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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) age 6-12 years. Absolute torque, and torque allometrically scaled to body mass and fat-free mass, were derived to allow comparison of strength irrespective of body size. Using a cross-sectional design, 26 OWB (body mass index (BMI) Z score: 2.28 ± 0.77, 52% females) children were matched in age and height with 26 TW (BMI Z score: -0.39 ± 0.96, 52% females). Participants 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 one-way ANOVA's. 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 to 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 that 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 orthopaedic issues such as slipped capital femoral epiphysis and tibia vara (Blount's disease), as well as excess weight contributing to a reduced capacity to undertake daily activities of childhood (40). Obesity has been associated with reduced participation in physical activity (39), with those who do not take part in physical activity being 17–44% more likely to become obese. 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 three distinct but inter-related components: 1) exercise deficit disorder, 2) pediatric dynapenia, and 3) 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 (27,28,29,35). Functional movement skills (e.g. squats, lunges and hurdle steps) were also found to be 39% lower in children with OWB compared to 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 plantarflexors and hip flexors and extensors, make significant contributions to the maintenance of body support against gravity (34), whilst the hip abductors and adductors have been shown to predict frontal plane hip moments during walking (33). In simulated gait studies, muscle weakness (produced by a reduction in modelled muscle force) in the plantarflexors, 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).

In order 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 utilized 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 fat-free 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. In order 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 participant 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 to TW children (1,2,16,40). However, when isometric and isokinetic knee extensor strength was ratio and allometrically scaled to body mass, children with OWB were reported to be weaker (2,26,40), or equal in strength to that of 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 comparison of strength irrespective of body size.

METHODS

Experimental Approach to the Problem

In order 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 employed. Participants were matched on sex, age and height.

Participants

A group of 26 participants with OWB were matched by sex (52% female), age and height (age: 9.3 ± 0.9 y; height: 1.36 ± 0.08 m) to 26 TW children (age: 9.2 ± 0.9 y; height: 1.39 ± 0.07 m). Parental or guardian informed consent was obtained for each participant in addition to informed assent from the children. Ethical approval was granted from the host institution. Participants were excluded if they had any medical condition or injury affecting musculoskeletal, neuromuscular or orthopaedic integrity, or were taking part in specific strength training. Participants were categorised into TW and OWB groups (participants with overweight and obesity were then grouped together to make the OWB group) by age and sex specific 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 (BMI) for both groups was calculated (BMI = mass / height^2). Physical activity level for both groups was captured via the physical activity questionnaire for older children (PAQ-C). No significant differences ($p > 0.05$) in PAQ-C scores was 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, USA). For this purpose, children were seated in the chamber, wearing tight swimwear and a swimming cap and were asked to remain still whilst 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 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, USA). Standardised positional set ups were used and then adjusted for each participant to assure alignment of joint axis with the centre of rotation of the dynamometer arm (Table 1). To reduce the risk of unwanted movement during contractions, stabilisation straps were applied tightly over the contralateral leg and torso, and participants were instructed to cross their arms over their chest. Verbal encouragement was provided throughout.

To familiarise the participants with the equipment and the isometric task, three sub-maximal isometric contractions were performed prior to each isometric exercise. These contractions also provided a task-specific warm-up. A mandatory 2-minute rest period to minimise fatigue was given between warm-up and maximal contractions. Participants then performed two 5 s maximal isometric contractions for each joint position with maximal effort, interspersed with 45 s rest periods, the order of joint position which was randomised. 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.

Table 1. Summary of isometric testing muscle group, joint position angle and isokinetic dynamometer set up position.

Muscle group	Joint position (º)	Position
Ankle dorsiflexion	90° foot-tibia	Supine
Ankle plantarflexion	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

Isokinetic trials were completed with the same setup as isometric trials (Table 1). Isokinetic movements were performed within each participant's own range of motion. Each extension and flexion contraction was performed three times starting from an extended joint position. Participants were instructed to push and pull against the lever arm as hard and fast as they could. Isokinetic velocity for plantarflexion and dorsiflexion was set at 30°/s, and extension and flexion of the knee and hip were set at 60°/s. An average of the peak torque from three 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.

