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The Relationship Between Gait Mechanics and Radiographic Disease Severity in Knee Osteoarthritis

Ershela L. Sims et al.[1,2*]
[1]*Department of Biological Anthropology and Anatomy, Duke University*
[2]*Applied Science Department, NC School of Science and Mathematics*
USA

1. Introduction

Osteoarthritis (OA) is a multifactorial degenerative joint disease affecting more than 10% of adults over the age of 55 (Baliunas et al., 2002; Miyazaki et al., 2002). Radiographic indications of OA can be found in at least one joint in most people over 65; with prevalence rates as high as 80% in people over the age of 75, depending on the joint (Helmick et al., 2008; Lawrence et al., 2008; Lawrence et al., 1998; Sangha, 2000). Systematic autopsy studies reveal near universal pathological signs of OA in people over age 65 (Sangha, 2000). It is the most prevalent type of arthritis (Lawrence et al., 2008) and the knee is one of the most commonly affected joints. Symptomatic knee OA affects 4.3M adults over age 60 (Dillon et al., 2006). Moreover, OA of the knee is particularly debilitating in terms of normal locomotor activity and as such has devastating physical and psychological effects (Maly et al., 2006; Nebel et al., 2009).

Characterized by pain and lack of mobility, osteoarthritis of the knee may have a profound influence on gait patterns. Among the most commonly reported differences are slower walking speeds, shortened step lengths, larger double support times (the period of time in the gait cycle when both feet are in contact with the ground), as well as decreased hip range of motion and knee range of motion angles as compared to a non-arthritic population (Al-Zahrani & Bakheit, 2002; Andriacchi et al., 1977; Baliunas et al., 2002; Brinkmann & Perry, 1985; Kaufman et al., 2001; Messier et al., 2005a; Messier et al., 1992). Patients also exhibit decreased knee angular velocity (Messier, 1994; Messier et al., 1992), a change compensated for by increased hip angular velocity (Messier, 1994). In addition, patients with knee OA have been shown to demonstrate both altered ground reaction forces and increased dynamic

[*]Francis J. Keefe[3], Daniel Schmitt[1], Virginia B. Kraus[4], Mathew W. Williams[5], Tamara Somers[3], Paul Riordan[3] and Farshid Guilak[6]
[1]*Department of Biological Anthropology and Anatomy, Duke University, USA*
[3]*Department of Psychiatry and Behavioral Science, Duke University, USA*
[4]*Department of Rheumatology and Immunology, Duke University, USA*
[5]*Department of Emergency Medicine, Wake Forest Baptist Medical Center, USA*
[6]*Department of Surgery, Duke University, USA*

loads on the medial compartments of the knee as characterized by the external knee adduction moment compared to healthy, age-matched controls (Al-Zahrani & Bakheit, 2002; Baliunas et al., 2002; Messier et al., 1992; Mundermann et al., 2005). Research has determined that disability is a major consequence of lower limb OA (Creamer et al., 2000). The pain, stiffness, and decreased range of motion associated with OA often interfere with activities of daily living; of the 10% of Americans over 55 years old who are affected by knee OA, a quarter have clinically significant disability (Baliunas et al., 2002). In fact, knee OA has been referred to as the leading cause of impaired mobility in the elderly (Guccione et al., 1994).

The etiology of knee OA is not entirely clear. In the past, the scientific community dismissed OA as the inevitable age-related wear-and-tear of articular cartilage. However, given the debilitating effects of the disease on the general population, this area of research has grown and studies indicate that OA is a dynamic process with a multifactorial etiology that is more complex than suggested by the age-related wear-and-tear model (Anderson-MacKenzie et al., 2005; Andriacchi et al., 2004; Senior, 2000). OA research has identified a number of risk factors for knee OA. These include obesity, gender, age, repeated trauma to joint tissues, and lower extremity injuries. Obesity has been found to be a risk factor for both the development (Davis et al., 1989; Felson et al., 1997; Hart & Spector, 1993) and progression of OA (Reijman et al., 2007; Sharif et al., 1995). Women have a significantly greater risk of developing knee OA than men (Srikanth et al., 2005), with the ratio of women to men affected by knee OA as high as 4:1 (Sangha, 2000). A study by Lohmander et al., determined that previous ACL injury in female soccer players was associated with a high prevalence of knee OA (Lohmander et al., 2004). As previously mentioned, people with osteoarthritis of the knee exhibit aberrant gait patterns compared to their non-arthritic counterparts. Some gait changes observed in knee OA may be indicative of compensatory mechanisms, while others are associated with the onset and development of disease. Multiple studies have that suggested many of the associated gait abnormalities attempt to compensate for joint instability (Al-Zahrani & Bakheit, 2002) or seek to minimize loading of the affected joint and thus mitigate pain (Baliunas et al., 2002; Kaufman et al., 2001; Manetta et al., 2002; Mundermann et al., 2005; Mundermann et al., 2004). In order to better understand the variety of factors influencing OA as well as its progression, researchers have systematically examined a number of variables that might explain variations in gait and mobility in persons with knee OA (Cooper et al., 2000; Hurwitz et al., 2002; Lohmander et al., 2004; Nebel et al., 2009; Syed & Davis, 2000). Among the variables that have been examined are: static knee alignment (Hurwitz et al., 2002), body composition (Messier, 1994; Messier et al., 2005b; Syed & Davis, 2000), pain and psychosocial variables (Maly et al., 2005; Nebel et al., 2009; Somers et al., 2009), previous lower extremity injury (Lohmander et al., 2004) and even gait biomechanics (Miyazaki et al., 2002; Teichtahl et al., 2003). Some studies further investigated these relationships to determine which factors influence gait variation by sex (McKean et al., 2007; Sims et al., 2009a) and by race (Sims et al., 2009b). One such study found that radiographic disease severity accounted for 21% of the variance in knee adduction moment in men, while it did not contribute at all in women (Sims et al., 2009a).

