Effects of Adiposity on Walking Muscle Function in Children: Implications for Bio-Feedback and Assistive Devices

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Introduction

Obesity is a global public health issue, and obese children are advised to engage in daily physical activity. Obesity affects the mechanics of walking [1], the most common and arguably essential form of physical activity. In children, altered gait kinematics and kinetics may increase the risk of musculoskeletal injury/pathology of the hip and knee joints during physical activity and diminish a child's ability to engage in sufficient physical activity [2]. The musculoskeletal mechanisms responsible for the altered gait in obese children are not well understood, and since all prior pediatric obesity gait studies have compared between groups of obese & non-obese children, it is unknown how the amount of adiposity affects gait. Quantifying the muscle force requirements of walking across a range of adiposity in children can provide insight into the role that an imbalance between muscle and fat mass may play in the exhibited altered gait kinematics. This information can be utilized to guide the design of interventions/tools (e.g. bio-feedback, assistive exoskeletons) aimed at normalizing gait mechanics in overweight/obese children. The purpose of this study was to investigate the relationship between adiposity and lower extremity kinematics, muscle force requirements, and individual muscle contributions to the acceleration of the center of mass (COM) during walking in children.

Methods

We collected kinematic and kinetic data using a motion capture system (Vicon), an obesity-specific marker set [3], and a force-measuring treadmill (Bertec) as children walked at self-selected & dynamically consistent speeds. We used OpenSim to scale a musculoskeletal model to the anthropometrics of each participant (n= 14, age= 8-12 years, body fat percentage (BF%)= 16-41%) and used the experimental data to generate dynamic musculoskeletal simulations of walking. We used a weighted static optimization method to predict muscle forces [4], and an induced acceleration analysis [5] to determine the individual muscle contributions to the acceleration of the COM. Muscle force output was normalized by dual x-ray absorptiometry derived approximations of lean mass to estimate muscle force requirements relative to the size/strength of the tissue responsible for producing force. We focused the current investigation on the muscles previously associated with the altered gait mechanics exhibit by obese children, namely, the vasti (VAS), gluteus medius (GMED), gastrocnemius, (GAS) and soleus (SOL).

Results

We found a negative correlation between average stance phase knee flexion angle and BF% (r = -0.54) and a positive correlation between pelvic obliquity range of motion and BF% (r = 0.78) (Figure 1). Absolute muscle forces had significant, positive correlations with BF%, except for VAS, which had no correlation. There were significant correlations between BF% and muscle force requirements relative to lean body weight for vasti (r = -0.60), gluteus medius (r = 0.65) and soleus (r = 0.59) (Figure 2). Contributions to COM acceleration from the vasti were negatively correlated to BF% (vertical: r = -0.75, posterior: r = -0.68, respectively), while no other significant correlations between muscle contributions to COM acceleration and BF% existed.

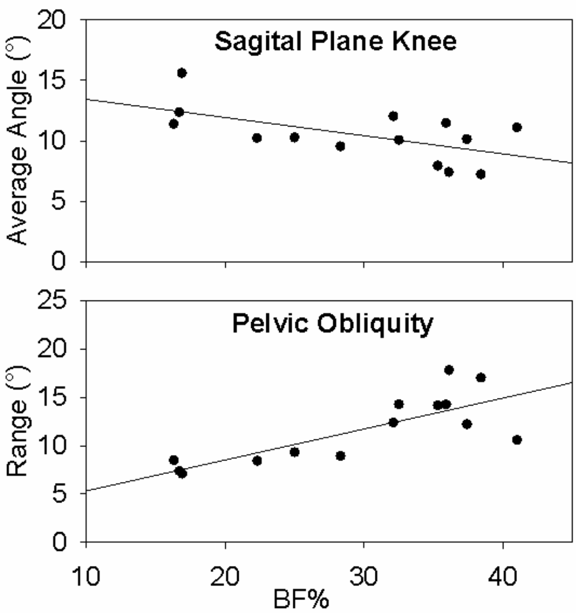

Figure 1: Relationships between BF% and average stance knee flexion angle and pelvic obliquity range of motion.

