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Musculoskeletal Risk Factors as Predictors of Injury in Community-Dwelling Women

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Abstract

Background—Participating in health related physical activity (PA) may increase risk for musculoskeletal injury (MSI).

Purpose—To estimate the prevalence of structural/biomechanical risk factors in community-dwelling women and associated risk for incidence of MSI in women who are physically active.

Methods—The Women's Injury (WIN) Study is a surveillance of PA behaviors and MSI in women aged 20 to 83 years. An orthopedic examination was performed prior to entry into the study to assess presence of structural/biomechanical risk factors. 886 women completed data collection by reporting weekly PA behavior and MSI for up to 3 years (2007–2009) with the average participant enrolled for 98 weeks. To estimate MSI risk associated with each risk factor separately, time to first MSI was modeled using proportional hazards regression with time-dependent PA covariates, controlling for age, body mass index (BMI) and previous injury.

Results—Over the course of the study, 236 of the women (26.6%) reported at least one MSI that was PA related. We found a significant association between number of high flexibility risk factors and PA-related injury at all levels of PA exposure (HR=1.15; CI=1.04–1.27 for moderate to vigorous (MVPA); HR=1.16; CI=1.05–1.28 for moderate PA; HR= 1.15; CI=1.04–1.27 for vigorous PA).

Conclusions—When participating at any level of PA for health benefits, women with hypermobility in multiple muscle groups or joints should be watchful for musculoskeletal symptoms and should be counseled not to ignore symptoms when they first occur.

Keywords

physical activity behavior; hypermobility; physical activity guidelines; structural factors

INTRODUCTION

In 2008, 63% of deaths were due to non-communicable diseases (NCDs) (40). Smoking and physical inactivity are the two primary risk factors for NCDs, with each contributing to about 5 million deaths annually (25). Reducing physical inactivity has and will continue to be a public health priority to reduce NCDs and the associated burden. The recommendation for a minimum of 150 minutes per week of moderate aerobic physical activity (PA) for all adults is an example of a public health effort to improve health by reducing physical inactivity (38).

Participating in PA for health benefits is a long-term behavior choice that is difficult for some people and not without potential drawbacks. Meeting the U.S. Dept. of Health and Human Services (DHHS) PA guidelines has been associated with increased risk for musculoskeletal injury (MSI) (30). In a surveillance study of 909 community-dwelling women over a period of up to 3 years, women who met the PA guidelines for moderate to vigorous activity were more likely to report PA injuries than women who did not meet guidelines (HR= 1.39, CI=1.05–1.85) (30). There are studies examining associations of intensity and duration of PA on MSI in healthy, recreationally active adults (19), as well as studies regarding associations of structural/biomechanical factors on MSI in selective sports (15, 17), on runners, (8, 27) and in training of military recruits (10). However, we are unaware of any studies addressing structural/biomechanical risk factors for MSI in people participating in PA sufficient for health benefits. Understanding structural/biomechanical risk factors for MSI when undertaking PA for health benefits would be valuable for educating people about these risk factors and potentially preventing MSI. The purpose of this study was to estimate the prevalence of specific structural/biomechanical risk factors in community-dwelling women as well as the associated risk for incidence of MSI in women who are physically active.

METHODS

The Women's Injury (WIN) Study is a surveillance of PA behaviors and MSIs in adult community-living women aged 20 to 83 years. Participants were recruited from the general population in the Dallas, Texas area. Recruitment efforts included contacting women who had previously expressed interest or been involved in other Cooper Institute studies. Additional recruitment strategies included advertisements, health fairs, word of mouth, and community meetings. Women who needed an assistive device to ambulate, or who had a disease or condition that limited their mobility or limited or interfered with their usual daily or recreational activities were excluded. Details of the WIN study are presented elsewhere (2). Study procedures were approved annually by The Cooper Institute's Institutional Review Board. Upon entry into the study, informed consent for participation was obtained, a questionnaire of demographic and medical history information was completed, and a baseline orthopedic examination was conducted by a physical therapist.

