Hip and Knee Frontal Plane Biomechanics in People with Medial Compartment Knee Osteoarthritis

by

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ABSTRACT

Objectives: To investigate differences between hip abductor muscle strength, hip and knee adduction moments and knee joint alignment in people with moderate/severe and mild medial compartment knee osteoarthritis (OA), and people without OA, and identify variables explaining variance in knee adduction moment in participants with OA.

Background: It has been suggested that weakness of hip abductor muscles may lead to displacement of the centre of mass of body away from the stance limb during gait, resulting in increased knee adduction moment, a predictor of disease progression.

Methods: Participants with medial compartment knee OA were divided into moderate/severe (n=23) and mild OA groups (n=15) based on radiographic grading. Control subjects were recruited to match participants in the moderate/severe group for age and gender (n=23). Hip abductor and adductor muscle isometric strength was measured using the Biodex dynamometer. Gait speed and hip and knee peak adduction moments and percentage of the stance phase where these occurred were obtained using a three dimensional motion analysis system and two force platforms. Knee alignment and severity of OA were measured from radiographs. Statistics: Univariate analysis of variance (ANOVA) was performed to determine group differences. Stepwise linear regression analysis was performed to identify the variables which contribute to variation in knee adduction moment. Results: Moderate/severe OA group participants had higher body mass index (BMI) than the mild OA and control group (p=0.01) and greater varus alignment compared to the control group (p<0.01). There was no difference between the mean hip abductor and adductor muscle strength and hip and knee adduction moments among the three groups. Peak hip (p=0.02) and knee adduction moments (p<0.05) occurred later in stance phase of gait in the moderate/severe OA group as compared to
control group. Knee joint alignment (26%), hip abductor muscle isometric strength (20%), gait speed (16%) and hip adduction moment (11%) explained 73% of variance in the knee adduction moment in the participants with OA. **Conclusion:** Findings from this study do not support the theory that weakness of the hip abductor muscles contributes to higher knee adduction moments.
ACKNOWLEDGEMENTS

At the outset, I humbly express my gratitude to my Imam for all His guidance and blessings.

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CHAPTER 1
INTRODUCTION

Osteoarthritis (OA) is a degenerative joint disease associated with aging, which may lead to impairment and disability (1). Various joints are affected by OA, including joints of the hand and spine and weight-bearing joints, such as the hip, knee and ankle. OA leads to degeneration of articular cartilage and simultaneous sclerosis of subchondral bone. Periarticular erosions occur, followed by reactive bone formation leading to the development of osteophytes. Other characteristics include joint space narrowing which contributes to capsular and ligamentous laxity, weakness of muscles around the joint and subsequent joint instability and deformity (2,3). Osteoarthritis produces joint pain, stiffness, swelling, and limited mobility (4), which may cause reduced quality of life and social contact.

Osteoarthritis is the most common type of arthritis, affecting 10% of the Canadian population (4,5). In Canada, OA is two and a half times more prevalent than heart disease and six times more prevalent than cancer (5). The incidence of OA increases in people older than 45 years and, on the whole, men and women are affected in equal numbers. However, more men are affected before 55 years, and more women are affected thereafter (6). Approximately 85% of Canadians will be affected with OA by the age of 70 years (5). Osteoarthritis is one of the major causes of disability in older adults (6). The consequences of OA and its increased prevalence in the older population, a population which continues to grow as the baby boomer generation ages, will result in increasing costs to the Canadian health care system (7).

The knee joint is the most commonly affected weight bearing joint (8). Oliveria et al. (8) quantified the incidence of knee OA among the members of a health maintenance
organization in Massachusetts, USA using the Kellgren/Lawrence scale (K/L scale) (9) for radiographic grading and joint symptoms to identify cases of OA. The incidence of knee OA was 240/100,000 person-years, as opposed to 100/100,000 and 88/100,000 person-years for hand and hip OA, respectively. Wilson et al. (10) reported that approximately half a million cases of primary hip and knee OA may arise per year in the white population of United States. The Framingham Study revealed that 6.1% of individuals aged 30 years and above have symptomatic knee OA, defined as pain on most days and positive findings on the radiographs of the affected knee (11).

Knee OA results in the degeneration of femoral and tibial articular cartilage, characterized by softening, fibrillation, ulceration and, eventually, loss of the cartilage leading to joint space narrowing. The changes in subchondral areas of the femur and tibia include marginal outgrowths, osteophytes, and bony sclerosis which are visible on knee radiographs (12). Moreover, inflammatory infiltrates are present in the synovium and laxity of surrounding ligaments may also occur. Weakness of muscles around the knee joint is also prevalent in individuals with knee OA (2,13). A clinical diagnosis of knee OA is based on radiographic evidence combined with the presence of pain in the knee joint (2,14).

Research indicates that the onset and progression of knee OA are related to various biological and mechanical factors. Biological risk factors include age, gender, obesity, genetic predisposition, low levels of physical activity and associated muscle weakness and previous joint inflammation or disease. Mechanical risk factors include excessive and abnormal joint loading, previous joint injury and malalignment of the articulating bones. The higher incidence of medial versus lateral compartment knee OA is attributed to the normally higher load through the medial compartment during weight-bearing activities.
Medial compartment damage due to OA contributes to varus malalignment which further increases the load on the medial compartment and contributes to the progression of OA (16-18).

The magnitude of knee joint loading during gait and the distribution of forces on the medial compartment of the knee are determined by performing quantitative gait analysis (19-21). The external knee adduction moment is commonly used as an index of medial compartment load and has been reported as a reliable and valid measure (21-23). The knee adduction moment is, primarily, the product of frontal plane ground reaction force and the perpendicular distance from the force to the knee joint axis (24). Individuals with more severe medial compartment knee OA have higher adduction moments compared to those with less severe OA (14,23,25,26) and without knee OA (25,27). Moreover, a high knee adduction moment results in increased risk of disease progression in people with knee OA (16,17). The knee adduction moment has been shown to correlate with various characteristic features of medial compartment knee OA including tibial bone mineral content (21), bone mineral density (26), pain, alignment (14), joint space width (14,23), and OA severity as represented by scores on the K/L scale (23).

The higher knee adduction moment in people with medial compartment knee OA is postulated to be related to a larger lever arm magnitude, due to a medial shift of frontal plane ground reaction force from the center of rotation of the knee joint due to varus alignment (27). Therefore, medial knee joint loading may be lowered by strategies that decrease the lever arm magnitude (24). Strategies adopted by people with knee OA include increasing the toe-out angle (28-30) and leaning the trunk towards the stance limb during gait (31). Decreased gait speed (25,32) also reduces medial compartment loading by lowering the magnitude of the ground reaction force. Using a cane on the contralateral
side of the affected lower extremity may reduce the knee adduction moment by decreasing magnitude of both the ground reaction force and lever arm (33). Moreover, the goal of the surgical intervention of high tibial osteotomy (34,35) and conservative techniques, such as shoe wedges (36-38) and valgus bracing (39), is to reduce varus alignment and the lever arm magnitude.

The hip abductor muscles play an important role in controlling the trunk and position of the pelvis in the frontal plane during the stance phase of the gait cycle (40). Researchers have suggested that lack of control of the pelvis due to hip abductor muscle weakness during stance phase may allow the pelvis to drop to the swing side which results in shifting of the centre of mass of the body away from the stance limb (27,41). The shift of centre of mass would increase the lever arm of the frontal plane ground reaction force at both the hip and knee joints of the stance limb, which would increase the external adduction moment at these joints. Therefore, hip abductor muscle weakness could, theoretically, result in higher hip and knee adduction moments (27,41). It is generally agreed that the knee adduction moment is higher in people with medial compartment knee OA, particularly in those with more severe OA (23,25-28,42,129). However, some reports indicate that the hip adduction moment is lower in people with more severe knee OA compared to those without knee OA (27,43,129).

Despite the theoretical expectation that the hip abductor muscles of the affected lower extremity may be weaker in people with medial compartment knee OA, only one study was found which quantified hip abductor muscle strength in people with knee OA compared to those without knee OA, and they did not find a difference (44). There is also little information available in the literature on the relationship between the hip and knee adduction moments and the contribution of the hip adduction moment to explain the
variation in the knee adduction moment. Therefore, the purpose of this study is to quantify hip abductor muscle strength in people with and without knee OA and investigate the relationships between hip abductor muscle strength, hip adduction moment and knee joint loading.

1.1 Objectives

Specifically, the objectives of the study are:

1. to determine differences in the hip abductor and adductor muscle strength, hip and knee adduction moments, and knee alignment between people with moderate/severe knee OA versus those with mild knee OA and without knee OA; and

2. to determine whether hip abductor muscle strength and the hip adduction moment contribute to variation in knee adduction moment.

1.2 Hypotheses

We hypothesize that:

1. people with moderate/severe medial compartment knee OA will have weaker hip abductor muscles compared to those with mild OA and without knee OA;

2. people with moderate/severe knee OA will demonstrate higher peak hip and knee adduction moments and greater varus alignment compared to those with mild OA and no diagnosis of knee OA;
3. hip abductor muscle strength and the hip adduction moment will contribute to the variation in the knee adduction moment; the relationship between hip abductor muscle strength and knee adduction moment will be negative, and the relationship between hip adduction moment and knee adduction moment will be positive.
CHAPTER 2
LITERATURE REVIEW

2.1 Factors Contributing to the Onset and Progression of Knee Osteoarthritis

Two categories of risk factors for knee OA have been identified, biological and mechanical. Biological risk factors include age, gender, obesity, genetic predisposition, low levels of physical activity, associated muscle weakness and previous joint inflammation or disease. Excessive and abnormal joint loading, previous joint injury and malalignment of the articulating bones constitute the mechanical risk factors for knee osteoarthritis.

In people who are obese, the prevalence of knee OA, as indicated by radiographic signs, increases (45,46). It has been argued that obesity is a consequence of OA of the lower extremity joints, as the symptoms of OA often limit an individual’s mobility resulting in a sedentary lifestyle and an increase in body weight. However, it has been demonstrated that increased body weight precedes the development of disease in the knee joint (47,48). This finding is supported by the fact that weight loss reduces the risk for subsequent development of knee OA (49). Lower body weight has also been shown to improve physical function, reduce disability and decrease joint symptoms, including pain, in people with knee OA. These improvements likely occur through a decrease in load on the knee joint and surrounding soft tissues (50,51). Similarly, Messier et al. (50) found that weight loss combined with an exercise regimen was effective for decreasing the symptoms of knee OA.

Genetic predisposition is also a risk factor for OA; however, not all joints have the same genetic susceptibility. At the knee joint, genetic predisposition accounts for a small percentage of OA, while genetic factors account for more than 50% of OA occurrence in
the hand joints (52,53). In general, women are more genetically prone to OA than men for most joints (11).

Low levels of physical activity and muscle weakness have been implicated in the etiology of knee OA. In sedentary individuals, physical inactivity may lead to weight gain which increases joint load. Inactivity may also result in muscle weakness due to disuse (54). Individuals with knee OA demonstrate reduced quadriceps femoris muscle strength compared to those without knee OA (13,44,55-57). Quadriceps muscle weakness is also greater than hamstrings muscle weakness in people with knee OA (13,55,56).

There is some evidence that quadriceps femoris muscle weakness precedes the development of knee OA (55). Quadriceps femoris muscle strength was found to be 15-18% lower at baseline in 107 women who subsequently developed radiographic signs of knee OA (after 31 months), as compared to those who did not develop knee OA (n = 13) after adjusting for body weight and lower extremity muscle mass. However, the baseline values obtained for men who later developed radiographic signs of knee OA were not lower than those values for men who did not develop knee OA. Muscle weakness may result in reduced ability of the muscles around the knee joint to absorb forces during joint movement, resulting in higher loads being transmitted across the articular surfaces (55). Muscle weakness may also lead to instability of the knee joint (11) which may increase the risk of damage to the joint’s articular cartilage during weight-bearing activities (54). Moreover, once the disease is established, joint pain along with other symptoms may also result in lack of physical activity and further weakness of quadriceps femoris muscle.

Previous joint injuries, such as fractures involving the articular surfaces, joint dislocations and ligament and meniscal injuries also increase the risk for development of knee OA (58-61). Studies revealed that a high proportion of individuals with previous
anterior cruciate ligament injury subsequently presented with radiographic signs of knee OA (62,63). In another study, individuals with intact anterior cruciate ligaments who had undergone meniscectomy demonstrated radiographic features of knee OA 16 years after removal of the meniscus (64).

Repetitive joint loading may result in alterations in composition, structure, metabolism and mechanical properties of joint tissues (65). Occupational and leisure activities contribute to repetitive loading of the knee joint. Occupations involving activities with high knee joint loading, such as kneeling, squatting and lifting heavy objects, increase the risk for developing knee OA compared to occupations which do not involve these activities (66). Men are at a higher risk for knee OA related to occupation, as they perform these occupations more commonly than women (66). Professional sportspersons, including competitive runners, were shown to have a higher risk for development of knee OA related to repetitive knee joint loading (67,68). However, no such finding was reported for recreational runners (69,70).

Malalignment of the articulating bones may also increase the risk of subsequent development of knee OA (16). Altered alignment will affect the load distribution within the compartments of the knee joint (20), with varus alignment resulting in increased forces across the medial compartment of the knee and valgus alignment causing increased forces across the lateral compartment (17).

At the knee joint, medial compartment OA changes are more common than lateral compartment joint changes (16,71). This finding may be attributed to the fact that, during gait more force is transmitted to the medial compartment than the lateral compartment in people with neutral knee alignment (15,19,32,72). Morrison (72) and Harrington (32) found the magnitude of peak knee joint force to be 3.03 and 3.5 times body weight,
respectively, during the stance phase of the gait cycle. Similarly, Schipplein and Andriacchi (19) reported that during the stance phase of gait 71% (or 2.25 ± 0.39 times body weight) of the peak joint reaction force at the knee joint (approximately 3.2 times body weight) was transmitted through the medial compartment.

In a varus aligned limb, greater than normal medial compartment loading occurs during gait (3) which may increase the risk of subsequent medial compartment OA. Brouwer et al. (16) reported that, in 43 knees with varus alignment and no radiographic signs of OA at baseline, the risk of developing OA (after 6.6 ± 0.5 yr) increased two-fold compared to those with normal alignment. However, for valgus aligned knees there was only a trend towards increased risk of developing OA (p = 0.06). Further analyses based on body mass index indicated that the risk for developing medial compartment knee OA in people with varus alignment was only found in those with a body mass index equal to or greater than 25 kg/m² (16). Conversely, Hunter et al. (15) did not find an association between varus alignment at baseline and subsequent development of medial compartment OA in an epidemiological study of 1,705 people followed for a mean of 8.75 years, after adjusting for age, gender and body mass index.

Varus alignment has been shown to increase the risk of progression of medial compartment knee OA (16-18). Baseline severity of varus and valgus alignment of the knee joint in people with knee OA was shown to be correlated with decreased medial (r = 0.52) and lateral (r = 0.35) knee joint space, respectively after 18 months (17). Teichtahl et al. (18) studied the association between static knee alignment and radiographic features in 121 people with knee OA. Their results revealed that increasing varus knee alignment was associated with increased risk of progression of joint space narrowing and osteophyte formation in the medial compartment of knee joint. Brouwer et al. (16) reported that in 11
out of 95 knees with medial compartment knee OA, the presence of varus alignment at baseline increased the risk of progression of OA 6.6 (± 0.5) years later.

