and consistent across the different outcome measures, which suggests that sample variation was adequate to answer our research questions. We adjusted for comorbidity but not for pain in other regions of the body, which may have influenced our findings.

The pain measure used during isometric quadriceps muscle strength testing is admittedly crude, with unknown measurement properties in this population of patients. In addition, a dynamometer was used, so the results may not apply to manual muscle tests. The findings of a lack of confounding or effect modification apply only to isometric tests and not necessarily to other types of strength tests or to patients with other disorders. Our sample was skewed toward mild disease with only minimal amounts of pain and compromised function. It may be that reports of pain during strength testing are a less rare event in samples of patients who report more severe daily pain and functional loss. Use of evidence-based estimates to interpret our beta coefficients when assessing for confounding may not be accurate, and we were unable to identify literature-based estimates for the 20-m walk test or the repeated chair standing test. Finally, because little work has been done on this topic, we chose to frame our study as one of parameter estimation rather than hypothesis testing. Accordingly, no power calculations were performed.

In conclusion, we found that pain during maximal isometric quadriceps muscle strength testing neither modifies nor confounds the relationship between quadriceps muscle strength and either WOMAC-PF subscale scores nor the 3 performance measures. Acknowledging that most of the people in our sample had mild or moderate disease, our findings suggest that isometric quadriceps muscle strength tests maintain their relationship with self-report or performance-based disability mea-

sures even when pain is elicited during testing.

Both authors provided concept/idea/research design, writing, and data analysis. Dr Riddle provided project management. Mr Stratford provided consultation (including review of manuscript before submission).

The study was approved by the institutional review board at the Osteoarthritis Initiative (OAI) Coordinating Center, the University of California at San Francisco.

The OAI is a public-private partnership comprising 5 contracts (N01-AR-2-2258, N01-AR-2-2259, N01-AR-2-2260, N01-AR-2-2261, and N01-AR-2-2262) funded by the National Institutes of Health, a branch of the US Department of Health and Human Services, and conducted by the OAI study investigators. Private funding partners include Merck Research Laboratories, Novartis Pharmaceuticals Corporation, GlaxoSmithKline, and Pfizer Inc. Private sector funding for the OAI is managed by the Foundation for the National Institutes of Health. The manuscript was prepared using an OAI public use data set and does not necessarily reflect the opinions or views of the OAI investigators, the National Institutes of Health, or the private funding partners. The investigators in this study are not part of the OAI investigative team.

The authors did not have any financial support or other benefits from commercial sources for the work reported on in the article or any other financial interests that could create a potential conflict of interest or the appearance of a conflict of interest with regard to the work.

DOI: 10.2522/ptj.20110034

## References

1 Chambers MA, Moylan JS, Reid MB. Physical inactivity and muscle weakness in the critically ill. *Crit Care Med.* 2009;37(10 suppl):S337–S346.

2 Fransen M, McConnell S, Bell M. Exercise for osteoarthritis of the hip or knee. *Cochrane Database Syst Rev.* 2003;(3): CD004286.

3 Reid KF, Naumova EN, Carabello RJ, et al. Lower extremity muscle mass predicts functional performance in mobility-limited elders. *J Nutr Health Aging.* 2008;12: 493–498.

4 Farquhar SJ, Chmielewski TL, Snyder-Mackler L. Accuracy of predicting maximal quadriceps force from submaximal effort contractions after anterior cruciate ligament injury. *Muscle Nerve.* 2005;32: 500–505.

5 Kent-Braun JA, Le Blanc R. Quantitation of central activation failure during maximal voluntary contractions in humans. *Muscle Nerve.* 1996;19:861–869.

6 *International Classification of Functioning, Disability and Health: ICF*. Geneva, Switzerland: World Health Organization; 2001.

7 Hazard RG, Haugh LD, Green PA, Jones PL. Chronic low back pain: the relationship between patient satisfaction and pain, impairment, and disability outcomes. *Spine (Phila Pa 1976).* 1994;19:881–887.

8 O'Reilly SC, Jones A, Muir KR, Doherty M. Quadriceps weakness in knee osteoarthritis: the effect on pain and disability. *Ann Rheum Dis.* 1998;57:588–594.

9 Thompson DP, Urmston M, Oldham JA, Woby SR. The association between cognitive factors, pain and disability in patients with idiopathic chronic neck pain. *Disabil Rehabil.* 2010;32:1758–1767.

10 Tyson SF, Hanley M, Chillala J, et al. Sensory loss in hospital-admitted people with stroke: characteristics, associated factors, and relationship with function. *Neurorehabil Neural Repair.* 2008;22:166–172.

