Gait & Posture 32 (2010) 263–268

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Sagittal and frontal plane joint mechanics throughout the stance phase of walking in adolescents who are obese

A.G. McMillan [a,*], A.M.E. Pulver [a], D.N. Collier [b], D.S.B. Williams [a]

[a] Department of Physical Therapy, 2410E Health Sciences Building, East Carolina University, Greenville, NC 27834, United States
[b] Department of Pediatrics, Brody School of Medicine at East Carolina University, Greenville, NC, United States

ARTICLE INFO

Article history:
Received 17 September 2009
Received in revised form 25 March 2010
Accepted 8 May 2010

Keywords:
Obesity
Adolescents
Walking
Biomechanics

ABSTRACT

The incidence of obesity has increased dramatically in children and adolescents, and with this comes health risks typically associated with adult obesity. Among those health consequences are musculoskeletal damage and pain. Previous studies have demonstrated inconsistent effects of increased body mass on movement patterns in adults and children who are obese. The purpose of this study was to investigate frontal and sagittal plane mechanics during walking in adolescents who were obese. Adolescents (12–17 years) who were obese were recruited from a weight management program, and healthy weight peers (matched for age, race and gender) were recruited from the community. Three-dimensional motion analysis of the lower extremities was performed during walking. Analysis of kinematic and kinetic data from 36 adolescents who were obese and healthy weight revealed significant differences in mechanics at all lower extremity joints in both sagittal and frontal planes. Subjects who were obese seemed to use movement strategies that minimized joint moments, especially at the hip and knee during walking. The lower extremity mechanics during walking in the subjects who were obese raise concerns about maintenance of structural integrity of the lower extremity joints over time, given the repeated high stresses across the joints even with walking. Neither the long term consequences of these atypical movement patterns, nor the ability to alter these patterns through therapeutic activities or weight loss has been investigated in adolescents who are obese.

1. Introduction

Childhood obesity, defined by the Centers for Disease Control and Prevention as having a body mass index (BMI) greater than the 95th percentile for age and gender, has become an epidemic, with 17.4% of all adolescents (12–19 years) in the United States classified as obese [1]. Chronic conditions such as cardiovascular disease and diabetes, commonly seen in adults who are obese, are now seen in adolescents who are obese [2,3]. Musculoskeletal conditions, including osteoarthritis, low back pain, and soft tissue injury, are often associated with obesity [4,5]. Increased body mass, with increased forces across weight-bearing joints, has been causally implicated in many of these musculoskeletal conditions [5].

Forces on joint surfaces are increased during any weight-bearing activity, including walking. Increased body mass may increase risk of damage and injury to joint surfaces and other musculoskeletal structures with repetitive loading during weight-bearing activities. Many have hypothesized that movement patterns are significantly different in individuals who are obese. While most studies report that children and adults who are obese walk slower, with a wider step width, shorter steps, and increased double support time/decreased single limb support time [6–9]. Nantel et al. [10] reported no difference in gait velocity, cadence, stride length or double limb support time in obese versus healthy weight (HW) children.

Reports of kinematic and kinetic characteristics of walking in individuals who are obese are inconsistent. Peak knee flexion angles during stance phase of walking have been reported as being lower in children and adults who are obese [11,12] while others reported no difference in these angles [8,9]. Peak plantarflexion angles have been reported as lower [9] and higher [10] in obese versus HW subjects. The lower plantarflexion angles were noted in subjects with significantly slower gait velocity [9]. No differences in sagittal plane hip and knee moments have been found between obese and HW subjects during walking [8,11,12]. Compared to HW adults, sagittal plane ankle moments of obese adults have been reported as lower [8] and higher [12] during walking. Nantel et al. [10] reported the only difference in lower extremity sagittal plane kinetics during walking was an earlier shift from hip extension moment to hip flexion moment in obese versus HW children.

Less data is available for frontal plane biomechanics during walking. Compared to HW individuals, peak hip frontal plane

* Corresponding author. Tel.: +1 252 744 6232; fax: +1 252 744 6240.
E-mail address: Grossmcmillana@ecu.edu (A.G. McMillan).

0966-6362/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.gaitpost.2010.05.008

angles during stance phase have been reported as significantly more abducted in adults who are obese [9], and as significantly more adducted in children who are obese [13]. The greater hip abduction angles were reported in subjects who walked significantly slower than their lean peers [9]. Greater knee valgus and rearfoot inversion during walking has been reported in children who are obese (compared to HW peers) [13], while studies have alternately reported higher knee adduction moments [13] and knee abduction moments [11] in obese versus HW children.

In summary, a variety of investigations of the effects of obesity on characteristics of walking have yielded inconsistent results. Studies to date have included adults and children (8–13 years old). Frontal and sagittal plane biomechanics in hip, knee and ankle at specific points during the stance phase of walking in adolescents who are obese have not been reported. The purpose of this study was to examine the sagittal and frontal plane lower extremity biomechanics during walking in adolescents who were obese versus HW peers.

2. Methods

2.1. Subjects

Both male and female adolescents who were obese and HW were recruited for this study. Inclusion criteria were: age (12–17 years), BMI (less than the 85th percentile for age and gender for HW group; and greater than 95th percentile for age and gender for obese group). Potential subjects were excluded if they had musculoskeletal, neuromuscular, and/or cardiopulmonary conditions other than obesity that would limit movement or compromise safety. Participants who were obese were recruited from a local healthy weight program. Healthy weight participants were recruited from the community and matched by age, gender, and race. Written informed consent by a parent/legal guardian and written assent by the adolescent were obtained for each participant prior to data collection. This study was approved by the University and Medical Center Institutional Review Board.

