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The influence of body mass index and velocity on knee biomechanics during walking

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ABSTRACT

Obesity has been associated with both the development and progression of knee osteoarthritis. Being overweight or obese from a young age is likely to decrease the age of onset for co-morbidities of obesity such as osteoarthritis. However, research on osteoarthritis has thus far focused on older adults. Therefore, the purpose of this study was to determine whether young adults who are overweight or obese exhibit biomechanical risk factors for knee osteoarthritis at either their preferred walking velocity or at 1 m/s, which was slower than the preferred velocity. Thirty healthy young adults formed three equal groups according to body mass index. Three dimensional kinetics and kinematics were collected while participants walked overground at both velocities. Joint moments were normalized to fat free weight and height. The preferred walking velocity of obese participants was slower than that of normal weight individuals. There were no differences in knee flexion excursion, peak knee flexion angle, normalized peak knee flexion moment or normalized peak knee adduction moment among groups. Obese participants walked with lower peak knee adduction angle than both overweight and normal body mass index participants and several shifted towards knee abduction. All groups had smaller knee flexion excursion, peak knee flexion angle, peak knee flexion moment and peak knee adduction moment at 1 m/s compared to preferred walking velocity. Overall, young and otherwise healthy overweight and obese participants have knee biomechanics during gait at preferred and slow walking velocities that are comparable to normal weight adults.

1. Introduction

Osteoarthritis is common in older adults, with 12% of adults over the age of 65 suffering from knee osteoarthritis [1]. Obesity has been associated with the development of diabetes, heart disease and cancer [2] as well as and progression of knee osteoarthritis [3]. It has been shown that higher than normal body weight puts more stress on the knee joint cartilage and increases the rate of cartilage degeneration [4]. From 1960 to 1999 the rate of obesity in adults in the United States jumped from 13.4% to a staggering 30.9% [5]. A 2001 [6] investigation of disabled adults reported that the leading cause of disability was osteoarthritis and rheumatism. The consequences of obesity are becoming ever more important as the obesity epidemic spreads among today's youth. In only four years, between 1999 and 2003, the percentage of overweight children and young adults rose from 28.2% to 36.6%. The percentage of obese children and young adults rose from 13.9% to 17.1% [7]. Being overweight or obese from a young age has increased the incidence co-morbidities of obesity such as increased prevalence in type 2 diabetes [8]. Therefore, it is hypothesized that increasing obesity in children and young adults will likely decrease the age of onset for other co-morbidities of obesity such as osteoarthritis. Therefore, it is important to understand the influence of overweight and obesity on risk factors for osteoarthritis in young adults.

The relationship between osteoarthritis and the biomechanics of gait has been researched extensively in older adults. Individuals with knee osteoarthritis walk with decreased knee flexion excursion [9–11], decreased peak knee flexion angle [10,12], decreased peak external knee flexion moments, normalized to height and body weight [10], greater stance phase peak knee adduction angles [13], and greater peak external knee adduction moments normalized to body weight or body weight and height [10,12,14–17], when compared to healthy individuals. Individuals with more severe osteoarthritis exhibit greater peak knee

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adduction moments normalized to body weight than those with less severe osteoarthritis [16]. Longitudinal research has also suggested that healthy individuals with higher than normal peak knee adduction moments normalized to body weight are more likely to develop osteoarthritis [17]. There appears to be some overlap between the consequences of obesity on gait biomechanics and biomechanical risk factors for osteoarthritis [3,17]. Greater peak knee adduction angles [18] have been observed in obese individuals compared to normal weight individuals. It has also been observed that obese individuals walk with less knee flexion in early stance than normal weight individuals [19]. The literature is inconclusive in regards to peak external knee flexion moment and obesity with Browning and Kram [20] reporting absolute moments and the DeVita and Hortobágyi [19] reporting moments normalized to body mass. Furthermore, individuals with knee osteoarthritis walk at a slower preferred walking velocity than healthy individuals [10]. Changes in walking velocity have been associated with changes in the kinematics and kinetics of gait in both normal weight and obese individuals [20]. Having participants walk at their preferred velocity provides a good indication of the individual's daily gait pattern. However, a fixed walking velocity is necessary to determine the direct effect of body mass index (BMI) on gait.

Therefore, the purpose of this study was to determine whether young adults who are overweight or obese exhibit biomechanical risk factors for knee osteoarthritis during walking that have been reported previously in the literature. Comparisons were made at both preferred walking velocity and a fixed walking velocity. We hypothesized that, at both walking velocities, peak knee flexion angle, knee flexion excursion and external peak knee flexion moment during weight acceptance will decrease as BMI increases from normal to overweight to obese in young adults. We also hypothesized that, at both walking velocities, peak knee adduction angle and external peak knee adduction moment will increase as BMI increases from normal weight to overweight to obese in young adults.

2. Methods

2.1. Participant details

Thirty participants (Table 1) between the ages of 18 and 35 years were recruited from the University and surrounding community to participate in this study. Participants were recruited according to BMI to have five males and five females in each of three groups: normal weight (BMI less than 25), overweight (BMI from 25 to 29.9), and obese (BMI 30 or greater) [21]. Participants were excluded if they had a previous injury or surgery that may affect gait, were currently injured, required the use of a walking aid or reported an existing diagnosis of lower extremity osteoarthritis. Participants were also excluded if they answered "yes" to any question on the Physical Activity Readiness Questionnaire [22].

