Absolute and Allometrically Scaled Lower-Limb Strength Differences Between Children With Overweight/Obesity and Typical Weight Children

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Abstract

The purpose of this study was to compare isometric and isokinetic hip, knee, and ankle strength in children with overweight/obesity (OWB) and typical weight (TW) of age 6–12 years. Absolute torque and torque allometrically scaled to body mass and fat-free mass were derived to allow for comparison of strength irrespective of body size. Using a cross-sectional design, 26 OWB (body mass index [BMI] Z score: 2.28 ± 0.77, 54% females) children were matched in age and height with 26 TW (BMI Z score: -0.39 ± 0.96, 54% females). Subjects performed maximal isometric and isokinetic contractions in ankle dorsiflexion and plantarflexion, knee flexion and extension, hip flexion and extension, and isometric hip abduction and adduction. Between-group differences in absolute and normalized isometric and isokinetic strength were compared with 1-way analysis of variances. Statistical significance was set at $p < 0.05$. Children with OWB had significantly greater absolute torque in the knee flexors and extensors (15–21%) and greater isokinetic ankle dorsiflexion (8%) but lower isometric hip abduction (21%) compared with TW children. When strength was allometrically scaled to body mass, children with OWB were significantly weaker at the ankle (19–25%), hip (21–36%), and in the knee extensors (12–15%). When torque was allometrically scaled to fat-free mass, children in the OWB group had greater knee flexor and extensor strength (12–14%) but were weaker in isometric hip abduction (33%) and isokinetic hip flexion and extension (29–40%). The results demonstrated that deficits in strength, relative to body mass, at the ankle and hip may be greater than those of the knee. These strength deficits in the group with OWB highlight the need for targeted musculoskeletal strength interventions to incorporate all lower-limb muscle groups.

Key Words: pediatric, muscle function, torque, body mass index, scaling, fat-free mass

Introduction

Childhood obesity is associated with significant metabolic, physiological, and health comorbidities on a global scale (23). Children with overweight/obesity (OWB) may experience more episodes of musculoskeletal pain and complex orthopedic issues such as slipped capital femoral epiphysis and tibia vara (Blount disease), as well as excess body mass contributing to a reduced capacity to undertake daily activities of childhood (40). Obesity has been associated with reduced participation in physical activity (38), with those who do not take part in physical activity being 17–44% more likely to become obese (39). This pandemic of physical inactivity has been suggested to cause a condition called the pediatric inactivity triad, which has been observed in physically inactive youth involving 3 distinct but inter-related components: (a) exercise deficit disorder, (b) pediatric dynapenia, and (c) physical illiteracy (13).

The biomechanical effects of childhood obesity are well documented and include greater step width, reduced knee flexion, and larger moments during stance for hip flexion and adduction, knee adduction, and ankle inversion (27–29,35). Functional movement skills (e.g., squats, lunges, and hurdle steps) were also found to be 39% lower in children with OWB compared with typical weight (TW) children (11). It has been suggested that impaired function in children with OWB may be due to relative muscle weakness (30). This was supported by Tsiros et al. (40) who found children with higher body fat had 14–17% reduced functional knee extensor strength, relative to their mass. However, there is a paucity of data on other muscle groups in young children.

Muscles at the ankle and hip play a vital role during activities of daily living (26,40). For example, the ankle plantar flexors and hip flexors and extensors make significant contributions to the maintenance of body support against gravity (34), whereas the hip abductors and adductors have been shown to predict frontalplane hip moments during walking (33). In simulated gait studies, muscle weakness (produced by a reduction in modeled muscle force) in the plantar flexors, hip abductors, and hip flexors, but not in the hip and knee extensors, resulted in unbalanced joint moments and compensatory activation of other muscles (42).

To compare muscle strength between groups of different body size, strength values are normalized to a measure of mass. The aim of normalization is to remove the effects of body size to account for greater muscle strength due to a larger mass. Previous studies have used a broad range of normalization techniques to compare muscle strength in OWB and TW children. For example, studies have used simple ratio standards (strength divided by mass or fatfree mass [FFM]) to enable comparison between OWB and TW children (1,2,26). The problem with a ratio-scaling approach is that a linear relationship between body size and strength cannot be assumed. To account for the disproportionate increase in strength relative to body size, allometric scaling has been proposed (44).

Allometric scaling has been recommended as a method of normalization, whereby body size or mass is raised to a scaling exponent (30,43). This exponent can be determined through theoretical analysis or by log-linear regression of experimental data. However, deriving a common allometric exponent for different subject groups requires careful assessment of the common exponent (43). Allometric scaling models based on regression analysis must be carefully evaluated for appropriateness of fit (31). Regression diagnostics, including normality and distribution of residual errors, are required to check the underlying assumptions of a model (45). The appropriateness of an allometric model for scaling torque to mass can be tested through the independence (i.e., no significant correlation) of the power ratio (allometrically scaled torque) and the independent variables (body mass and FFM) (45).