2.2 Hip Abductor Weakness as a Risk Factor in Development of Knee OA

Hip abductor muscle weakness has also been implicated as a risk factor for development and/or progression of medial compartment knee OA (27,41). The hip abductor muscles maintain the pelvis in a neutral position and prevent it from tilting towards the swing limb in the frontal plane during the stance phase of the gait cycle. Weakness of the hip abductor muscles may result in dropping of the pelvis towards the swing limb during the single limb support phase of gait (40). Chang et al. (41) suggested that the drop of the pelvis towards the swing limb shifts the centre of mass of the body away from the stance limb, resulting in increased loading on the medial compartment of the stance limb knee joint due to the increase in the moment arm.

Mundermann et al. (27) analyzed the loading condition of lower extremity joints in 42 people with medial compartment knee OA and age, sex, weight and height-matched individuals without knee OA. Gait analysis was performed in order to measure the external moments at the hip, knee and ankle joints. Individuals with more severe OA had higher external knee adduction moments and lower external hip adduction moments in the stance phase of gait as compared to their age, gender, weight and height-matched control group. However, those with less severe knee OA had similar external hip adduction moments as the control group participants. The authors suggested that weakness of the hip abductor muscles might contribute to the higher loading at the knee. They also suggested that patients with more severe knee OA have relatively weaker hip abductor muscles than control participants and those with less severe knee OA. Decreased hip
abductor muscle strength may result in an inability to efficiently reduce the load at the knee joint during the stance phase of gait, which may increase the risk of progression of medial compartment knee OA. However, if the center of mass moves away from the stance limb both the hip and knee adductor moment should increase due to the increase in moment arm. The authors do not explain the lower hip adduction moment found in the participants with more severe OA.

In a subsequent study, Mundermann et al. (31) suggested that trunk lean towards the stance limb would reduce the external hip and knee adduction moments by moving the center of mass towards the stance limb, decreasing the moment arm at both the hip and knee. These authors studied the effect of trunk lean on the hip and knee adduction moment in 19 healthy young adults (12 men, 7 women; mean age 22.8 ± 3.1 yr). Participants performed trials of normal gait and trials in which they were asked to increase trunk lean by a self-selected degree towards the stance limb. The results revealed that the hip and knee adduction moments during trials with increased trunk lean (Trunk sway 10 ± 5˚) were significantly lower than during normal gait trials (p < 0.01).

The assumption that higher hip adduction moment is associated with higher medial compartment load at the knee is challenged by Chang et al. (41). These authors performed an 18-month prospective study in 57 individuals with medial compartment knee OA (103 knees; mean age 67 ± 8.7 yr) to determine predictors of progression of OA. Multiple factors, including age, BMI, knee pain severity, varus alignment, hip adduction moment, presence of hip OA, hip symptoms, physical activity and gait speed, were measured at baseline. Loss of joint space was used to determine OA disease progression at 18 months. The results revealed that only 17 of the 103 knees demonstrated progression at follow-up and that high mean peak external hip adduction moment was protective in terms of
progression. After adjusting for the other baseline measures it was found that the odds for medial compartment OA progression were lower in participants having higher external hip adduction moments (odds ratio 0.43). The authors stated that the external hip adduction moment is equal to the internal hip abduction moment and argued that the internal hip abduction moment is related to the strength of the hip abductor muscles. They extended the argument to say that stronger hip abductor muscles are therefore protective. Biomechanically, however, a higher external hip adduction moment should result in increased loading of the medial compartment, a higher knee adduction moment and consequently more rapid progression of OA. Therefore, the mechanism that accounts for the protective effect of the high external hip adduction moment in the study by Chang et al. (41) is unclear.

2.3 Gait Analysis

Quantitative gait analysis is a valuable tool for assessing the changes in walking patterns of people with knee OA (73). Given the prevalence of medial compartment knee OA (71) and increased loading of the medial compartment during walking (19,72), quantitative gait analysis may provide insight regarding the pathology and progression of the disease. Gait analysis may also offer direction for non-surgical interventions which could impede disease progression and reduce pain in individuals with knee OA (73).

The gait cycle commences from the point at which one event of the cycle takes place to the point the same event recurs in the same limb, usually from foot contact to subsequent foot contact of the same foot (74). The cycle is divided into two phases, namely stance phase and swing phase. During stance phase, which comprises 60-62% of the cycle, the reference lower extremity is in contact with the ground. Swing phase
occupies the 38-40% of the cycle when the reference lower extremity is not in contact with the ground (74,75). These phases are both further divided into sub-phases which are expressed in terms of a percentage of the entire gait cycle.

2.3.1 Temporal and Distance parameters of the Gait Cycle

Temporal and distance parameters are the most commonly measured gait variables. Temporal variables of the gait cycle include stance time, single-limb and double-support time, swing time, stride and step time, cadence and speed. Distance variables include stride length, step length, step width and toe-out angle (74). Various systems are available for measurement of these variables, including foot switches, instrumented walkways, accelerometers and optoelectronic systems (78). Olney (74) suggested that age, gender, height, formation of bony prominences, mass distribution in different body segments, joint mobility, muscle strength, clothing and footwear and the psychological state of the individual are factors which may influence temporal and distance variables.

Several studies have documented differences in temporal and distance parameters in people with knee OA compared to control participants (Table 1). People with knee OA tend to have shorter step length (80,82), slower gait speed, decreased cadence (80,81), and single limb support time, and longer stride time and double limb support time (80) compared to those without knee OA. At a fixed gait speed, OA participants walk with shorter step length but take more steps per minute and have shorter double limb support time than people without knee OA (82).
Table 1: Temporal and Distance Parameters of the Gait Cycle.

<table>
<thead>
<tr>
<th>Author’s Name and Year</th>
<th>Participants (male = m, female = f; mean age = yr)</th>
<th>Temporal and Distance Variables Reported</th>
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</table>
| Teixeira and Olney, 1996 (79) | People with knee OA (6 m, 5 f; 70.2 ± 7.8 yr) | Stride Time (s) 1.42 ± 0.19  
Stride length (m) 1.06 ± 0.33  
Stride Speed (m/s) 0.44 ± 0.15  
Cadence (strides/min) 42.97 ± 5.54  
Stance Ratio (% Gait Cycle) 67 ± 5  
Stance time (s) 0.96 ± 0.18 |
| Chen et al., 2003 (80) | People with knee OA (OA) (20 f; 65.5 ± 9.3 yr); Elderly Group (EG) (15 f; 63.5 ± 11.3 yr) Young Control (YG) Group (20 f; 21.7 ± 4.5 yr) | Stride time (s) OA = 1.38 ± 0.17  
EG = 1.22 ± 0.15  
YG = 1.08 ± 0.12  
Step Length (m) OA = 0.50 ± 3.6  
EG = 0.56 ± 4.3  
YG = 0.63 ± 3.2  
Gait Speed (m/s) OA = 0.71 ± 0.1  
EG = 0.91 ± 0.17  
YG = 1.15 ± 0.16  
Cadence (steps/min) OA = 87.70 ± 10  
EG = 99.30 ± 12.3  
YG = 112.2 ± 11.8  
Single Limb Support (% Gait Cycle) OA = 35 ± 2.6  
EG = 36 ± 2  
YG = 36.6 ± 9.2  
Double Limb Support (% Gait Cycle) OA = 29.4 ± 3.4  
EG = 27.5 ± 2.8  
YG = 22.0 ± 4.2 |
| Maly, 2005 (81) | People with knee OA (n = 54; 68.3 ± 8.7 yr) People without OA (POA) (n = 52; 63.6 ± 6.4 yr) | Gait Speed (m/s) OA = 1.02 ± 0.2  
POA = 1.12 ± 0.2  
Stride Length (m) OA = 1.2 ± 0.2  
POA = 1.3 ± 0.2  
Cadence (strides/min) OA = 50.2 ± 6.6  
POA = 51.7 ± 5  
Stance Phase (% gait cycle) OA = 68 ± 3.2  
POA = 65 ± 2.7  |
| Bejek et al., 2006 (82) | People with knee OA (OA) (8 m, 12 f; 68.2 ± 7.1 yr) People without OA (POA) (8 m, 12 f; 68.8 ± 9.1 yr) | Fixed Gait Speed (m/s) 0.55  
Step Length (m) OA = 0.72 ± 0.07  
POA = 0.87 ± 0.01  
Cadence (steps/min) OA = 106.9 ± 8.7  
POA = 89.6 ± 13.8  
Swing Phase (% gait cycle) OA = 31.3 ± 2.2  
POA = 32.3 ± 6.7  
Double Limb Support (% gait cycle) OA = 19.5 ± 1.1  
POA = 21.5 ± 1.7 |

Values are means ± standard deviation.
2.3.2 Kinematic Parameters

Joint kinematics provide information on movement of the body segments, including linear and angular accelerations, velocities and displacements without considering the forces responsible for the movements (78). The most common kinematic variable reported is the angular segment displacement which describes the range of motion of a body segment as related to an adjacent segment (83). The acquisition of kinematic data is performed using various technologies, including electrogoniometers (56), accelerometers (84), cinematography and various types of computerized motion analysis systems (77). A three-dimensional computerized motion analysis system may help to identify rotational abnormalities in the transverse plane which may be confused with coronal or sagittal plane abnormalities (75).

Currently, three-dimensional motion analysis systems are most commonly used for gait analysis due to superior image quality, lower testing time and cost effectiveness (76). The systems consist of infrared light-emitting (active) or reflective (passive) markers, charged-couple device cameras and sophisticated personal computers (76,77). The passive markers reflect infrared light emitted by the diodes placed around the lens of camera, and computer software or dedicated hardware circuits recognize the markers in the video frames. The active markers flash sequentially and the position is detected by the cameras based on flash timing (76). Both of these types of three-dimensional systems eliminate the problem of marker identification, and the resultant joint angles can be viewed within minutes of data collection (77). The three-dimensional coordinates of all markers are calculated based on two-dimensional data obtained from the cameras, the location of markers and internal parameters (76).
Messier et al. (57) performed kinematic analyses of 15 people with knee OA (4 men; 11 women; mean age 58.67 ± 2.29 yr) and age, mass and gender matched control participants. They reported that mean knee angular velocity was 8% (p = 0.04) and knee extension velocity was 7% lower (p = 0.03) in the OA group as compared to the control group. In participants with OA, the velocity of the affected leg was 7% less than the unaffected leg (p < 0.01) and the affected leg had 3% lower knee joint range of motion (p = 0.004) and 15% lower mean hip angular velocity (p = 0.01). The authors concluded that individuals with knee OA adopted a walking pattern that reduced knee angular velocity and knee joint range of motion in both lower extremities.

2.3.3 Kinetic Parameters

Kinetic analyses provide information on forces acting on the joints, muscle moments and energy requirements during gait (74). Kinetic variables include ground reaction forces which consist of three components: vertical, anterior-posterior and medial-lateral shear forces. The forces are measured by force transducers or force plates (78).

Force variables are fed into a link segment model along with kinematic and anthropometric data of the participant and an inverse dynamics approach is used to calculate joint moments (74,78). In the link segment model, the body is considered as a model consisting of different segments and each segment is considered as a separate rigid body. A free body diagram is then drawn from the distal to proximal segments such that the foot is drawn first, followed by shank, thigh and other proximal segments (85). Joint moments may be described as internal or external moments (75). Internal moments at a joint refer to the moments contributed by muscles, ligaments and joint capsule (41,74).
External moments are produced by the external forces, including ground reaction forces (74,75).

**2.4 Measurement of Medial Compartment Load**

The magnitude of medial compartment loading during walking can be estimated by the external knee adduction moment (19,20). The knee adduction moment is primarily the product of the frontal plane ground reaction force and the perpendicular distance from the knee joint centre of rotation to the ground reaction force (24) (Figure 1). An increased knee adduction moment during gait indicates an increased load across the medial compartment of the joint (24). Hurwitz et al. (21) validated the use of the knee adduction moment as a predictor of knee joint loading based on bone mineral content of the proximal tibia in healthy individuals. They reported a significant positive correlation ($r = 0.56$) between the peak knee adduction moment and the ratio of medial to lateral bone mineral content of the proximal tibia. A significant correlation ($r = 0.52$) has also been reported between the peak knee adduction moment and the ratio of bone mineral density of the medial to lateral tibial plateau in people with medial compartment knee OA (26). Andriacchi et al. (86) argue that a higher adduction moment represents increased loading of the medial compartment which results in increased bone mineral content in the medial plateau of the proximal tibia as compared to the lateral plateau. Similarly, Amin et al. (87) reported that a higher knee adduction moment at baseline, as a result of increased medial compartment loading, led to the development of chronic knee pain in an elderly population. Knee adduction moment at baseline was 39% higher in individuals who eventually developed chronic knee pain compared to those who did not develop knee pain at follow-up.
Figure 1: Illustration of Hip and knee Adduction Moment during Stance Phase of Gait Cycle (right leg) in a C-Motion Computer Software Generated Lower Limb Model.
A = Hip moment arm.
B = Frontal plane ground reaction force vector.
C = Representation of direction of hip adduction moment.
D = Centre of mass.
E = Knee moment arm.
F = Representation of direction of knee adduction moment.
The peak external knee adduction moment has been reported to be significantly greater in people with medial compartment knee OA as compared to age, gender, weight and height-matched control participants (23,25,27,28,42,129). Peak knee adduction moment is higher in people with more severe OA (K/L grade ≥ 3), as compared to those with less severe OA (K/L grade ≤ 2) (23,25-27) and control participants (25,27). Thorpe et al. (42) used the K/L grading scale to determine OA severity and reported that people with mild (K/L grade 2) and moderate knee OA (K/L grade 3) had higher peak knee adduction moment (p < 0.05) compared to an asymptomatic group (K/L grade 0 or 1) during the mid-stance phase of the gait cycle.

In people with medial compartment knee OA, the knee adduction moment is also a predictor of the risk of progression of OA (14,88). Miyazaki et al. (14), in a comparison of individuals with radiographic progression of OA and those without progression, reported that the knee adduction moment was higher in the former group compared to the latter group. The risk of progression of radiographic knee OA increased 6.46 times with a 1% increase in the knee adduction moment.

Hurwitz et al. (89) measured the knee adduction moment and pain in 53 people with knee pain and radiographic evidence of medial compartment knee OA. The participants performed gait trials after a two-week wash-out period of analgesic medication and two weeks after being placed on acetaminophen, non-steroidal anti-inflammatory or placebo medication. For analysis, participants were divided into three groups: those with an increase in pain between the two trials (10 points or more on the pain scale), those with no change and those with less pain at follow-up compared to baseline (10-point difference). The pain scale was based on a 50-point scoring system, where higher values represented less pain. There was a significant inverse correlation (r = -0.48) between
change in pain and change in knee adduction moment, such that those with the greatest
decrease in pain had the highest increase in knee adduction moment. The mean knee
adduction moment was significantly lower at follow-up in participants in the group with
increased pain compared to their baseline values (n = 7, p < 0.05) and there was a trend
for the knee adduction moment to be higher in the group with decreased pain (n =18, p =
0.09). There were no significant differences in the knee adduction moment values
between the three pain groups at baseline. At follow-up, those in the increased pain group
had lower mean knee adduction moments compared to the other two groups (p < 0.05).
They postulated that an inhibition of protective reflex occurs in those with decreased pain,
which results in increased joint loading and higher knee adduction moments. The authors
further postulated that mechanisms other than decreasing walking speed are employed to
decrease the knee adduction moment in people with increased pain.

