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The effects of pediatric obesity on dynamic joint malalignment during gait

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RUNNING TITLE: Functional malalignment in obese children

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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 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 analysed 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.

**KEYWORDS:** locomotion; orthopaedic; child; body weight

## 1. Introduction

Among other serious comorbidities, paediatric obesity has been associated with orthopaedic complications (Chan and Chen, 2009, Gettys et al., 2011, Shultz et al., 2009a). Severe orthopaedic 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 55-87% 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 orthopaedic 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 orthopaedic 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 orthopaedic 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 increased base of support; this finding is consistent across all literature and suggests a strategy for increasing dynamic stability (D'Hondt et al., 2011, Deforche et al., 2009, Hills and Parker, 1991, Hills and Parker, 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, Hills and Parker, 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., 2010, Shultz et al., 2009b). 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. Material and 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 hours 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 ( $\text{kg}/\text{m}^2$ ).

### 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 200Hz. 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 6Hz; joint angular displacement was analysed 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 organised 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 analysed 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 spent more time in an adducted hip position, while non-obese children maintain a more abducted position throughout gait.

The transverse plane resulted in the greatest number of group differences. Obese children had greater maximal hip internal rotation than non-obese children. The lack of hip external rotation in obese children led to a significant group difference in both directions of hip rotation. Subsequently, significant group differences occurred for the integral values of both hip internal and external rotation. Obese children displayed significantly less maximal tibial internal rotation and more maximal tibial external rotation than non-obese children. However, the integral values for tibial rotation were not significantly different between groups. Obese children also displayed prominent foot abduction, creating a toe out progression throughout gait. The non-obese group had greater variation in foot progression, but the lack of foot adduction within the obese group resulted in significant group differences for both directions. Similarly, obese children spent significantly more time in a toe out progression, and significantly less time in a toe in progress, compared to non-obese children.

#### 4. Discussion

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. Although previous



research has indicated changes to gait kinematics, this study highlights characteristics of joint displacement that relate dynamic joint dysfunction to previously reported static findings in obese children.

Non-obese children demonstrated a greater maximal angular displacement within sagittal plane motion, specifically at the knee and hip; however, there was no significant change to the integral of displacement. The findings indicate that non-obese children are capable of a greater range of motion without detriment to the overall kinematic curve. Previous research has suggested that obese children choose a gait strategy more strongly associated with energy recovery (Blakemore et al., 2013). Within this study, obese children employed a smaller range of motion, but maintained otherwise similar sagittal plane joint kinematics to the non-obese children. The more rigid movements would provide increased dynamic stability (Shultz et al., 2011), but generate less energy during gait.

Dynamic joint dysfunction was primarily identified in the frontal and transverse planes, **which is in conflict to previous research by the author (Shultz et al., 2009b). However, the current study used a larger sample size and more elaborate laboratory set-up (i.e. increased number of cameras, larger capture volume), which could better identify existing group differences, particularly in these planes of motion.** Obese children were found to have a more adducted and internally rotated hip, combined with an externally rotated knee and abducted foot. The joint alignments were maintained throughout gait for the hip and foot, with obese children having larger integral values for hip adduction, internal rotation, and ankle external rotation. Hip and ankle rotation was so dominant that obese children did not display hip external rotation or foot adduction throughout the entire gait cycle. Subsequently, non-obese children were found to have significantly greater amounts of hip abduction and external rotation, and foot adduction; however, their values were within expected ranges of motion for normal pediatric gait (Bovi et al., 2011). The combination of frontal and transverse plane malalignments indicate that obese children move with their knees spaced closer

together and their feet spaced farther apart, thus maintaining a genu valgum position throughout functional movement (Espandar et al., 2010). The wider stance associated with genu valgum malalignment has also been noted in obesity research and is considered a strategy for increasing dynamic stability in obese children (Deforche et al., 2009, Shultz et al., 2011). However, the presence of a dynamic genu valgum could indicate the increased step width is a consequence of the posture. Inversely, it could also be noted that the dynamic genu valgum could be the result of consistently positioning the feet to encourage dynamic stability. Unfortunately, this theory is beyond the scope of this study; future longitudinal research is needed to determine causality. **Similarly, this study is unable to determine if the altered gait strategy is influenced by mechanical constraints, as range of motion was not investigated. Future cross-sectional research would be needed to elucidate if changes occur as part of active motor control, or are a consequence of restricted movement.**

With normal knee alignment, load is disproportionately applied to the medial aspect of the knee. It is believed that while genu varum would dramatically increase medial loading during gait (and thus, increase risk of osteoarthritis), genu valgum would need to be severe in order to offset the medial loading (Johnson et al., 1980). Thus, the dynamic genu valgum presented in this study could be a strategy to minimize already substantial loading to the medial compartment of the knee. However, more recent research has found that genu varus and valgum have similar effects on medial and lateral osteoarthritis progression, respectively (Sharma et al., 2001). More concerning is the five-fold increase in osteoarthritis progression in adult patients who recalled having bow-legs (genu varum) or knock-knees (genu valgum) during childhood (Schouten et al., 1992). Obesity has been strongly correlated to early progression of osteoarthritis (Felson et al., 1988); the additional loading associated with a genu valgum posture would further increase the risk of knee osteoarthritis, specifically to the lateral compartment.

