Gait & Posture 61 (2018) 220–225

Contents lists available at ScienceDirect

Gait & Posture

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

Full length article

Biomechanical characteristics of lower limb gait waveforms: Associations with body fat in children

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ARTICLE INFO

Keywords:
Pediatric obesity
Principle component analysis
3D motion capture
Kinematics
Kinetics

ABSTRACT

Background: Childhood obesity is associated with musculoskeletal dysfunction and altered lower limb biomechanics during gait. Few previous studies have explored relationships between childhood obesity measured by body fat and lower limb joint waveform kinematics and kinetics.

Research question: What is the association between body fat and hip, knee and ankle joint angles and moments during gait and in 7 to 11 year-old boys?

Methods: Fifty-five boys participated in the study. Body fat was measured by air displacement plethysmography. Hip, knee and ankle 3D waveforms of joint angles and moments were recorded during gait. Principle component analysis was used to reduce the multidimensional nature of the waveform into components representing parts of the gait cycle. Multiple linear regression analysis determined the association between the components with body fat.

Results: Higher body fat predicted greater hip flexion, knee flexion and knee internal rotation during late stance and greater ankle external rotation in late swing/early stance. Greater hip flexion and adduction moments were found in early stance with higher body fat. In mid-stance, greater knee adduction moments were associated with high body fat. Finally, at the ankle, higher body fat was predictive of greater internal rotation moments.

Significance: The study presents novel information on relationships between body fat and kinematic and kinetic waveform analysis of paediatric gait. The findings suggest altered lower limb joint kinematics and kinetics with high body fat in young boys. The findings may help to inform research in to preventing musculoskeletal co-morbidities and promoting weight management.

1. Introduction

Childhood obesity is associated with a greater incidence of musculoskeletal pain and dysfunction. Studies have reported links between orthopaedic conditions (e.g. Slipped Capital Femoral Epiphysis), increased musculoskeletal pain, foot problems, lower limb joint osteoarthritis and aberrant lower limb biomechanics and obesity [1–3]. Excessive and misplaced forces across lower limb joints may predispose to joint dysfunction resulting in increased stress, joint pathology and pain [4,5]. Greater understanding of the biomechanical impact on childhood obesity is important to fully understand the impact of musculoskeletal structure and function, to inform rehabilitation strategies for obesity related joint and soft-tissue dysfunction, and prevent musculoskeletal co-morbidities.

The impact of childhood obesity on clinical gait characteristics has been documented; obese children are reported to walk slower, with a greater base of support and longer stance phase duration [6,7]. To date, five studies have described associations between childhood obesity and three-dimensional (3D) kinematic/kinetic changes in the lower limb [8–12] with conflicting findings. Both significantly greater [9] and lower [11] hip abduction moments have been reported when comparing obese/overweight (OW/OB) children with healthy-weight controls. McMillan et al. [10] reported less hip flexion at initial contact, whereas Cimolin et al. [12] reported greater hip flexion at the same gait event. Three studies have reported reduced knee flexion angle in OW/OB participants [8,11,12] yet all reported conflicting findings for

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https://doi.org/10.1016/j.gaitpost.2018.01.019
Received 25 July 2017; Received in revised form 18 January 2018; Accepted 21 January 2018

frontal plane knee moments; Gushue et al. [8] reported greater knee abduction moments, McMillan et al. [11] reported reduced knee abduction moment and Cimolin et al. [12] reported no significant difference. Three studies report reduced ankle plantarflexion moments in OW/OB children [8,10,11] and one study reported no significant differences [12].

Conflicting findings in previous studies may result from two methodological factors; (1) The definition of obesity used to define groups and, (2) the method of analysing gait data. Earlier studies have used BMI Z-Scores to define OW/OB groups which are based on arbitrary cut-offs (e.g > 99%, > 97%, > 95%) rather than fat measurements as a continuous variable. Furthermore, defining OW/OB by BMI Z-Scores has low sensitivity meaning some OW/OB children are grouped as healthy-weight whereas measures of body fat provide greater confidence in the degree of obesity in children [13]. Previous work by the authors has utilised waveform analysis to determine relationships between foot motion and body fat in the same cohort as that reported in the current article [14]. Analysis of complete waveforms does not rely on the selection of peak or event data to describe gait (commonly reported in previous studies), but instead enables examination over the entirety of the gait cycle.

Looking at the evidence to date, the overall impact of obesity on paediatric gait biomechanics is not understood. However, to the authors' knowledge, no study has used complete waveform analysis to provide a detailed lower limb kinematic and kinetic analysis in children. The aim of this study was to identify relationships between percentage body fat and lower limb gait waveforms in young boys.