Measurements

Anthropometric, muscle strength, muscle length/flexibility, structural, and ligament laxity measures were taken during the baseline orthopedic examination. A description of the

orthopedic tests and measures is presented, followed by a description of PA and injury surveillance. Orthopedic tests and measures were taken once at the start of the study, while PA and injury was surveyed over the duration of the study for up to 3 years.

Anthropometric measurements—Height and weight were measured with a stadiometer (Meyer Distributing, Twinsburg, OH) and digital scale (Tanita Corporation, Arlington Heights, Ill) respectively. Skinfold measurements were taken at 3 sites (triceps, suprailiac, and thigh) with a Lange caliper (Beta Technology, Santa Cruz, CA) and percentage of body fat was estimated using the Jackson-Pollock equation (20).

Muscle strength measurements—For strength measurements, two trials were performed for each side and the mean for the two trials was recorded. Grip strength was measured with a Jamar grip dynamometer (Sammons Preston Inc, Bolingbrook, IL) according to standardized testing procedures developed by the American Society for Hand Therapists (16).

Lower extremity muscle strength was measured with the Human Performance Measurement (HPM) system (Human Performance Measurement Inc, Arlington, TX). HPM is a computer-automated system that assesses a selection of sensorimotor functions called basic elements of performance (BEP). The BEP IIIa is a handheld dynamometer (HHD) and a component of the HPM system that measures and records isometric muscle strength in newton-meters (Nm) of torque. Lower extremity muscle strength testing was performed bilaterally on the following muscle groups: hip abductors, hip external rotators, knee extensors, and knee flexors. Previous studies show that strength of the tester can be a factor in the reliability of forces measured with a HHD (1, 39). To remove tester strength as a variable, straps were used to stabilize the dynamometer during testing of all lower extremity muscle groups. Reliability of strength testing of the hip abductors and external rotators ($ICC_{3,3}=0.97$ and 0.85) (6) and knee extensors and flexors ($ICC_{3,2}=0.93$ and 0.84 , respectively) (34) using a HHD stabilized with a strap has been demonstrated. For all lower extremity muscle tests, the examiner used one hand to stabilize the body part tested while maintaining the position of the HHD under the stabilization strap with the other hand. All strength values were adjusted for body weight prior to data analysis.

Muscle length and flexibility measurements—Lumbar spine flexion and extension flexibility and muscle length of the hamstrings and gastrocnemius were assessed using the BEP VIIa, an electronic inclinometer component of the HPM system.

To measure lumbar spine flexion, participants stood upright with arms at the side. The tester demonstrated the motion to the participant and instructed her to bend forward as far as possible, keeping her knees straight. Lumbar spine extension was measured in the same manner except that the participant was instructed to lean back as far as possible, keeping her knees straight. Three test trials were performed for each and the mean of the two closest trials recorded. A full description of lumbar spine flexion and extension measurement methodology is published elsewhere (37). Intrarater reliability of lumbar spine measurements using the BEP VIIa electronic inclinometer and the measurement procedures described above has been excellent for lumbar flexion ($ICC_{3,2}=0.97$) and extension ($ICC_{3,2}$

=0.94) (37). Inter-rater reliability for the same measurements yielded ICC_{2,2} of 0.90 and 0.78 for lumbar spine flexion and extension, respectively (37).

For muscle length measurements of the hamstring, the active knee extension test was performed. The participant lay supine with the test hip and knee each flexed 90°, while the opposite leg was kept supported on the table in an extended position. The tester then stabilized the flexed hip while the participant actively extended her knee as far as possible. The degree to which she could actively extend the knee while the hip was kept flexed 90° was measured using the inclinometer and recorded in degrees of knee flexion. Reliability of the active knee extension test has been demonstrated (ICC's = 0.94 to 0.96) (7, 34) and is commonly used in the clinic to quantify hamstring muscle length. Muscle length of the gastrocnemius muscle was measured as degrees of ankle dorsiflexion attainable when measured with the knee extended, effectively lengthening the gastrocnemius muscles across the knee and ankle simultaneously. Reliability of this measurement was previously demonstrated (ICC_{3,2}=0.94–0.96) (34). Muscle length tests of the hamstrings and gastrocnemius were performed bilaterally.

