The Relationship Between the Knee Adduction Moment and Knee Pain in Middle-aged Women Without Radiographic Osteoarthritis

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ABSTRACT. ***Objective***. An abnormally high knee adduction moment increases the medial tibiofemoral compartment load at the knee during gait, and is an important biomechanical marker of joint pathology. This cross-sectional study examines the relationship between the knee adduction moment and knee pain in middle-aged women without radiographic knee osteoarthritis (OA).

Methods. Three-dimensional Vicon gait analyses were performed on 20 women who had knee pain but no radiological evidence of joint pathology.

Results. In multivariate analysis, the peak knee adduction moment during the late stance phase of gait was inversely associated with knee pain [ß: -10.1 (95% CI -17.6, -2.7), p = 0.01] after adjustment for body mass index (BMI) and age. This explained that the knee adduction moment during late stance contributed 32% of the variance in knee pain. The peak knee adduction moment during early stance was not significantly associated with knee pain prior to and after adjustment for BMI and age.

Conclusion. There is a significant inverse association between the peak knee adduction moment during late stance and the amount of knee pain experienced by women without radiographic evidence of joint pathology. This may represent a compensatory mechanism to reduce medial tibiofemoral joint load in the setting of knee pain. (J Rheumatol 2006;33:1845–8)

Key Indexing Terms:
KNEE PAIN ADDUCTION MOMENT GAIT OSTEOARTHRITIS

Knee pain is a major problem[1], with one-quarter of people over age 55 years in Europe experiencing an episode of persistent knee pain in the past year[2]. Additionally, knee pain is more common than back pain in older adults[3] and has been touted as the latest musculoskeletal "epidemic." Nevertheless, knee pain is not necessarily accompanied by significant joint pathology, and its association with radiographic osteoarthritis (OA) is poor[4]. In people with established knee OA, the prevalence of knee pain rises with increasing radiographic severity of joint pathology[5]. These data indicate that knee pain is a major problem in people with and without significant pathology.

Biomechanical factors are likely to be important in the development of knee pain, although it is unclear how gait kinetics and kinematics are related to symptoms such as knee pain. The knee adduction moment concentrates joint load to the medial tibiofemoral compartment during the stance phase of gait, and has been associated with longitudinal development of chronic knee pain[6]. However, knee pain is inversely associated with the knee adduction moment in people with symptomatic radiographic knee OA[7]. This inverse relationship between pain and knee joint kinetics may represent a compensatory mechanism to reduce medial tibiofemoral load and subsequent pain in the setting of knee OA. Whether similar trends are apparent in people without radiographic evidence of knee OA who are experiencing knee pain is unclear. To determine this, we used a cross-sectional study to examine the relationship between the knee adduction moment during the stance phase of gait and self-reported knee pain in 20 women without radiological OA of the knee.

MATERIALS AND METHODS

Subjects. Twenty women were selected for this study from an existing database from our department examining healthy aging, as described[8]. Initially, all subjects were recruited on the basis of being pain-free [< 2 cm on a visual analog scale (VAS)] and free of radiographic knee OA in their dominant knee at baseline. At a 2 year followup, the first 20 women who agreed to par-

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ticipate in gait analyses were included. These women completed the Western Ontario and McMaster University Osteoarthritis Index (WOMAC) to assess their level of knee pain on the same day as gait analyses (Table 1). This study was approved by the Alfred Hospital ethics committee. All subjects gave written informed consent to participate.

The exclusion criteria were a history of knee OA or symptoms requiring medical treatment [e.g., use of nonsteroidal antiinflammatory drugs (NSAID)], inflammatory arthritis, planned or previous knee joint replacement, malignancy, fracture in the last 10 years, inability to walk 50 feet without the use of assistive devices, hemiparesis, and any other musculoskeletal, cardiovascular, or neurological conditions that would impair normal gait. Subjects with evidence of radiographic knee OA at baseline, such as osteophytes, bony cysts, joint space narrowing, and subchondral sclerosis were excluded.

Gait analyses. Three-dimensional (3-D) gait analyses were conducted in the Musculoskeletal Research Centre, La Trobe University, Australia. A 6-camera Vicon motion analysis system® (Oxford Metrics, Oxford, UK) was used to capture 3-D data during 4 walking trials on a 14 meter hard-surfaced walking track at a frequency of 50 Hz. Ground reaction forces were measured by a Kistler 9281 force-platform (Kistler Instruments, Winterthur, Switzerland) that was positioned at the midpoint of the walking track. Subjects were blinded to the position of the force-platform to ensure that their gait patterns were unchanged on the approach to the platform. When the participant clearly struck the force-platform with the foot of the limb desired for analyses, the trial was considered successful. Inverse dynamic analyses were performed using "PlugInGait" (Oxford Metrics) software, as described[9], to obtain external joint moments calculated about an orthogonal axis system located in the distal segment of the joint. Peak external knee adduction moments (Nm × kg^{-1}) during early and late stance were recorded while the subjects were instructed to walk without footwear at a normal pace to capture their natural gait patterns (Figure 1). These moments were then normalized to a percentage of body mass multiplied by height, in accord with the literature describing knee adductor moments[6,7].