Conversely, Miyazaki et al. (14) reported that baseline knee adduction moment
correlated positively with the pain score (r = 0.30) in people with medial compartment
OA, indicating that the lower the knee adduction moment, the lower the severity of pain
experienced. Gait analysis was performed in 74 people with medial compartment knee
OA following a four-week washout period of anti-inflammatory medication and physical
therapy. These authors further suggest that the knee adduction moment is a stronger
predictor of pain in the medial compartment of the knee than varus alignment and joint
space width.

The knee adduction moment in people with medial compartment knee OA is reported
to be positively related to alignment of the knee joint, as represented by the Hip-Knee-
Ankle angle (14,26). The more varus the knee joint, the higher the load on the medial
compartment, and hence the higher peak knee adduction moment. Moreover, the knee
adduction moment is associated positively with OA severity, as measured by the K/L scale (23) and negatively with cartilage loss, as indicated by joint space width (14,23).

The higher knee adduction moment in people with medial compartment knee OA is in part related to a larger lever arm magnitude at the knee joint due to varus alignment (24). The greater lever arm magnitude is a result of a medial shift of the frontal plane ground reaction force from the center of rotation of the knee joint. Therefore, the adduction moment, and hence medial knee joint loading, may be lowered by strategies which decrease the lever arm magnitude and shift the ground reaction force closer to the center of rotation of knee joint (24). This strategy is the goal of the common surgical intervention of high tibial osteotomy (34,35). The objective of using shoe wedges (36-38) and valgus bracing (39) is also to correct varus alignment and reduce the lever arm magnitude.

Recently, Birmingham et al. (22) studied the test-retest reliability of the knee adduction moment during gait in individuals with medial compartment knee OA. The intraclass correlation coefficient (ICC) and the standard error of measurement (SEM) were used to determine the reliability of the knee adduction moment. Results of the study revealed an ICC of 0.86 and SEM 0.36 percent body weight times height (%Bw.Ht), indicating that the knee adduction moment is a reliable measure of knee joint loading. The sensitivity and specificity of the baseline knee adduction moment for radiographic progression of disease has also been reported to be 88 and 83%, respectively (14).

The knee adduction moment is often normalized to the participant’s body weight and height and is expressed in the units of percentage bodyweight and height, i.e. %Bw.Ht. Normalization is performed for the convenience of comparison between subject
populations. The findings from studies which have reported knee adduction moments in individuals with and without OA of the knee are listed in Table 2.

2.5 Measurement of Knee Joint Alignment

The alignment of the lower extremity is a principal determinant of load distribution through the knee joint (17). Frontal plane lower limb alignment is usually determined by analyzing full limb radiographs of the hip, knee and ankle joints in the anterior-posterior view (3,17,27). The weight-bearing axis of the lower extremity is represented by a line passing from the centre of the femoral head to the centre of the ankle joint (3,17,43) (Figure 2). In a neutrally-aligned lower extremity, the weight-bearing axis passes very close to the centre of the knee joint (3). Varus alignment is the medial deviation of the weight-bearing axis from the centre of knee joint and valgus alignment is the lateral deviation of the weight-bearing axis (3,17).

Frontal plane lower limb alignment is quantified by the Hip-Knee-Ankle (HKA) angle, which is the angle formed by the mechanical axes of the femur and tibia (3,17,27,90,91). The mechanical axis of the femur is the line joining the centre of the femoral head to the centre of the knee joint. The mechanical axis of the tibia is represented by a line joining the centre of the knee joint to the centre of the ankle joint (3,17,90,91). The HKA angle is expressed as degrees of deviation from 180°, such that an HKA value of 0° represents a 0° deviation from neutral alignment. The sign convention of HKA represents varus alignment as a negative value and valgus as positive value (3,92). However, some authors have reported varus alignment as positive angles and valgus as negative angles (27,93).
Table 2: Knee Adduction Moment Values during Stance Phase.

<table>
<thead>
<tr>
<th>Authors’ Name and Publication Year</th>
<th>Participants (gender: male = m, female = f; mean age: years = yr)</th>
<th>Mean Peak Knee External Adduction Moment (%Bw.Ht)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schipplein et al., 1991 (19)</td>
<td>People without knee OA (6 m, 9 f; 62 yr)</td>
<td>3.30 ± 0.67</td>
</tr>
<tr>
<td></td>
<td>Participants with knee OA (11 m, 8 f; 55 yr)</td>
<td>4.19 ± 1.51</td>
</tr>
<tr>
<td>Sharma et al., 1998 (23)</td>
<td>Participants with knee OA (31 m, 23 f; 62.4 ± 10.1 y)</td>
<td>Left side (moderate OA) 3.30 ± 1.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(severe OA) 5.1 ± 0.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Right side (moderate OA) 2.8 ± 0.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(severe OA) 4.1 ± 0.7</td>
</tr>
<tr>
<td>Wada et al., 2001 (26)</td>
<td>Participants with knee OA (10 m, 59 f; 74 yr, age range 54 - 83 yr)</td>
<td>Mild knee OA = 3.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(range 1.1 – 7-4)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Severe knee OA = 5.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(range 0.4 – 8.4)</td>
</tr>
<tr>
<td>Miyazaki et al., 2002 (14)</td>
<td>Participants with knee OA (16 m, 58 f; 69.5 ± 7.5 yr)</td>
<td>Participants without OA progression = 4.0 ± 1.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Participants with OA progression = 6.1 ± 1</td>
</tr>
<tr>
<td>Mundermann et al., 2004 (25)</td>
<td>Participants with knee OA (20 m, 24 f; 65.4 ± 10 yr)</td>
<td>3.27 ± 0.88</td>
</tr>
<tr>
<td></td>
<td>Control participants (20 m, 24 f; 63.3 ± 10.7 yr)</td>
<td>3.16 ± 0.92</td>
</tr>
<tr>
<td>Birmingham et al., 2007 (22)</td>
<td>Participants with knee OA (21 m, 10 f; 44 ± 11 yr)</td>
<td>2.54 ± 0.96</td>
</tr>
<tr>
<td>Mundermann et al., 2007 (31)</td>
<td>Individuals without knee OA (12 m, 7 f; 22.8 ± 3.1 yr)</td>
<td>2.0 ± 0.7</td>
</tr>
<tr>
<td>Specogna et al., 2007 (90)</td>
<td>Participants with knee OA (27 m, 13 f; 44 ± 9 yr)</td>
<td>2.8 ± 0.8</td>
</tr>
</tbody>
</table>

Knee adduction moment and age values are mean ± standard deviation. 
%Bw.Ht = Percentage body weight times height.
Figure 2: Anterior-posterior View Full-Limb Radiograph of an Individual with Mild OA Indicating Femoral Mechanical Axis (FM axis), Tibial Mechanical Axis (TM axis), Load-Bearing Axis (LB Axis), Hip-Knee-Ankle Angle (HKA) and Knee Joint Centre (KJC). Note the proximity of load bearing axis to the centre of knee joint.
Alternatively, the HKA may be estimated from the anatomic axis angle using a radiograph of the knee joint (16,18,44). The anatomic axis angle is the angle formed by the intersection of two lines drawn through the midshaft of the femur and tibia (94). The anatomic axis angle is offset approximately 5° from the HKA angle and has been shown to highly correlate with the HKA angle (r = 0.75; p < 0.0001) (91,94-96).

In individuals with healthy knees, the lower extremities are often in varus alignment (3,91,92). Moreland et al. (91) reported a mean varus angulation of 1.5° (± 2) and 1.1° (± 2.1) in right and left lower extremities, respectively, in a group of 25 healthy young men of mean age 30 years. Cooke et al. (3) used precision radiographs to determine the knee alignment in 79 healthy young individuals between the ages of 18 and 25 years. Mean knee joint alignment of these individuals was -1.0 ± 2.8°. In another study, Cooke et al. (92) reported a varus angulation of 0.96 ± 2.82° for young healthy individuals aged 30 years and younger, whereas those aged 45 years and older had a varus angulation of 0.98 ± 2.97°.

People with medial compartment knee OA present with greater lower limb varus angulation compared to individuals without OA (3,92). Moreover, varus angulation increases with severity of OA (17). Cooke et al. (92) reported that people with knee OA who presented with medial compartmental changes in the knee joint had a mean varus alignment of 7.2 ± 4.8°, which was significantly greater than observed in the healthy population. Similarly, Prasad (43) reported a varus alignment of 6.67 ± 4.23 in people with medial compartment knee OA. Sharma et al. (17) reported a mean baseline value of 3.34° varus alignment in people with medial compartment knee OA.
2.6 Measurement of Knee OA Severity

A common manifestation of knee OA is the appearance of radiographic signs of the disease (97). Various systems are used to grade the radiographic severity of OA, including the K/L grading system (9), the Ahlbäck classification (98) and a grading system described by Cooke et al. (99). These grading systems involve analysis of joint space narrowing, presence of osteophytes and the condition of subchondral bone from radiographs. The greater the OA disease severity the higher the grading scores.

The K/L grading system (9) is commonly used to estimate radiographic severity of knee OA. The system defines OA on the basis of presence of osteophytes at the joint (11). A five-point scale (0-4 points) is used to grade the joint based on the presence of various features of disease severity, including osteophytes, loss of joint space, subchondral sclerosis and cyst formation (100). The grading scores and respective radiographic features are as follows: 0 = no osteophytes; 1 = possible osteophyte lipping; 2 = definite osteophytes and possible narrowing of joint space; 3 = moderate multiple osteophytes and definite narrowing of joint space, some sclerosis and possible deformity of bone contour; 4 = large osteophytes, marked narrowing of joint space, severe sclerosis and definite deformity of bone contour (23,27). Although widely used, weaknesses have been reported in the K/L grading system, such as low inter-reader consistency (99), and various recommendations have been made to improve its efficiency (100).

The grading system described by Cooke et al. (99) incorporates a 13-point scoring system based on four categories, including joint space, presence of femoral osteophytes, subluxation and erosion of the tibia. Joint space, femoral osteophytes and subluxation are graded on a scale of 0-3, with 0 being normal and 3 being severe, whereas tibial erosion is scored on a scale of 0-4, with 0 being no erosion and 4 being severe tibial erosion. The
scores for each category are summed. A total score of 0 represents a normal knee joint, where as a score of 13 represents maximum radiographic disease severity. High values of inter-reader reliability have been reported (Table 3). Moreover, significant correlations have been reported between total and individual variable scores and the HKA angle which represents lower limb alignment (Table 3). These findings are in agreement with other studies which have also reported significant correlations between knee joint alignment and radiographic signs of OA (16,18).

2.7 Measurement of Muscle Strength

Muscle strength is measured using a variety of testing devices, including strain gauges, weights and counter-weights, spring balances and hand-held and isokinetic dynamometers (101). All provide objective measures of muscle force or torque (102). Hand-held and isokinetic dynamometers have been used most often to measure muscle strength in patient populations (102-104).

Hand-held dynamometers are portable, relatively inexpensive and easy to use; hence they are frequently utilized in the clinical settings and in research studies to measure isometric muscle force (102,103). A simple hand-held dynamometer is comprised of a handle, a resistance surface with an embedded force transducer and a digital display. The examiner holds the dynamometer on the limb segment to be tested and applies resistance through the handle while the participant resists the force. The digital screen displays the values of peak force. Time-to-peak force and total test duration are also recorded by some dynamometers (102). Various types of hand-held dynamometers have been introduced, including computer-assisted hand-held dynamometers (105), those with motion sensors which detect limb position and a pocket personal computer (102). Dynamometers
Table 3: Inter-Reader Reliability and Correlation Coefficient Values for Radiographic Grading System of Cooke et al.

<table>
<thead>
<tr>
<th>Grading Variable</th>
<th>Inter-Reader Reliability</th>
<th>Correlation Coefficient for HKA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joint Space</td>
<td>0.88*</td>
<td>0.70*</td>
</tr>
<tr>
<td>Femoral Osteophytes</td>
<td>0.65*</td>
<td>0.64*</td>
</tr>
<tr>
<td>Tibial Erosion</td>
<td>0.84*</td>
<td>0.81*</td>
</tr>
<tr>
<td>Subluxation</td>
<td>0.75*</td>
<td>0.51*</td>
</tr>
<tr>
<td>Total Score</td>
<td>0.92</td>
<td>0.77*</td>
</tr>
</tbody>
</table>

(*) p<0.001; no p-value was reported for total inter-reader reliability score.
attached to specially designed portable steel frames, which eliminate the need for the examiner to hold the device, have also been described (103).

High values of test-retest reliability have been reported when using hand-held dynamometers (106). Wang et al. (106) tested the isometric strength of 8 muscle groups of both lower extremities of 41 community dwelling older adults (11 men; 23 women) with a mean age of 76 (± 1.2) years and a history of falling. They reported ICC values between 0.97 and 1.0 and standard error of measurement values between 0.21 to 0.39 kg. Isometric strength values obtained using hand-held dynamometers have been reported to correlate with those obtained by isokinetic dynamometers (102). Using hand-held and isokinetic dynamometers, Li et al. (102) measured the strength of hip flexor, knee extensor and ankle plantarflexor and dorsiflexor muscles of 28 healthy individuals (7 men, 21 women) of mean age 30.5 (± 12) years. They reported that the isometric strength values recorded by a hand-held dynamometer, except for hip flexor muscle strength, were not significantly different from those recorded by the isokinetic dynamometer. Significant correlations (r = 0.60 - 0.93; p<0.01) were reported between the strength values recorded by both types of dynamometer.

It has also been reported that hand-held dynamometers underestimate lower extremity isometric muscle strength (102,104), since considerable upper extremity strength is required for the tester to maintain the position of the dynamometer and to obtain an accurate measure of muscle strength. In addition, information on joint position during strength testing is generally not provided by hand-held dynamometers (102).

Isokinetic dynamometers eliminate the problem of strength inequality between tester and participant and provide precise measurement of dynamic as well as static muscle strength (104). Other advantages of isokinetic dynamometers include generation of
strength curves and accurate information on the parameters, such as peak force, power, endurance and angle of maximal force (102). Isokinetic dynamometers allow the measurement of both concentric and eccentric muscle strength at a constant angular velocity with adjusting resistance throughout the joint range of motion (107).

The Biodex isokinetic dynamometer (Biodex Medical Systems, Shirley, New York, USA) is considered a gold standard for measurement of muscle strength (104). The participant performs angular joint motion by moving the lever arm of the dynamometer which is guided by a gearbox. A servomotor drives the gear box and initiates angular velocity control after receiving amplified output from 4 torque transducers embedded in the centre of the area through which the central axle passes. A feedback mechanism controls the angular velocity of the lever arm by comparing the angular velocity of the central axle with preset reference voltages. Joint torque is recorded throughout the range of motion of the lever arm as the subject exerts maximal effort at the preset velocity. Gravity correction is also performed by the Biodex software. During isometric contractions the lever arm of the dynamometer provides resistance against the motion of the limb and isometric muscle force is recorded (108).

