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Effect of valgus knee alignment on gait biomechanics in healthy women

Matthew C. Hoch [a,*], Joshua T. Weinhandl [b]

[a] School of Physical Therapy and Athletic Training, College of Heath Sciences, Old Dominion University, Health Sciences 3120, Norfolk, VA 23539, United States
[b] Department of Kinesiology, Recreation, and Sports Studies, The University of Tennessee, Knoxville, TN 37996, United States

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ABSTRACT

The purpose of this study was to compare lower extremity kinematics and kinetics between women with greater or lesser degrees of valgus knee alignment during gait. Nine women with greater valgus knee alignment (11.9 ± 1.6°) were compared to nine women with lesser valgus knee alignment (6.6 ± 2.4°). Participants completed a biomechanical assessment of overground walking for the right limb. Dependent variables included sagittal and frontal plane joint angles and moments for the hip, knee, and ankle at peak vertical ground reaction force, along with knee abduction angular impulse. Sagittal and frontal plane excursions for the hip, knee, and ankle were calculated from heel strike to the peak angle for each variable. The greater valgus alignment group demonstrated lower knee abduction moment ($p = 0.007$), lower knee adduction angle ($p < 0.001$), and greater ankle inversion moment ($p = 0.034$) at peak vertical ground reaction force, as well as lower knee abduction angular impulse ($p = 0.007$), and knee adduction ROM ($p = 0.026$). No other group differences were identified for any kinematic or kinetic variables ($p > 0.05$). Less knee adduction angle and excursion coupled with lower knee abduction moment and angular impulse in women with greater knee valgus indicates these individuals may be experiencing biomechanics which promote lateral tibiofemoral joint loading.

1. Introduction

In the United States, symptomatic knee osteoarthritis (KOA) affects 14 million adults with 2 million cases under the age of 45 (Deshpande et al., 2016). While the incidence of diagnosed symptomatic KOA is highest in ages 55–64 (Losina et al., 2013), a history of traumatic knee injury such as ACL rupture can drastically expedite the onset of this condition (Lohmander et al., 2004, 2007). While KOA is most common in the medial tibiofemoral compartment, roughly 10% of patients present with primary involvement in the lateral compartment with greater rates in women (Felson et al., 2002; Wise et al., 2012). Therefore, there is a need to explore how factors such as knee alignment and biomechanics may promote lateral knee loading in women and create a potential mechanism for lateral KOA development.

People with valgus knee alignment have demonstrated greater rates, risk of disease progression, and risk of incidence for lateral KOA compared to people with a normal or varus alignment (Brouwer et al., 2007; Cerejo et al., 2002; Eckstein et al., 2008; Felson et al., 2013; Sharma et al., 2001; Teichtahl et al., 2006). Furthermore, women experience greater rates of lateral KOA compared to men which has further supported frontal plane knee alignment as a contributing factor to the development of this condition (Felson et al., 2013; Wise et al., 2012).

Several studies have determined that individuals with KOA and a valgus alignment are more likely to express biomechanics which promote lateral tibiofemoral loading during gait (Butler et al., 2011; Hart et al., 2015; Leitch et al., 2013; Weidow et al., 2006). Middle-aged and elderly patients with lateral KOA exhibited smaller peak knee abduction moments, less knee adduction excursion, and less knee flexion compared to patients with medial KOA and healthy controls during gait (Butler et al., 2011; Leitch et al., 2013; Weidow et al., 2006). In addition, people with lateral KOA and a history of ACL reconstruction demonstrated greater peak knee flexion, lower peak knee internal rotation, and less peak hip flexion compared to healthy controls (Hart et al., 2015). Overall, it appears lateral KOA is linked to valgus knee alignment which may be associated with biomechanical alterations during gait which contribute to increased lateral knee loading.

It is less clear if young, healthy individuals with greater knee valgus alignment and no history of traumatic knee injury demonstrate gait biomechanics which may increase the risk of lateral KOA over the lifespan. A finite element modeling study determined that a healthy subject with a valgus alignment demonstrated greater lateral compartment stress compared to a normal or varus

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* Corresponding author.
E-mail address: mhoch@odu.edu (M.C. Hoch).

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aligned healthy subject during gait (Yang et al., 2010). Also, valgus aligned women without KOA demonstrated less hip flexion and knee adduction compared to normal aligned women during gait (Barrios et al., 2016). This study identified kinematic deviations in young healthy women consistent with increased lateral knee loading; however, joint kinetics were not reported which limits the ability to determine how knee alignment influenced force attenuation. Understanding the kinematic and kinetic alterations associated with valgus knee alignments would be useful to extrapolate how the biomechanics observed in younger populations may be related to those previously observed in older populations with KOA.

While preliminary evidence suggests young healthy women with a valgus alignment exhibit biomechanics that promote lateral knee loading during gait, a more comprehensive analysis which examines kinematics and kinetics is warranted. Also, examining variables such as knee abduction angular impulse would provide more insight into forces throughout stance. If biomechanical deviations are identified based on frontal plane knee alignment this may provide the impetus to further investigate if prevention efforts are necessary to mitigate the risk of KOA. Therefore, the purpose of this study was to compare lower extremity kinematics and kinetics between women with greater or lesser static valgus knee alignment during gait.