It has long been hypothesized that changes in gait and joint biomechanics impact the onset and progression of OA. Mechanical factors such as joint loading and knee adduction moment during walking have been linked to the progression of knee OA (Hurwitz et al., 2002; Miyazaki et al., 2002; Mundermann et al., 2005). A study by Miyazaki et al., found that baseline knee adduction moment could predict radiographic OA progression (Miyazaki et

al., 2002). Alteration of mechanical loads, often through ligament abnormality, has been linked to the development of OA and pathological changes associated with the disease. Studies have shown that cartilage dynamically responds and adapts to mechanical stimuli (Smith et al., 2000). With this in mind, Andriacchi and colleagues proposed a model of the disease with two stages: initiation and progression (Andriacchi et al., 2004). In the initiation phase, a physical injury that may be chronic or traumatic such as ACL injury causes a significant shift in the load bearing contact site of the joint surface. Unaccustomed to frequent loading and unable to adapt due to time constraints or aging, the newly stressed cartilage becomes damaged. In the progression phase, the degeneration of the cartilage passes an irreversibility threshold that leaves the tissue vulnerable to further loads and progressive damage (Andriacchi et al., 2004). Kinetically, the pathogenesis of OA is strongly associated with the knee adduction moment (Amin et al., 2004; Baliunas et al., 2002; Hurwitz et al., 2002). Individuals with increased knee adduction moment are more likely to develop chronic knee pain, which is most frequently associated with OA (Amin et al., 2004) and OA subjects with greater knee adduction moments tend to have more severe OA (Mundermann et al., 2005; Mundermann et al., 2004; Sharma et al., 1998).

The relationship between joint mechanics and radiographic disease severity is not yet fully understood. Some previous research has shown that radiographic OA correlates poorly with functional limitation (Summers et al., 1988), while other research has found that change in radiographic OA is related to the incidence of severe functional limitation (White et al., 2010). Nebel and colleagues found that radiographic disease severity accounted for as much as 18% of the variance in knee range of motion and 23% of the variance in peak vertical ground reaction force (Nebel et al., 2009). One factor that might explain these varied results is study design. Studies differ with regard to the level(s) of radiographic disease being examined as well as the particular lower extremity biomechanics that are investigated. Many investigations of the biomechanics of gait in persons with knee OA have been based on a population of patients with moderate and/or severe OA (Baliunas et al., 2002; Kaufman et al., 2001; Landry et al., 2007). Studies that focus solely on OA patients with severe disease have provided beneficial information on gait changes associated with end stage disease. Unfortunately, however, these studies tell us little about the progression of OA or how mild and moderate stages differ from end stage disease. Investigations of gait mechanics across multiple levels of disease severity (mild, moderate, and severe) can provide needed information on the mechanical processes of OA disease progression. Some studies have investigated the effect of increasing levels of radiographic osteoarthritis disease severity on gait parameters (Astephen et al., 2008; Sharma et al., 1998; Wilson et al., 2011; Zeni & Higginson, 2010). However, these studies have largely focused on biomechanical variables associated with joint loading. Sharma and colleagues found that there is a significant relationship between the adduction moment and radiographic OA disease severity, even after controlling for age, sex, and pain level (Sharma et al., 1998). Another study found that the magnitude of the knee adduction moment during stance and the magnitude of the knee flexion angle during gait are associated with structural knee OA severity measured from radiographs in patients clinically diagnosed with mild to moderate levels of disease (Wilson et al., 2011). Finally, a study of patients with moderate and severe radiographic OA found that OA patients had significantly lower knee and ankle joint moments, joint excursion, and ground reaction forces when walking at self selected speeds (Zeni & Higginson, 2010). However, when they accounted for speed in the statistical analysis, the only significant

difference was knee joint excursion. The current study seeks to add new data to this discussion by not only investigating variables associated with loading of the knee, but also spatiotemporal variables that are often reduced in patients with knee OA (György et al., 1976).

While our group has published other studies on gait mechanics of an OA population (Nebel et al., 2009; Sims et al., 2009a; Sims et al., 2009b; Somers et al., 2009) that involve radiographic findings, this study examines that link in much more detail. The purpose of this study was to further our understanding of the relationship between radiographic disease severity and gait patterns in persons with knee OA. This study not only focused on gait variables in patients with severe OA, it also examined gait variables in patients across all severity levels (mild, moderate, and severe). We predicted that more severe knee OA would correlate positively with increased gait disability measured through slower walking speed, shorter strides, lower peak vertical forces, greater knee adduction moments, smaller loading rates and a more limited knee range of motion. We further hypothesized that significant differences in gait mechanics would exist between the three radiographic disease severity levels, even after controlling for speed.