The mechanical reliability and validity of position, torque and velocity measurements of the Biodex System 3 isokinetic dynamometer have been quantitatively measured by Drouin et al. (107). Position was measured at 5° increments through the available range of motion, torque measures were evaluated by hanging 6 different calibrated weights from the lever arm and velocity was measured in a range of 30°/s to 500°/s in a 70° arc of motion. The authors reported the dynamometer system to be mechanically reliable and valid for all the variables tested, except for velocities of 300°/s and above. Taylor et al.
(108) also found that the Biodex dynamometer was a valid and reliable system to measure static and dynamic muscle strength.

2.8 Effect of Age and Knee OA on Muscle Strength

Older adults have decreased muscle strength compared to younger individuals (109-112). Johnson et al. (110) measured isokinetic and isometric hip abductor and adductor muscle strength in standing in 38 healthy adult women (mean age 23 ± 1.7 yr) and 38 older women (mean age 74 ± 6.8 yr). Peak isometric abduction and adduction torque values were 34% and 24% lower in older women, respectively (p < 0.01). The isokinetic peak torque values for abduction were 44% and for adduction were 56% lower in older women (p < 0.01). Porter et al. (109) measured concentric and eccentric peak torque of knee extensor muscles in healthy young (age range 20-29 yr) and older (age range 62-89 yr) individuals. The peak concentric and eccentric torque values for older men were equal to 58.3 and 75.1% and for older women were equal to 46.6 and 61.7% of their respective younger groups.

In people with knee OA, a reduction in lower extremity muscle strength has also been reported, compared to age-matched control participants (13,44,55-57). Yamada et al. (44) performed strength testing of quadriceps, hamstrings, and hip adductor and abductor muscles in 32 women with knee OA (mean age 62.3 ± 8 yr) and in 13 control participants (mean age 60.5 ± 6.5 yr). Quadriceps muscle strength was significantly lower in people with knee OA compared to control group (p < 0.05). No difference was found in the other muscles tested. Similarly, Messier et al. (57) measured the isokinetic strength of knee flexor and extensor muscles in 15 people with OA (4 men; 11 women; mean age 58.7 ± 2.3 yr) and age, mass and gender-matched control participants (mean age 58.1 ± 2.1).
Peak isokinetic knee extension ($p = 0.05$) and flexion ($p < 0.01$) values for the affected side in OA participants were significantly lower than values in both the dominant and non-dominant limbs of the control group. Stauffer et al. (56) also reported that in knee OA patients (36 men; 29 women; mean age 65 yr) maximal isometric contraction values for hamstring and quadriceps muscles were equal to 70% and 55%, respectively, of the age and sex-matched control participants.

### 2.9 Summary

Loading of the knee joint during the gait cycle plays a prominent role in the development and progression of medial compartment knee OA. In people with medial compartment knee OA more force is transmitted through the medial compartment of the knee joint compared to those without OA. The adduction moment is a reliable and valid measure of medial compartment loading. It has been suggested that increased medial compartment loading may be a result of weakness of hip musculature which allows the pelvis to drop towards the swing side, thereby shifting the centre of mass of the body away from the stance limb during the stance phase of the gait cycle. Weakness of the hip abductor muscles may additionally result in the alteration of hip joint biomechanics by altering frontal plane hip moments. Biomechanically, alterations in frontal plane hip moments would influence knee joint loading. Little research has been conducted to determine the role of hip abductor muscle strength and hip biomechanics in loading of the medial compartment of the knee joint. The purpose of this study was to quantify hip abductor muscle strength in people with medial compartment knee OA and to determine the influence of frontal plane hip biomechanics on loading of the medial compartment of the knee joint.
CHAPTER 3

METHODS

3.1 Research Design

This investigation was part of a larger study evaluating the influence of hip abductor muscle strengthening on pain, function and medial compartment knee loading in people with knee OA. This was a cross-sectional study using data obtained at baseline for participants who entered the larger study from January to October, 2007. The cross-sectional design was incorporated in this study because very little is known about the strength of the hip abductor muscles or the relationship between knee joint moments and hip muscle strength in people with knee OA compared to those without knee OA.

3.2 Participants

A convenience sample of individuals with medial compartment knee OA was recruited for this study. When participants had bilateral medial compartment knee OA, data from the more affected side, as identified by radiographic OA grade, were analyzed. If participants with unilateral knee OA had evidence of both medial and lateral compartment OA, only data from those with predominantly medial compartment OA were included in the analysis.

The OA group was divided into two sub-groups based on the radiographic grade: mild OA subgroup (radiographic score of \( \leq 2 \)), and a moderate/severe OA subgroup (radiographic score \( \geq 3 \)). Radiographic grade was determined using the scale by Cooke et al. (99). The division of the OA group into mild and moderate/severe OA subgroups was based on evidence in the literature that those with severe medial compartment knee OA...
have higher knee adduction moment as compared to those with mild OA and those without knee OA (23,25-27).

A convenience sample of control participants without knee OA was also recruited for the study. Control participants were matched for age, gender, height and weight to the participants with moderate/severe knee OA.

3.2.1 Recruitment of Participants

3.2.1.1 Knee OA Group

Participants with knee OA were recruited through the practices of orthopedic surgeons in Kingston, through newspaper advertising and through notices posted in churches and seniors’ centers located in the Kingston area. Inclusion criteria were: age ≥ 40 years; self-reported knee pain for most days of the month; at least some difficulty with two or more items on the physical function subscale of WOMAC and physician-diagnosed medial compartment knee OA as confirmed by x-ray, arthroscopy or MRI. Radiographic evidence of medial knee OA was indicated by definite osteophytes in the medial tibiofemoral compartment in one or both knees i.e. grade ≥ 1 on the scale described by Cooke et al (99,113-115).

Participants were excluded from the study if they had any of the following: intraarticular corticosteroid or viscosupplementation injection into either knee during the previous three months; significant co-morbidities, including significant heart disease, stroke, and active treatment for cancer, that would be a contraindication for exercise and for gait and strength testing; OA arising secondary to other types of arthritis, e.g. rheumatoid arthritis; known OA or previous trauma affecting one or both hips; or previous replacement of any joint in the lower extremities (41,113) (Appendix I).
Individuals who were receiving rehabilitation services for knee OA or performing a hip strengthening program at the time of testing were also excluded.

3.2.1.2 Control Group

Participants in the control group were recruited through newspaper advertisements and posters in churches and seniors’ centers in the Kingston area. Participants were included in the study if they had no diagnosis of hip or knee OA or rheumatoid arthritis, and no history of hip or knee trauma or pain (Appendix II). Participants in the control group, at the point of initial contact with the investigator, were asked specific questions concerning joint stiffness, pain and swelling during their daily activities to rule out the possibility of any indication of hip or knee OA. Radiographs of both knees of control group participants were also obtained to confirm that they did not have knee OA. Control group participants were matched with people with moderate/severe knee OA by gender, age (± 5 yr), height (± 5 cm) and mass (± 5 kg).

3.3 Setting

Testing was conducted in the Motor Performance Laboratory at Queen’s University, Kingston, Ontario and knee radiographs were taken in the Radiology Department at Kingston General Hospital. Participants gave informed consent before participating (Appendix III). Typically, all testing was completed in one session lasting approximately 2-2.5 hours. Occasionally, radiographs were taken on a different day due to participant fatigue or scheduling issues.
3.4 Measurement Protocol and Outcome Measures

3.4.1 Knee OA Grading and Alignment

Bilateral anterior-posterior knee radiographs in weight-bearing were obtained for all participants at baseline. For participants with knee OA who had recent weight-bearing radiographs of the knees (within 6 months of the date of testing), permission was requested to view these radiographs and new radiographs were not obtained in these cases. The standard method used by the Radiology Department of Kingston General Hospital was adopted for knee radiographs. Participants were asked to stand with their weight equally distributed on both legs and knees were positioned in the “patellar ahead” position. The foot position was not forced; rather participants were assumed to be in natural alignment when both patellae were facing anteriorly and feet were positioned comfortably.

Digital images were obtained from the radiology department at a later date on anonymous compact discs with only the subject code to identify the participant. Grading of OA disease severity was performed by an orthopedic surgeon according to the scale described by Cooke et al. (99).

Measures of frontal plane knee alignment were determined bilaterally from the knee radiographs of all participants using a computer software program (Horizon Image Viewer, version 1.5, OAISYS Medical Inc.). Measurements were performed by a study investigator who had been trained in the use of the software program. Since the radiographs obtained in our study were those of the knee joint only and did not include the hip and ankle joints, an indirect approach involving the derivation of the HKA angle from anatomic axis angle was used (94). The anatomical axis angle is the angle formed at the centre of the knee joint by the lines connecting the long axes of the femoral and tibial
shafts (94). The HKA angle was estimated by subtracting 5° from the anatomic axis angle (91,94-96) (Figure 3).

3.4.2 Gait Analysis

Gait trials were completed on an 8 m walkway in the Motor Performance Laboratory. The Optotrak Motion Analysis System (Northern Digital Inc., Waterloo, Ontario) was used to collect three-dimensional kinematic data during gait. This system consists of infrared sensitive cameras that capture the location of infrared emitting diodes (IREDs). Clusters of IREDs were placed on the dorsum of the foot (on the shoes in midline over the metatarsal area), lateral shank (just distal to the knee joint), lateral thigh (proximal to the knee joint), over the sacrum and over the 7th cervical/1st thoracic spinous processes (Figure 4). The clusters were secured in place with Velcro straps and/or taped in order to prevent their movement during the walking trials. IREDs were connected to strobers attached to a belt around the participant’s waist. The strobers were connected to the Optotrak computer via cables.

Two Advanced Mechanical Technology (AMTI) force plates (Newton, MA) embedded in the walkway of the Motor Performance Laboratory recorded ground reaction forces to provide data for calculation of kinetic variables (Figure 4). Spatial registration was performed between the Optotrak system and force plates prior to the data collection session. For each participant, five good walking trials were obtained and processed using computer software. Trials were considered to be good if participants
**Figure 3:** Knee Anterior-Posterior View Radiograph Indicating the Anatomic Axis Angle.
Note: The lines are drawn from the mid-shafts of the femur and tibia.
Figure 4: Lateral View of C-Motion Computer Software Generated Model Indicating the Location of Infra-Red Emitting Diodes, Force Platforms and Lab Axes. Note: Frontal plane is represented by the Y-axis.
walked at their natural pace, only one foot was on the force plate at a time and all the markers were visible from the heel strike to the toe-off of the affected extremity.

The kinematic and kinetic data obtained during gait trials were processed through C-Motion computer software (C-Motion Inc, Rockville, MD) and gait speed and hip and knee adduction moment data were obtained. Gait speed was calculated using C-Motion as the average speed of the five trials.

Frontal plane hip and knee moment data of the good trials were exported from C-Motion software to MSExcel® software. The exported dataset was comprised of hip and knee adduction moment values of both lower extremities during the stance phase of the gait cycle; however, only data from the affected side of OA group participants and the corresponding lower extremity of the control group were analyzed. In the MSExcel® environment, the data for each trial were plotted using separate curve-diagrams for hip and knee moments. The stance phase of the respective lower extremity was divided into 100 points representing 100% of the stance phase. Visual inspection was performed to identify and exclude the curves which did not have a definitive first peak and were different in shape from the rest of the participant’s curves. The number of trials used in the analyses ranged from 1-5 trials and average moment curves were calculated for each participant.

Peak values in the first 50% of stance phase were calculated for the hip and knee from the respective average moment curves. Peak adduction moment values were determined as the highest value in the first 50% of the stance phase which was preceded by at least 5 values in ascending order and followed by 5 values in descending order. The peak hip and knee adduction moment values were normalized to mass and height and expressed as
%Bw.Ht. The point in the stance phase where the peak moment occurred in each trial was also recorded and the average was used in analyses.

3.4.3 Strength Measures

Isometric strength of the hip abductor and adductor muscles was measured for the selected limb using the Biodex System 3 Isokinetic Dynamometer. The Biodex dynamometer has been shown to be a reliable and valid instrument for measuring muscle strength (108,116). The participants stood in an upright position with their back against the back of the dynamometer chair and a pillow in between them and the chair to provide a cushion. The participant’s trunk and pelvis were stabilized using Velcro straps and the dynamometer pad was secured tightly with a Velcro strap around the lower thigh just superior to the knee (Figure 5). The axis of rotation of the dynamometer was aligned with the participant’s anterior superior iliac spine as per instructions in the Biodex manual. Range of motion of the hip joint was set from neutral to approximately 30° of abduction.

The order of abductor and adductor muscle isometric strength testing was randomized for all participants and a rest period of 2 min was provided between each test. The position of the hip joint for testing both muscle groups was at 0° of abduction. Following practice trials, three isometric contractions were performed for both hip abduction and adduction and each contraction was maintained for 5 s, followed by a 10 s rest. Verbal encouragement was provided to facilitate maximum effort. The force data were sampled at 100 Hz. Torque data were filtered with a 6 Hz low-pass filter (Butterworth, 6th order). Filtering of the data was performed for each repetition to reduce the possibility of selecting incorrect peak torque values due to motion artifact.
Figure 5: Position for Hip Abductor and Adductor Muscle Isometric Strength Testing using the Biodex System 3 Isokinetic Dynamometer.
Peak isometric muscle torque values were calculated for each trial from the raw force data using MATLAB® software (Math Works Inc, MS). These values were then entered into an MSExcel® worksheet and mean peak isometric torque values were determined for hip abductor and adductor muscle torque. Mean peak torque values were normalized to each participant’s body weight and expressed in units of Nm/kg.

3.5 Assessment of Knee Pain, Physical Function and Activity

3.5.1 Western Ontario and McMaster Universities Osteoarthritis Index

The Western Ontario McMaster Universities Osteoarthritis Index (WOMAC) was used to determine the level of knee symptoms reported by the OA group (Appendix IV). WOMAC is a self-administered questionnaire designed for patients with knee and/or hip OA. The questionnaire consists of 24 questions relating to joint pain, stiffness and physical function (117). High levels of responsiveness, reliability and construct validity for the WOMAC have been demonstrated (117). Other studies have provided further evidence of the reliability and validity of this instrument (118,119). The questionnaire takes 5-10 min to complete.

The scoring of WOMAC was performed separately for the three subscales. Each question was scored on a scale of 0-4, with 0 being none and 4 being extreme pain, stiffness or difficulty in physical function. The scores of all the questions on each subscale were then added and the sum was divided by the number of questions on the respective subscale. For example, the sum of scores on the pain subscale questions was divided by 5 as the pain subscale consists of 5 questions. For each subscale the maximum score is 4. Low scores represent less pain stiffness and difficulty in performing physical
functions, where as high scores indicate more pain, stiffness and difficulty in performing physical functions.

3.5.2 Five-Time-Sit-to-Stand Test

All participants completed the Five-Time-Sit-to-Stand Test (FTSST). The FTSST is used as a physical performance measure to assess lower extremity strength and balance during rising to an upright position from a chair (120-122). Test-retest reliability has been reported at r = 0.84 (122) and concurrent validity for the FTSST has been established (122,123).

Participants performed the FTSST by folding their arms across their chest and sitting with their back against an armless chair (height: 43 cm; depth: 47.5 cm). Using a standardized protocol, the examiner provided the following instructions: “I want you to stand up and sit down five times as quickly as you can when I say ‘Go’.” Time was recorded with the word “Go” and stopped when the participant’s buttocks touched the chair on the fifth repetition. Participants were instructed to stand up fully with each repetition of the test and not to touch the back of the chair on descending. Participants were allowed to place their feet comfortably under them during testing. Time to perform the test was recorded in seconds.

