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SEX DIFFERENCES IN BIOMECHANICS ASSOCIATED WITH KNEE OSTEOARTHRITIS

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Abstract

Osteoarthritis of the knee is seen more frequently in females than males. However, few studies have examined the interplay of gender, gait mechanics, pain, and disability in persons with osteoarthritis. This study examines the influence of anthropometrics, radiographic disease severity, pain, and disability on gender differences in gait mechanics in patients with knee osteoarthritis. Gait mechanics for 26 men and 30 women, were collected using 3-D kinematics and kinetics. Women had a significantly lower knee adduction moment than men, and a significantly higher stride frequency. Within female subjects, variations in gait mechanics were primarily explained by weight, BMI, pain, and disability. In males, variations in gait mechanics were primarily explained by age and disability.

Keywords

Osteoarthritis; knee; gait mechanics; gender; disability

Introduction

Osteoarthritis (OA) affects nearly 27 million Americans and is of growing concern among the United States' aging population, with most people over the age of 65 having radiographically demonstrable OA in at least one joint (Lawrence et al., 2008; Sangha, 2000). Osteoarthritis of the knee is one of the most common forms of OA, and the pain and stiffness associated with knee OA often interfere with activities of daily living. Of the 10% of Americans over age 55 who are affected by knee OA, a quarter have clinically significant disability (Baliunas et al., 2002). The occurrence and severity of OA is influenced by a variety of factors including age, body weight, and gender. The prevalence of knee OA rises steeply with age: from 0.1% in people aged 25–34 to 10–20% in people aged 65–74 and more than 30% in people over 75 (Sangha, 2000). OA of the knee is also strongly correlated with increased body mass (Corti & Rigon, 2003; Reijman et al., 2007; Sangha, 2000).

Previous research has shown that women are more prone than men to OA involving the knee (Arden & Nevitt, 2006; Corti & Rigon, 2003; Kaufman, Hughes, Morrey, Morrey, & An, 2001; Sangha, 2000; Srikanth et al., 2005) Women also tend to report more pain during clinical examination (Affleck et al., 1999; Davis, 1981). In a meta-analysis Srikanth et al., found a significantly increased risk and significantly greater severity of knee OA in women (Srikanth et al., 2005). Sangha et al., cites the ratio of women to men affected by knee OA as high as 4:1(Sangha, 2000). Additionally, the effect of gender becomes more pronounced over the age of 50 years. Prior to age 50, women's risk of OA is similar to that of men (Arden & Nevitt, 2006). Findings of this kind have led much of the literature to focus on biological explanations, particularly the role of sex hormones and menopause. Some studies have indicated that estrogen replacement therapy has been effective in decreasing the risk of OA in postmenopausal women but the data are conflicting (Spector, Nandra, Hart, & Doyle, 1997; Zhang et al., 1998). Although the exact mechanistic cause of increased OA in women is unclear, it has been assumed that women also experience greater disability associated with this increased OA. Based on what is known about the increased incidence, severity, and response to knee OA, the hypothesis to be tested in this paper is that gait disability is higher in women than in men.

To test this hypothesis it is important to have an understanding of any significant differences in gait pattern between healthy men and women. Kerrigan and colleagues have published three studies regarding gender and gait (Kerrigan, Riley, Nieto, & Croce, 2000; Kerrigan, Todd, & Croce, 1998; Smith, Lelas, & Kerrigan, 2002). One study found that women walk with higher cadence, increased hip flexion and decreased knee extension before foot strike, increased knee flexion moment at pre-swing, and a tendency towards higher peak joint powers (Kerrigan et al., 1998). Another study examined knee joint torques in healthy men and women during barefoot walking and found no gender differences and thereby concluding that men and women have a similar biomechanical risk for knee OA (Kerrigan et al., 2000). The third study showed that women displayed greater pelvic obliquity and decreased vertical displacement of center of mass (Smith et al., 2002).

