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The effects of pediatric obesity on dynamic joint malalignment during gait

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ABSTRACT

Background: There is a greater prevalence of lower extremity malalignment in obese children during static posture; however, there has been less examination of dynamic joint function in this cohort. Therefore, the purpose of this study was to determine kinematic differences that exist between obese and non-obese children that would support previously reported static joint malalignment.

Methods: Forty children were classified as obese ($n = 20$) or non-obese ($n = 20$). Lower extremity joint kinematics were collected during five walking trials at a self-selected pace. Peak joint displacement and amount of joint motion throughout the gait cycle (calculated as the integrated displacement curve) were analyzed for group differences.

Findings: Non-obese children had greater peak knee and hip extension during gait; however, there were no group differences in the integrated sagittal displacement curve. Obese children had greater peak angular displacement and integrals of angular displacement for peak hip adduction, hip internal rotation, and foot abduction (toe-out) than non-obese children. Obese children also had greater peak knee external rotation than non-obese children.

Interpretation: Non-obese children showed greater range of motion in the sagittal plane, particularly at the hip and knee. Frontal and transverse plane differences suggest that obese children function in a more genu valgum position than non-obese children. Static measures of genu valgum have been previously associated with pediatric obesity; the findings indicate that there are also dynamic implications of said malalignment in obese children. Genu valgum presents increased risk of osteoarthritis for obese children and should be considered when prescribing weight bearing exercise to this cohort.

1. Introduction

Among other serious comorbidities, pediatric obesity has been associated with orthopedic complications (Chan and Chen, 2009; Gettys et al., 2011; Shultz et al., 2009a). Severe orthopedic conditions, such as adolescent tibia vara and slipped capital femoral epiphysis, are almost exclusively found in obese children and adolescents (Gettys et al., 2011; Shultz et al., 2009a). However, there has also been a greater prevalence in other impairments of musculoskeletal health across a significant percentage of obese youth. Postural deformities, such as lumbar hyperlordosis and genu recurvatum, occur at higher rates in obese children, compared to non-obese children (de Sa Pinto et al., 2006). Within the frontal plane, genu valgum deformities have been positively associated with body mass index (BMI) (O'Malley et al., 2012), with several research groups finding prevalence rates between 55 and 87% in obese youth (de Sa Pinto et al., 2006; Jannini et al., 2011). Muscular function has also been affected, as obese children have higher prevalence of tight lower extremity muscles, specifically the quadriceps (de Sa Pinto et al., 2006; Jannini et al., 2011; O'Malley et al., 2012). Obesity has also influenced joint stiffness, with negative associations existing between BMI and the ranges of motion for hip flexion, hip abduction, and knee flexion (O'Malley et al., 2012). The increased prevalence of orthopedic impairment supports the findings of more frequent musculoskeletal complaints in obese children, specifically at the knee, foot, and lower back (Stovitz et al., 2008). However, the measurements used to assess orthopedic complication and muscular dysfunction have been largely clinical and based on static postures. More dynamic measures of musculoskeletal impairment are necessary in order to understand the impact of associated orthopedic complications on the functional movement of obese children.

Previous studies have investigated kinematics during gait, with conflicting results. Obese children walk with a greater step width and

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increased base of support; this finding is consistent across all literature and suggests a strategy for increasing dynamic stability (Deforche et al., 2009; D'Hondt et al., 2011; Hills and Parker, 1991, 1992; Shultz et al., 2011). However, the increased step width could also be associated with structural constraints, including increased thigh girth and genu valgum. The majority of gait research has focused on sagittal plane motion, and early work in the area indicated that obese children utilize less hip and knee flexion when walking at a self-selected speed (Hills and Parker, 1991, 1992). This more rigid and upright posture could result in the aforementioned clinical findings of tight quadriceps and reduced range of motion at the hip and knee. Some subsequent research has supported these initial findings (Gushue et al., 2005) while other work has not found differences in joint kinematics of obese children (Shultz et al., 2009b). Very little research has investigated the gait of obese children in the frontal and transverse planes (McMillan et al., 2010; Shultz et al., 2009b), and those findings have primarily focused on increased joint loading than observed differences in kinematics (Shultz et al., 2009b, 2010). However, the clinical prevalence of genu valgum in obese children warrants a more robust investigation into the joint kinematics of this cohort, with specific interest in changes that occur to the frontal and transverse plane. Therefore, the purpose of this study was to determine if kinematic changes exist in the gait of obese children, which would be consistent with the clinical findings of joint malalignment.