Measures of structural factors and ligament laxity—A battery of clinical tests assessed the presence of structural factors believed to be predictors of musculoskeletal injuries based on previous studies of military recruits (10), sports participants (35), runners (8,28,36), or on clinical judgment. Clinical tests included measurement of genu recurvatum, genu varum/valgum as determined by pelvic-patellar ratio, true leg length difference, functional leg length difference, knee Q-angle, and navicular drop test. Additionally, 3 ligament laxity tests were conducted. Anterior cruciate ligament (ACL) and posterior cruciate ligament (PCL) laxity were assessed using a MEDmetric KT 1000™ arthrometer (MedMetric, San Diego, CA) with the knee flexed 20°, in neutral rotation, and an applied force of 89N (18)(11). Laxity of the anterior talofibular ligament (ATFL) was assessed using a non-instrumented anterior drawer test. Clinical judgment of a positive anterior drawer test of the ankle as determined by presence of ligament laxity is commonly used in the clinic. Although there have been attempts to implement instrumentation of the ankle drawer test, the manual test remains the most important clinical test for assessing anterolateral ankle ligament stability and the test has been shown to have acceptable reliability (ICC=0.94) (12). Space limitation does not allow a description of each test but a description and relevant references are available from the author.

Website surveillance of physical activity and injury—PA and injury surveillance started once the baseline orthopedic examination was completed. Participants entered information weekly on moderate and vigorous aerobic PA via the Internet. Moderate PA included activities such as brisk walking, bicycling, gardening, or any PA that caused small increases in breathing or heart rate that would not make one strain. Vigorous PA included running, heavy yard work, or any PA causing large increases in breathing or heart rate and would eventually make one strain. Women reported weekly participation in PA as days and minutes per week. Using the recommendation by the 2008 Physical Activity Guidelines for Americans (38), total moderate to vigorous physical activity (MVPA) was calculated by summing the number of moderate PA minutes with 2 times the number of vigorous PA

minutes per week. It should be noted that participants were not asked to *change* their level of PA, but simply to report it weekly as described below.

For injury surveillance, participants responded weekly to, “Did you have an injury (new, old, or recurrent) this week that caused you to see a health care provider or interrupted your daily activities for 2 or more days?” Study personnel then followed up with a telephone call, typically within 48–72 hours of a reported injury, to confirm that the injury truly was a MSI and to obtain additional information such as how the injury occurred and whether it was related to performing PA.

Data Analysis

To determine the prevalence of structural/biomechanical risk factors in community-dwelling women, values outside the normal range as defined in the literature were used. When normative values were not defined in the literature, the top or bottom quintile values were used as potential risk factors for MSI. The practice of using the top or bottom quintile of values as being “outside of normal” when a specific value has not been identified is common practice in the literature (10, 21).

Presence of risk factors was assessed in four categories: a) muscle strength, b) muscle length and flexibility, c) structural, and d) ligament laxity. For each of the categories, a score determined by the total number of positive tests in that category was assigned as follows.

For all muscle strength variables, tests were coded as being positive for presence of a risk factor when the measure was in the bottom quintile of our sample distribution for any of the muscle groups on the right or left side. Since strength measures were obtained bilaterally on 5 different muscle groups, a participant’s score could range from 0 (not in bottom quintile on for any muscle group) to 10 (in the bottom quintile for all 5 muscle groups bilaterally). For muscle length and flexibility variables, 2 categories of risk factors were identified: hypermobility and hypomobility. Tests were coded as being positive for presence of hypermobility when the measure was in the top quintile, and positive for presence of hypomobility when the measure was in the bottom quintile of our sample distribution. Since there were mobility measures for lumbar flexion and extension, right and left gastrocnemius and hamstring muscle groups, a participant’s score could range from 0 to 6 for hypermobility and 0 to 6 for hypomobility. For structural risk factors, a participant’s score could range from 0 to 10 (right and left recurvatum $>5^\circ$ (33), right and left Q-angle $>20^\circ$ (14, 28), right and left navicular drop $>10\text{mm}$ (3, 31), true leg length difference $>10\text{mm}$ (5, 32), functional leg length difference $>10\text{mm}$ (5, 32), top quintile pelvic-patellar ratio for genu valgum and bottom quintile pelvic-patellar ratio for genu varum (10). For ligament laxity variables, scores could range from 0 to 5: right and left ACL $>6\text{mm}$ (11, 18), positive ATFL test (12), and excessive PCL difference ($>2\text{mm}$) between sides (13).