One study of gait during level walking and stair ascent and descent in OA sufferers found that women had significantly increased knee flexion moments during level walking and stair descent and increased knee extension moments during all three tasks compared to men (Kaufman et al., 2001). However, this did not suggest higher levels of disability in women, just differences in knee motion. McKean et al., (2007), found gender differences among their osteoarthritic sample; but in contrast to Kaufman et al. (2001), the women in their study exhibited lower knee range of motion, and produced lower knee flexion and external rotation moments. In addition, their female subjects maintained a high knee adduction moment for a longer period (McKean et al., 2007).

The study presented here quantifies gait differences in men and women and the relationship of those differences to obesity, radiographic disease severity, or psychosocial factors. In addition this study will examine which factors influence gait mechanics within gender.

Methods

Patients

Fifty-six subjects (26 male, 30 female) with knee osteoarthritis participated in this study. To avoid the influence of race on psychosocial factors and gait mechanics (Golightly & Dominick, 2005), the study population was comprised of only Caucasian subjects. All data presented were collected as part of a baseline evaluation of a subset of the participants enrolled in an ongoing study (OA Life) evaluating the separate and combined effects of lifestyle behavioral weight management and pain coping skills training interventions for knee OA. Study entry required that patients meet the American College of Rheumatology criteria for symptomatic knee OA, (Altman et al., 1986) along with the following inclusion criteria: body mass index greater than 25 kg/m^2 and less than 42 kg/m^2, chronic knee pain, and no other weight bearing joint affected by OA as assessed by clinical examination. Exclusion criteria included: significant medical conditions that would increase risk of an adverse experience (e.g. myocardial infarction), already involved in regular exercise, an abnormal cardiac response to exercise, a non-OA inflammatory anthropathy, and regular use of corticosteroids. The study was approved by the Duke University Medical Center Institutional Review Board and all participants provided informed consent.

Disease severity

Weight-bearing, fixed-flexion (30 degrees) posterioranterior radiographs of both knees were taken with the SynaFlexer™ X-ray positioning frame (Synarc, San Francisco, CA)(Peterfy et al., 2003). Disease severity was assessed using the Kellgren and Lawrence (K/L) radiographic grading system (Kellgren & Lawrence, 1957). This system rates the level of disease on a scale of 0–4, with a score of 0 representing no disease, 1 representing mild disease, 2 representing moderate disease, 3 representing moderate to severe disease, and 4 representing severe disease. In the current study K/L grades<1 were excluded from analysis.

Anthropometric Measures

Weight in kilograms and height in meters was recorded for each patient. Height and weight were used to compute body mass index (BMI). Details regarding demographics by gender are presented in Table 1.

Gait Mechanics

Three-dimensional kinematic data were collected using a motion analysis system (Motion Analysis Inc, Santa Rosa, CA). In preparation for data collection, patients completed three practice trials along a 30 meter walkway at the speed at which they normally perform their daily walking activities. Gait velocity was measured using two wireless infrared photocell timing devices (Brower Timing Systems, Draper Utah) positioned 5 meters apart. Following the practice trials, kinematic data were collected at 60Hz. Reflective markers were placed bilaterally at the following landmarks: acromion process, lateral epicondyle of the humerus, wrist, anterior superior iliac spine, thigh, lateral knee, shank, lateral malleolus, calcaneus, and foot (2^{nd} webspace). A marker was also placed at the superior aspect of the L5-sacral interface to aid in defining the pelvis. In addition, markers were placed bilaterally on the medial femoral condyle and medial malleolus for identification of joint centers during the collection of a static trial. Once the static trial was completed, the four medial markers were removed. Patients performed five walking trials along the walkway at their self-selected speed. Time synchronized ground reaction force data were collected at 1200Hz using AMTI force plates (Advanced Medical Technologies Inc., Watertown, MA). Variability in walking velocity was restricted to 5%; trials outside of this range or trials during which the subject did not contact at least one of the force plates cleanly were repeated. EvaRT (Motion

Analysis Inc, Santa Rosa CA) software was used to track the reflective markers and condition the data. The raw data were smoothed using a 4th order, recursive Butterworth filter with a 6Hz cutoff frequency. Three trials at each speed in which all markers were identified and the subject had clean contact with the force plate were averaged to yield kinetic and kinematic data. Spatiotemporal variables (velocity, stride frequency, stride length, and support time) as well as peak vertical ground reaction force (PVF), knee adduction moment, hip adduction moment, and knee range of motion (KROM) were computed using OrthoTrak (Motion Analysis Inc, Santa Rosa CA). Stride length data were normalized to subject height and kinetic data were normalized to height and weight.