2.2. Equipment

Kinematic data were collected using eight Hawk infrared digital cameras (Motion Analysis Corp., Santa Rosa, CA) with a sample rate of 120 Hz. Force data were collected using two synchronized force plates (AMTI, Watertown, MA) with a sampling rate of 960 Hz. Retro-reflective spherical markers were attached directly to the skin on each subject's trunk and lower extremities at the sternum, T1, T10, L5/S1, iliac crests, acromion processes, greater trochanters, medial and lateral femoral condyles, medial and lateral malleoli, posterior and lateral heels, and 1st and 5th metatarsal heads. Rigid arrays of markers were also placed on thighs and lower legs. Anatomical/joint markers (those defining joint centers and segment coordinate axes) were left on only during static calibration trial; 22 tracking markers remained on the subject's calcaneus, shank, thigh, pelvis, and trunk during walking trials [13].

2.3. Experimental procedures

Participants were instructed to walk down a 15-foot walkway at a self-selected pace without looking down at the ground. In order to account for any differences in lower extremity mechanics that may exist due to differences in gait velocity, subjects were further matched on gait velocity. This resulted in 18 subjects in each group (Table 1). Each participant performed warm-up trials prior to data collection to establish a starting point so that each foot hit one of the force platforms during walking trials. Data collection continued until the subject completed at least 10 successful trials in which each foot contacted a force platform with no apparent change in gait pattern to purposefully hit the platforms.

2.4. Data analysis

Raw coordinate data were smoothed using a second order recursive Butterworth filter at 12 Hz for kinematics and 50 Hz for kinetics. EvaRT v5.0.4. Software (Motion Analysis Corp., Santa Rosa, CA) was used for data collection and initial processing of the raw data. Further processing was performed using Visual 3D software (C-Motion, Inc., Germantown, MD). Trials were normalized to the stance phase of gait (0% = initial contact, 100% = toe off). For subjects who were obese, hip joint centers were defined using a modified model to account for excessive subcutaneous tissue that would have significantly offset the location of the hip joint centers in these subjects. Specifically, the hip joint centers were calculated by first placing the anatomical markers on the skin over the greater trochanters. Anthropometric measures were then taken with calipers to approximate how much soft tissue was over the greater trochanters. This number was then used as an offset number and it was entered into the model file for Visual 3D. Virtual greater trochanter markers were then established and used to determine hip joint centers. Finally, hip joint centers were estimated by taking 25% of distance from each virtual greater trochanter marker. Moments were normalized to subject's mass and height. Sagittal and frontal plane angles and moments at specific events (initial contact, toe off), and peak angles and moments during early stance (1st 30%), midstance (40–60%), and late stance (last 30%) were selected for statistical analysis. Data were averaged across all trials for each subject, and group averages were calculated and used for statistical analyses. Student's t-tests were used to determine the differences between the obese and HW groups on the variables of interest. An α value of 0.05 was selected for statistical significance. Bonferroni corrections were performed due to multiple comparisons, resulting in corrected p value of 0.005 for kinematic data and 0.007 for kinetic data.

Table 2
Sagittal plane kinematic and kinetic variables, with mean (SD) and p values. HW: healthy weight.

	Obese	HW	p-Value
Sagittal plane kinematic variables (°)			
Ankle angle at initial contact	−0.87 (6.01)	0.76 (2.77)	0.15
Ankle peak angle during early stance	−7.77 (5.32)	−4.69 (2.21)	0.02
Ankle peak angle during late stance	7.19 (5.17)	7.18 (3.31)	0.50
Ankle angle at toe off	−9.99 (5.08)	−6.82 (4.09)	0.02
Knee angle at initial contact	−1.38 (7.35)	−7.10 (3.41)	0.003
Knee peak angle during early stance	−11.26 (7.03)	−16.09 (6.35)	0.02
Knee peak angle during midstance	−4.17 (7.93)	−7.22 (4.72)	0.09
Knee angle at toe off	−40.82 (7.90)	−37.28 (5.28)	0.06
Hip angle at initial contact	18.01 (10.50)	30.47 (9.62)	0.000
Hip peak angle during late stance	−12.45 (11.04)	−4.69 (9.90)	0.02
Hip angle at toe off	−7.76 (11.73)	1.00 (9.61)	0.01
Sagittal plane kinetic variables (Nm/kg m)			
Ankle peak moment during early stance	0.11 (0.05)	0.11 (0.04)	0.44
Ankle peak moment during late stance	−0.67 (0.13)	−0.88 (0.07)	0.000
Knee peak moment at initial contact	−0.19 (0.06)	−0.28 (0.11)	0.001
Knee peak moment during early stance	0.20 (0.14)	0.12 (0.14)	0.05
Knee peak moment during late stance	−0.10 (0.14)	−0.31 (0.11)	0.000
Hip peak moment at initial contact	−0.43 (0.12)	−0.72 (0.23)	0.000
Hip peak moment during late stance	0.37 (0.16)	0.24 (0.08)	0.002

3. Results

Sagittal plane. Subjects who were obese had a significantly lower plantarflexion moment during late stance compared to the HW group (Table 2 and Fig. 1D). The obese group had significantly less knee flexion at initial contact (Table 2 and Fig. 1B). In general

Table 1
Subjects characteristics.

	Female/Male	African-American/ Caucasian	Age (years)	Height (m)	Weight (kg)	Actual BMI	BMI % (for age/gender)	BMI z-score
Obese group (n = 18)	17/1	15/3	15.0 (1.5)	1.6 (0.1)	121.2 (30.8)	44.6 (10.2)	> 99	2.54 (0.34)
HW group (n = 18)	13/5	14/4	14.6 (1.8)	1.6 (0.1)	53.2 (7.0)	20.3 (2.0)	55.1 (22.8)	0.15 (0.65)
p-Value			0.23	0.10	0.000	0.000		0.000