3.5.3 Physical Activity Scale for the Elderly

The physical activity level of all participants was determined using the Physical Activity Scale for the Elderly (PASE) (Appendix V). The PASE is a self-administered measure designed to assess occupational, household, and leisure activities typically performed by older adults (125). The validity of the PASE has been demonstrated in
community-dwelling older adults without physical limitation (124,125) and in older adults with knee pain and physical disability (128). Furthermore, good test-retest reliability (r = 0.75) was demonstrated in 222 community dwelling older adults (124). The test can be completed in a time period of 5 to 15 minutes.

Scoring of the PASE is performed by multiplying a specific value of weight assigned to each activity (Total Activity Weight = 309) with the respective value of the activity frequency. The values obtained for all activities are then summed to give a total PASE score. Higher scores indicate greater levels of activity.

3.6 Procedures

The purpose of the study was explained to participants at the point of initial contact with the principal investigator via telephone. Questions were asked about the inclusion/exclusion criteria as an initial screening for eligibility. An appointment was then determined for the data collection session. Prior to starting data collection on the scheduled day, the entire procedure was explained to participants in detail and they were requested to carefully read and then sign the consent form.

Participants were asked to change into shorts and their height (m) and weight (kg) were measured. Clusters of IREDS were then placed on the various anatomical locations and participants performed practice walking trials. Following the practice trials, participants performed actual walking trials at their natural (self-selected) walking speed. Five walking trials in which the feet correctly contacted the force plate (whole foot on a single force plate) were retained to be processed by the computer software. Before removing the IRED clusters, the recorded trials were checked to ensure that there were no missing kinetic or kinematic data for any of the walking trials. During this time
participants completed the WOMAC and PASE questionnaires. The FTSST was then performed by all participants, followed by hip abductor and adductor muscle isometric strength testing using the Biodex Isokinetic Dynamometer. Participants were positioned appropriately and the strength tests were performed for both lower extremities.

After completing the tests at the Motor Performance Laboratory, participants were accompanied by the principal investigator to the Radiology Department of Kingston General Hospital where knee radiographs were taken. Once digital images were obtained, the variables of interest were measured.

3.7 Data Analysis

The means of all the variables of interest were entered group wise in a SPSS® (SPSS Inc., IL) worksheet. Prior to analysis data were reviewed to determine whether the distribution was normal for all variables in each of the three groups. Variables were individually analyzed for the normal distribution by determining the skewness and kurtosis values. A skewness or kurtosis value of more than twice its standard error was taken to indicate a departure from symmetry (126). This method revealed that the values of all outcome measures (muscle strength, hip and knee adduction moments and alignment) met the assumption of normal distribution. PASE, BMI and occurrence of peak hip and knee adductor moment in the control subjects demonstrated significant skewness and kurtosis. FTSST data were significantly skewed in the moderate/severe OA group. Since the primary outcome measures met the requirement for normal distribution, and for the sake of consistency, parametric statistics were used in all analyses.

The three groups were compared using a univariate analysis of variance (ANOVA) test where group was the independent variable. The variables compared included subject
characteristics of age, height, weight, body mass index, gait speed, FTSST and PASE. The primary outcome measures of HKA, hip abductor and adductor muscle isometric strength, peak hip and knee adduction moments and the occurrence of the peaks of hip and knee adduction moments during stance phase of the gait cycle were also analyzed using an ANOVA. The level of significance was set at 0.05. A Bonferroni post-hoc test was performed to identify the different means if the F-value was significant.

The mean scores of the WOMAC pain, stiffness and physical function subscales were compared between the moderate/severe OA and mild OA groups using an independent student t-test.

Stepwise linear regression analysis was performed to identify the variables which contributed to the variation in the mean peak knee adduction moment. The variables entered into the model included HKA angle, hip abductor and adductor muscle isometric strength, gait speed, peak hip adduction moment, OA disease severity and WOMAC pain subscale score.
CHAPTER 4

RESULTS

4.1 Participants

Thirty-eight participants with knee OA (18 men, 20 women) were recruited for the study. Participants with knee OA were divided into two groups based on disease severity as measured by Cooke et al. (99). Those with a score ≤ 2 on the scale (n = 15; 6 men, 9 women) were assigned to the mild group and participants with a score ≥ 3 (n = 23; 12 men, 11 women) were included in the moderate/severe group. In the mild OA group, 2 participants (both men) had a score of 1 on the grading scale and 13 participants (4 men, 9 women) had a grading score of 2. In the moderate/severe OA group, 14 participants (8 men, 6 women) had moderate OA (score of 3-5), and 9 participants (4 men; 5 women) had severe OA (score ≥ 6). Over all in the moderate/severe OA group, 8 participants (4 men, 4 women) had a score of 3, 6 participants (4 men, 2 women) had a score of 4, 2 participants (both women) had a score of 6, 4 participants (2 men, 2 women) had a score of 7, 2 had a score of 8 (both men) and 1 participant (woman) had a score of 9 on the grading scale. The control group (n = 23) was matched to the moderate/severe OA group for age, gender, weight and height. The results revealed that 32 participants (14 men; 18 women) had bilateral knee OA; data from the more affected side was used for analysis.

Descriptive statistics, gait speed and PASE and FTSST scores for the three groups are reported in Table 4. Matching was successful for gender and age. It was very difficult to recruit control participants who were matched to within ± 5 kg body weight and ± 5 cm height of the OA group. Age and gender, therefore, became the primary criteria for matching as the study progressed. An ANOVA revealed that the group with moderate/severe OA was heavier and had a higher Body Mass Index (BMI) compared to
both the control and mild OA groups. There was no difference in weight or BMI between the mild OA and control groups (Table 4). The mean height of the three groups did not differ.

An ANOVA of the data presented in Table 4 revealed no significant differences between the three groups in age, gait speed or PASE. That gait speed did not differ rules out the possibility of gait speed being a confounding factor in comparing kinetic data between groups. PASE scores were not significantly different between the three groups, indicating that participants in all groups demonstrated a similar level of activity for leisure, household and occupational pursuits. The moderate/severe OA group required a significantly longer time than the control group to complete the FTSST \( (p < 0.05) \). There was no difference in FTSST scores between the moderate/severe and mild OA groups or between the mild OA and control groups.

### 4.2 WOMAC Scores

The WOMAC scores for pain, stiffness and physical function subscale scores of the moderate/severe OA and mild OA groups are listed in Table 5. Higher scores on the WOMAC subscales indicate greater severity of pain, stiffness and difficulty in physical function. Overall, the results revealed that moderate/severe OA participants had more pain, stiffness and difficulty in performing physical functions as compared to the individuals with mild knee OA; however, only the mean stiffness score was significantly higher in the group with more severe knee OA.
Table 4: Descriptive Statistics, Gait Speed, PASE and FTSST.

<table>
<thead>
<tr>
<th></th>
<th>Moderate/Severe OA Group</th>
<th>Mild OA Group</th>
<th>Control Group</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n = 23</td>
<td>n = 15</td>
<td>n = 23</td>
<td></td>
</tr>
<tr>
<td>Age (yr)</td>
<td>66.39 (10.66)</td>
<td>59.47 (8.86)</td>
<td>65.22 (8.65)</td>
<td>0.08</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.74 (0.11)</td>
<td>1.72 (0.10)</td>
<td>1.72 (0.08)</td>
<td>0.55</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>90.37 (21)</td>
<td>75.17 (12.09)</td>
<td>71.04 (10.05)</td>
<td>0.00 a,b</td>
</tr>
<tr>
<td>Body Mass Index (kg/m²)</td>
<td>29.80 (6.86)</td>
<td>25.60 (3.04)</td>
<td>24.10 (3.35)</td>
<td>0.01 a,b</td>
</tr>
<tr>
<td>Gait Speed (m/s)</td>
<td>0.95 (0.22)</td>
<td>1.05 (0.22)</td>
<td>1.10 (0.19)</td>
<td>0.07</td>
</tr>
<tr>
<td>PASE</td>
<td>194.70 (79.62)</td>
<td>187.67 (62.17)</td>
<td>186.22 (93.97)</td>
<td>0.93</td>
</tr>
<tr>
<td>FTSST (s)</td>
<td>16.86 (9.39)</td>
<td>13.60 (6.63)</td>
<td>10.62 (3.26)</td>
<td>0.01 b</td>
</tr>
</tbody>
</table>

SD = Standard Deviation.
FTSST = Five-Time-Sit-to-Stand Test.
PASE = Physical Activity Scale for the Elderly.
a = significant difference (p<0.05) between Moderate/Severe OA and Mild OA Groups.
b = significant difference (p<0.05) between Moderate/Severe OA and Control Groups.
### Table 5: Comparison of WOMAC Scores between Moderate/Severe and Mild OA Groups.

<table>
<thead>
<tr>
<th></th>
<th>Moderate/Severe OA Group</th>
<th>Mild OA Group</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n = 23 Mean (SD)</td>
<td>n = 15 Mean (SD)</td>
<td></td>
</tr>
<tr>
<td>WOMAC Pain</td>
<td>1.31 (0.54)</td>
<td>0.96 (0.68)</td>
<td>0.08</td>
</tr>
<tr>
<td>WOMAC Stiffness</td>
<td>1.96 (0.89)</td>
<td>1.20 (0.92)</td>
<td>0.02*</td>
</tr>
<tr>
<td>WOMAC Physical Function</td>
<td>1.41 (0.58)</td>
<td>1.01 (0.80)</td>
<td>0.08</td>
</tr>
</tbody>
</table>

WOMAC = Western Ontario and McMaster Universities Osteoarthritis Index. SD = Standard Deviation. (*) significant difference (p<0.05) between the means of moderate/severe and mild OA groups as revealed by an independent t-test.

Note: The total score obtained is out of a maximum score of 4.
4.3 Comparison of Alignment, Moments and Strength Measures

Means and standard deviations of the alignment measures, hip and knee moments and their point of occurrence in the gait cycle, and hip abductor and adductor muscle isometric strength are presented in Table 6.

4.3.1 Knee Alignment

There was a significant difference in frontal plane knee alignment between the three participant groups (F = 9.645, p < 0.05) (Table 6). Post hoc analysis, performed using the Bonferroni method, revealed that the moderate/severe OA group had significantly greater varus alignment of the knee joint compared to the mild OA and control groups (Figure 6). However, no difference in knee alignment was found between the mild OA and control groups.

4.3.2 Hip and Knee Adduction Moments and Occurrence of Peak

Peaks of the hip and knee adduction moments were measured in the first 50% of the stance phase of the gait cycle. Visual examination of the hip and knee adduction moment curves revealed that all participants had distinctive peaks in the first half of the stance phase. However, this was not the case for peaks in the second half of the stance phase (Figures 7a,7b,8a,8b). Figures 7 and 8 represent the hip and knee adduction moments of a control participant (Figures 7a and 8a) and a participant with knee OA (Figures 7b and 8b). The external hip and knee adduction moment curves for the control participant demonstrate the characteristic double-peak pattern, with definitive first and second peaks in the two halves of the stance phase connected by a valley. However, the curves of the
Table 6: Knee Joint Alignment, Kinetic variables for Stance Phase of Gait Cycle and Hip Abductor and Adductor Muscle Strength.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Moderate/Severe OA Group</th>
<th>Mild OA Group</th>
<th>Control Group</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knee joint alignment (HKA angle)</td>
<td>-5.76 (4.90)</td>
<td>-2.23 (2.19)</td>
<td>-1.76 (1.46)</td>
<td>0.01&lt;sup&gt;a,b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Hip adduction moment (%Bw.Ht)</td>
<td>4.17 (0.79)</td>
<td>4.78 (0.67)</td>
<td>4.44 (0.80)</td>
<td>0.06</td>
</tr>
<tr>
<td>Occurrence of peak hip adduction moment (%Stance Phase)</td>
<td>33.48 (8.56)</td>
<td>29.67 (3.66)</td>
<td>28.22 (4.90)</td>
<td>0.02&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Knee adduction moment (%Bw.Ht)</td>
<td>2.93 (1.01)</td>
<td>2.78 (0.57)</td>
<td>2.46 (0.66)</td>
<td>0.14</td>
</tr>
<tr>
<td>Occurrence of peak knee adduction moment (%Stance Phase)</td>
<td>31.39 (8.82)</td>
<td>28.87 (6.24)</td>
<td>25.61 (4.19)</td>
<td>0.02&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Hip abductor muscle isometric strength (Nm/kg)</td>
<td>0.95 (0.29)</td>
<td>1.04 (0.34)</td>
<td>1.12 (0.39)</td>
<td>0.24</td>
</tr>
<tr>
<td>Hip adductor muscle isometric strength (Nm/kg)</td>
<td>0.83 (0.32)</td>
<td>0.96 (0.44)</td>
<td>1.12 (0.37)</td>
<td>0.08</td>
</tr>
</tbody>
</table>

<sup>a</sup> = Significant difference (p<0.05) between the means of moderate/severe OA and mild OA group.

<sup>b</sup> = Significant difference (p<0.05) between the means of moderate/severe OA and control group.

Note: Negative alignment values represent varus.
Figure 6: Knee joint alignment in Moderate/Severe OA (M/S OA), Mild OA and Control groups.
Values are means ± standard deviation.
(*) value significantly higher (p<0.05) than the mild OA and control groups.
Figure 7a: The External Hip Adduction Moment Curve of a Control Participant during Stance Phase of the Gait Cycle.

Figure 7b: The External Hip Adduction Moment Curve of the Affected Side of a Participant with Mild Knee OA during Stance Phase of the Gait Cycle.
**Figure 8a:** The External Knee Adduction Moment Curve of a Control Participant during Stance Phase of the Gait Cycle.

**Figure 8b:** The External Knee Adduction Moment Curve of the Affected Side of a Participant with Mild Knee OA during Stance Phase of the Gait Cycle.
hip and knee adduction moments of the OA participant do not demonstrate this pattern as there is no definitive second peak and the valley at mid stance is less evident. A similar pattern demonstrating an indistinctive second peak and a lack of valley for hip or knee adduction moment curves was found in 23 of the 38 participants with knee OA. Also, 10 control participants did not have a distinct hip or knee second peak. Therefore, only the first peaks of hip and knee adduction moments were analyzed for all participants.

Peak values in the first 50% of stance phase were identified as the highest values which were preceded by five values in ascending order and followed by five values in descending order. For ease of comparison between participants, the peak value was normalized to the participant’s weight and height and expressed in the units of percentage body weight multiplied by height.

Means and standard deviations of the kinetic data for all groups are presented in Table 6. The peak external hip and knee adduction moments in the first 50% of the stance phase were not different between groups (Figure 9, 10; Table 6).

The peaks of hip and knee adduction moments occurred significantly later in the stance phase in those with moderate/severe OA, as compared to the control group. There was no difference in the occurrence of the peak between the two groups with knee OA or between the mild OA and control groups (p > 0.05).
Figure 9: Comparison of Mean Peak Hip Adduction Moments between the Moderate/Severe OA (M/S OA), Mild OA and Control Groups. Values are means ± standard deviation. %Bw.Ht= Percentage body weight times height.
**Figure 10** Comparison of Mean Peak Knee Adduction Moments between the Moderate/Severe OA (M/S OA), Mild OA and Control Groups. Values are means ± standard deviation. 