11 Wood L, Peat G, Thomas E, et al. Associations between physical examination and self-reported physical function in older community-dwelling adults with knee pain. *Phys Ther.* 2008;88:33–42.

12 Almeida GJ, Schroeder CA, Gil AB, et al. Interrater reliability and validity of the stair ascend/descend test in subjects with total knee arthroplasty. *Arch Phys Med Rehabil.* 2010;91:932–938.

13 Reese NB. *Muscle and Sensory Testing*. 2nd ed. St Louis, MO: Elsevier Saunders; 2005.

14 Kendall FP, Provance P, McCreary EK. *Muscles: Testing and Function*. 4th ed. Baltimore, MD: Williams & Wilkins; 1993.

15 Daniels L, Worthingham C. *Muscle Testing Techniques of Manual Examination*. 5th ed. Philadelphia, PA: WB Saunders Co; 1986.

16 Stevens JE, Mizner RL, Snyder-Mackler L. Quadriceps strength and volitional activation before and after total knee arthroplasty for osteoarthritis. *J Orthop Res.* 2003;21:775–779.

17 Mizner RL, Petterson SC, Stevens JE, et al. Early quadriceps strength loss after total knee arthroplasty: the contributions of muscle atrophy and failure of voluntary muscle activation. *J Bone Joint Surg Am.* 2005;87:1047–1053.

18 Hall MC, Mockett SP, Doherty M. Relative impact of radiographic osteoarthritis and pain on quadriceps strength, proprioception, static postural sway and lower limb function. *Ann Rheum Dis.* 2006;65: 865–870.

19 Bellamy N, Buchanan WW, Goldsmith CH, et al. Validation study of WOMAC: a health status instrument for measuring clinically important patient relevant outcomes to antirheumatic drug therapy in patients with osteoarthritis of the hip or knee. *J Rheumatol.* 1988;15:1833–1840.

20 Woodward M. *Epidemiology Study Design and Data Analysis*. New York, NY: Chapman & Hall/CRC; 1999.

21 Altman RD, Hochberg M, Murphy WA Jr, et al. Atlas of individual radiographic features in osteoarthritis. *Osteoarthritis Cartilage.* 1995;3(suppl A):3–70.

22 Osteoarthritis Initiative study design protocol. Available at: http://www.oai.ucsf.edu/datarelease/docs/StudyDesignProtocol.pdf.

23 Bellamy N, Buchanan WW. A preliminary evaluation of the dimensionality and clinical importance of pain and disability in osteoarthritis of the hip and knee. *Clin Rheumatol.* 1986;5:231–241.

24 Bellamy N, Kirwan J, Boers M, et al. Recommendations for a core set of outcome measures for future phase III clinical trials in knee, hip, and hand osteoarthritis: consensus development at OMERACT III. *J Rheumatol.* 1997;24:799–802.

25 Bellamy N. The WOMAC Knee and Hip Osteoarthritis Indices: development, validation, globalization and influence on the development of the AUSCAN Hand Osteoarthritis Indices. *Clin Exp Rheumatol.* 2005;23(5 suppl 39):S148–S153.

26 Osteoarthritis Initiative operations manuals. Available at: http://www.oai.ucsf.edu/datarelease/OperationsManuals.asp.

27 Pautex S, Herrmann F, Le Lous P, et al. Feasibility and reliability of four pain self-assessment scales and correlation with an observational rating scale in hospitalized elderly demented patients. *J Gerontol A Biol Sci Med Sci.* 2005;60:524–529.

28 Jensen MP. The validity and reliability of pain measures in adults with cancer. *J Pain.* 2003;4:2–21.

29 Curb JD, Ceria-Ulep CD, Rodriguez BL, et al. Performance-based measures of physical function for high-function populations. *J Am Geriatr Soc.* 2006;54:737–742.

30 Low Choy NL, Brauer SG, Nitz JC. Age-related changes in strength and somatosensation during midlife: rationale for targeted preventive intervention programs. *Ann N Y Acad Sci.* 2007;1114:180–193.

31 Petterson SC, Raisis L, Bodenstab A, Snyder-Mackler L. Disease-specific gender differences among total knee arthroplasty candidates. *J Bone Joint Surg Am.* 2007; 89:2327–2333.

32 van Dijk GM, Veenhof C, Lankhorst GJ, Dekker J. Limitations in activities in patients with osteoarthritis of the hip or knee: the relationship with body functions, comorbidity and cognitive functioning. *Disabil Rehabil.* 2009;31:1685–1691.