Studies reporting knee extensor strength in children with OWB have reported similar or higher absolute muscle torque compared with TW children (1,2,16,40). However, when isometric and isokinetic knee extensor strength was ratio-scaled and allometrically scaled to body mass, children with OWB were reported to be weaker (2,26,40) or equal in strength compared with TW children (16). These contrasting findings between absolute and scaled strength values highlight the discrepancy between the increased muscular demands of weight bearing in children with OWB and relative muscle weakness for body size. The purpose of this study was to compare isometric and isokinetic hip, knee, and ankle strength in OWB and TW children. Absolute and allometrically scaled torque to body mass and FFM were derived to allow for comparison of strength irrespective of body size.

Methods

Experimental Approach to the Problem

To determine differences in absolute and allometric strength in the hip, knee, and ankle joints between OWB and TW children, a cross-sectional matched group study design was used. Subjects were matched on sex, age, and height.

Subjects

A group of 26 subjects (6–12 years old) with OWB were matched by sex (54% female), age, and height (mean ± SD: age: 9.3 ± 0.9 years; height: 1.36 ± 0.08 m) to 26 TW children (age: 9.2 ± 0.9 years; height: 1.39 ± 0.07 m). Parental or guardian informed consent was obtained for each subject in addition to written informed consent from the children. Ethical approval was granted from St. Mary's University Twickenham. Subjects were excluded if they had any medical condition or injury affecting musculoskeletal, neuromuscular, or orthopedic integrity or were taking part in specific strength training. Subjects were categorized into TW and OWB groups (subjects with overweight and obesity were grouped together to make the OWB group) by age- and sexspecific body mass index (BMI) Z score based on UK90 reference curves (6) using a Microsoft Excel macro developed for use with this growth reference (Child Growth Foundation, Chiswick, UK). Body mass index for both groups was calculated (BMI 5 mass/height $^{-2}$). The physical activity level for both groups was captured using the physical activity questionnaire for older children (PAQ-C). No significant differences ($p > 0.05$) in PAQC scores were found between groups (OWB: 3.25 ± 0.67; TW 3.43 ± 0.65).

Body density estimated from age and body volume was used to determine fat mass and fat-free mass. Body volume was measured using air displacement plethysmography (BOD POD; Life Measurement, Inc., Concord, CA). For this purpose, children were seated in the chamber, wearing tight swimwear and a swimming cap, and were asked to remain still while continuing normal tidal breathing. Two body volume measurements within 5% were measured and averaged for analysis. Raw body volume was corrected for isothermal air in the lungs and skin surface (17). Thoracic gas volumes were estimated from sex- and child-specific equations (14). Corrected body volumes were converted to body fat percentages using age- and sex-specific equations (24). Fat-free mass (kg) was calculated by dividing body mass by 100 and multiplying by the remaining percentage of body mass not attributed to fat mass (i.e., FFM%).

Procedures

Isometric and isokinetic strength were measured using isokinetic dynamometry (Cybex II; CSMI, Saughton, MA). Standardized positional set ups were used and then adjusted for each subject to assure alignment of the joint axis with the center of rotation of the dynamometer arm (Table 1). To reduce the risk of unwanted movement during contractions, stabilization straps were applied tightly over the contralateral leg and torso, and subjects were instructed to cross their arms over their chest. Verbal encouragement was provided throughout.

To familiarize the subjects with the equipment and the isometric task, 3 submaximal isometric contractions were performed before each isometric exercise. These contractions also provided a taskspecific warm-up. A mandatory 2-minute rest period to minimize fatigue was given between warm-up and maximal contractions. Subjects then performed two 5-second maximal isometric contractions for each joint position with maximal effort, interspersed with 45-second rest periods, the order of joint position which was randomized. An additional contraction was allowed if torque values differed by more than 10%. The trial with the greatest torque recording for each isometric exercise was used for further analysis. Verbal encouragement was provided throughout.

Isokinetic trials were completed with the same setup as isometric trials (Table 1). Isokinetic movements were performed within each subject's own range of motion. Each extension and flexion contraction was performed 3 times starting from an extended joint position. Subjects were instructed to push and pull against the lever arm as hard and fast as they could. Isokinetic velocity for plantar flexion and dorsiflexion was set at $30°\cdot s^{-1}$, and extension and flexion of the knee and hip were set at $60°\cdot s^{-1}$. An average of the peak torque from 3 repetitions was taken for each isokinetic trial and used for further analysis. Isometric and isokinetic data were filtered using a fourth-order 5-Hz zero-lag Butterworth filter.