%Bw.Ht = Percentage body weight times height.
4.4 Hip Abductor and Adductor Muscle Isometric Strength

Torque values were normalized to each participant’s body weight and expressed in Nm/kg to allow for comparison between groups. The results revealed that mean isometric strength of the hip abductor and adductor muscles did not differ between group (Figure 11, 12; Table 6).

Isometric strength of the hip abductor muscles was 15% and 7% lower in moderate/severe and mild OA groups, respectively, compared to the control group (Figure 11). This difference in muscle strength between groups was not significant (Table 6). Similarly, hip adductor muscle isometric strength in the moderate/severe OA group was 25% lower and in the mild OA group 13% lower than the control group (Figure 12). The p-value for hip adductor isometric strength differences approached significance (Table 6).
Figure 11: Comparison of Hip Abductor Muscle Isometric Strength between Moderate/Severe OA (M/S OA), Mild OA and Control Groups. Values are means ± standard deviation. Note: Statistical analysis revealed no significant differences between groups.
Figure 12 Comparison of Hip Adductor Muscle Isometric Strength between Moderate/Severe OA (M/S OA), Mild OA and Control Groups. Values are means ± standard deviation. Note: Statistical analysis revealed no significant differences between groups.
4.5 Variables Explaining Variation in Peak Knee Adduction Moment

Stepwise linear regression analysis revealed that four variables explained approximately 73% of the variation of the peak knee adduction moment (Table 7). Knee joint alignment explained approximately 26% of the variation in the knee adduction moment, followed by hip abductor muscle isometric strength (20%), gait speed (16%) and the hip adduction moment (11%). Hip adductor muscle isometric strength, OA disease severity and WOMAC pain did not contribute significantly to the model.

The results also revealed a positive relationship, as indicated by positive slope values, between the peak knee adduction moment and both hip abductor muscle isometric strength and the hip adduction moment. These findings indicate that higher values for hip abductor muscle strength and the hip adduction moment contributed to a higher knee adduction moment. Knee joint alignment and gait speed were negatively correlated with the knee adduction moment (negative slope value), indicating that the more varus the knee joint alignment and the higher the gait speed, the higher the knee adduction moment.
### Table 7: Variables Explaining Variation in Knee Adduction Moment

<table>
<thead>
<tr>
<th>Step</th>
<th>Variable(s) entered in the regression model</th>
<th>R-value</th>
<th>R²-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Knee alignment</td>
<td>0.51</td>
<td>0.26</td>
<td>0.01*</td>
</tr>
<tr>
<td>2</td>
<td>Knee alignment, Hip abductor isometric strength</td>
<td>0.68</td>
<td>0.46</td>
<td>0.00*</td>
</tr>
<tr>
<td>3</td>
<td>Knee alignment, Hip abductor isometric strength, Peak hip adduction moment</td>
<td>0.75</td>
<td>0.57</td>
<td>0.00*</td>
</tr>
<tr>
<td>4</td>
<td>Knee alignment, Hip abductor isometric strength, Peak hip adduction moment, Gait speed</td>
<td>0.86</td>
<td>0.73</td>
<td>0.00*</td>
</tr>
</tbody>
</table>

(*) Significant contribution (p<0.05) by the variable when entered in the regression model.
CHAPTER 5
DISCUSSION

The objectives of this study were to quantify hip abductor muscle strength and to analyze the relationship between hip abductor muscle strength and the loading of knee joint in people with medial compartment knee OA. The study investigated the difference between hip abductor and adductor muscle strength, hip and knee adduction moments and knee joint alignment in people with moderate/severe medial compartment knee OA, those with mild knee OA and healthy control participants. Parameters that explained the variation in knee adduction moment were also identified. The objectives were developed from a proposed theory that weakness of the hip abductor muscles in people with knee OA results in the displacement of the centre of mass of body away from the stance limb during stance phase of the gait cycle thereby increasing the moment arm and the load on the medial compartment of the knee joint.

5.1 Study Population and Functional Measures

The OA group consisted of 18 men and 20 women. The mean age of the moderate/severe OA group was 66.39 (± 10.66); the matched control group had a mean age of 65.22 (± 8.65). The participants in the moderate/severe OA group tended to be older than those of the mild OA group indicating greater severity of disease with older age in the study population.

The mean BMI values of moderate/severe and mild OA group participants were higher than the recommended value of 25 kg/m² for a healthy population; individuals with mild OA tended to be overweight (BMI = 25.60 ± 3.04) and those with moderate/severe OA tended to be borderline obese (BMI = 29.80 ± 6.86) (127). These
BMI values are in conformity with those reported in various studies on people with medial compartment knee OA (25-27,38,73). The tendency for higher weight in the OA participants proved to be a confounding factor for matching the control participants. At the commencement of the study, the aim was that the control group participants would be age, gender, weight and height matched to the OA group. However, as the study progressed it became increasingly difficult to recruit control participants who could be matched in weight and height to the OA participants. Therefore, some of the control group participants were only age and gender matched.

The assessment of occupational, household and leisure activities of the study population was performed using the PASE. PASE scores did not differ between the three groups and were higher than those reported in the literature for healthy individuals of the similar age, sedentary older individuals and people with chronic knee pain. Washburn et al. (124) reported mean PASE score of 102.9 (± 64.1) in a sample of 396 healthy individuals of mean age 73 years. In another study, Washburn et al. (125) reported mean PASE scores of 131.3 (± 70.4) for sedentary individuals of mean age 66.5 years (n = 190). These authors suggested that the higher score in the latter study was due to the younger mean age of the study participants. Martin et al. (128) reported a mean PASE score of 131.4 (± 71.1) in a group of 471 individuals with knee pain (mean age 71.72 ± 4.93).

The relatively high PASE scores in all three groups in the current study indicate that the study population was active in performing occupational, household, and leisure activities compared to participants in the earlier studies. Additionally, the lack of difference in PASE scores between the two OA groups and the control group indicates that the OA participants were successfully continuing to engage in physical activities.
regardless of the symptoms of the disease or that the disease was not of sufficient severity to hamper these activities. This is supported by the low WOMAC pain scores in the moderate/severe OA group.

The FTSST was used to assess lower extremity strength and balance during rising to an upright standing position from a chair. The time taken to complete the test was longer in the moderate/severe OA (16.86 ± 9.30 s) group compared to the control group (10.62 ± 3.26 s). Lord et al. (120) reported time to complete the FTSST in a group of 349 healthy older people (124 men; 225 women; mean age 78.9 ± 4.41) where male participants took an average of 12.8 (± 5.9) s and female participants took 12.9 (± 5.1) s to complete the test. FTSST duration has been shown to correlate with age (r = 0.16; p < 0.01). The difference in FTSST duration between the control participants in the current study and the study conducted by Lord et al. (120) may, therefore, be attributed to the older age of the study population in the Lord study, which ranged from 75 to 79 years.

The FTSST duration has also been shown to correlate with weight (r = 0.14; p < 0.01) (120). In this study the higher BMI values of the moderate/severe OA group may have contributed to the difference between this group and the control participants. It has been reported that the strength of the lower extremity muscles, for example the knee extensors and flexors and ankle dorsiflexors, explains the variability in the FTSST duration (120). Strength of knee extensors and flexors has been reported to be lower in people with knee OA (44,56,57). Given these reports, it may be inferred that weaker muscles around the knee joint may have contributed to the longer time taken by the moderate/severe OA group participants to complete the FTSST. A third explanation for the higher FTSST in the moderate/severe OA group may be that they have more discomfort during this activity and, therefore, load the limb more cautiously.
Gait speed was not different between the three participant groups. Participants were allowed to walk at a self-selected pace. Although variable from person to person and different in various groups of the population, the gait speed values of this study are comparable to those reported for people with knee OA (24,38,129) and people without knee OA (38,130). Discrepancy exists between the gait speeds reported in this study and that reported by Landry et al., 2007 (control group: gait speed = 1.38 ± 0.19 m/s, age 50.7 ± 3.9 y; OA group: gait speed = 1.30 ± 0.19 m/s, age 58.2 ± 8.3 y) which may be attributed to different ages of the study participants in the two studies, as younger people tend to walk faster than older individuals (80). Gait speed may influence loading of the hip and knee joints by altering the magnitude of frontal plane ground reaction force. Decreased gait speed has been suggested as a strategy to reduce the knee adduction moment and thus the loading on the medial compartment of the knee joint (25). Reducing speed may result in knee adduction moments closer in magnitude to individuals without knee OA. If that were the case, it may not be feasible to compare the knee adduction moment values between groups as the difference in moments may not be revealed. Similar gait speeds in the groups being compared allows comparison of kinetic variables. Additionally, given the PASE and WOMAC physical function scores of both OA groups, it may be speculated that this OA population was as physically active as the control group and hence there was no difference in gait speed. The similarity of gait speed between the groups in this study suggests that hip and knee adduction moment values were not biased by a reduced gait speed strategy of the OA participants.

The WOMAC scale is designed specifically for the people with knee and hip OA, therefore this measure was not obtained for control group participants. The pain and physical function subscale scores did not differ between the moderate/severe OA and
mild OA groups. However, the stiffness subscale score of the moderate/severe group was significantly higher than in the mild the OA group. Astephen et al. (129) reported higher scores for all three subscales of WOMAC in people with severe OA (K/L score 3; 33 men; 28 women; WOMAC scores: Pain = 10.62 ± 5.82, stiffness = 4.47 ± 1.76, physical function = 34.37 ± 17.80) as compared to moderate OA (K/L score 2; 20 men; 40 women; WOMAC scores: Pain = 7.53 ± 3.94, stiffness = 3.65 ± 1.66, physical function = 23.19 ± 13.07). Given this report, it may be argued that the moderate/severe OA group in the current study included a small number of severe OA participants and therefore the difference between the pain and physical function subscales in the two OA groups only approached significance.

5.2 Knee Alignment

The average knee alignment of the participants of this study was negative indicating varus alignment. This is in conformity with reports that the normally aligned knee joint is usually in slight varus alignment (3,91,92). The alignment values obtained for the control group in this study (-1.76° ± 1.46) are similar to those reported in literature which range from -1.0 to -1.5° (3,91,92).

The moderate/severe OA group had significantly greater varus alignment (-5.76 ± 4.90) as compared to the mild OA (-2.23 ± 2.19) and control group (-1.76 ± 1.46). This is in agreement with the report that increasing severity of OA results in greater varus alignment of the knee joint (15). The alignment values of the moderate/severe OA group are similar to those reported by Mundermann et al. (31) for people with severe knee OA (-5.7°). Prasad (43) also reported similar alignment values in people with knee OA (-6.67 ± 4.23). Cooke et al. (3) reported greater varus (-7.2° ± 4.8) in a group of 128 individuals.
(men 62; women 66) with medial compartment knee OA. In individuals with knee OA, factors such as cartilage loss, meniscal degeneration, bone attrition, osteophytes and ligament damage may contribute to the malalignment of knee joint (15). Thus, as medial compartment damage progresses, greater varus alignment is expected.

5.3 Hip Adduction Moment and Occurrence of the Peak Moment

The hip adduction moment did not differ between the three groups in this study (p = 0.06). The values obtained in the three groups in our study are comparable to those reported by Chang et al. (41) (4.41 ± 0.11 %Bw.Ht) and Maly (81) (OA group = 3.97 %Bw.Ht; control group = 4.84 %Bw.Ht). However, Astephen et al (129) reported higher hip adduction moments for people with moderate knee OA (5.81 %Bw.Ht) and asymptomatic individuals (7.03 %Bw.Ht). The difference between the Astephen et al. (129) study and the current study may be attributed to the younger age (Moderate OA group = 58.32 ± 9.31 yr; Asymptomatic group = 50.27 ± 10.09 yr) and faster gait speed (Moderate OA group = 1.25 ± 0.22 m/s; Asymptomatic group = 1.36 ± 0.19 m/s) of the Astephen et al. (129) study population. Younger people tend to walk faster which may result in higher hip adduction moments as compared to the older individuals.

The absence of a significant difference in the hip adduction moments between the three groups (p = 0.06) does not support one of the hypotheses of this study. The hip adduction moment is primarily the product of frontal plane ground reaction force vector and lever arm length (Figure 1). A change in either of the constituent variables will result in alteration of the hip adduction moment magnitude. Gait speed was similar between the groups in this study and, therefore, was unlikely to influence the magnitude of the ground reaction force. Reduction in lever arm magnitude has been suggested as a strategy to
reduce knee joint load in people with medial compartment knee OA (24). The lever arm may be reduced by increasing the toe-out angle (28-30). Another strategy, namely trunk lean, has been proposed to reduce the lever arm by moving the center of mass of the body towards the stance limb (31). This would decrease the lever arm and the adduction moment at both the hip and knee. The fact that the hip moments did not differ between the groups suggests that these strategies were not used by participants with moderate/severe OA in this study. The fact that only 9 of the 23 participants in the moderate/severe group had severe OA as measured by the Cooke et al scale (99) would support this argument.

There was a trend towards a lower hip adduction moment value in the moderate/severe OA group compared to control participants, suggesting that a trunk lean or foot rotation strategy may have been used by some participants. Lower hip adduction moments have been reported for people with knee OA compared to those without OA in previous studies. Astephen et al. (129) reported significantly lower values of hip adduction moments for moderate (0.99 ± 0.26 Nm/Kg) and severe OA groups (0.96 ± 0.34 Nm/Kg) as compared to an asymptomatic group (1.17 ± 0.28 Nm/Kg). Mundermann et al. (27) also reported a 20.3% lower hip adduction average moment in people with severe OA (n = 23) as compared to matched control participants (p = 0.024). It is possible that participants in these studies used a strategy, such as toe out angle or trunk lean towards the stance limb, to decrease load on the medial compartment of the knee.

The peak hip adduction moment in the moderate/severe OA group occurred later in the gait cycle than the peak of the control group. This may be related to a more cautious loading of the limb by participants with moderate/severe OA as more rapid loading may precipitate pain. Similarly, participants may also unload the affected lower extremity at a
slower speed. The stance phase of the gait cycle may, therefore, be elongated. Longer stance phase (or shorter swing phase) time in people with knee OA as compared to those without knee OA has been reported by various researchers (79,81,82,129). Increase in the stance time may also help people with knee OA to reduce the pain in the knee joint (79).

5.4 Knee Adduction Moment and Occurrence of the Peak Moment

The knee adduction moment values reported in this study are similar to those reported in previous studies in people with knee OA (23-26) and those without knee OA (19,25). However, discrepancy exists between the results of other studies and this study where the average knee adduction moment for people with moderate/severe OA was 2.93 ± 1.01 %Bw.Ht. Schippelein et al. (19) reported a knee adduction moment of 4.19 ± 1.51 %Bw.Ht in a group of 11 men and 8 women (mean age 55 yr) with medial compartment knee OA. The higher adduction moment value reported by these researchers may be attributed to the average varus deformity of 9.0° and knee flexion contractures of as high as 15° in their study population. Wada et al. (26) also reported higher knee adduction moment (median = 5.3 %Bw.Ht) for those with severe knee OA (K/L grade 3-4) which may be attributed to the high varus knee alignment of this group (14°). Similarly, Miyazaki et al. (14) reported higher knee adduction moments for people with progressive (6.1 ± 1 %Bw.Ht) and non-progressive knee OA (4.0 ± 1.4 % Bw.Ht) at six year follow-up. Participants in this study were older (progressive OA = 70.5 ± 6.2 yr; non-progressive 68.7 ± 8.7 yr) which may indicate more severe OA.