## 5. Conclusions

This is the first study to identify dynamic genu valgum in the gait of obese children. Increased prevalence of genu valgum has been clinically diagnosed in obese children (de Sa Pinto et al., 2006, Jannini et al., 2011); the findings of this study indicate that the static posture can influence functional movement. Gait strategies that have previously been suggested as a result of increasing dynamic stability are also related to the maintenance of a genu valgum posture throughout gait. While genu valgum may be a strategy to minimize substantial loading to the medial compartment of the knee, the musculoskeletal malalignment and excess mass place obese children at greater risk of early osteoarthritis progression.

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**Table 1 Descriptive statistics (Mean  $\pm$  SD) of obese and non-obese participants**

	<b>OBESE (N=20)</b>	<b>NON-OBESE (N = 20)</b>	<b><i>p-value</i></b>
Age (years)	10.8 $\pm$ 1.4	10.4 $\pm$ 1.6	0.400
Weight (kg)	56.97 $\pm$ 12.85	34.46 $\pm$ 6.52	<0.001
Height (m)	1.52 $\pm$ 0.11	1.41 $\pm$ .09	0.001
Body Mass Index (BMI; kg/m <sup>2</sup> )	24.31 $\pm$ 2.73	17.15 $\pm$ 1.40	<0.001
Walking speed (km/h)	3.61 $\pm$ 0.43	4.01 $\pm$ 0.46	0.006

Table 2. Group Differences for Maximal Angular Displacement: Mean (SD)

Joint	Angular Displacement (deg)	OBESE (N = 20)	NON-OBESE (N=20)	p-value
Hip	Flexion <sup>#</sup>	35.94 (6.87)	36.92 (5.50)	0.723
	Extension	4.80 (7.00)	7.60 (5.72)	0.033
	Abduction	4.20 (2.67)	6.66 (3.92)	0.060
	Adduction	10.80 (3.73)	5.81 (3.49)	0.001
	Internal Rotation	13.84 (8.97)	5.06 (8.15)	<b><u>0.047</u></b>
	External Rotation	-2.23 (8.27)	5.22 (8.54)	<b><u>0.016</u></b>
Knee	Flexion <sup>#</sup>	62.08 (3.94)	64.06 (3.79)	0.174
	Extension	2.91 (3.80)	6.24 (4.00)	0.010
	Internal Rotation	9.06 (5.70)	13.70 (6.36)	<b><u>0.018</u></b>
	External Rotation	10.67 (6.14)	6.71 (4.78)	<b><u>0.018</u></b>
Ankle	Plantarflexion	13.68 (5.91)	14.79 (15.57)	0.391
	Dorsiflexion	7.30 (5.37)	10.72 (17.91)	0.512
	Inversion	11.24 (6.36)	8.76 (8.07)	0.553
	Eversion	4.19 (7.31)	7.23 (7.81)	0.707
Foot	Adduction (Toe-In)	-12.63 (10.36)	4.68 (18.54)	<b><u>0.009</u></b>
	Abduction (Toe-Out)	27.74 (8.58)	12.41 (18.24)	<b><u>0.022</u></b>

<sup>#</sup> **Walking is considered a significant covariate (p<0.05)**



Table 3. Group Differences for the Area Under the Curve: Mean (SD)

Joint	Area Under the Curve (deg*s)	OBESE (N = 20)	NON-OBESE (N=20)	p-value
Hip	Flexion	18.24 (5.56)	18.08 (4.06)	0.800
	Extension	0.98 (1.32)	1.27 (1.26)	0.196
	Abduction <sup>#</sup>	0.79 ( 0.72)	2.46 (1.99)	0.006
	Adduction	4.89 (2.11)	2.01 (2.08)	<0.001
	Internal Rotation	9.04 (7.47)	3.70 (4.76)	0.005
	External Rotation	0.77 (1.63)	3.62 (4.46)	0.010
	Knee	Flexion <sup>#</sup>	21.50 (2.42)	20.66 (2.64)
Extension		0.27 (0.59)	0.73 (1.09)	0.070
Internal Rotation		3.23 (3.59)	4.72 (3.23)	0.122
External Rotation		2.58 (2.35)	1.76 (2.09)	0.284
Ankle	Plantarflexion	3.14 (1.75)	3.70 (2.58)	0.115
	Dorsiflexion	2.72 (3.75)	4.93 (15.23)	0.486
	Inversion	6.15 (4.72)	4.28 (5.06)	0.807
	Eversion	1.11 (2.61)	3.21 (5.35)	0.289
Foot	Adduction (Toe-In)	0.09 (0.41)	6.70 (8.86)	0.001
	Abduction (Toe-Out)	20.55 (8.67)	10.45 (10.85)	0.013

<sup>#</sup> Walking is considered a significant covariate (p<0.05)

## Highlights:

1. Obese children seem to function in a more genu valgum position than non-obese.
2. Genu valgum may be a strategy to minimize medial loading at the knee.
3. Genu valgum could increase the risk of osteoarthritis in obese children.

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