2.2. Data collection

Prior to commencing the study, procedures were approved by the University's Institutional Review Board. Participants provided written informed consent prior to their participation. Height and weight were measured to confirm BMI for group membership, and participants completed the Physical Activity Readiness Questionnaire as the final inclusion criterion. Prior to arrival for data collection, participants were instructed to maintain normal hydration levels for body composition analysis. Body composition was measured using segmental bioelectrical impedance analysis (Tanita BC-418, Tanita Corporation of America, Inc., Arlington Heights, IL). To determine the current knee pain and function, participants completed the Knee Injury and Osteoarthritis Outcome Score (KOOS) questionnaire [23]. The KOOS is comprised of five sections. The score for each section is calculated on a normative scale to provide a value out of 100, for a total possible score of 500 [9]. Participants also rated their current knee pain in each knee using a ten point visual analog scale from zero being no pain at all to ten being intolerable pain [24]. Participants completed the 6-min walk [25] and timed up and go [26,27] functional activity tests. Participants then prepared for gait analysis by changing into laboratory shorts, socks and footwear (BITE Footwear, Redmond, WA) and were instrumented with retro-reflective anatomical and tracking markers while standing in a standard position on a template [28]. Anatomical markers were placed bilaterally on the iliac crest, greater trochanter, medial and lateral epicondyles, medial and lateral malleoli, and the first and fifth metatarsal heads. Four non-collinear tracking markers were attached to molded thermoplastic shells [29] on the pelvis, thighs and shanks [30] and three separate non-collinear markers on the heels. Measures from each participant's dominant leg, the leg the participant would use to kick a ball, was used for data analysis.

Kinematic data (120 Hz) and kinetic data (1200 Hz) were collected using a seven camera three-dimensional motion capture system (Vicon Inc., Oxford, UK) synchronized with two force platforms (Advanced Mechanical Technologies, Inc., Watertown, MA). Initially, a standing trial was collected while the participant stood on the template used during marker placement. The anatomical markers were then removed. Participants walked overground across a 10-m walkway contacting two force platforms in the center of the walkway, one with each foot. They walked at their self-selected velocity for a total of five acceptable trials. This was followed by walking at a fixed walking velocity, within five percent of 1.0 m/s, for five acceptable trials. An acceptable trial consisted of the participant contacting both force platforms without appearing to alter their stride. Walking velocity was monitored using two photo-cells placed 3 m apart on either side of the force platforms and attached to a timer. Prior to data collection at each walking velocity, participants completed practice walking trials as needed to contact the force platforms without targeting.

2.3. Data analysis

Minimum sample size was estimated using G*Power3 software [31] for an alpha level of 0.05 and a beta of 0.80. Sample size calculations were based on differences between healthy adults and those with knee osteoarthritis reported in the literature [9,15]. A minimum of 18 participants (6 per group) was indicated. Therefore, inclusion of 30 participants (10 per group) should be adequate to detect significant differences among conditions. Three-dimensional kinematic and kinetic data were processed using Visual 3D software (C-Motion Inc., Rockville, MD). Marker coordinate data were filtered using a 6 Hz low-pass recursive Butterworth filter. Force platform data were filtered using a 50 Hz low-pass recursive Butterworth filter. Heel contact and toe-off were identified by a threshold of 20 N of vertical ground reaction force. Customized laboratory software (Matlab, The Mathworks Inc., Natick, MA) extracted the dependent variables from the stance phase data for each trial for each participant's dominant leg. Weight acceptance was the first half of the stance phase. Knee flexion excursion was the difference between the peak knee flexion angle during weight acceptance and the knee flexion angle at footstrike. Peak knee flexion angle, peak external knee flexion moment, peak knee adduction angle, and peak external knee adduction moment were the maximum value of each during weight acceptance. Joint moments were normalized to participant's height and fat free body weight. Fat free body weight was calculated by subtracting the body fat weight, determined from bioelectrical impedance analysis, from the total body weight. This was used to account for individual differences in lean body mass and stature without masking any effects of additional fat mass on gait biomechanics. For all participants, the mean of five trials was calculated for each variable in each condition. The group mean value for each variable in each condition was then determined.

Descriptive statistics were calculated for each of the five dependent variables. Two-way mixed analysis of variance (group by velocity) was used to compare each dependent variable, with walking velocity as a repeated measure (SPSS Inc., Chicago, IL). When a significant omnibus *F*-ratio was observed ($p < 0.05$), post hoc pairwise comparisons were made to determine where the differences occurred.

Table 1
Average participant demographic characteristic for each group (mean ± standard deviation).

Group	Normal	Overweight	Obese
Age (years)	23.0 ± 4.1	22.6 ± 1.3	23.8 ± 5.6
Height (m)	1.74 ± 0.08	1.77 ± 0.09	1.72 ± 0.10
BMI (kg/m^2)*	22.4 ± 2.1	26.9 ± 1.3	34.4 ± 3.9
Body fat %*	17.1 ± 8.6	26.7 ± 7.8	33. 0 ± 10.5
Mass (kg)*	67.6 ± 10.0	84.7 ± 10.0	101.9 ± 13.6
Fat mass (kg)*	11.4 ± 5.6	22.4 ± 6.6	33.5 ± 11.2
Fat free weight (N)	551.7 ± 114.0	611.4 ± 111.9	670.7 ± 148.8

BMI: body mass index.
* Significant difference between groups ($p < 0.05$).

3. Results

Descriptive statistics for group demographics (Table 1) and functional test results (Table 2) supported our expectations of group characteristics. The groups were statistically similar in age, height, and lack of knee pain or symptoms according to the visual analog pain scale and the KOOS. As expected, the obese group had greater mass, greater body fat percentage, slower preferred