We identified the twentieth (P_{20}) and eightieth (P_{80}) sample percentiles of continuous risk. Next, we estimated hazard ratios for MSI risk factors using Cox regression with time-dependent PA covariates and discrete (weekly) time scale. Minutes of time-dependent PA (moderate, vigorous or MVPA) used to predict injury in each week was determined by averaging reported activity from baseline to the previous week. We initially included risk-

factor $\times$ age and risk factor $\times$ PA interaction terms in each model but removed these if they were not statistically significant. All models included age and BMI as additional covariates and were stratified by previous injury. We justified the proportional hazards assumption by testing cumulative sums of residuals (26). SAS/STAT®, version 9.2 (Cary, NC) was used for all analyses.

RESULTS

An orthopedic examination was conducted on 918 women but 9 never completed any weekly PA reports. For the remaining 909 women, age range from 20 to 83 ($M=52.7\pm12.5$) and body mass index (BMI) ranged from 16.7 to 67.1 ($M=27.6\pm6.2$). Our goal was to recruit a minimum of 25% minority participation, and this goal was nearly achieved with 77% of our participants being White and the remaining being non-White (Black, Hispanic/Latina, other). Although participants reported weekly PA behavior and MSI for up to 3 years, the average participant was enrolled for 98 weeks and submitted an average of 92 weekly reports of PA and injury. An additional 23 participants had missing values for one or more of the predictor variables, bringing the total number of participants excluded from data analysis to 32 and a total sample size of 886 women. Over the course of the study, 236 of the women (26.6%) reported at least one MSI that was PA-related. A more complete description of the injuries sustained, including body part affected, cause of injury, and number of women sustaining more than one injury is reported elsewhere (30).

Table 1 lists the muscle strength and flexibility values at the 20th percentile and 80th percentile. For the structural and ligament laxity variables, the number and percentage of participants who demonstrated presence of risk as defined in the literature are presented in Table 2 along with number of participants with presence of the risk factor who reported an injury. Pelvic-patellar ratio is presented differently from other structural variables because presence of risk is defined in the literature as the top quintile (genu varum) or bottom quintile (genu valgum) (10). Therefore, P_{20} represents the value of genu varum below which the extremes of genu varum fall and P_{80} represents the value of genu valgum above which the extremes of valgum fall (Table 1).

We calculated hazard ratios to identify the risk of MSI for women having risk factors in the categories of muscle strength, muscle length/flexibility, structural or ligament laxity, taking into consideration the number of hours of MVPA, moderate PA or vigorous PA. We found no interaction effects between any of the categories of risk factors and either age or number of hours of exposure to MVPA, moderate PA or vigorous PA. The main effects of risk factor category and PA exposure were then explored. A statistically significant association was found between number of high flexibility risk factors and occurrence of PA-related injury at all levels of PA exposure ($HR=1.15$; $CI=1.04-1.27$ for MVPA exposure; $HR=1.16$; $CI=1.05-1.28$ for moderate PA; $HR=1.15$; $CI=1.04-1.27$ for vigorous PA). That is, a woman's risk of PA-related injury increases by 15%-16% with presence of each additional high flexibility risk factor at any age or level of PA exposure. All other categories of risk factors (muscle strength, low muscle length/flexibility, structural, ligament laxity) had no significant effect on risk of injury.