Table 1: Summary of the isometric testing muscle group, joint position angle, and isokinetic dynamometer setup position.

Muscle group	Joint position (°)	Position
Ankle dorsiflexion	90° foot-tibia	Supine
Ankle plantar flexion	90° foot-tibia	Supine
Knee extension	60° (0° being full extension)	Seated
Knee flexion	30° (0° being full extension)	Seated
Hip flexion	30°	Supine
Hip extension	60°	Supine
Hip abduction	Neutral	Side lying
Hip adduction	20°	Side lying

Each isometric torque variable (corrected for limb weight) was ratio-scaled to body mass (kg) and FFM (kg) using equations 1 and 2, respectively:

$$\frac{\text{Torque}}{\text{Body mass(or Body mass} \times \text{leg length)}} = \frac{\text{Measured torque}}{\text{Body mass(or Body mass} \times \text{leg length)}}, \quad (1)$$

$$\frac{\text{Torque}}{\text{FFM(or FFM} \times \text{leg length)}} = \frac{\text{Measured torque}}{\text{FFM(or FFM} \times \text{leg length)}}, \quad (2)$$

where, leg length was defined as the linear distance between the anterior superior iliac crest and medial malleolus on the dominant limb. The allometric relationships between torque and body size variables (body mass and FFM) were firstly linearized by taking natural logarithms. An exponent common to both groups was then fitted according to the following model (equation 3):

$$\ln\text{Torque} = \ln a + c\text{Group} + b \ln \text{Body size} + \ln \varepsilon. \quad (3)$$

This allowed for the identification of an exponent free from the influence of the group. Using the derived body size exponents, a power function ratio was constructed (Torque/Body size^b), which is theoretically size-independent. The normality of residual distribution (1nε) was examined using the Kolmogorov–Smirnov test, and the assumption of homoscedasticity was confirmed by a nonsignificant correlation between the absolute residual and independent body size variable (ln body size).

For an allometric model to be deemed appropriate, there should be no significant correlation between the allometrically scaled torque measurement and the independent variable (30). Therefore, each allometrically scaled torque variable was assessed against body mass^b and FFM^b using linear regression. Only isokinetic knee extensor strength scaled to body mass demonstrated a significant correlation after allometric scaling had been applied ($r = 0.36$, $p = 0.010$). There were no other significant relationships in isometric or isokinetic variables when allometrically scaled to body mass or FFM (Figures 1 and 2).

Statistical Analyses

Statistical analyses were performed using SPSS (24.0; IBM Corp., Amonk, NY). Differences in group characteristics were ascertained using independent-samples t-tests. Between-group differences in absolute and normalized isometric and isokinetic strength were compared with 1-way analysis of variances. The threshold for statistical significance was set at $p \leq 0.05$. Where significant differences were found, Cohen's d was calculated to determine the magnitude of difference in conditions. Changes were considered trivial <0.2; small 0.2–0.6; moderate 0.6–1.2; and large 1.2–2.