2. Methods

A convenience sample of women between the ages of 18 and 55 years and physically active at least 3 times per week for a minimum of 30 min were recruited from a large pubic university through recruitment flyers and word of mouth. All participants completed a health questionnaire and were excluded if they had a history of lower extremity surgery, experienced a lower extremity injury or condition within the previous six months, or reported any current lower extremity pain. Participants were grouped based on previously published normative values for tibiofemoral angles measured with a handheld goniometer (Lee et al., 2011; Nguyen and Shultz, 2007). In summary, participants with a tibiofemoral angle >10° were included in the greater valgus alignment group while participants with tibiofemoral angles between 4° and 10° were included in the lesser valgus alignment group. Tibiofemoral angles between 4° and 10° have been previously described as "ideal" anatomical tibiofemoral angles (Lee et al., 2011; Mahaluxmivala et al., 2001). This is supported by Nguyen and Shultz (Nguyen and Shultz, 2007) who identified a median tibiofemoral angle of 10° in young healthy women. Written informed consent was obtained from all participants in compliance with the Institutional Review Board.

2.1. Procedures

Once enrolled in the study, a static frontal plane tibiofemoral angle was measured using a plastic 12″ goniometer. This angle was formed by the anatomical axes of the femur and tibia in the frontal plane. The goniometer axis was placed over the knee center (midpoint between the medial and lateral joint line in the frontal plane), the stationary arm was aligned along the line from the knee center to the midpoint between the anterior superior iliac spine and the most prominent aspect of the greater trochanter, and the movable arm was aligned along a line from the knee center to the midpoint between the medial and lateral malleoli (Nguyen and Shultz, 2007; Weinhandl et al., 2016). Previous investigators have demonstrated strong test-retest reliability (ICC = 0.87, SEM = 0.7°) using this technique (Nguyen and Shultz, 2007).

Participants also completed a biomechanical assessment of overground walking gait for the right limb. For all testing procedures, participants wore spandex shorts, a tight fitting shirt or sports bra, and their own athletic shoes that were used regularly for at least one month. To track lower extremity kinematics, 26 retro-reflective skin markers were placed on the participants (Weinhandl et al., 2010). Several markers were used exclusively for the standing calibration trial which included the left and right iliac crests and greater trochanters, lateral and medial femoral epicondyles, lateral and medial malleoli, and first and fifth metatarsal heads. Tracking markers were placed on the left and right anterosuperior iliac spine and the left and right posterosuperior iliac spine along with four-marker clusters attached to elastic Velcro straps placed on the thigh segment, shank segment, and heel of the shoe on the right limb. Three-dimensional marker coordinate data were collected at 200 Hz using an eight-camera motion analysis system (Vicon, Centennial, CO, USA). Synchronously, three-dimensional ground reaction force data were measured at 1000 Hz using a forceplate (Bertec, Columbus, OH, USA).

A three second standing calibration trial was collected and calibration markers were removed. Participants then walked at their self-selected walking speed on a 15 m walkway. All participants completed several practice passes on the walkway to become accustomed to the task. The walkway permitted multiple steps to be completed before reaching the data capture volume and forceplate. Walking speed was assessed using two infrared photocell switches (Model 63501-IR, Lafayette Instrument, IN, USA) with a digital timer (Model 54035-A, Lafayette Instruments, Lafayette, IN, USA). The mean walking speed from five trials was calculated and used as a target walking speed during data collection. During data collection, each participant performed multiple walking trials in which the individual was within 1% of the target speed and contacted the forceplate with their entire right foot (Hamill et al., 1984; Hannah et al., 1984; Matsusaka et al., 1985). In the event a trial was outside the target speed or the foot did not fully contact the forceplate, the trial was discarded and repeated until five successful trials were recorded for analysis.

Data reduction was completed with Visual3D (v5.01, C-Motion Inc., Rockville, MD, USA). Raw three-dimensional marker coordinate data and ground reaction force data were low-pass filtered through a fourth-order, zero lag, recursive Butterworth filter with 12 Hz and 50 Hz cutoff frequencies, respectively. In order to describe the position and orientation of each segment, right handed Cartesian local coordinate systems were defined for the pelvis, thigh, shank, and foot segments. Three-dimensional ankle, knee, and hip angles were calculated using a joint coordinate system approach and reported relative to the static standing trial (Grood and Suntay, 1983). Ankle joints centers were defined as the midpoint between the medial and lateral malleoli markers (Wu et al., 2002) and knee joint center was defined as the midpoint between the medial and lateral epicondyle markers (Grood and Suntay, 1983). The hip joint center was defined as 25% of the distance from the ipsilateral to the contralateral greater trochanter (Weinhandl and O'Connor, 2010). Body segment parameters were estimated from Dempster (Dempster, 1955), and joint moments were calculated using a Newton-Euler approach (Bresler and Frankel, 1950). Joint moments were reported in the distal segment coordinate system and normalized by body mass. A vertical ground reaction force threshold of 15 N indicated initial foot contact and toe-off of the right foot (Barnes et al., 2011).

Dependent variables identified for statistical analysis included the sagittal and frontal plane joint angles and moments for the hip, knee, and ankle at peak vertical ground reaction force (pVGRF), along with knee abduction angular impulse. Finally, sagittal and frontal plane excursions for the hip, knee, and ankle were calculated from heel strike to the peak angle for each variable.