Pain and Disability Measurement

Functional status of each patient was assessed using the Arthritis Impact Measurement Scales (AIMS). The AIMS is a 66 item, self-administered questionnaire which is broken down into 9 scales. The 9 scales are subsequently combined into a three-component model that yields scores for physical disability, psychological disability and pain. The pain score is based on the severity of arthritis pain, frequency of acute pain, the duration of stiffness in the morning, and the frequency of pain in one or more joints. Psychological disability is based on anxiety and depression, and physical disability is based on difficulty experienced during physical activities. A low score on any of the scales indicates a high health status (Meenan, Gertman, & Mason, 1980).

Stiffness, and difficulty with physical tasks related to OA were measured using the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) Version VA3.1. The WOMAC OA index used in this study was a visual analog scale that consisted of three subscales that assessed pain (5 questions), stiffness (2 questions), and physical function activities (17 questions). The range of scores on each of these subscales was between 0-100mm; with higher WOMAC scores reflecting a worse condition (Bellamy, Buchanan, Goldsmith, Campbell, & Stitt, 1988).

Statistical Analysis

Statistical analysis was performed using SPSS (version 12.0.1 for windows, SPSS, Inc., Chicago, IL). An independent samples t-test was used to determine gender differences in anthropometrics, radiographic disease severity (rOA), and gait mechanics, as well as self-reported disease-related characteristics. Stepwise regression analysis was used to examine the relationships of anthropometrics (age, BMI, height, and weight), rOA, velocity, self-reported pain, self-reported physical disability, and self-reported psychological disability to gait mechanics (α=0.05). These relationships were evaluated for each gender group separately. In order to determine the relative importance of gait variables in explaining gender differences, logistic regression was performed. A multivariable analysis was performed that included only variables for which gender differences were found to be significant in the univariate analysis (α=0.05), in order to reduce the number of comparisons. Next odds ratios were calculated in order to determine the likelihood that a variable was more strongly associated with a particular gender. An odds ratio (OR) of 1 indicates that there were no differences between the groups; an OR>1 indicates that the value was higher in females.

Results

Comparison of males and females

Anthropometrics—The results of the t-tests for anthropometric differences are shown in Table 1. There was no significant difference in age (p=0.174), K/L grade (p=0.214), or BMI

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(p=0.263) between males and females. However, males were significantly taller (p<0.001) and heavier (p=0.002) than the females.

Gait Mechanics—There was no significant difference in velocity between genders (p=0.388). Significant differences did exist, however, in stride frequency (p=0.028) and knee adduction moment (p=0.011). Women had higher stride frequency and smaller knee adduction moment (KAM) than men. The results are summarized in table 2.

Pain and Disability—As seen in Table 3, there were no significant gender differences in AIMS and WOMAC pain scores. Nor was there a significant gender difference in joint stiffness as measured by the WOMAC scale. There was however, a statistically significant difference between males and females in WOMAC function score (p=0.042). Males had a lower WOMAC function score than females which indicated that they felt they had less difficulty with tasks than females. There was also a statistically significant gender difference in both the AIMS psychological (p=0.004) and physical (p=0.033) disability scores (Table 3), indicating again that males in this study felt that they had a better psychological and physical health status.

Predictors of gait mechanics within male versus female groups

Variations in gait mechanics within the female participants—In the regression analysis (Table 4) for the females, velocity accounted for the largest proportion of variance in stride length and stride frequency. Weight however accounted for 30% of the variance in support time, K/L grade accounted for 13% of variance in PVF, and AIMS physical disability accounted for 15% of the variance in PVF and 11% of the variance in stride frequency. AIMS pain also accounted for 11% of the variance in PVF. In addition, BMI accounted for 22% of the variance in velocity for females, followed by AIMS physical disability (12%) and age (12%).

