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Effects of obesity on the biomechanics of stair-walking in children

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ABSTRACT

Anthropometric characteristics, particularly body mass, are important factors in the development and progression of varus/valgus angular deformities of the knee and have long-term implications including increased risk of osteoarthritis. However, information on how excessive body weight affects the biomechanics of dynamic activities in children is limited. The purpose of this study was to test the hypothesis that during stair-walking lower extremity joint moments normalized to body mass in obese children are greater than those in normal-weight children. Eighteen obese children (10.5 ± 1.5 years, 148 ± 10 cm, 56.6 ± 8.4 kg) and 17 normal-weight children (10.4 ± 1.3 years, 143 ± 9 cm, 36.7 ± 7.5 kg) were recruited. A Vicon system and two AMTI force plates were used to record and analyze the kinematics and kinetics of ascending and descending stairs. Significant differences in spatio-temporal, kinematic and kinetic parameters during ascending and descending stairs between obese and normal-weight children were detected. For stair ascent, greater hip abduction moments (+23%; $p = 0.001$) and greater knee extension moments (+20%; $p = 0.008$) were observed. For stair descent, smaller hip extension moment (−52%; $p = 0.031$), and greater hip flexion moments (+25%; $p = 0.016$) and knee extension moments (+15%, $p = 0.008$) were observed for obese subjects. To date, it is unclear if and how the body may adapt to greater joint moments in obese children. Nevertheless, these differences in joint moments may contribute to a cumulative overloading of the joint through adolescence into adulthood, and potentially result in a greater risk of developing knee and hip osteoarthritis.

1. Introduction

The prevalence of adult and childhood obesity continues to increase in most countries of the world [1]. In Germany, the prevalence of pediatric obesity increased by 50% in the last decade. One in six children is affected by overweight or obesity [2], and four out of five obese teenagers remain obese in adulthood [1]. Obesity may cause orthopedic problems not only during childhood but may also have long-term implications for musculoskeletal health during adolescence and into adulthood.

Anthropometric characteristics, particularly body mass, have been identified as important factors for the development and progression of foot deformities [3,4], varus/valgus angular deformities of the knee [3,5,6], slipped capital femoral epiphysis [3] and have long term implications for developing osteoarthritis (e.g. [7–10]). However, only few studies investigated the interrelation of these factors during dynamic activities in obese persons and particularly in obese children. The few studies on kinematic and kinetic indices of obese subjects' movement reported differences in movement strategy between normal and obese subjects for rising from a chair [11,12] and for level-gait [13–21]. Additional trunk movement in the preparation phase of rising from a seated position indicated that obese children experience a greater difficulty in performing this movement [11]. To accomplish the sit-to-stand task, obese adults moved with a reduced trunk flexion and repositioned their feet backwards from the initial position resulting in smaller hip moments and greater knee joint moments [12].

Compensatory movement changes during gait in obese persons include slower walking velocities, longer double support phases, wider stance widths [14 (adults)], greater degree of asymmetry [19 (children)] and all in all a more "tentative ambulation" [18, 19 (children)]. In addition, obese adults have shorter step lengths, smaller knee range of motion and a more erect walking pattern [13, 14 (adults), 18 (children)]. However, only few studies investigated the influence of obesity on ambulatory kinetics [13, 15 (adults), 16, 20, 21 (children)]. While greater absolute joint moments for obese subjects were identified at the hip, knee and ankle in the sagittal

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[13, 15 (adults) 20, 21 (children)], frontal [20,21] and transverse [21] planes, there are inconsistent findings when the moments are scaled to bodyweight. Modification patterns for obese subjects have been reported for the hip to reduce work done by the hip flexors [16 (children)], the knee [13 (adults)] with smaller knee extensor moments, and the ankle with either greater peak dorsiflexor moments [21 (children)], greater plantarflexor moments [13 (adults)] or smaller plantarflexor moments [15 (adults), 20 (children)]. Although these results indicate that obese persons reorganize their walking pattern, the current literature does not support clear conclusions regarding systematic effects of obesity on gait pattern and joint moments. Because adaptations detected in obese adults may not necessarily reflect adaptations in obese children, further research about biomechanical adaptations of obese children's movement should be established.

Similarly, while some information is available on functional joint loading during level walking and rising from a chair in obese persons, to date no information is available on joint moments during other daily activities such as, for instance, stair-walking. Stair-walking is particularly important because greater ground reaction forces and knee moments are required for stair-walking tasks compared to those required for level walking [22,23]. In addition, body mass index has been associated with greater difficulty of descending and ascending stairs [24]. Therefore, the purpose of this study was to test the hypothesis that during stair-walking lower extremity joint moments normalized to body weight in obese children are different from those in normal-weight children.

2. Methods

2.1. Subjects

Eighteen obese children (10.5 ± 1.5 years; 148 ± 10 cm; 56.6 ± 8.39 kg) and 17 normal-weight children (mean ± standard deviation; age: 10.4 ± 1.3 years; height: 143 ± 9 cm; mass: 36.7 ± 7.5 kg) were recruited for this study. Obesity was defined as having a body mass index (BMI) at or above the 95th percentile of BMI for age, and normal-weight was defined as having a BMI between the 15th percentile and the 85th percentile of BMI for age [25]. Subjects were excluded if they had experienced any lower extremity injury during the past six months. The study was approved by the institutional review board. One parent of each subject signed an informed consent form prior to participation.