2. Methods

2.1 Participants

A total of 189 (46 men, 143 women) patients with radiographic OA in at least one knee and persistent knee pain participated in this study. Study entry required that patients meet the American College of Rheumatology criteria for osteoarthritis of the knee (Altman et al., 1986), along with the following inclusion criteria: body mass index (BMI) 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: a 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. All data presented were collected as part of a baseline evaluation of a subset of the participants enrolled in an ongoing randomized trial (OA Life #NCT00305890) evaluating the separate and combined effects of 1) lifestyle behavioral weight management and 2) pain coping skills training interventions for knee OA. Data were collected at the baseline evaluation prior to randomization to treatment conditions. The study was approved by the Duke University Medical Center Institutional Review Board, and all participants provided informed consent.

Weight-bearing, fixed-flexion (30 degrees) posteroanterior radiographs of both knees were taken with the SynaFlexer™ X-ray positioning frame (Synarc, San Francisco, CA) (Peterfy et al., 2003). The x-rays were scored by a grader with high intra- and inter-rater reliability (Addison et al., 2009), and radiographic disease severity was established 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 addition to the standard system, OA severity levels were created for the current study, and designated as follows: mild (K/L =1), moderate (K/L= 2 or 3), and severe (K/L = 4); limbs with K/L<1 were excluded from analyses. For subjects with bilateral knee OA, the limb with the highest K/L grade was

recorded as the most affected limb and was the only limb used in all data analyses. The breakdown of participants with unilateral versus bilateral knee OA was 149 bilateral and 40 unilateral.

2.2 Protocol

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 two speeds: the speed at which they normally perform their daily walking activities (normal) and the maximum speed they felt comfortable achieving (fast). These two speeds were chosen in order to assess the speed at which the participants are most comfortable and to determine how their gait mechanics changed when presented with a challenge. Gait velocity was measured using two wireless infrared photocell timing devices (Brower Timing Systems, Draper Utah) positioned 5 meters apart and the patient's target walking velocity for each speed was determined. Following the practice trials, kinematic data were collected at 60Hz. Reflective markers were placed bilaterally at the following landmarks: anterior superior iliac spine, thigh, lateral knee (at the joint line), shank, lateral malleolus, calcaneus, and foot (2nd 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 collection of a static trial. After completion of the static trial, the 4 medial markers were removed. Patients performed five walking trials along the walkway at each of the self-selected speeds.

Time synchronized ground reaction force data were collected at 1200Hz using AMTI force platforms (Advanced Medical Technologies Inc., Watertown, MA). Variability in walking velocity for each speed 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. The following variables were measured: velocity, stride frequency, stride length, support time, peak vertical ground reaction force, knee range of motion across the entire gait cycle, and peak knee adduction moment. Loading rate and time to peak vertical ground reaction force were also determined from measured ground reaction forces. These outcome measures were computed using OrthoTrak 6.3 (Motion Analysis Inc, Santa Rosa CA). Stride length data were normalized to subject height, ground reaction force data was normalized to body weight, and the adduction moment data was normalized to height and weight. Since the current study does not include a control population for the basis of comparison, mean values the gait measures will be compared to control data acquired from the literature. Both sets of control kinematic data were collected at 60Hz using a Motion Analysis system and kinetic data were collected using two force platforms.

2.3 Statistical analysis

Statistical analysis was performed using SPSS (version 12.0.1 for windows, SPSS, Inc Chicago IL). Correlation between level of OA and the gait variables was evaluated using

Pearson's correlation coefficient (r), and significance level was adjusted accordingly to $p<0.005$ (Bonferroni's adjustment). This analysis was performed at each speed (normal and fast). A 1x3 analysis of variance was used to compare means for velocity and knee range of motion for the different levels of radiographic disease severity at each speed ($\alpha=0.05$). Since it has been reported that support time is influenced by walking speed (Andriacchi et al., 1977), a 1x3 analysis of covariance was used to compare means for support time for the different levels of radiographic disease severity at each speed ($\alpha=0.05$). Since previous research has also determined that the magnitude of the vertical ground reaction force is affected by walking speed (Andriacchi et al., 1977), means for peak vertical ground reaction force, loading rate, and time to peak were compared to level of radiographic disease severity at each speed level using an analysis of covariance as well. Post-hoc testing (LSD) was performed when necessary.

3. Results

Descriptive statistics for subject demographics are presented in Table 1 and gait characteristics for the OA subjects at both speeds are given in Table 2. Demographics and gait mechanics were characteristic of a population of overweight OA patients with varying degrees of radiographic severity (Table 3).

Variable	Mean (SD)	% (n)
Age (years)	58.54 (9.72)	
Height (m)	1.67 (0.081)	
Weight (kg)	94.74 (16.22)	
BMI (kg/m²)	34.17 (4.36)	
Sex:		
Female		76 (143)
Male		24 (46)
Race:		
Black		35 (66)
White		63 (119)
Other		2 (4)
Disease severity:		
Mild		12 (23)
Moderate		61 (116)
Severe		27 (50)

Table 1. Descriptive Statistics for Subject Demographics. BMI: Body Mass Index.