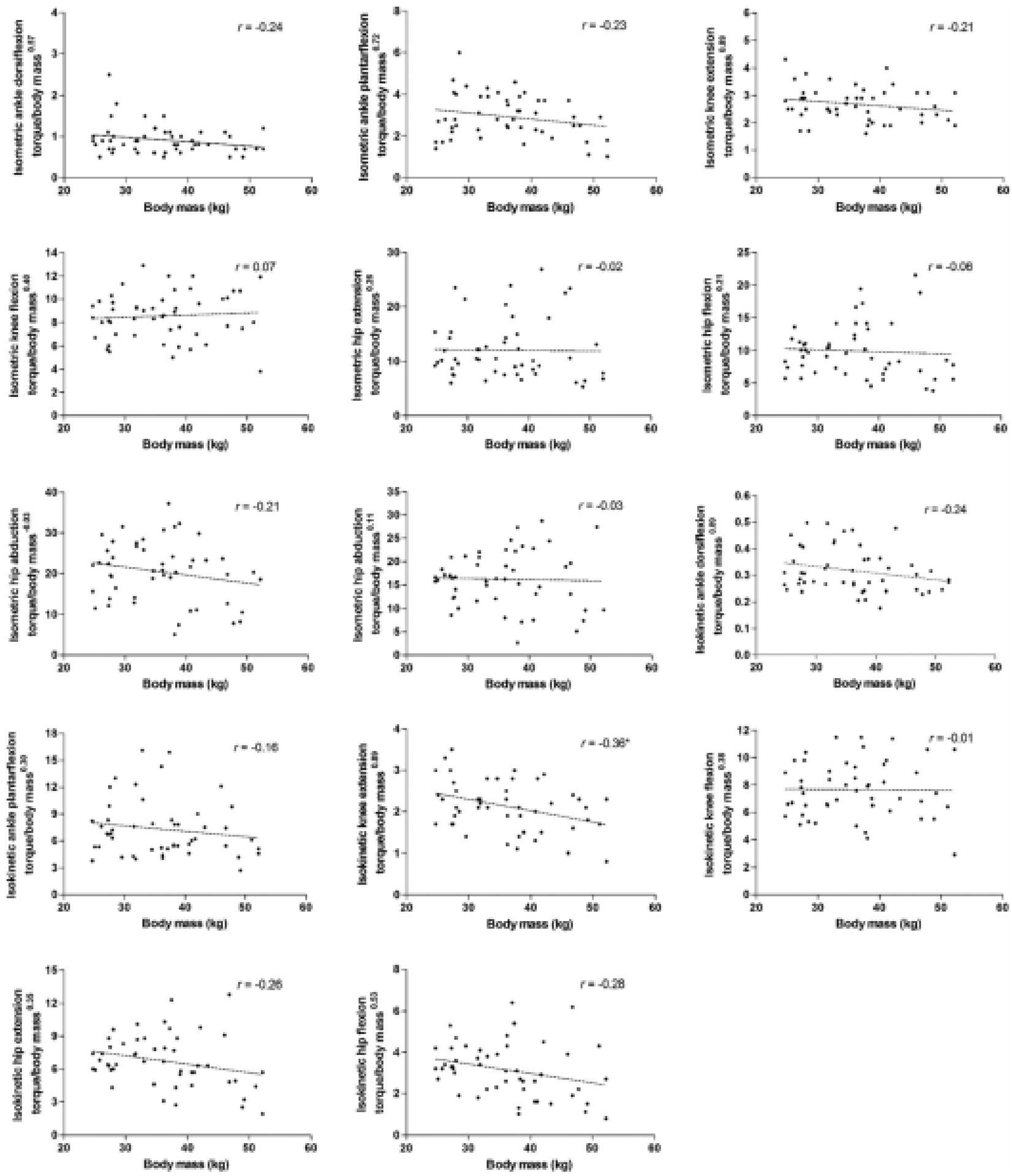

Figure 1: Correlations between body mass and isometric and isokinetic ankle, knee, and hip torque allometrically scaled to body mass in OWB and TW children.