DISCUSSION

We found a significant association between number of high flexibility risk factors and occurrence of MSI in women, regardless of PA exposure. Measures of lumbar flexion and extension flexibility, right and left gastrocnemius, and right and left hamstrings flexibility were all examined, so a woman's hypermobility score could range from 0 to 6. Our results revealed that a woman's risk for MSI increased by 15%–16% for each additional high flexibility risk factor, and this risk did not vary significantly with age or level of PA exposure. Reduced flexibility was not associated with increased MSI. The body of literature in regards to reduced flexibility and MSI has been mixed but mostly supportive of no association. A Cochrane review of 25 trials assessing the effects of interventions for preventing soft tissue running injuries revealed that there was no evidence that stretching decreases lower limb soft tissue injuries (41). Several authors found a 'U'-shaped relationship between flexibility and MSI, meaning that injuries in infantry soldiers were more common in the most flexible and least flexible quintiles (9, 22). Blair, Kohl, and Goodyear studied flexibility of the gastrocnemius, hamstrings and back extensors using the sit-and-reach test in sedentary workers who started a fitness program, and found that those with higher flexibility were slightly more likely to be injured (4). In a study of predictors of injury in 532 novice runners preparing for a 4-mile running event, measures of hip internal and external rotation and ankle dorsiflexion were not related to injury (8).

The main difficulty in comparing the results of our study to previous findings is that most studies of potential predictive factors for MSI have been conducted on mostly male military recruits who are subjected to intense and rapid increases in training volume to which they are unaccustomed. In our study of community-dwelling women, participants were not asked to change their habitual activity. To confirm that our participants' habitual activity did not change, we assessed the long term stability of reported PA measures across the study period and found the reported PA behaviors to be remarkably consistent (29). The consistent PA behavior throughout our study could explain why biomechanical factors found to be predictive of MSI in other studies were not associated with injury in ours. For example, in an earlier study of lower extremity structure and alignment as predictors of overuse injury, increased genu valgus was predictive of overuse injury (RR=1.9; 95% CI=1.1–3.3), but the study included only male infantry recruits. The recruits participated in 12 weeks of army basic training where they ran or marched an average of 40 minutes on each of 5–6 days per week.(9) In another study, predictors of running-related injuries were examined in novice runners who started training for a 4-mile running event (8). Degree of navicular drop was a significant predictor of injury in female participants (HR= .87; 95% CI= 0.77–0.98) but not in male participants. Participants in this Buist (8)study of novice runners could only be included if they had not been running on a regular basis. Therefore, the training for a 4-mile running event represented a change in their habitual training.

In our study, community dwelling women were studied for an average of 98 weeks. They were not asked to change their habitual PA, so they likely avoided the common "training errors" that frequently lead to injury. Since the women were not asked to participate in PA at levels that they were unaccustomed to, it may simply take longer for an injury to develop, even in the presence of risk factors. Women who did not sustain an injury in the time period

studied, may sustain one later. A study of musculoskeletal factors as predictors of MSI in community-dwelling women should be conducted over a longer period of time to validate the results of our study.

In a previously published paper regarding MSI and self-reported PA behavior, we provide evidence that community-dwelling women who met the PA guidelines for 150 min/week was associated with an increase in PA related MSI and that further increasing PA to 300 min/week resulted in even higher rates of PA related MSI when compared to women not meeting guidelines (30). Because the injuries were self-reported with a relatively small portion of women seeking medical intervention for their injuries, we did not have a medical diagnosis for most of the MSI sustained. Similarly, in our current study of musculoskeletal risk factors as predictors of MSI, we have no way of knowing the specific injury or severity of injury that women with excessive mobility sustained. We do know however, that the majority of injuries sustained overall were minor and that associated large expenses were uncommon (23).

When participating at any level of PA for health benefits, women should be concerned about increased risk of injury if they have hypermobility in multiple muscle groups or joints. Unfortunately, there is no known resolution to the problem of hypermobility other than avoiding activities that may cause further stretching of the muscles or joints. Perhaps the most important information to provide to women with hypermobility risk factors is not to ignore musculoskeletal symptoms when they first occur. Muscle weakness, hypomobility, and other biomechanical and structural characteristics studied do not appear to put women at increased risk when participating in PA for health benefits. Given that hypomobility did not increase risk for MSI while hypermobility did increase risk in women participating in PA, the results of our study in combination with previous studies (24, 41) do not support the practice of stretching for warm up before PA.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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