2. Methods

2.1. Participants

Forty children, aged 8 to 12 years old, were recruited from the Brisbane Metropolitan area through press releases on local radio and in newspapers, by physician referral, and via publicly posted advertisements. Twenty children were classified as obese, (Cole et al., 2000) and were matched to non-obese children of similar age and gender. Prior to participation, participants and their parent/guardian completed a health history questionnaire. Participants were excluded if they had a neuromusculoskeletal disease, or a lower extremity condition (injury or surgery) in the previous 6 months. Participants and their parents/guardians gave written informed assent and consent, respectively, prior to beginning the study. All protocols were approved by the University Human Research Ethics Committee.

2.2. Materials and procedure

As part of a larger study to investigate the effects of acute loads on gait kinetics, children were asked to take part in two testing sessions, which were scheduled one week apart. The reported findings of this study will be limited to the initial testing session, which included measurements of anthropometry and three-dimensional motion analysis of gait. During all testing sessions, the children were barefoot and wore a tight-fitting one-piece suit. All children had been fasted for at least 4 h prior to participation.

2.2.1. Anthropometric measurements

Height was measured to the nearest 0.1 cm with a Harpenden stadiometer (Holtain Ltd, Wales). Body mass was measured to the nearest 0.1 kg using an electronic scale. These measurements were then used to calculate BMI (kg/m^2).

2.2.2. Kinematic analysis

Hip, knee, and ankle joint kinematics were assessed in the sagittal, frontal, and transverse planes. Three-dimensional motion capture was completed using an eleven camera motion analysis system (Vicon Nexus 1.8.2, Vicon Motion Systems, Ltd., Oxford, UK) at a sampling rate of 200 Hz. Marker placement and calibration were conducted according to the protocol by Shultz et al. (Shultz et al., 2009b). Calibration included a static posture trial, as well as trials to obtain functional joint centers at the hip and knee; these trials were used to identify segments of the lower extremity. Participants were asked to walk across a 6-m gait track at their normal walking speed, with emphasis placed on looking straight ahead. Three to five trials were accepted for analysis when marker dropout was less than 20 consecutive frames. Walking speed was calculated as the linear velocity of the right anterior pelvic marker. Kinematic data were filtered using a bi-directional low-pass Butterworth filter with a cut-off frequency of 6 Hz; joint angular displacement was analyzed using Visual 3D 4.96.11 (C-Motion, Inc., Germantown, MD, USA). Joint angular displacement was calculated as the relative orientation of the distal segment to the proximal segment. Data were normalized to a gait cycle, then exported and organized in Microsoft Excel; participant data was averaged across trials prior to further analysis. Matlab 7.11 (Mathworks, Natick, MA) assessed the maximum angular displacement, as well as the area under the curve (integral), for each direction of motion. Integrals were calculated using Simpson's rule. Maximal angular excursion has been assessed in previous research; the integral will evaluate the extent of joint displacement and the time spent with the joint displaced in a specific direction.

2.3. Statistical analysis

Independent t-tests were used to determine differences in descriptive characteristics between groups. Walking speed can affect joint kinematics (Schwartz et al., 2008); therefore, an independent *t*-test was used to determine group differences in walking speed. As walking speed was found to be significantly greater in non-obese children, walking speed was considered a covariate in further statistical analysis. To determine the appropriate statistical analyses, a Shapiro–Wilk test was used to determine that assumptions of normality were met. A correlation analysis was also conducted on the angular joint displacements, to determine existing relationships between dependent variables. The analysis indicated that the transverse plane motions for the hip, knee, and ankle were strongly correlated. Thus, a multiple analysis of covariance (MANCOVA) was used to determine group differences in maximal joint displacement in the transverse plane. Analyses of covariance (ANCOVA) were used to determine group differences in maximal joint displacement of the sagittal and frontal planes, as well as the area under the curve. Data were analyzed using SAS 9.3 (SAS Institute Inc., Cary, NC, USA), with a significance level set at $P < 0.05$.

3. Results

Descriptive statistics for each group can be found in Table 1.

There was little group difference in the maximal angular displacements within the sagittal plane. Non-obese children reached greater maximal hip and knee extension compared to obese children (Table 2). However, the increased maximal angular displacement was not supported by a significantly greater integral of displacement (Table 3).

Within the frontal plane, obese children have significantly greater maximal hip adduction, while non-obese children show a trend towards greater maximal hip abduction ($P = 0.06$). These findings are corroborated by the integral data, which showed that obese children

Table 1
Descriptive statistics (mean ± SD) of obese and non-obese participants.

	Obese (n = 20)	Non-obese (n = 20)	*P*-value
Age (years)	10.8 ± 1.4	10.4 ± 1.6	0.400
Weight (kg)	56.97 ± 12.85	34.46 ± 6.52	<0.001
Height (m)	1.52 ± 0.11	1.41 ± .09	0.001
Body mass index (BMI; kg/m^2)	24.31 ± 2.73	17.15 ± 1.40	<0.001
Walking speed (km/h)	3.61 ± 0.43	4.01 ± 0.46	0.006