Infrared markers and a knee alignment device (KAD) were placed in accord with the specifications recommended by the Vicon Clinical Manager's User Manual[10]. Markers were placed on the left and right anterior superior iliac spine, thigh (lower lateral third), ankle (lateral malleoli), shank (lower third), forefoot (second metatarsal head on the midfoot side of the equines break between the forefoot and midfoot), heel (such that a line joining the forefoot markers reflected the long axis of the foot), and sacrum.

Anthropometric analyses. Body mass index (BMI) (kg/m^2) was calculated by measuring mass to the nearest 0.1 kg (shoes and bulky clothing removed) using a single pair of electronic scales and measuring height to the nearest 0.1 cm (shoes removed) using a stadiometer.

Knee radiography. Standard knee radiographs were performed (anteroposterior, lateral, and skyline) to assess for radiographic OA at study entry, on each subject's dominant knee, which was defined as the knee the subject stepped off from when initiating walking.

Assessing knee pain. Knee pain was measured by summing the 5 measures in the pain dimension of the WOMAC, where each measure was determined by a 10 cm VAS[11]. Higher scores on the WOMAC indicated greater levels of reported pain. The WOMAC VAS is a valid and reliable tool for assessing knee pain in people with joint pathology, and has also been used in normal knees[12,13].

Statistical analyses. The gait data were initially examined for features that would impede interpretation such as non-normality, non-linearity of the associations, and outlying observations. Analyses were performed on the dominant leg only, since combining the right and left leg fails to acknowledge independence between knees or possible asymmetrical alignment of the lower limbs. The knee adduction moments occurring at early and late stance were individually averaged over 4 trials and peak values were reported (Table 1, Figure 1). Linear regression analysis was used to determine the relationship between pain and the knee adduction moment. The confounders age and BMI were entered into the regression model in a single step. Pain was regarded as the predictor variable and the peak knee adduction moment was considered the outcome variable. Results with $p < 0.05$ (2-tailed) were considered to be statistically significant. All analyses were performed using SPSS (version 12, SPSS, Cary, NC, USA).

Table 1. Mean magnitudes of biomechanical and pain data*.

	Mean
Knee adduction moment (early stance)†	4.1 (1.0)
Knee adduction moment (late stance)†	2.1 (0.7)
Pain (WOMAC)	15.4 (12.1)

* Results reported as mean (± standard deviation). † Adduction moments are normalized to percentage body weight (kg) multiplied by height (m).

RESULTS

The mean age of the 20 participating women was 61.0 ± 5.3 years. The mean BMI was 25.3 ± 4.2 kg/m^2 and the average

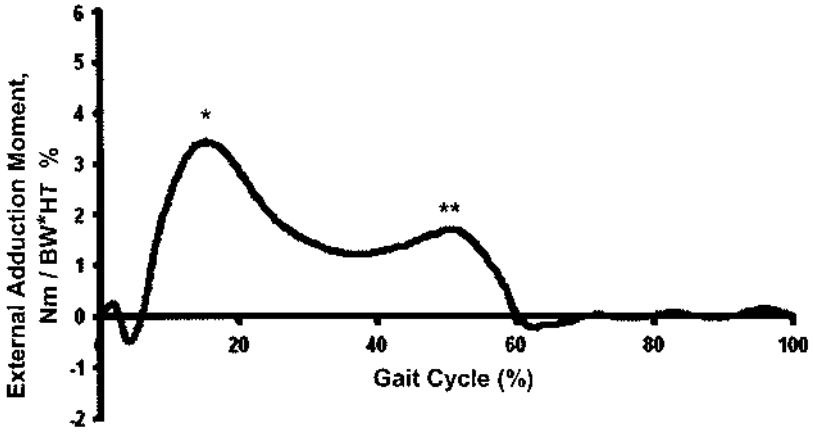

Figure 1. External knee adduction moment profile. *Peak external knee adduction moment during early stance. **Peak external knee adduction moment during late stance. Copyright CHESM, University of Melbourne, Melbourne, Australia. Used with permission.

height of the cohort was 1.64 ± 0.07 m, while the average weight was 66.6 ± 10.8 kg. The mean magnitudes and standard deviations for the peak external knee adduction moments are presented in Table 1. Univariate and multivariate analyses for the correlation data between the peak knee adduction moments and knee pain are presented in Table 2.

DISCUSSION

We observed an inverse relationship between the peak knee adduction moment and knee pain during the late stance phase of human locomotion in the absence of radiographic knee OA.