Variable	Normal Speed	Fast Speed
Velocity (m/s)	1.123 (0.190)	1.504 (0.301)
Stride Frequency	0.903 (0.086)	1.111 (0.122)
Stride Length (m)	1.193 (0.172)	1.374 (0.221)
Support Time (%)	63.17 (3.37)	60.77 (3.77)
KROM (degrees)	57.85 (9.36)	59.64(8.58)
PVF (BW)	1.047 (0.077)	1.154 (0.126)
KAM(%BW*HT)	0.367(0.200)	0.380 (0.197)
Loading Rate (%BW/s)	9.26 (3.46)	15.11 (7.47)
Time to Peak (s)	0.204 (0.056)	0.137 (0.035)

Table 2. Gait mechanics at self selected normal and fast speeds. All values are mean (SD). KROM: knee range of motion; PVF: peak vertical ground reaction force; KAM: knee adduction moment.

Variable	Current Study	Messier 1992	Zeni 2009	Kaufman 2001
Velocity (m/s)	1.123 (0.190)	1.097 (0.359)		1.090 (0.11)
Stride Length (m)	1.193 (0.172)	1.196 (0.251)		
Support Time (%)	63.17 (3.37)	64.01 (0.43)		
KROM (degrees)	57.85 (9.36)			54.00 (7.00)
PVF (BW)	1.047 (0.077)		1.048 (0.05)	
KAM(%BW*HT)	0.367(0.20)	0.150 (0.03)		0.39 (0.28)
Loading Rate (%BW/s)	9.26 (3.46)	20.61 (2.34)	8.33 (1.44)	

Table 3. Comparison of the gait mechanics from the current study, at a normal self-selected walking speed, to data from the literature (Kaufman et al., 2001; Messier et al., 1992; Zeni & Higginson, 2010). All values are mean (SD). KROM: knee range of motion; PVF: peak vertical ground reaction force; KAM: knee adduction moment.

Variable	Current Study		Messier, 2005	Kaufman, 2001
Velocity (m/s)	1.123 (0.190)	↓	1.296 (0.084)*	1.17 (0.14)
Stride Length† (m)	1.193 (0.172)	↓	1.307 (0.050)†	
Support Time (%)	63.17 (3.37)	↑	61.14 (0.65)**	
KROM (degrees)	57.85 (9.36)			60.0 (4.0)
KAM (%BW*HT)	0.367(0.200)			0.360 (0.36)
Loading Rate (%BW/s)	9.26 (3.46)	↓	20.13 (2.48) ‡	

Table 4. Comparison of gait mechanics of OA patients at a normal self-selected walking speed to control subject data from the literature (Kaufman et al., 2001; Messier et al., 2005a). All values are mean (SD). KROM: knee range of motion; PVF: peak vertical ground reaction force; KAM: knee adduction moment. Statistically significant differencs: † denotes $p<0.05$, * denotes $p<0.005$ and denotes ‡ $p<0.0001$. **For support time: $p<0.06$

OA patients in this study walked slower, had a shorter stride length, smaller knee range of motion, spent more time in the support phase and had a smaller loading rate than their counterparts without OA (Table 4).

3.1 Correlations

None of the spatiotemporal variables showed a strong correlation with radiographic disease severity. However, a few variables had a weak statistically significant correlation with K/L grade (Table 4). Knee range of motion (KROM) was inversely correlated with radiographic disease severity ($p<0.001$) at both self selected speeds and peak vertical ground reaction force was inversely correlated with radiographic disease severity ($p<0.005$) at both speeds. Stated another way, subjects in this study with more severe radiographic disease severity walked with a smaller knee range of motion and had smaller ground reaction forces than their counterparts with less severe radiographic disease severity.

Variable	Normal Speed	Fast Speed
KROM (degrees)	r = -0.306†	r = -0.307†
PVF (% BW)	r = -0.240*	r = -0.230*

Table 5. Correlations of radiographic disease severity with gait data. All correlations were significant ($p<0.005$)* and ($p<0.001$) †. KROM: knee range of motion; PVF: peak vertical ground reaction force.

3.2 Analysis of variance

The results of the analysis of variance for velocity by level of radiographic disease severity (Figure 1) demonstrated that there was a significant difference in walking velocity between mild and severe OA and moderate and severe OA at the fast speed. There were no significant differences in mean walking velocity by severity level at the normal walking speed. Differences in mean knee range of motion and mean peak vertical ground reaction force by level of OA severity existed at both speeds (Figures 2 and 3). Patients with severe OA had the smallest knee range of motion and the smallest peak vertical ground reaction force in all instances. The statistical analysis revealed significant differences in knee range of motion between patients with mild and severe OA at the normal and fast speeds as well as moderate and severe OA at the normal and fast speeds (Figure 2). The analysis of variance for stride length did not show any differences by OA severity level at either speed.