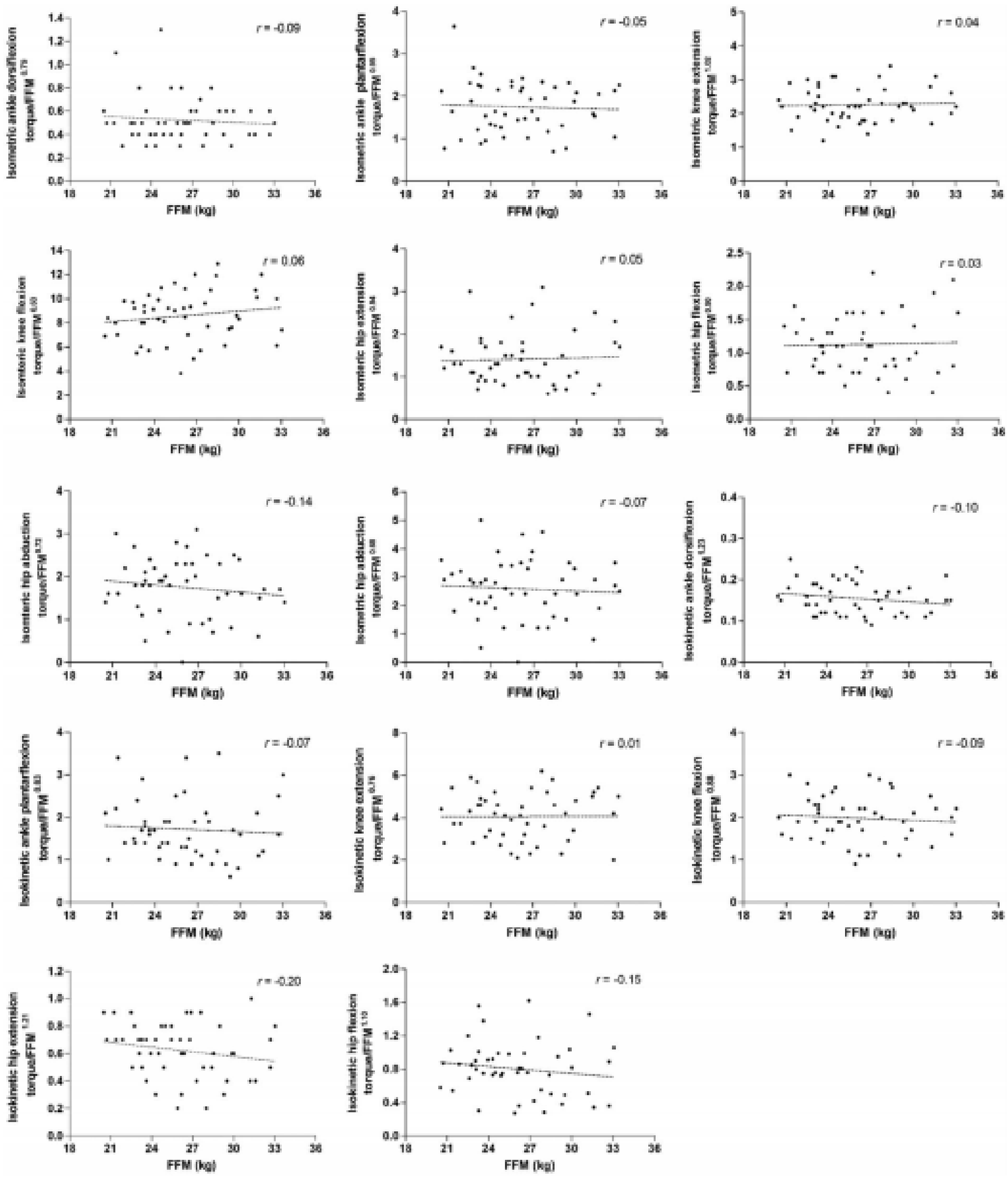

Figure 2: Correlations between body mass and isometric and isokinetic ankle, knee, and hip torque allometrically scaled to FFM in OWB and TW children. FFM 5 fat-free mass.

Results

There were no statistically significant differences in age (p = 0.431) or height (p = 0.058) between OWB and TW groups. The group with OWB had significantly higher body mass (OWB: 42.3 ± 6.6 kg, TW: 30.0 ± 4.2 kg, p < 0.001), BMI Z scores (OWB: 2.28 ± 0.77; TW: -0.39 ± 0.96, p < 0.001), body fat % (OWB: 35.6 ± 8.6%; TW: 16.4 ± 4.6%, p < 0.001), and fat-free mass (kg) (OWB: 27.0 ± 3.3 kg; TW: 25.0 ± 3.3 kg, p < 0.01) compared with the TW group.

The results showed that children with OWB had significantly lower absolute isometric hip abduction torque compared with the TW group (effect size [ES] = 0.54; mean difference: -3.59; 95% confidence interval [CI] [-7.32 to 0.13)}. In addition, the OWB group had significantly greater isometric knee flexor (ES = - 0.66; mean difference: 6.13; 95% CI [1.08–11.2]) and extensor torque (ES = -0.72; mean difference: 12.30; 95% CI [3.19–21.41]) and significantly greater isokinetic knee flexor (ES = -0.46; mean difference: 3.48; 95% CI [20.81 to 7.78]) and extensor torque (ES 5 20.55; mean difference: 6.39; 95% CI [0.03–12.74]). Isokinetic ankle dorsiflexion torque was also significantly greater in the OWB compared with the TW group (ES = -0.50; mean difference: 0.78; 95% CI [20.09 to 1.67]) (Tables 2 and 3). There were no other absolute differences in ankle or hip strength between the groups.

Torque Scaled to Body Mass

When torque was allometrically scaled to body mass, the group with OWB produced significantly lower isometric (ES = 0.53; mean difference: -0.19; 95% CI [-0.396 to 0.004]) and isokinetic ankle dorsiflexion (ES = 0.63; mean difference: -0.05; 95% CI [-0.097 to 0.007] and isometric (ES = 0.48; mean difference: -0.29; 95% CI [-0.63 to 0.04]) and isokinetic knee extension (ES = 0.52; mean difference: -0.32; 95% CI [-0.66 to 0.01]), isokinetic hip flexion (ES = 0.75; mean difference: -1.01; 95% CI [-1.72 to -0.29]) and extension (ES = 0.69; mean difference: -1.64; 95% CI [-2.92 to -0.36]), and isometric ankle plantar flexion (ES = 0.53; mean difference: -0.056; 95% CI [-1.14 to 0.02]) and hip abduction (ES = 0.51; mean difference: -3.84; 95% CI [-8.05 to 0.36]) (Tables 2 and 3).