The results of this study revealed no difference between the values of peak knee adduction moment of moderate/severe OA, mild OA and control groups. This is in discordance with the hypothesis that people with moderate/severe OA will have higher
peak knee adduction moments, and the evidence in the literature that people with medial compartment knee OA have higher knee adduction moments (14,23,25-27). The similar knee adduction moment values in the three groups may be due to the low number of people with severe knee OA in this study. Secondly, the participants with moderate/severe OA were physically active as indicated by he PASE scores and had relatively low pain scores on the WOMAC. This suggests that despite the severity of radiological disease, this group did not have symptoms that interfered with occupational, household and leisure activities. The only indication of functional limitation was the longer time taken by the participants with moderate/severe OA in the FTSST which may be related to weakness of the knee musculature.

The moderate/severe OA group did have greater varus alignment values compared to the other two groups, which should result in a higher knee adduction moment. It is possible that some participants with moderate/severe knee OA adopt strategies such as increasing toe out angle or trunk lean to the stance side during gait to reduce medial compartment load. The finding that the hip adduction moment was lowest in the moderate/severe OA group and that other researchers have found significantly lower hip adduction moments in people with severe knee OA compared to control participants supports this theory.

The peak knee adduction moment occurred significantly later in the moderate/severe OA group as compared to the control group. The peak tended to occur at the same point in the cycle as the hip adduction moment peak. This may be considered as an adaptive strategy of the moderate/severe OA group to control the loading of the knee joint and ultimately aggravation of pain.
5.5 Hip Abductor and Adductor Muscle Isometric Strength

It was hypothesized that the people with moderate/severe knee OA would have weaker hip abductor muscle strength compared to the individuals with mild OA and the control group. This hypothesis was based on the evidence in the literature that loading of medial compartment of knee joint is higher in people with knee OA, and the theory that weak hip abductor muscles may contribute to the higher loading of knee joint. The weakness of hip abductor muscles may result in drop of the pelvis on the swing side thereby increasing the load on the medial compartment of the knee.

The results of this study did not support this hypothesis, as no difference was found between the isometric strength of hip abductor or adductor muscles between the three groups. Yamada et al. (44) also did not find any difference between hip abductor and adductor muscle isometric strength in 32 women with medial compartment knee OA and 13 control participants. These results suggest that hip abductor muscle weakness does not lead to inadequate trunk control resulting in pelvic drop to the swing side and higher hip and knee adduction moments. It is probable that the hip abductor muscles are capable of controlling the pelvis in the frontal plane. It has been reported that during gait hamstring muscles contract at a level of between 15-40 % of the maximum voluntary contraction (131). Therefore, despite the presence of age-related weakness, pelvic control may be normal in people with knee OA unless muscle strength declines below the threshold needed for control.

Given the reports of weakness of quadriceps and hamstrings muscles in people with knee OA (44,56,57) the lack of difference between the hip muscle strength in OA participants and control group individuals may be questioned. The weakness of muscles around the knee joint may be attributed to their proximity to the osteoarthritic joint. One
would tend to use the muscles around knee as little as possible to prevent the pain due to joint load related to muscle forces. However, the muscles around hip joint may be too distant from the knee to lose strength due to the knee OA.

5.6 Variables Explaining Variation in Knee Adduction Moment

The variance in the knee adduction moment was explained by knee alignment, hip abductor muscle isometric strength, peak hip adduction moment and gait speed. Other variables, including hip adductor muscle isometric strength, OA severity and WOMAC pain, which potentially could contribute to the variance, did not contribute to the model.

The significant contribution of knee joint alignment to the variance of knee adduction moment may be attributed to alteration in the lever arm due to the varus angulation of the knee. The negative $\beta$-value indicates that the more varus the alignment the higher the knee adduction moment. Although the force vector is the same at the hip and knee, an increase in varus alignment at the knee would only affect the knee frontal plane moment. Hunt et al. (132) found that knee joint alignment explained 25% of variance in the knee adduction moment in people with medial compartment knee OA ($n = 114$). Hurwitz et al. (28) also reported that knee joint alignment explained the highest percentage of variation in peak knee adduction moment. The alignment explained 53% of the variation in the knee adduction moment followed by the presence of osteophytes (8%) and WOMAC function (2%).

Hip abductor muscle isometric strength explained the next highest percentage of the variation in the knee adduction moment. The relationship was positive, indicating that higher values for abductor muscle strength are related to higher knee adduction moments. This finding does not support the theory that weaker hip abductor muscles lead to pelvic
drop to the swing side and shift of body weight away from the stance limb. Higher muscle strength values would be expected to reduce the knee adduction moment. The explanation for this finding is unclear. Strength of lower extremity muscle has been found to be related to gait speed (133). The Pearson correlation coefficient for the relationship between gait speed and hip abductor muscle strength in this study was 0.60 (p < 0.001). It is possible that gait speed is a confounding factor in this relationship. Further research is recommended to explain the relationship between the strength of hip abductor muscles and knee adduction moment.

The hip and knee adduction moment share a common constituent variable, namely the frontal plane ground reaction force vector. Therefore, the positive relationship between hip and knee adduction moment may be explained on a biomechanical basis. An increase in hip adduction moment based on the ground reaction force vector magnitude would also result in an increase in the knee adduction moment.

Gait speed explained approximately 16% of variance in the peak knee adduction moment with a negative $\beta$-value. This indicates that the lower the knee adduction moment, the faster the gait speed. Thorp et al. (42) reported that gait speed explained 16% of variance in the knee adduction moment in terminal stance in a group of 66 individuals (17 men; 49 women) with knee OA and 28 control participants (10 men; 18 women). They also reported a negative $\beta$-value (-0.25, $p < 0.01$) for gait speed. Lower knee adduction moment may be associated with less pain in the knee joint and, therefore there may be no need to reduce the gait speed. Conversely, as the adduction moment increases due to joint damage the gait speed may be reduced as a strategy to reduce knee pain.
5.7 Limitations of the Study

Some of the participants in the moderate/severe OA group could not be matched for weight and height. However, mean height was not different between the two groups. Individuals with knee OA generally tend to be overweight and have high BMI values. For those with very high BMI values, only age and gender-matched control participants were recruited. Therefore, it is acknowledged that this difference in BMI may have influenced the findings. However, strength and moments are normalized to body weight which should mitigate any bias due to body weight.

Given the symptoms of the disease including joint pain, stiffness and weakness of muscles around the knee joint, people with knee OA are generally reported to be less physically active as compared to control participants (134). The participants of the two OA groups in this study were as physically active as control group participants as measured on the PASE. Therefore, the findings may not be representative of the general OA population and may only be applicable to this particular group of people and/or the physically active population with knee OA. There were only 9 participants in the moderate/severe group classified as having severe OA which may, in part, be responsible for the lack of difference in hip and knee frontal plane moments between the groups in this study.

During the gait trials, participants were asked to put their hands on the lower abdomen in order to prevent covering of thigh IREDS. This may have resulted in an alteration in the normal gait pattern of the participants. Additionally the attachment of markers and awareness of the presence of force plates may also have affected participants’ gait.

Isometric strength of hip abductor and adductor muscles was measured in this study. During gait and most other activities of daily living the muscles perform isotonic
contractions. Therefore, inferences based on the measurement of isometric strength may not apply to activities involving isotonic contractions. The participants of this study came to the laboratory for testing at various times of the day. It is recognized that at the end of a working day one may be fatigued. Therefore, those who came to the laboratory at the end of the day, after finishing their job, may have had some fatigue which could have influenced their strength measures and gait parameters.

5.8 Future Studies

Alterations in gait that occur in people with knee OA are complex. Some changes may be due to the disease itself; for example, the higher knee adduction moment reported in many studies is related to medial compartment damage and varus alignment of the knee. However, various gait strategies may be adopted, for example toe out or trunk lean, to decrease medial compartment load and hence knee pain. These adaptations may be seen in temporal and distance parameters, as well as kinematic and kinetic measures in all three planes. Further, study is needed of the complex relationships between measures in three planes at the hip, knee and ankle as well as measures of foot angle and trunk lean in order to better understand the changes seen in gait patterns of people with knee OA. Such analyses will facilitate the understanding of gait alterations in this condition and aid in the development and evaluation of conservative and surgical treatments designed to minimize loads and delay progression of the condition.

Given the progressive nature of OA, it is suggested that future gait studies should divide the OA population on the basis of disease severity, i.e. mild, moderate and severe groups. These groups should be studied separately to identify gait and strength changes occurring at various stages of the disease. Additionally, a comparison of OA groups based
on disease severity would yield valuable information on the relationship of various gait strategies and the severity of OA which may help to identify any particular trend in individuals at the similar stage of OA. Longitudinal studies would also be beneficial in determining change over time in the same population.
CHAPTER 6
CONCLUSION

1. The hip abductor and adductor muscle isometric strength did not differ between groups. Hip abductor muscle strength explained the variation in the knee adduction moment; however this relationship was positive. These findings do not support the theory that weakness of hip abductor muscles in people with knee OA impairs control of the pelvis, allowing it to drop to the swing side during stance, thereby increasing load on the medial compartment of the knee.

2. The hip and knee joint frontal plane moments in individuals with moderate/severe OA of the medial compartment of knee joint did not differ from those of people with mild OA and without OA. The similar knee adduction moment values in the three groups may be due to the low number of people with severe knee OA in this study. Secondly, the participants with moderate/severe OA were physically active as indicated by the PASE scores and had relatively low pain scores on the WOMAC.

3. The knee joints of those with moderate/severe OA were in more varus alignment as compared to those with mild OA and without OA. Higher varus alignment will increase the lever arm at the knee joint and result in higher loading of the medial compartment of knee in people with moderate/severe OA. Although knee joint alignment was explained the highest percentage of variance in the knee adduction moment, the greater varus alignment in individuals with moderate/severe OA did not result in higher loading of knee joint in this group as compared to mild OA and control group. It is possible that participants with moderate/severe knee OA use gait strategies such as increasing toe out
angle or trunk lean to minimize knee joint load and are able to successfully maintain the knee adduction moment at a level similar to that of the individuals with mild OA and without OA.

4. The knee joint alignment (26%) was explained the highest percentage of variance in knee adduction moment followed by hip abductor muscle strength (20%), gait speed (16%) and hip adduction moment (11%).
BIBLIOGRAPHY


(81) Monica Maly. Mobility in people with knee osteoarthritis [Ph.D. Thesis]. Canada: Queen's University at Kingston (Canada); 2005.


APPENDIX I

Checklists for Participation in Knee Osteoarthritis Study

For potential participants with knee osteoarthritis:

_____ no corticosteroid injection in knee within previous 3 months

_____ no significant medical problems (including significant heart disease, stroke and active treatment for cancer)

_____ osteoarthritis not occurring as a result of other types of arthritis, including rheumatoid arthritis and other systemic inflammatory arthropathies

_____ no joint infection

_____ no known osteoarthritis or previous trauma affecting one or both hips

_____ no previous replacement of any joint in the lower extremities

_____ not receiving rehabilitation services for knee osteoarthritis at time of testing

_____ not performing a hip strengthening exercise program at the time of testing
For potential volunteers for control group:

____ no significant medical problems (including significant heart disease, stroke and active treatment for cancer)

____ no known diagnosis of knee osteoarthritis

____ no history of hip or knee injury or pain

____ no known osteoarthritis affecting one or both hips

____ no previous replacement of any joint in the lower extremities

____ not performing a hip strengthening exercise program at the time of testing
APPENDIX III

CONSENT FORM

School of Rehabilitation Therapy
Queen’s University
Kingston, Ontario

TITLE OF PROJECT: The influence of a home program of hip abductor exercises on gait parameters and muscle strength in persons with knee osteoarthritis

BACKGROUND INFORMATION
Overview of the Study
You are being invited to participate in a research study directed by Elizabeth Sled, PhD candidate, and Dr. Elsie Culham, Faculty Advisor, in the School of Rehabilitation Therapy. This study will examine the influence of a home program of hip exercises on walking patterns and hip muscle strength in people with knee osteoarthritis. The muscles of the hip and thigh may have an effect on the forces acting at the knee joint by controlling the position of the pelvis and/or by acting as lateral stabilizers for the knee. Research suggests that the function of the hip muscles during walking may be decreased in people with knee osteoarthritis. Therefore, strengthening the hip muscles may be an effective strategy for reducing stress on the arthritic knee.

Elizabeth Sled will read through this consent form with you. She will describe procedures in detail and answer any questions you may have.

DETAILS OF THE STUDY
Aim of the Study: to determine the influence of an eight-week home program of exercises for the hip muscles on walking patterns and hip muscle strength in people with knee osteoarthritis.

We invite you to participate as part of the knee osteoarthritis group if you have been diagnosed with knee osteoarthritis by your doctor, are 40 years of age or older, have knee pain on most days of the month and have at least some difficulty in daily function due to your knee pain. You are invited to participate as part of the control group if you have no diagnosis of knee or hip osteoarthritis and no history of hip or knee injury or pain.

Description of the Testing
Initial Testing Session: Testing will be conducted in the Motor Performance Laboratory at the School of Rehabilitation Therapy and in the Radiology Department at Kingston General Hospital. The initial testing session will last approximately 2 – 2.5 hours and will involve the following measures:
1) **Questionnaires:** You will be asked to complete two brief questionnaires which will obtain information about your physical activities and your knee pain during daily function.

2) **Baseline measurements:** Your weight and height will be measured using a regular weigh scale and tape measure.

3) **Walking Performance:** You will be asked to wear shorts for the walking tests. Surface markers will be positioned on your skin at the foot, ankle, knee, hip, lower back and base of the neck, and straps will be used to hold the markers in place. You will be asked to walk along an 8-metre indoor walkway at a comfortable speed wearing your normal footwear. Two large camera systems will detect the movement of the markers as you walk across the floor. You will be provided with rest breaks in between walking trials. We will collect five good walking trials from each side of the body.

4) **Hip Muscle Strength Testing:** You will stand with your back supported against the muscle strength testing device. A padded cuff will be positioned around your lower thigh just above your knee. You will be asked to keep your knee straight and to take your leg out to the side and back to the midline in a small range of movement while providing maximum effort against the resistance of the machine. Testing will be performed at a comfortable speed and 5 repetitions will be completed. You will also be asked to push against the cuff without any movement of your leg, holding for 5 seconds 3 times. The tests will then be repeated for the opposite leg. You will be given a 2-minute rest between tests.

5) **Physical Performance Measures:** You will be asked to rise from a regular chair and then sit again as fast as you can for 5 repetitions.

**Exercise Program:** If you are a participant in the group with knee osteoarthritis you will be taught a home exercise program. An additional 30 minutes will be required after the testing for one of the researchers, a physical therapist, to teach you several simple exercises for the hip muscles. You will be instructed in how to contract your hip muscles during walking, stepping up on a step and standing on one leg. You will also be taught a sidelying leg lift exercise using elastic tubing around your lower thigh to provide resistance. You will be asked to perform these exercises four times per week (on alternate days) for 8 weeks.