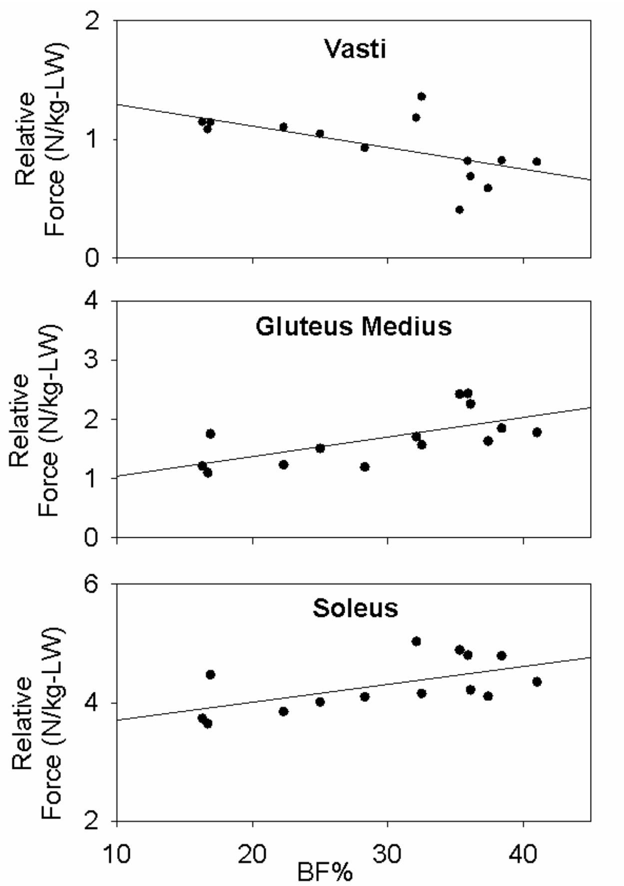

Figure 2: Relationships between BF% and muscle force requirements relative to lean-weight (LW).

Discussion

As BF% increased, we found reduced stance knee flexion angles, increased pelvic obliquity range of motion, decreased relative demand of the vasti, but increased relative demand of the gluteus medius and soleus. We found that relative gluteus medius forces had a strong positive correlation to BF%. This suggests that as BF% increases, gluteus medius may be operating closer to its maximum force production and therefore may be especially susceptible to functional weakness/fatigue during walking. In addition to supporting the torso in the frontal plane during single limb stance, the main function of gluteus medius is to reposition the COM from one leg to another during double support. While the contribution of gluteus medius to the medial acceleration of the COM did not change with BF%, there was a strong positive relationship between pelvic obliquity range of motion, which is controlled primarily by gluteus medius, and BF%. This may suggest that the locomotor control strategy for muscle function prioritizes the fulfillment of functional roles (i.e. supporting, breaking/propelling, and balancing the body) rather than maintaining normal joint angles. Greater pelvic obliquity during single limb stance results in a drop of the contralateral hip joint center and a downward shift of the swing limb. This likely explains the reduction in knee flexion angle with increasing adiposity because walking with a straighter stance limb would maintain toe-clearance and tightly controlled kinematics [6] of the swing limb (Figure 3). Since walking with a straighter leg results in reduced knee extensor moments, this may explain the reduction in the relative vasti force requirements in children with greater BF%.

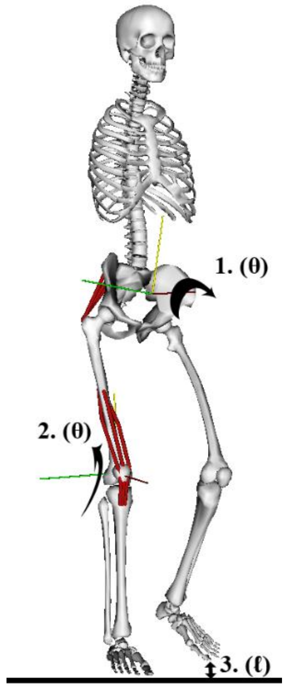

Figure 3: The potential relationship between increased pelvic obliquity, stance limb knee flexion, and toe clearance during walking. (1) Increased pelvic obliquity results in a drop of the contralateral hip joint center, while (2) the stance limb becomes more extended to allow the swing limb (3) to maintain toe clearance.

Conclusion

Our results suggest that changes in the relative force requirements of certain lower extremity muscles during walking (e.g. gluteus medius, which must fulfill functional requirements in the frontal plane) may lead to the altered walking mechanics exhibited in children with higher BF%. The development of activities, interventions, biofeedback and/or assistive devices that can improve the function of the hip abductors and plantar flexors may help to facilitate meaningful bouts of walking physical activity in overweight/obese children while reducing the risk for musculoskeletal injury.

References

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