A previous longitudinal cohort study found that people who had developed chronic knee pain at followup gait analyses had higher knee adduction moments at baseline than people who did not develop chronic knee pain[6]. This result suggests that a larger than normal knee adduction moment is associated with the development of chronic knee pain. However, once symptomatic radiographic OA is apparent, increased knee pain has been shown to be associated with a significant decrease in the peak external knee adduction moment[7]. Similarly, our results supported an inverse relationship between the knee adduction moment and knee pain during the late stance phase of human locomotion among women without radiographic knee OA.

A potential limitation of our study is the modest sample size. However, because of restriction of the sample to healthy middle-aged women, we were able to reduce the effect of potential confounders such as age and sex. We also dealt with confounders by adjustment in the analyses. But the restrictions we used mean that it is not possible to generalize our results to men and those with disease. Moreover, subject selection ensured that our results are only generalized to women with newly developed (< 2 years' duration) self-reported knee pain. Radiographs were not performed at the time of gait analyses. All women in this study were completely free from any radiographic knee OA on examination 2 years earlier. It is possible that in some women very early changes of radiological OA had developed in the intervening period. However, given the short timespan, this is unlikely. For example, in the Framingham Study, which examined an older population than ours, the incidence rate for the development of radiological OA was 15.6% over 9 years[14].

We observed a negative association between the knee adductor moment and knee pain during late, but not early stance. This temporal relationship may be a consequence of body mass being more aligned over the lower limb during mid to late stance relative to the early stance phase of gait. That is, pain may become more prominent during late stance when body mass is concentrated to the medial tibiofemoral compartment via the peak knee adduction moment. However, given that this was effectively a pilot study, with a relatively small sample size (n = 20), we cannot exclude the possibility of an association between knee pain and the knee adductor moment during early stance. Moreover, given that this was a hypothesis-generating study, no *a priori* calculation of sample size was given. Nevertheless, to provide a measure of the strength of these results, we have provided 95% confidence intervals for the regression coefficients. These indicate the plausible range of strength of association based on our data. Finally, our study was cross-sectional, and no conclusion can therefore be made regarding the natural history between pain and altered biomechanics. Larger longitudinal studies that include male subjects are required to enhance the generalizability of our findings and to determine the natural history between pain and the magnitude of the knee adduction moment.

The negative linear association between the knee adduction moment and knee pain raises the possibility that women experiencing knee pain may adopt a compensatory gait pattern to reduce their knee adduction moment and thus medial tibiofemoral load. A toe-out gait pattern is one mechanism that influences knee adduction moment variability[15-17], and healthy subjects may adopt this as a compensatory mechanism to reduce the pain that may otherwise result from increased medial knee joint loads. Additionally, it may be that people who are able to adopt a compensatory reduction of the knee

Table 2. Associations between knee pain, quality of life, and knee adduction moments: univariate and multivariate analyses.

	Univariate Analysis Regression Coefficient (95% CI)*	p	Multivariate Analysis Regression Coefficient (95% CI)**	p
Pain (WOMAC)				
Peak knee adduction moment (early stance)	–5.2 (–11.1, 0.67) Partial R^2 = 16%	0.08	–4.6 (–11.0, 1.8) Model R^2 = 19% Partial R^2 = 12%	0.15
Peak knee adduction moment (late stance)	–10.3 (–17.6, –2.9) Partial R^2 = 32%	0.009	–10.1 (–17.6, –2.7) Model R^2 = 39% Partial R^2 = 32%	0.01

* Change in reported measures of pain per unit increase in the peak knee adduction moment during early or late stance. ** Change in reported measures of pain per unit increase in the peak knee adduction moment during early or late stance after adjusting for the body mass index and age.

adduction moment in the setting of knee pain protect themselves against the development of knee OA, although this will need to be examined longitudinally. It may also be that a reduction of the knee adduction moment in the setting of knee pain is an early predictive marker for the onset of imminent OA.

Our results have potential implications for the treatment of knee symptoms. It may be that antiinflammatory or analgesic therapy that masks knee pain also negates the compensatory mechanisms that decrease knee joint loads during gait in those people with early knee symptoms[18]. Indeed, NSAID treatment in people with knee OA has been shown to concurrently reduce symptomatic pain and increase the knee adduction moment[19]. Clinical interventions that target effective analgesia without increasing knee joint loads in people with knee pain may have the best longterm outcome in patients.

The knee adduction moment during late stance was inversely associated with knee pain in women without radiographic evidence of degenerative knee joint changes. This association may represent a compensatory mechanism to reduce medial tibiofemoral joint load and subsequent pain during walking. Further work is needed to determine whether this protects against the development of knee OA, as well as the implications that interventions that reduce knee pain (e.g., analgesic medication) have on modifying this potential biomechanical compensatory mechanism.

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