The results of the analyses of covariance for support time, knee adduction moment and loading rate did not reveal any significant differences between the different levels of radiographic disease severity at either speed. While not significantly different from the other groups, patients with moderate OA spent the least amount of time in the support phase of the gait cycle at the normal walking speed. At the fast speed, the more severe the level of OA, the more time spent in support. While these differences were not statistically significant, loading rate at the normal self selected speed was greater in patients with mild OA and decreased with increasing level of OA. At the fast speed, variation in loading rate by OA severity was inconsistent. Again, while not significantly different, mean knee adduction moment decreased with increasing radiographic severity at the normal walking speed and it increased with increasing radiographic severity at the fast speed. The analysis of covariance for peak vertical ground reaction force (Figure 3) determined that there was a statistically significant difference between moderate and mild OA and moderate and severe OA at the fast speed. Statistically significant differences in mean peak vertical ground reaction force also existed between the levels of radiographic OA at the normal speed.

The analysis of covariance for the time to peak vertical reaction force (Figure 4) did not reveal any differences in time to peak for the different levels of radiographic disease severity.

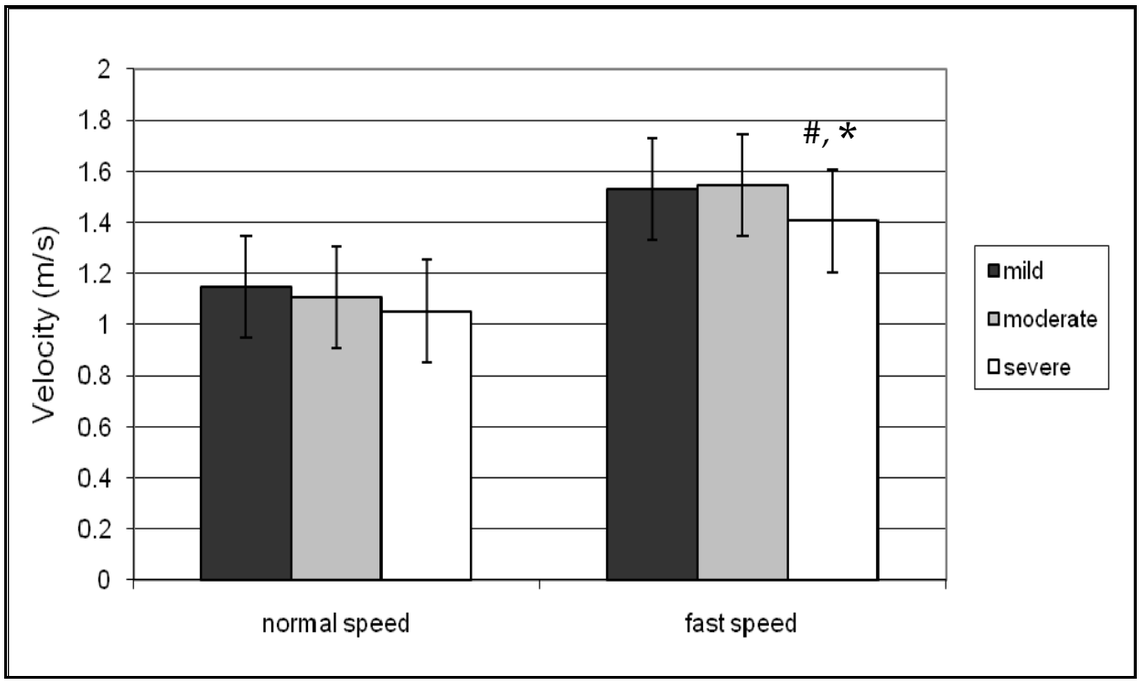

Fig. 1. Analysis of variance results for velocity (# denotes a significant difference from mild OA and * denotes significant difference from moderate OA)