Table 2: Isometric ankle, knee, and hip torques between OWB and TW children, expressed in absolute terms and allometrically scaled to body mass^b (N·m·kg^{1b}) and FFM^b (N·m·kg FFM^{-1b}).*†

	Absolute		Allometrically scaled to body mass			Allometrically scaled to FFM		
	Torque (N·m)	p	BM^b	Torque/body mass (N·m·kg^{-1b})	p	FFM^b	Torque/FFM (N·m·kgFFM^{-1b})	p
Isometric ankle dorsiflexion								
OWB	6.9 (2.0)	0.900	0.57	0.8 (0.2)	0.029‡	0.79	0.5 (0.1)	0.199
TW	7.0 (3.0)			1.0 (0.4)			0.6 (0.2)	
Isometric ankle plantar flexion								
OWB	38.9 (11.3)	0.389	0.72	2.6 (0.8)	0.030‡	0.95	1.7 (0.5)	0.378
TW	37.8 (15.7)			3.2 (1.2)			1.8 (0.7)	
Isometric knee flexion								
OWB	38.2 (10.4)	0.009‡	0.40	8.7 (2.3)	0.283	0.63	4.8 (1.2)	0.043‡
TW	32.1 (6.9)			8.4 (1.7)			4.3 (0.9)	
Isometric knee extension								
OWB	69.6 (18.3)	0.005‡	0.89	2.5 (0.6)	0.044‡	1.02	2.4 (0.5)	0.040‡
TW	57.3 (13.3)			2.8 (0.6)			2.1 (0.4)	
Isometric hip flexion								
OWB	21.1 (10.9)	0.489	0.211	9.6 (5.0)	0.279	0.90	1.1 (0.5)	0.242
TW	21.1 (6.7)			10.3 (3.1)			1.2 (0.3)	
Isometric hip extension								
OWB	31.5 (16.7)	0.329	0.26	11.9 (6.2)	0.418	0.94	1.4 (0.7)	0.431
TW	29.7 (11.6)			12.2 (4.7)			1.4 (0.5)	
Isometric hip abduction								
OWB	16.3 (7.2)	0.028‡	−0.03	18.4 (8.2)	0.035‡	0.72	1.5 (0.7)	0.002‡
TW	19.8 (5.6)			22.3 (6.3)			2.0 (0.5)	
Isometric hip adduction								
OWB	23.8 (11.8)	0.404	0.11	15.7 (7.8)	0.283	0.68	2.5 (1.3)	0.178
TW	24.4 (5.6)			16.7 (3.9)			2.7 (0.6)	

*FFM = fat-free mass; OWB = overweight and obese; TW = typical weight.
†Values are mean (*SD*).
‡$p < 0.05$.

Table 3: Isokinetic ankle, knee, and hip torque between OWB and TW children, expressed in absolute terms and allometrically scaled to body mass 3 leg length^b (N·m·kg^{-2b}) and to FFM 3 leg length^b (N·m·kg FFM^{-2b}).*†

	Absolute		Allometrically scaled to body mass × leg length			Allometrically scaled to FFM × leg length		
	Torque (N·m)	p	BM^b	Torque/body mass × leg length (N·m·kg^{-2b})	p	FFM^b	Torque/FFM × leg length (N·m·kg FFM^{-2b})	p
Isokinetic ankle dorsiflexion								
OWB	5.9 (1.5)	0.038‡	0.89	0.29 (0.07)	0.011‡	1.22	0.16 (0.04)	0.392
TW	5.1 (1.6)			0.34 (0.08)			0.15 (0.04)	
Isokinetic ankle plantar flexion								
OWB	18.5 (7.0)	0.257	0.30	6.6 (2.5)	0.070	0.83	1.6 (0.6)	0.082
TW	20.1 (9.7)			8.0 (3.6)			1.9 (0.8)	
Isokinetic knee flexion								
OWB	27.9 (8.5)	0.049‡	0.38	7.7 (2.2)	0.479	0.88	2.0 (0.6)	0.257
TW	24.3 (6.6)			7.6 (1.9)			1.9 (0.5)	
Isokinetic knee extension								
OWB	40.0 (12.9)	0.024‡	0.89	2.0 (0.6)	0.032‡	0.76	4.3 (1.2)	0.112
TW	33.6 (9.2)			2.3 (0.6)			3.9 (1.0)	
Isokinetic hip flexion								
OWB	16.5 (9.2)	0.154	0.56	2.5 (1.3)	0.005‡	1.06	0.7 (0.4)	0.042‡
TW	18.7 (5.4)			3.4 (0.8)			0.9 (0.2)	
Isokinetic hip extension								
OWB	19.8 (8.8)	0.115	0.35	5.9 (2.6)	0.006‡	1.21	0.5 (0.2)	0.003‡
TW	22.4 (6.3)			7.6 (1.8)			0.7 (0.1)	

*FFM = fat-free mass; OWB = overweight and obese; TW = typical weight.
†Values are mean (*SD*).
‡$p < 0.05$.