2. Methods

2.1. Selection and description of participants

Fifty-five boys, aged 7 to 11 years, participated in the study (Table 1). Ethical approval was obtained (Ref No. ETH/13/11). Participants were recruited from a convenience sample of local schools and clubs. Parental consent and child assent was obtained prior to testing. Participants were excluded from participating if any medical conditions affecting neuromuscular and orthopaedic integrity or any complications contributing to altered foot posture and/or gait disturbance were identified from a health screening questionnaire.

2.2. Instrumentation and procedures

2.2.1. Measures of anthropometrics and body fat

Body fat was measured by air displacement plethysmography using a Bodpod (Life Measurement, Inc, Concord, CA, USA). Procedures for this study have been described in our previous study [14]. Estimates of body volume were derived from pressure measures within the Bodpod chamber and converted to body fat percentage (relative to body mass) using age- and gender-specific equations. Weight was measured to the nearest 0.1 kg using Bodpod scales and height measured to the nearest 0.5 cm using a portable Leicester stadiometer (Seca Vogel, Hamburg, Germany). Body Mass Index (BMI) score was calculated as height/weight^2 and reported as an age and sex specific z-score (UK90 data set) [15].

Table 1
Mean, SD and range of age, anthropometric and spatiotemporal characteristics of sample population (n = 55).

	Mean	SD	Range
Age (years)	9.55	1.18	7–11
Height (m)	1.40	0.08	1.19–1.59
Weight (kg)	37.69	10.67	22.32–68.67
BMI (kg/m^2)	18.41	4.00	12.34–29.62
BMI Z-score	0.55	1.58	−2.87–3.54
BMI Centile (%)	59.99	36.08	0.21–99.98
Body fat mass (%)	23.78	9.33	9.46–42.06
Walking velocity (m s^{-1})	1.33	0.19	0.95–1.81
Cadence (steps/min)	131.69	15.66	105.77–171.52
Stance Phase duration (%)	57.29	2.32	52.60–65.16
Total single support duration (%)	49.86	1.85	41.59–56.70
Step Width (mm)	81.59	28.18	29.47–156.38
Step length (m)	0.60	0.06	0.41–0.79

2.2.2. Measures of spatiotemporal and 3D biomechanics of the lower limb during gait

An eight-camera Vicon Nexus motion capture system (Vicon Motion Systems Ltd, Oxford, UK) was used to track and record the motion of skin mounted reflective markers at 200 Hz during barefoot walking. All participants walked at self-selected speed.

Fifteen 12 mm retro-reflective markers were attached (by one operator, RM) to the right and left legs of each participant in line with the Plug-in Gait protocol. An 'instrumented pointer device' was used to create virtual markers representing the ASIS landmarks to reduce skin-mounted displacement by adipose tissue [16]. The location of the ASIS virtual markers were tracked using skin-mounted markers attached to each iliac crest. Seven segments were reconstructed from marker trajectories from which joint relative angular motion and moments were calculated (Visual 3D, C-Motion Inc., MD, USA). Two floor mounted force plates (Bertec, Model MIE Ltd, Leeds, UK) recorded ground reaction forces during gait trials at 1000 Hz. Joint moments were filtered using a low-pass Butterworth filter with a cut-off frequency of 10 Hz. The gait cycle was defined from initial contact (determined as an increase in vertical force above 20 N) through foot-off and the subsequent initial contact of the same foot. Sagittal, frontal and transverse angular motion and moments were described for the hip, knee and ankle joints. 3D angles and moments from each participant were extracted as 51 data points normalised over the entire gait cycle for angular data, and over the stance phase for moment data. Joint moments are presented as external joint moments. For each participant mean and standard deviations were calculated from six successful gait cycles across the 51 data points forming the waveforms.

2.3. Statistical analysis

2.3.1. Principal component analysis

Principal component analysis (PCA) was employed to reduce the major modes of variation in the data to fully explore angular motion and moments over the entire gait cycle. Previous research on paediatric gait has employed PCA to analyse multiple waveforms utilising separate matrices and further information on its application to the gait data is presented [14]. A brief overview of PCA is included in this paper and readers are referred to recent work [17,18] for a detailed overview. The four PCA steps were applied as follows: (1) generation of a co-variation matrix containing 55 participants and 51 data points, (2) retention of components that cumulatively explained 90% of the variation in the waveform, (3) application of a Varimax orthogonal rotation to maximally explain variability in the original waveforms, (4) identification of the part of the gait cycle represented by the component [18]. The output of PCA is a regression score (estimated coefficient representing a participant's score on a component) which was calculated for each participant based on their 3D angular motion or moments within each principal component. Positive regression scores indicated dorsiflexion, eversion and abduction and negative regression scores indicated plantarflexion, inversion and adduction. This regression score was used for subsequent analysis by multiple linear regression.

2.3.2. Multiple linear regression

To determine the association between body fat (predictor variable) and 3D angular motion and moments (predicted variables), multiple linear regression was undertaken. Based on potential confounding