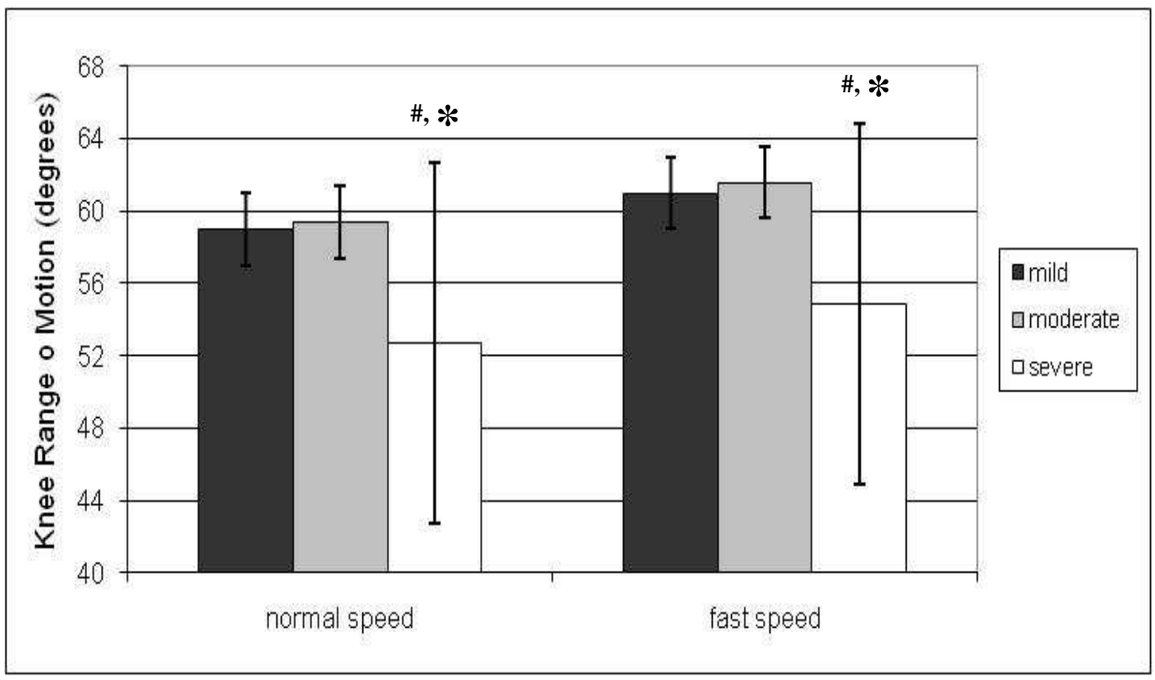

Fig. 2. Analysis of variance results for knee range of motion. # denotes significant difference from mild OA, * denotes significant difference from moderate OA

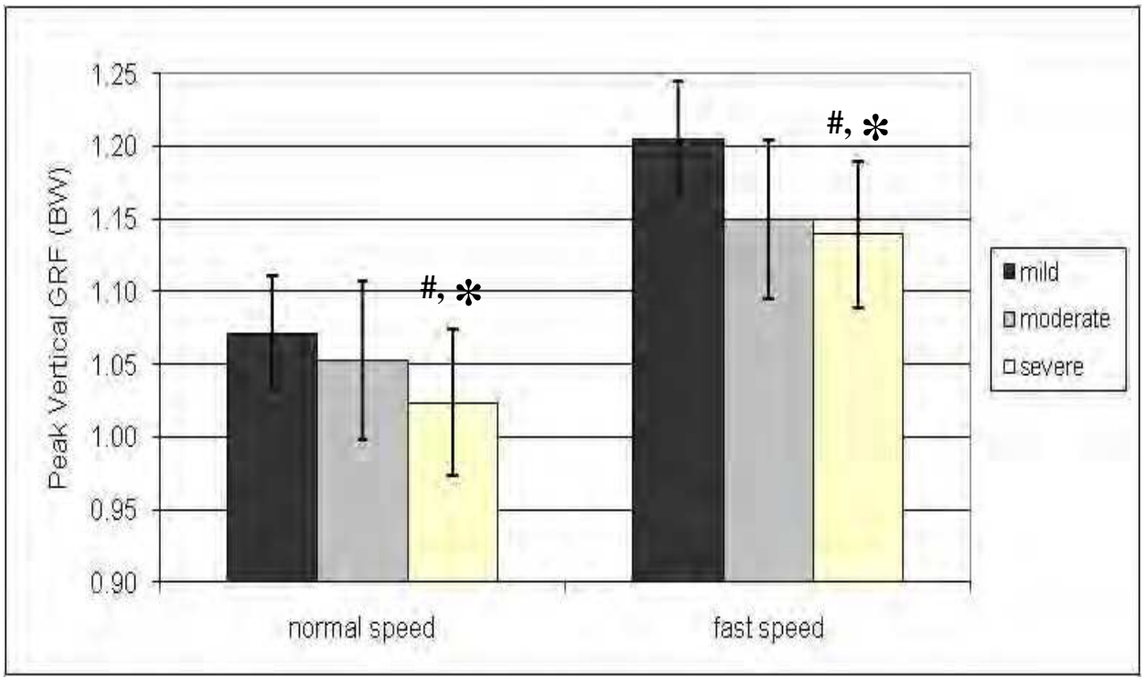

Fig. 3. Analysis of covariance results for peak vertical ground reaction force; # denotes significant difference from mild OA and * denotes significant difference from moderate OA