Variations in gait mechanics within the male participants—In the regression analysis for the males, velocity accounted for the largest proportion of variance in stride length and support time. Velocity also explained a significant, but lower proportion of variance in stride frequency (26%). Disease severity (K/L grade) was the only variable that explained a significant proportion of variance in knee adduction moment (21%). Age was the strongest predictor (41%) of the variance in stride frequency. Among males, the only self-report variable that predicted a significant proportion of variance was AIMS physical disability (41%).

Logistic Regression—When all variables were considered together in a multivariable logistic regression model, two variables retained significance simultaneously. In these models, one can identify the unique predictive value of each predictor (i.e. after controlling for other significant variables). Table 5 displays the odds ratios derived from the logistic regressions containing variables that were significant predictors of gender (female). The odds ratios confirmed that female gender was associated with younger age and shorter height.

Discussion

It is well know that women have higher incidence of knee than men (Sangha, 2000; Srikanth et al., 2005). Kaufman suggested that gait differences between men and women partially explained the increased prevalence of OA in women (Kaufman et al., 2001). Kerrigan et al. argued that gait patterns suggested that men and women were at equal risk of OA. Our study addresses these conflicting viewpoints directly. Our sample included men and women of the same age, BMI, and radiographic OA (rOA) severity. Few significant differences in gait mechanics exist between men and women in the current study. Our female subjects did take more frequent strides than male subjects; but this is consistent with the findings of Kerrigan et al. in a healthy population (Kerrigan et al., 2000). There was a gender difference in knee adduction moment, a key factor associated with OA of the knee, but it was small and the relationship was opposite of the direction that might have been anticipated based on previous studies (Al-Zahrani & Bakheit, 2002; Baliunas et al., 2002; Messier et al., 2005). Women in this study had a smaller knee adduction moment than men.

Thus, in our study we found no critical gender differences in gait mechanics between men and women with the same degree of rOA. In that context, it should be the case that this study would reveal little to no gender differences in self-report pain, or physical and psychological disability. Contrary to that expectation, men reported higher levels of physical function and higher levels of psychological and physical confidence associated with their disease. This finding suggests, as previous research has (Keefe et al., 2000) that women with knee OA have more negative feeling regarding their condition than do men with OA regardless of disease severity or disability.

Although this study showed few gait differences across gender, it did reveal unexpected differences in which factors influenced gait disability within gender. Those differences reveal biomechanically and clinically relevant information for treatment of OA in women and men.

For both genders, velocity was a high contributor to variance in several of the gait parameters. However, there were distinct gender differences in which variables contributed to variance in velocity. In the males, it appeared that physical disability contributed to the majority of variance in velocity; in the females velocity was mostly driven by BMI.

There were a few other variables (KAM, PVF, and stride frequency) that had distinct gender differences in which parameters contributed to their variance. In the males, KAM was influenced by radiographic disease severity, but in females, knee adduction moment was not influenced by any of the covariates. The stride frequency in females was primarily influenced by velocity, whereas in males it was primarily influenced by age. These findings could potentially explain the gender differences in stride frequency that were found. Previous literature has shown that stride frequency increases with age and walking speed (Masumoto et al., 2007). The significantly lower stride frequency seen in men may be explained by the faster walking speed seen in the females; particularly since walking speed contributed to the greatest variance in stride frequency in females. It may also be explained by the fact that the men in this study are older and that age explains 41% of the variance in stride frequency.

The results of this study are surprising, despite the fact that women reported greater physical and psychological disability, men and women showed broad similar gait patterns with no evidence of substantially higher gait disability in women. As previous studies have reported, men and women differ in the incidence and sometimes the radiographic severity of OA (Srikanth et al., 2005). Women also tend to report more severe pain (Affleck et al., 1999; Davis, 1981) and psychological and physical disability (Keefe et al., 2000). Therefore, one would assume that women would show greater levels of gait disability than men; in the current study this was not the case.