2.2. Equipment (staircase set-up, systems)

The experimental staircase consisted of six steps (Fig. 1). The step dimensions were 17 cm (riser) and 28 cm (tread) with a stair slope of 31°. No handrail was used. Kinematic and kinetic recordings were collected simultaneously by a ten camera, three-dimensional motion analysis system (VICON, MX Camera System, Oxford Metrics Ltd., UK) and two force platforms (AMTI, Model BP600900, Advanced Mechanical Technology, Watertown, MA) positioned as the 3rd and 4th stair step. Kinematic data were sampled at 200 Hz, and ground reaction forces were collected at a rate of 1000 Hz.

2.3. Subject preparation and procedure

All subjects walked barefoot and wore swimsuits to allow an unobstructed attachment of reflective markers to the skin. Reflective markers were placed according to the Vicon Plug In Gait (PIG) full-body marker set[a], and anthropometric measurements were taken. For the PIG model the hip joint is calculated by the method described by Davis et al. [26] using pelvis size and leg length as scaling factors. One factor determining pelvis size is the inter-ASIS (anterior superior iliac spine) distance, which is difficult to assess via markers in obese subjects. Therefore inter-ASIS distance was measured manually and input into the model. All subjects were asked to ascend and descend the stairs, placing only one foot on each step with a cadence of 110 steps per minute. This cadence was identified as comfortable stair-walking speed in pretests and was given by a metronome. No instructions for arm position were given. For each subject, testing consisted of one static standing trial and as many ascending and descending trials as needed until three valid trials for each condition could be recorded. A trial was considered valid when the given cadence was achieved and no visible alterations in the stride characteristics were detected. Sufficiently long rest periods were given between trials to avoid fatigue.

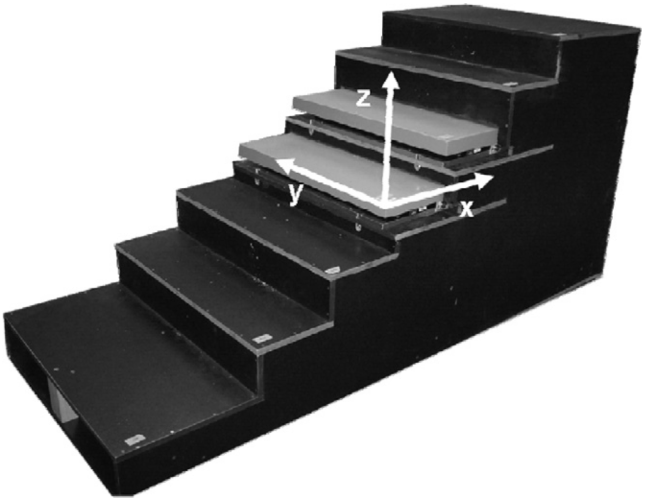

Fig. 1. Staircase set up. Independent force plates were imbedded in steps 3 and 4 of the six-step staircase.

2.4. Data analysis

Three-dimensional coordinates of the reflective markers were collected during the locomotion task. All trajectories were filtered using a generalized cross-validated spline technique as reported by Woltring [27]. Relative angles were calculated using the Vicon Nexus[a] PIG analysis package. According to the Vicon PIG[a] definitions, the local *x*-, *y*- and *z*-axes corresponded to flexion–extension, abduction–adduction and rotation at the hip and knee, respectively, and dorsiflexion–plantarflexion, eversion–inversion and internal–external rotation at the ankle, respectively.

Prior to parameter calculation, ground reaction forces were filtered with a 4th-order 7 Hz Butterworth filter to eliminate the slight oscillation of the staircase. The relatively low cut-off frequency also eliminated impact forces, and hence only active forces were analyzed. An inverse dynamics approach of the PIG model[a] was used to calculate net moments at the ankle, knee and hip joints, respectively. Because no anthropometric data set for obese children is available, the standard values for adults [28] implemented in the Vicon PIG model[a] were used. Even though these values might differ from those of children, it has been shown that during stance phase the effects of these differences are negligible [29]. Ground reaction forces and net joint moments were normalized by body mass and were expressed as internal moments.

The gait cycle was defined as initial foot contact on the step with the embedded platform (3rd or 4th step). The gait cycle ended with the subsequent foot contact of the same foot. All gait events were expressed as a percentage of the gait cycle (100%). Ensemble averages of the three trials were calculated for angular displacements and moments at each percent of the gait cycle. Key variables included in the statistical analyses were: time of double and single support; percentage of foot-off during gait cycle; step width; maximum and minimum value for thorax, pelvis, hip, knee and ankle angles in the sagittal and frontal planes, respectively; maximum ground reaction forces in the anterior–posterior, medio-lateral and vertical directions, respectively; and maximum hip, knee and ankle moments in the sagittal and frontal planes, respectively.

2.5. Statistical analysis

Gait symmetry was tested using *t*-tests for paired samples. Variables showing no significant differences were averaged across the sides. Variables showing significant differences between right and left leg are presented in Table 1. For these variables, further analysis consisted only of the right side, because the right foot was always placed on the 3rd step and therefore was always the 3rd consecutive foot-plant for both stair ascending and descending. Significant differences between obese and normal-weight subjects were detected using a MANOVA with parameters grouped for spatiotemporal parameters and for each joint for kinematic and kinetic parameters. The mean deviation in inter-marker distance was calculated and compared between the two groups using independent *t*-tests. The significance level was set a priori to 5%.

3. Results

3.1. Inter-marker distance

While greater skin movement at the hip was observed for the obese group (distance left ASIS to PSIS (posterior superior iliac