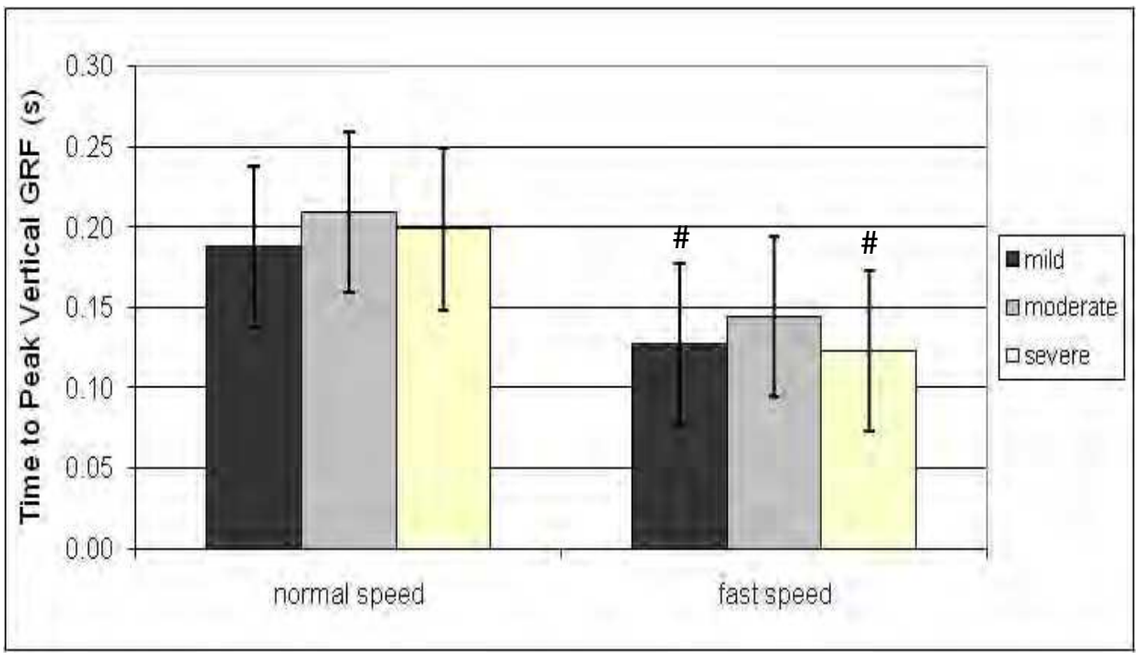

Fig. 4. Analysis of covariance results for time to peak vertical ground reaction force; # denotes a significant difference from moderate OA at the normal speed, however at the fast speed there was a significant difference between mild and moderate and moderate and severe levels of radiographic disease severity.

4. Discussion

Given the conflicting results of previous studies, the purpose of this study was to further examine the relationship between radiographic disease severity and gait patterns in persons with knee OA by not only looking at radiographic grade, but by looking at gait patterns in subjects grouped by severity level. This study expanded on previous work by investigating differences in gait mechanics across all levels of radiographic severity (mild, moderate, and severe). The current study investigated joint mechanics, as well as spatiotemporal gait characteristics.

It was predicted that more severe levels of knee OA would correlate positively with increased gait disability measured through slower walking velocity, shorter strides, lower peak vertical forces, greater knee adduction moments, smaller loading rates and a more limited knee range of motion. The results showed that four of these measures of gait disability differed significantly in patient groups having different levels of radiographic disease severity. It was further hypothesized that significant differences in gait mechanics would exist between the three radiographic disease severity levels, even after controlling for speed. This hypothesis was supported in that both peak vertical ground reaction force and time to peak vertical ground reaction force varied with radiographic disease severity independent of walking speed.

The gait biomechanics of the subjects in this study are consistent with previous reports. OA patients had a shorter stride length, slower walking velocity, lower stride frequency, a longer support time, and smaller loading rate than their counterparts without OA (Al-Zahrani & Bakheit, 2002; Brinkmann & Perry, 1985; Messier et al., 2005a; Messier et al., 1992). Furthermore, mean peak knee adduction moment and mean KROM were consistent with previous reported values in persons with OA (Baliunas et al., 2002; Kaufman et al., 2001; Messier et al., 2005a; Messier et al., 1992). When broken down by radiographic severity, subjects with more severe OA walked more slowly, with stiffer knees and loaded their limbs less.

Knee OA is the most common cause of disability in community dwelling elderly adults (Guccione et al., 1994) and these altered gait mechanics can potentially influence progression of OA and quality of life. For example, the typical mean walking speed for adults is 1.3 m/s and in general a reduction in walking velocity by 12% has clinical significance. The mean walking velocity in this study at the normal speed is at about a 14% reduction and for the patients with severe OA it is a 21% reduction. Given the increase in gait disability with increased OA severity found in this study, patients with severe radiographic disease may be unable to easily execute activities of daily living such as ambulation, and they may also be unable to complete the physical activities prescribed as part of the treatment plan for their OA disease.

As others studies have reported (Nebel et al., 2009; White et al., 2010; Wilson et al., 2011), the present study found that there was only a modest relationship between K/L grade and gait mechanics. Knee range of motion and peak vertical ground reaction force was inversely correlated with radiographic disease severity at both speeds. Each of these variables, as well as velocity, stride frequency, loading rate, knee adduction moment and time to peak vertical ground reaction force, were also examined by level of severity. Statistically significant differences were seen in four of these gait variables. As predicted, patients with severe OA had the smallest knee range of motion and the smallest peak vertical ground reaction force at both speeds. The influence of radiographic disease