Perhaps, more interesting is the finding that anthropometrics (BMI and weight) have a more profound relationship with gait disability in women and that self-reported disability and age have a stronger relationship with gait disability in men. These data reveal critical factors to consider when comparing men and women with OA. This study represents a first step in exploring gender and gait disability. Future studies that include women and men who differ in radiographic severity, as well as those men and women who have not sought out clinical care may reveal dissimilar and important differences in gait disability in men compared to women.

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Table 1

Participant characteristics by gender

	Males (n= 26)	Females (n=30)	p-value
Age (years)	63.69 (9.52)	60.40 (9.81)	0.210
K/L grade	3.15 (0.83)	2.835 (0.874)	0.168
BMI (kg/m^2)	35.26 (4.190)	33.10 (4.68)	0.076
Height (m)	1.75 (0.07)*	1.63 (0.06)	<0.001
Weight (kg)	108.93 (18.44)*	88.82 (16.16)	<0.001

*denotes significant difference (α=0.05)

Table 2

Gender differences in gait mechanics

	Males (n=26)		Females (n=30)		
	Mean	SD	Mean	SD	p-value
Velocity (m/s)	1.050	0.224	1.110	0.205	0.388
Stride Frequency (s^{-1})*	0.894	0.068	0.936	0.112	0.028
Normalized Stride Length	0.678	0.111	0.706	0.106	0.347
Support Time (% of gait cycle)	63.44	4.210	62.61	3.980	0.455
Knee range of motion (degrees)	59.72	7.020	60.66	5.340	0.574
Peak Vertical GRF (BW)	1.042	0.060	1.072	0.096	0.183
Peak Hip Abduction Moment (Nm/kg)	−0.244	0.281	−0.201	0.187	0.505
Peak Knee Adduction Moment (Nm/kg)*	0.424	0.203	0.299	0.148	0.011

* denotes significant difference (α=0.05)

Table 3

Gender differences in pain and disability measures

	Males (n=26)		Females (n=30)		
	Mean	**SD**	**Mean**	**SD**	**p-value (α=0.05)**
AIMS					
Pain	5.231	1.663	5.817	1.540	0.177
Physical disability*	1.309	0.931	1.930	1.028	0.033
Psychological disability*	2.176	1.204	3.322	1.599	0.004
WOMAC					
Pain	34.408	16.159	41.847	17.342	0.104
Joint stiffness	44.423	22.890	56.133	21.020	0.051
Physical function*	39.105	16.498	48.379	16.401	0.042

* denotes significant difference (α=0.05)

Table 4

Multivariate relationships of anthropometrics, disease severity, pain, and disability measures with gait variables.

	Males (n=26)				Females (n=30)			
		r^2	β	p		r^2	β	p
	AIMS Phys:	0.410	−0.640	0.002	BMI:	0.220	−0.589	0.001
Velocity					AIMS Phys:	0.116	−0.403	0.015
					Age:	0.117	−0.359	0.033
Stride Length	Velocity:	0.886	0.953	<0.0001	Velocity:	0.585	0.706	<0.0001
	Age:	0.034	−0.184	0.013	WOMAC FN:	0.070	−0.271	0.033
	Age:	0.406	0.447	0.007	Velocity:	0.288	0.644	0.001
Stride Frequency	Velocity:	0.255	0.621	0.0003	AIMS Phys:	0.111	0.350	0.041
	Height:	0.076	−0.335	0.042				
Support Time	Velocity:	0.556	−0.746	0.0001	Weight:	0.304	0.551	0.002
	--				AIMS Phys:	0.153	−0.733	0.001
PVF					K/L:	0.131	−0.444	0.016
					AIMS Pain:	0.113	0.389	0.045
KROM	--				--			
HAM	--				--			
KAM	K/L:	0.212	−0.460	0.036	--			

KROM= knee range of motion, PVF= peak vertical ground reaction force, HAM= hip adduction moment, KAM= knee adduction moment, and FN= function

Table 5

Odds Ratio derived from logistic regression model

	Odds Ratio	95% CI	p-value
Anthropometrics			
Height	<0.001	<0.001 – <0.001	0.0034
Age	0.868	0.769 – 0.980	0.0222