Discussion

The purpose of this study was to compare isometric and isokinetic hip, knee, and ankle strength in OWB and TW children. The main results were as follows: (a) Absolute isokinetic ankle dorsiflexion and isometric and isokinetic knee flexor and extensor torque were significantly greater in the OWB group compared with the TW group, whereas isometric hip abduction was significantly lower; (b) When torque was allometrically scaled to body mass, children with OWB were significantly weaker in isometric plantar flexion and dorsiflexion, isometric knee extension, and isometric hip abduction. Children with OWB were also weaker in isokinetic dorsiflexion, isokinetic knee extension, and hip extension and flexion; (c) When torque was allometrically scaled to FFM, isometric hip abduction and isokinetic hip flexion and extension were weaker, but isometric knee flexion and extension were significantly stronger in the group with OWB.

The finding of greater absolute strength in the knee is in line with the previous literature for the knee extensors (1,2,18,21,26,40). Tsiros et al. (40) reported higher absolute knee extensor torques of 14–17% in children with OWB, which is comparable with 19% found in this study. To the best of authors' knowledge, no previous study has reported absolute ankle dorsiflexor or hip abductor strength in OWB children. Ankle dorsiflexor moments during gait are reportedly higher in OWB compared with TW children (35), consistent with the findings of greater strength in the OWB group reported in the current study. The predominant role of the ankle dorsiflexors is to control rotation of the foot and support body mass at heel strike. Greater absolute strength observed at the ankle and knee in the OWB group has been attributed to a neuromuscular training effect of carrying excess fat mass (1). The OWB group also showed significant absolute hip abductor weakness compared with the TW group. Shultz et al. (37) observed that OWB children spend considerably more time in an adducted position during gait, whereas TW children spent more time in hip abduction. This shift to a greater weakness may prevent stabilization of the pelvis, causing collapse of the lower limbs, a phenomenon observed in kinematic analysis of OWB children (29).

Strength allometrically scaled to body mass eliminates the influence of size as a confounding factor in cross-sectional comparisons of groups (44). When the effects of body size were removed, the group with OWB was significantly weaker in a number of variables. Consistent with the findings of the current study, Tsiros et al. (40) found children with obesity to have significantly weaker knee extensors in isometric and isokinetic tests when allometrically scaled to body mass. Children with OWB have been reported to walk with a straighter knee (less knee flexion) throughout the stance phase (30). Some authors have suggested this is to allow for adequate toe clearance when the contralateral hip joint center drops (22), whereas others suggest this is because the extensors are unable to control for the excess mass due to relative muscular weakness (30). These results provide support to the latter, suggesting knee extensor weakness may be one cause of a straighter-leg gait pattern observed in groups with OWB.

The finding that ankle strength allometrically scaled to body mass was weaker in the group with OWB has not been reported previously. During ambulation, the medial gastrocnemius (ankle plantar flexor) has been reported to contract near-isometrically during much of the single-support phase of stance, which minimizes mechanical work and contributes to an efficient pattern of locomotion (15). Children with OWB have been shown to require greater power generation of the plantar flexors during walking, and coupled with lower relative strength, would mean the plantar flexors are working at a higher proportion of their maximum capacity, resulting in greater metabolic cost of walking. This finding may be concomitant with the slower walking speeds and longer stance phases observed in children with OWB (19), which may serve to minimize the metabolic cost of walking. Therefore, children with OWB may compensate for relatively weaker ankle plantar flexors by altering gait mechanics, thus reducing metabolic cost at the detriment of physical performance.

During gait, ankle dorsiflexors are active before lift-off and remain active throughout the swing phase and into the first 10% of the stance phase (5). These muscles work concentrically to dorsiflex the foot during the swing phase for ground clearance as the foot advances and eccentrically at heel strike to decelerate plantar flexion (3,7). Obese individuals present greater plantar flexion during gait because body mass is loaded to the heel, indicating that relative weakness of the dorsiflexors may reduce progression of the body over the stance limb (7) reducing functional performance.

A further novel finding was that children with OWB were weaker at the hip when torques were allometrically scaled to body mass. The role of the hip abductors during gait is to stabilize the trunk and hip during ambulation, control limb alignment, and transfer forces from the lower limb to the pelvis (25). Hip abduction strength is required to control external hip adduction moments during the single-leg support phase of gait (32). As previously seen in a typical-weight adolescent population, gait mechanics are particularly sensitive to weakness in the hip abductors (42), and therefore, reduced hip abductor strength relative to body mass may relate to greater hip adduction moments seen in pediatric populations with OWB (27).