For those participating in the exercise program, two follow-up visits with the physical therapist will occur in the laboratory or in your home (your preference) during the 8-week program. These visits will last about 30 minutes. The physical therapist will review your exercise program with you and teach you how to progress the exercises. You are also encouraged to contact the physical therapist by phone if you have any questions or concerns during the 8-week exercise period.
If you are part of the control group of participants without knee osteoarthritis you will be instructed to continue your daily activities, but not to begin any new exercise program, over the 8 weeks after the initial testing session.

**X-rays:** If you have not received a recent knee X-ray, you will be asked to have an x-ray taken on the date of your first visit or on a separate day at Kingston General Hospital. You will be required to stand on a turntable with your knees ahead and your feet positioned on markers. Your hips will be supported by adjustable pads to help maintain the position. A hand rest is available for support. You will be asked to distribute your weight evenly on both legs and to keep still during the sequence of x-rays. Front views of your knees will be taken. We will use these x-rays to grade the level of arthritis in your knee joint and to determine how your knee is aligned. The x-rays from the control group will be used to confirm the absence of knee osteoarthritis (as osteoarthritis may be present in people without knee pain) and to obtain the measures of knee alignment for comparison with those with osteoarthritis.

If you have had a recent knee x-ray, with your consent we will view these x-rays to grade the level of knee arthritis and determine your knee alignment.

**Final Testing Session:** All participants will be asked to return to the Motor Performance Laboratory 8 weeks after the initial testing session. You will complete the questionnaires again. We will also re-test your walking performance, hip muscle strength and sit-to-stand performance.

**Risks**
There are no known risks associated with the procedures used in this study. The radiation dosage for knee x-rays is well within safe limits, provided that participants have not been exposed to large amounts of radiation over the past year. You may experience some mild muscle soreness and fatigue with strength testing of the hip muscles and measurement of your walking performance. If you are participating in the home exercise program you may also experience mild muscle soreness and fatigue with the hip exercises.

**Benefits**
If you are participating in the home exercise program you may experience a decrease in knee pain and/or improved ability to perform your daily activities as a result of the exercises. The findings from this study may improve our understanding of the role of hip strengthening exercises as part of rehabilitation programs for people with knee osteoarthritis. Thus, the results of this study may benefit those with knee osteoarthritis in the future. There are no expected benefits for those participating as part of the control group.
Exclusions
You will not be considered for this study if you present with any of the following: corticosteroid injection into either knee within the previous three months; other significant medical problems (including significant heart disease, stroke, and active treatment for cancer) that would prevent you from being able to perform a hip exercise program or to participate in tests of walking performance and hip muscle strength; known osteoarthritis or previous trauma affecting one or both hips; and previous replacement of any joint in the lower extremities. You will not be considered if you are receiving rehabilitation services for knee osteoarthritis or performing a hip strengthening program at the time of testing.

Confidentiality
All information obtained during this study will be strictly confidential. Your anonymity will be protected at all times. A file number will be assigned to your data and this information will be kept in a secure location. Data will be stored in locked files and will only be available to the Principal Investigator and Faculty Advisor. You will not be identified in any publications or reports.

Voluntary Nature of Study / Freedom to Withdraw or Participate
Your participation in this study is voluntary. You may withdraw from this study at any time and your withdrawal will not affect your future medical care with your physician or at Kingston General Hospital or Hotel Dieu Hospital.

Statement of Subject and Signature
I have read and understand the consent form for this study. I have had the purposes, procedures and technical language of this study explained to me. I have been given sufficient time to consider the above information and to seek advice if I chose to do so. I have had the opportunity to ask questions which have been answered to my satisfaction. I am voluntarily signing this form. I will receive a copy of this consent form for my information.

If at any time I have further questions, problems or adverse events, I can contact:

Elizabeth Sled, Principal Investigator, (613) 533-6000, ext. 75593

OR

Dr. Elsie Culham, Acting Director and Faculty Advisor, School of Rehabilitation Therapy, Queen’s University, at (613) 533-6727

If I have questions regarding my rights as a research participant I can contact:

Dr. Albert Clark, Chair, Research Ethics Board, at 533-6081
By signing this consent form, I am indicating that I agree to participate in this study. I am aware that I may refuse to participate or withdraw at any time for any reason without any penalty to the care I will receive.

_________________________________________  _________________
Signature of Subject                                          Date

_________________________________________  _________________
Signature of Witness                                          Date

Statement of Investigator:
I have carefully explained to the participant the nature of the above research study. I certify that, to the best of my knowledge, the participant understands clearly the nature of the study and demands, benefits, and risks involved to participants in this study.

_________________________________________  _________________
Signature of Investigator                                          Date
APPENDIX IV

Western Ontario McMaster Universities Osteoarthritis Index (WOMAC)

INSTRUCTIONS TO PATIENTS

In Sections A, B and C questions will be asked in the following format and you should give your answers by putting an “X” in one of the boxes.

NOTE:

1. If you put your “X” in the left-hand box, i.e. then you are indicating that you have no pain

   None       Mild       Moderate       Severe       Extreme
   [X]        [ ]         [ ]            [ ]            [ ]

2. If you put your “X” in the right-hand box, i.e. then you are indicating that your pain is extreme

   None       Mild       Moderate       Severe       Extreme
   [ ]        [ ]         [ ]            [ ]            [X]

3. Please note:

   • that the further to the right you place your “X” the more pain you are experiencing
   • that the further to the left you place your “X” the less pain you are experiencing
   • Please do not place your “X” outside the box

You will be asked to indicate on this type of scale, the amount of pain, stiffness or disability you are experiencing. Please remember the further you place your “X” to the right, the more pain, stiffness or disability you are indicating that you experience.
INSTRUCTIONS TO PATIENTS

The following questions concern the amount of pain you are currently experiencing due to arthritis in your hips and/or knees. For each situation, please enter the amount of pain recently experienced. (Please mark your answers with an “X”)

QUESTION: How much pain do you have?

1. Walking on a flat surface.
   - None
   - Mild
   - Moderate
   - Severe
   - Extreme

2. Going up or down stairs.
   - None
   - Mild
   - Moderate
   - Severe
   - Extreme

3. At night while in bed.
   - None
   - Mild
   - Moderate
   - Severe
   - Extreme

4. Sitting or lying.
   - None
   - Mild
   - Moderate
   - Severe
   - Extreme

5. Standing upright.
   - None
   - Mild
   - Moderate
   - Severe
   - Extreme
Section B

INSTRUCTIONS TO PATIENTS

The following questions concern the amount of joint stiffness (not pain) you are currently experiencing in your hips and/or knees. Stiffness is a sensation of restriction or slowness in the ease with which you move your joints. (Please mark your answers with an “X”)

1. How severe is your stiffness after first wakening in the morning?
   
   None  Mild  Moderate  Severe  Extreme
   
   [ ] [ ] [ ] [ ] [ ]

2. How severe is your stiffness after sitting, lying or resting later in the day?

   None  Mild  Moderate  Severe  Extreme
   
   [ ] [ ] [ ] [ ] [ ]

Section C

INSTRUCTIONS TO PATIENTS

The following questions concern your physical function. By this we mean your ability to move around and to look after yourself. For each of the following activities, please indicate the degree of difficulty you are currently experiencing due to arthritis in your hips and/or knees. (Please mark your answers with an “X”)

QUESTION: What degree of difficulty do you have with:

1. Descending stairs.

   None  Mild  Moderate  Severe  Extreme
   
   [ ] [ ] [ ] [ ] [ ]
<table>
<thead>
<tr>
<th></th>
<th>Activity</th>
<th>None</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
<th>Extreme</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Ascending Stairs.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Rising from sitting.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Standing.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Bending to floor.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Walking on flat.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Getting in / out of car.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Going shopping.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Putting on socks/stockings.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Rising from bed.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
11. Taking off socks/stockings. None  Mild  Moderate  Severe  Extreme

12. Lying in bed. None  Mild  Moderate  Severe  Extreme

13. Getting in/out of bath. None  Mild  Moderate  Severe  Extreme

14. Sitting. None  Mild  Moderate  Severe  Extreme

15. Getting on/off toilet. None  Mild  Moderate  Severe  Extreme

16. Heavy domestic duties. None  Mild  Moderate  Severe  Extreme

17. Light domestic duties. None  Mild  Moderate  Severe  Extreme

THANK YOU FOR COMPLETING THE QUESTIONNAIRE
APPENDIX V

PHYSICAL ACTIVITY SCALE FOR THE ELDERLY

(P A S E )

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INSTRUCTIONS:

Please complete this questionnaire by either circling the correct response or filling in the blank. Here is an example:

During the past 7 days, how often have you seen the sun?

[0.] NEVER    [1.] SELDOM    [2.] SOMETIMES    [3.] OFTEN
          (1-2 DAYS)    (3-4 DAYS)    (5-7 DAYS)

Answer all items as accurately as possible. All information is strictly confidential.
LEISURE TIME ACTIVITY

1. Over the past 7 days, how often did you participate in sitting activities such as reading, watching TV or doing handcrafts?

   [0.] NEVER  \[\downarrow\]  [1.] SELDOM  \[\rightarrow\]  [2.] SOMETIMES  \[\rightarrow\]  [3.] OFTEN  \[\rightarrow\]
   \[1-2 DAYS\]  \[3-4 DAYS\]  \[5-7 DAYS\]
   GO TO Q.#2  \[\downarrow\]

1a. What were these activities?

   __________________________________________________

1b. On average, how many hours per day did you engage in these sitting activities?

   [1.] LESS THAN 1 HOUR  [2.] 1 BUT LESS THAN 2 HOURS
   [3.] 2-4 HOURS  [4.] MORE THAN 4 HOURS

2. Over the past 7 days, how often did you take a walk outside your home or yard for any reason? For example, for fun or exercise, walking to work, walking the dog, etc.?

   [0.] NEVER  \[\downarrow\]  [1.] SELDOM  \[\rightarrow\]  [2.] SOMETIMES  \[\rightarrow\]  [3.] OFTEN  \[\rightarrow\]
   \[1-2 DAYS\]  \[3-4 DAYS\]  \[5-7 DAYS\]
   GO TO Q.#3  \[\downarrow\]

2a. On average, how many hours per day did you spend walking?

   [1.] LESS THAN 1 HOUR  [2.] 1 BUT LESS THAN 2 HOURS
   [3.] 2-4 HOURS  [4.] MORE THAN 4 HOURS
3. Over the past 7 days, how often did you engage in light sport or recreational activities such as bowling, golf with a cart, shuffleboard, fishing from a boat or pier or other similar activities?

<table>
<thead>
<tr>
<th>0. NEVER</th>
<th>1. Seldom</th>
<th>2. Sometimes</th>
<th>3. Often</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1-2 days)</td>
<td>(3-4 days)</td>
<td>(5-7 days)</td>
<td></td>
</tr>
</tbody>
</table>

GO TO Q. #4

3a. What were these activities?

3b. On average, how many hours per day did you engage in these light sport or recreational activities?

<table>
<thead>
<tr>
<th>1. Less than 1 hour</th>
<th>2. 1 but less than 2 hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>3. 2-4 hours</td>
<td>4. More than 4 hours</td>
</tr>
</tbody>
</table>

4. Over the past 7 days, how often did you engage in moderate sport and recreational activities such as doubles tennis, ballroom dancing, hunting, ice skating, golf without a cart, softball or other similar activities?

<table>
<thead>
<tr>
<th>0. NEVER</th>
<th>1. Seldom</th>
<th>2. Sometimes</th>
<th>3. Often</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1-2 days)</td>
<td>(3-4 days)</td>
<td>(5-7 days)</td>
<td></td>
</tr>
</tbody>
</table>

GO TO Q. #5

4a. What were these activities?

4b. On average, how many hours per day did you engage in these moderate sport and recreational activities?

<table>
<thead>
<tr>
<th>1. Less than 1 hour</th>
<th>2. 1 but less than 2 hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>3. 2-4 hours</td>
<td>4. More than 4 hours</td>
</tr>
</tbody>
</table>
5. Over the past 7 days, how often did you engage in strenuous sport and recreational activities such as jogging, swimming, cycling, singles tennis, aerobic dance, skiing (downhill or cross-country) or other similar activities?

<table>
<thead>
<tr>
<th>[0.] NEVER</th>
<th>[1.] SELDOM</th>
<th>[2.] SOMETIMES</th>
<th>[3.] OFTEN</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1-2 DAYS)</td>
<td>(3-4 DAYS)</td>
<td>(5-7 DAYS)</td>
<td></td>
</tr>
</tbody>
</table>

GO TO Q.#6

5a. What were these activities?

5b. On average, how many hours per day did you engage in these strenuous sport and recreational activities?

<table>
<thead>
<tr>
<th>[1.] LESS THAN 1 HOUR</th>
<th>[2.] 1 BUT LESS THAN 2 HOURS</th>
</tr>
</thead>
<tbody>
<tr>
<td>[3.] 2-4 HOURS</td>
<td>[4.] MORE THAN 4 HOURS</td>
</tr>
</tbody>
</table>

6. Over the past 7 days, how often did you do any exercises specifically to increase muscle strength and endurance, such as lifting weights or pushups, etc.?

<table>
<thead>
<tr>
<th>[0.] NEVER</th>
<th>[1.] SELDOM</th>
<th>[2.] SOMETIMES</th>
<th>[3.] OFTEN</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1-2 DAYS)</td>
<td>(3-4 DAYS)</td>
<td>(5-7 DAYS)</td>
<td></td>
</tr>
</tbody>
</table>

GO TO Q.#7

6a. What were these activities?

6b. On average, how many hours per day did you engage in exercises to increase muscle strength and endurance?

<table>
<thead>
<tr>
<th>[1.] LESS THAN 1 HOUR</th>
<th>[2.] 1 BUT LESS THAN 2 HOURS</th>
</tr>
</thead>
<tbody>
<tr>
<td>[3.] 2-4 HOURS</td>
<td>[4.] MORE THAN 4 HOURS</td>
</tr>
</tbody>
</table>
HOUSEHOLD ACTIVITY

7. During the past 7 days, have you done any light housework, such as dusting or washing dishes?

[1.] NO     [2.] YES

8. During the past 7 days, have you done any heavy housework or chores, such as vacuuming, scrubbing floors, washing windows, or carrying wood?

[1.] NO     [2.] YES

9. During the past 7 days, did you engage in any of the following activities?

Please answer YES or NO for each item.

a. Home repairs like painting, wallpapering, electrical work, etc. NO YES
   1  2

b. Lawn work or yard care, including snow or leaf removal, wood chopping, etc. NO YES
   1  2

c. Outdoor gardening NO YES
   1  2

d. Caring for an other person, such as children, dependent spouse, or an other adult NO YES
   1  2
**WORK-RELATED ACTIVITY**

10. During the past 7 days, did you work for pay or as a volunteer?

   [1.] NO   [2.] YES

10a. How many hours per week did you work for pay and/or as a volunteer?

    _______________ HOURS

10b. Which of the following categories best describes the amount of physical activity required on your job and/or volunteer work?

   [Examples: office worker, watchmaker, seated assembly line worker, bus driver, etc.]

   [2] Sitting or standing with some walking.
   [Examples: cashier, general office worker, light tool and machinery worker.]

   [3] Walking, with some handling of materials generally weighing less than 50 pounds.
   [Examples: mailman, waiter/waitress, construction worker, heavy tool and machinery worker.]

   [Examples: lumberjack, stone mason, farm or general laborer.]
THANK YOU FOR TAKING THE TIME AND EFFORT TO COMPLETE THIS QUESTIONNAIRE!