severity on knee range of motion is understandable given that severe erosion of cartilage and presence of osteophytes as well as joint space narrowing could limit knee range of motion (Holla et al., 2011). It was expected that patients with severe OA would not load their limbs as much and load them more slowly to alleviate pain. Peak vertical ground reaction force decreased with increasing OA severity at both speeds. This alteration in gait mechanics is consistent with the notion that patients are seeking to reduce loading at the knee. Finally, time to peak vertical GRF was greatest in patients with moderate OA; the differences were statistically significant at the fast speed. It is important to note that, in this study, differences related to peak vertical ground reaction force were not a function of slower walking speed. This is in contrast to previous work that has suggested alterations in gait variables may arise partially as a result of altered walking speed (Mundermann et al., 2004; Zeni & Higginson, 2010). In this study, walking velocity did not differ as a function OA disease severity at the normal walking speed. However when challenged to walk at a fast speed, patients with severe OA walked significantly slower than patients with mild and moderate OA. Given that the external KAM during walking has been associated with radiographic disease severity (Sharma et al., 1998; Zeni & Higginson, 2010), it was expected that such a correlation would be observed in the current study, however, it was not. Some trends for knee adduction moment were revealed though. At the normal speed knee adduction moment decreased with increasing level of severity and the exact opposite was true at the fast walking speed; knee adduction moment increased with increasing radiographic severity. The trend at the fast speed was consistent with previous studies (Miyazaki et al., 2002; Wilson et al., 2011). A similar trend was observed for loading rate. While differences in loading rate were not statistically significant, loading rate decreased with increasing radiographic severity at the normal speed and it increased with increasing level of severity at the fast speed.

Based on the variables that differed by radiographic severity: velocity, knee range of motion, peak vertical ground reaction force, and time to peak vertical ground reaction force, it appears that subjects may have altered their gait mechanics as part of a compensatory strategy. These alterations may also be the result of altered control strategies (e.g. increased time to peak vertical ground reaction force) that may result in damaging gait patterns. Factors such as obesity, pain severity, and helplessness have been suggested to be important determinants of physical limitation in patients with knee OA (Creamer et al., 2000). Perhaps the compensatory strategies exhibited by the patients in this study are related to pain they experience with increasing disease severity. While the current study did not investigate the influence of pain on gait mechanics, a previous study by this group did find that pain accounted for as much as 24% of the variance in walking speed in patients with knee OA after controlling for demographics and disease severity (Somers et al., 2009). Another possible explanation for the compensatory gait mechanisms is kinesiophobia, or pain-related fear of movement, which refers to the fear of movement and injury due to consequent pain (Somers et al., 2009). If the patients with more severe OA are experiencing more pain, then it may be affecting their movement. Findings by Heuts et al., 2004 in which they found self-reported level of pain to be significantly correlated with functional limitations support this theory. Furthermore, there is increasing interest in the role of pain cognitions, specifically pain catastrophizing and pain-related fear in predicting adjustment to OA disease (Heuts et al., 2004; Somers et al., 2008; Somers et al., 2009). Somers and colleagues found that pain-related fear and pain

catastrophizing explained a significant amount of variance in walking velocity and that pain catastrophizing was a significant individual predictor of walking velocity (Somers et al., 2009). Thus further investigation of the influence of pain and pain cognitions on the relationship between OA severity and additional gait variables (knee range of motion, peak vertical ground reaction force, and time to peak vertical ground reaction force), might be beneficial.

5. Conclusion

The purpose of this study was to examine the relationship between radiographic disease severity and gait patterns in persons with knee OA by looking at gait mechanics and joint loading in subjects across all severity levels. The results indicate that variation in gait could not be fully explained by K/L grade; although, when K/L grade was used to form different levels of radiographic disease severity, significant differences did exist. The results showed that significant differences existed in peak vertical ground reaction force and time to peak vertical ground reaction force by level of radiographic severity, even after controlling for walking speed. This study continues to point to osteoarthritis of the knee as a multifactorial disease. While radiographic disease severity is related to changes in gait biomechanics, the aberrant gait patterns could be a combination of radiographic disease severity and the pain experienced at a given severity. It may even be related to a combination of pain cognitions and radiographic disease severity. The authors suggest that future work should be done to look at the influence of pain and pain related fear of movement or other pain cognitions on gait mechanics within each severity group.

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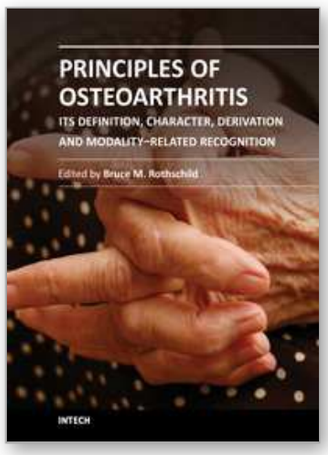

Principles of Osteoarthritis- Its Definition, Character, Derivation and Modality-Related Recognition

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This volume addresses the nature of the most common form of arthritis in humans. If osteoarthritis is inevitable (only premature death prevents all of us from being afflicted), it seems essential to facilitate its recognition, prevention, options, and indications for treatment. Progress in understanding this disease has occurred with recognition that it is not simply a degenerative joint disease. Causative factors, such as joint malalignment, ligamentous abnormalities, overuse, and biomechanical and metabolic factors have been recognized as amenable to intervention; genetic factors, less so; with metabolic diseases, intermediate. Its diagnosis is based on recognition of overgrowth of bone at joint margins. This contrasts with overgrowth of bone at vertebral margins, which is not a symptomatic phenomenon and has been renamed spondylosis deformans. Osteoarthritis describes an abnormality of joints, but the severity does not necessarily produce pain. The patient and his/her symptoms need to be treated, not the x-ray.

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Slavka Krautzeka 83/A
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