The gluteus maximus (hip extensor) plays an important role in early stance by supporting bodymass and controlling hip extension (8). Gait analysis has shown that during stance, children with obesity moved into hip extension earlier than TW children, which brings the body over the hip joint earlier, therefore, requiring less hip extensor strength (30). Earlier hip extension may be a compensatory mechanism to reduce external hip flexor moments in children with OWB to overcome the relative weakness of the hip extensors to support body mass.

Hip flexor muscle activity is important during the preswing part of the gait cycle, when the leg is accelerated as a biarticular pendulum that progresses the swing limb during swing (4). Gait analyses of pediatric cohorts with OWB have demonstrated greater hip external extension moments in midstance to late stance (27,30). Weaker hip flexors may contribute to greater external hip extensor moments, affecting the ability to propel the body forward (36).

Strength allometrically scaled to FFM is presumed to represent the quality and contractile properties of the muscle (40). When torque variables in this study were expressed relative to FFM, children in the OWB group were weaker in isometric hip abduction (33%), isokinetic hip extension (40%), and flexion (29%) and stronger in isometric knee flexion (12%) and extension (14%), but no differences were present at the ankle. The results at the knee contradict Tsiros et al. (40) who found no difference in knee extensor strength allometrically scaled to FFM between OWB and TW children. However, Abdelmoula et al. (1) found isometric knee extensor torque normalized to thigh lean mass and thigh muscle mass was greater in children with obesity. This may be due to favorable muscle characteristics as evidenced by Garcia-Vicencio et al. (16) who reported significantly greater knee extensor pennation angle, anatomical cross-sectional area, and voluntary activation levels in female adolescents with obesity.

The reduced hip abductor strength in the group with OWB is supported by the finding that boys with obesity present greater hip adduction during the stance phase of gait (29). Lerner et al. (22) showed that demands on the hip abductors, to control frontal plane movement during walking, were much higher in adults with obesity compared with TW adults when hip abductor forces were expressed relative to lean mass. This finding suggests that the hip abductors may be more susceptible to fatigue, consistent with our finding of hip abductor weakness relative to FFM in the group with OWB. The findings of strength allometrically scaled to FFM suggest that the carriage of excessive mass has a neuromuscular training effect on knee flexors and extensors but a detrimental effect on hip muscles torque output. Indeed, Devita and Hortobagyi (9) reported adults with OWB to have equal knee torque and power during gait, despite carrying ;80% extra mass compared with TW adults. The authors propose that individuals with OWB reorganize neuromuscular function to maintain skeletal health of the knee joint but not the hip or ankle joints (9).

This study is not without limitations. The use of BOD POD to determine body composition only allows estimation of whole-body FFM; therefore, normalizing torque values may not give musclespecific information on the quality and contractile properties of the muscle. A further limitation was the correlation between allometrically scaled isokinetic knee extensor torque and body mass (Figure 1). After allometrically scaling absolute torque, there was a significant negative correlation between torque and body mass, meaning as the sample got heavier, torque decreased. The use of a common exponent to scale torque of 2 groups with differing body composition may underlie the failure to remove the association (43). This finding raises important methodological considerations when comparing strength in OWB and TW individuals.

Although the findings of the current study indicate a difference in lower-limb strength, particularly at the hip and ankle, the implications for physical activity and functional performance were not explored. The relationships between body fat, knee extensor strength, six-minute–timed walk, cardiorespiratory fitness, and self-reported physical functioning have been explored in a pediatric population using structural equation modeling (41). Future research is needed to widen the understanding of the relationships between gait mechanics, lower-limb strength, physical activity, and functional performance to identify targets for interventions.

Practical Applications

The findings highlight the need for strength training programs in children with OWB, to focus not only the knee but also training for the hip and ankle. This point was supported by a recent study in overweight adults, which showed deficits in strength at the ankle and hip were comparable or greater than that of the knee (20). Previous reports indicate that resistance training in children has the potential to deliver improvements in health and fitness, provided appropriate guidelines are followed (12). To maximize strength gains and reduce the risk of injury associated with muscle weakness, OWB children would benefit from resistance training at lower training intensities and then gradually progressing intensity, volume, or both while maintaining optimal technique. Training induced strength gain in children is related to neural mechanisms rather than hypertrophic factors (12). Improvements in motor skill performance and coordination may play a significant role in strength gains from resistance training (12) and may improve confidence of OWB children to be more physically active. Resistance training programs in OWB adolescents have been shown to be beneficial for reducing body fat, increasing isokinetic strength of knee flexors and extensors and physical fitness (10). OWB children should have greater opportunity to participate in lower-limb strength programs (in clinics, clubs, and schools) to promote motor performance and physical activity while reducing the health comorbidities associated with obesity in adulthood.

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