33 Katz JN, Chang LC, Sangha O, et al. Can comorbidity be measured by questionnaire rather than medical record review? *Med Care.* 1996;34:73–84.

34 Palmieri-Smith RM, Thomas AC, Karvonen-Gutierrez C, Sowers MF. Isometric quadriceps strength in women with mild, moderate, and severe knee osteoarthritis. *Am J Phys Med Rehabil.* 2010;89:541–548.

**35** Baker KR, Xu L, Zhang Y, et al. Quadriceps weakness and its relationship to tibiofemoral and patellofemoral knee osteoarthritis in Chinese: the Beijing osteoarthritis study. *Arthritis Rheum.* 2004;50:1815–1821.

**36** Amin S, Baker K, Niu J, et al. Quadriceps strength and the risk of cartilage loss and symptom progression in knee osteoarthritis. *Arthritis Rheum.* 2009;60:189–198.

**37** Belo JN, Berger MY, Reijman M, et al. Prognostic factors of progression of osteoarthritis of the knee: a systematic review of observational studies. *Arthritis Rheum.* 2007;57:13–26.

**38** Belo JN, Berger MY, Koes BW, Bierma-Zeinstra SM. Prognostic factors in adults with knee pain in general practice. *Arthritis Rheum.* 2009;61:143–151.

**39** Dunlop DD, Semanik P, Song J, et al. Risk factors for functional decline in older adults with arthritis. *Arthritis Rheum.* 2005;52:1274–1282.

**40** Mallen CD, Peat G, Thomas E, et al. Predicting poor functional outcome in community-dwelling older adults with knee pain: prognostic value of generic indicators. *Ann Rheum Dis.* 2007;66:1456–1461.

**41** Peters TJ, Sanders C, Dieppe P, Donovan J. Factors associated with change in pain and disability over time: a community-based prospective observational study of hip and knee osteoarthritis. *Br J Gen Pract.* 2005;55:205–211.

**42** Roos EM, Bremander AB, Englund M, Lohmander LS. Change in self-reported outcomes and objective physical function over 7 years in middle-aged subjects with or at high risk of knee osteoarthritis. *Ann Rheum Dis.* 2008;67:505–510.

**43** Sharma L, Cahue S, Song J, et al. Physical functioning over three years in knee osteoarthritis: role of psychosocial, local mechanical, and neuromuscular factors. *Arthritis Rheum.* 2003;48:3359–3370.

**44** Kwon S, Perera S, Pahor M, et al. What is a meaningful change in physical performance: findings from a clinical trial in older adults (the LIFE-P study). *J Nutr Health Aging.* 2009;13:538–544.

**45** Kennedy DM, Stratford PW, Wessel J, et al. Assessing stability and change of four performance measures: a longitudinal study evaluating outcome following total hip and knee arthroplasty. *BMC Musculoskelet Disord.* 2005;6:3.

**46** Pua YH, Cowan SM, Wrigley TV, Bennell KL. The Lower Extremity Functional Scale could be an alternative to the Western Ontario and McMaster Universities Osteoarthritis Index physical function scale. *J Clin Epidemiol.* 2009;62:1103–1111.

**47** Kleinbaum DG, Kupper LL, Nizam A, Muller KE. *Applied Regression Analysis and Other Multivariables Methods.* 4th ed. Boston, MA: Duxbury; 2008.

**48** van der Esch M, Steultjens M, Harlaar J, et al. Joint proprioception, muscle strength, and functional ability in patients with osteoarthritis of the knee. *Arthritis Rheum.* 2007;57:787–793.

**49** Riddle DL, Wade JB, Jiranek WA, Kong X. Preoperative pain catastrophizing predicts pain outcome after knee arthroplasty. *Clin Orthop Relat Res.* 2010;468:798–806.

**50** Roos EM, Lohmander LS. The Knee injury and Osteoarthritis Outcome Score (KOOS): from joint injury to osteoarthritis. *Health Qual Life Outcomes.* 2003;1:64.

**51** Lim BW, Hinman RS, Wrigley TV, Bennell KL. Varus malalignment and its association with impairments and functional limitations in medial knee osteoarthritis. *Arthritis Rheum.* 2008;59:935–942.

**52** Stratford PW, Kennedy DM, Maly MR, Macintyre NJ. Quantifying self-report measures' overestimation of mobility scores postarthroplasty. *Phys Ther.* 2010;90:1288–1296.