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

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

Equation 1

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

Equation 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):

$$\ln\text{Torque} = \ln a + c\text{Group} + b \ln \text{Body size} + \ln \epsilon$$

Equation 3

This allowed for the identification of an exponent free from the influence of 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 ($\ln \epsilon$) was examined using the Kolmogorov-Smirnov test and the assumption of homoscedasticity was confirmed by a non-significant 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 (Figure 1 and 2).

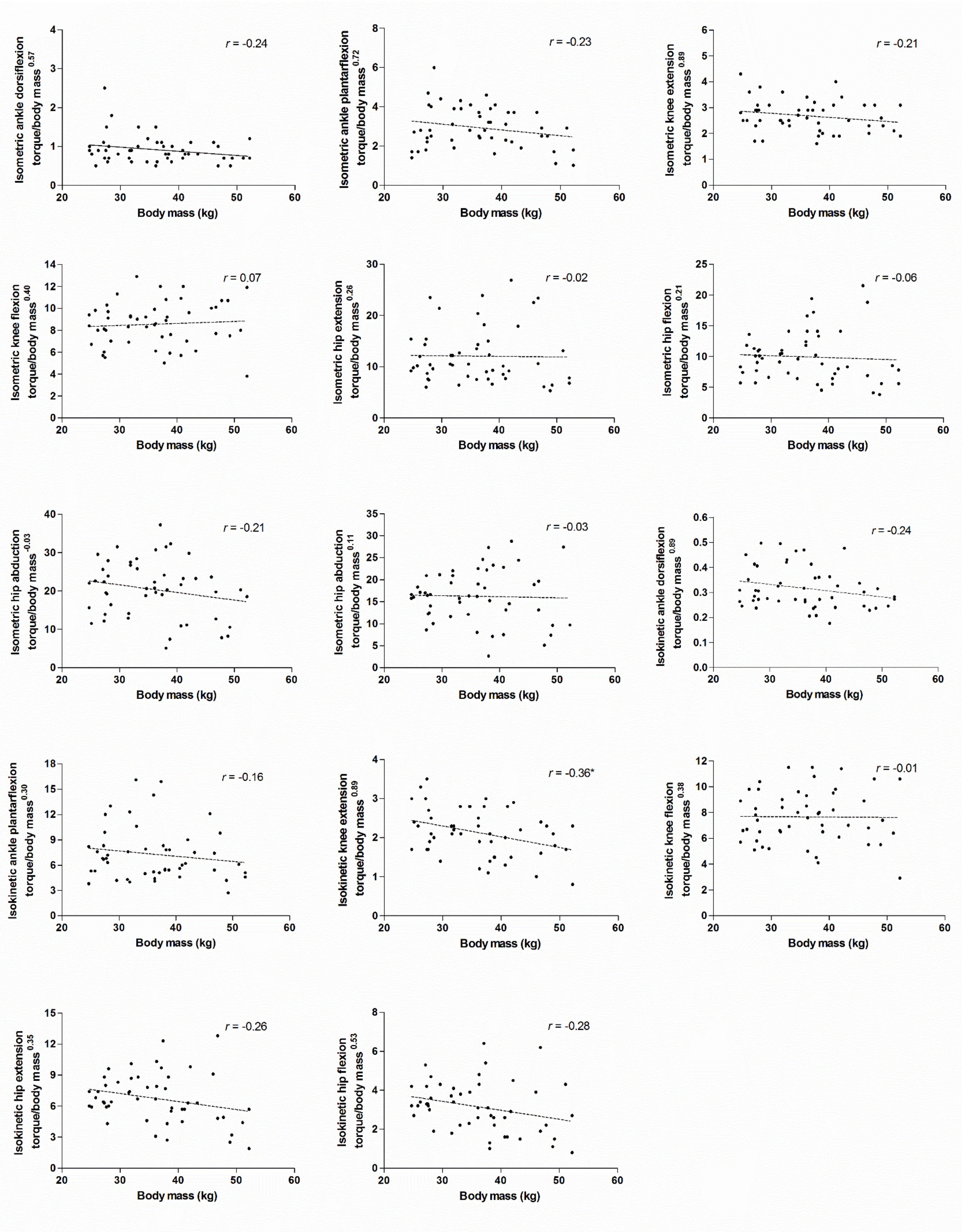

Figure 1. Correlations between body mass and isometric and isokinetic ankle, knee and hip torque allometrically scaled to body mass in OBW and TW children.

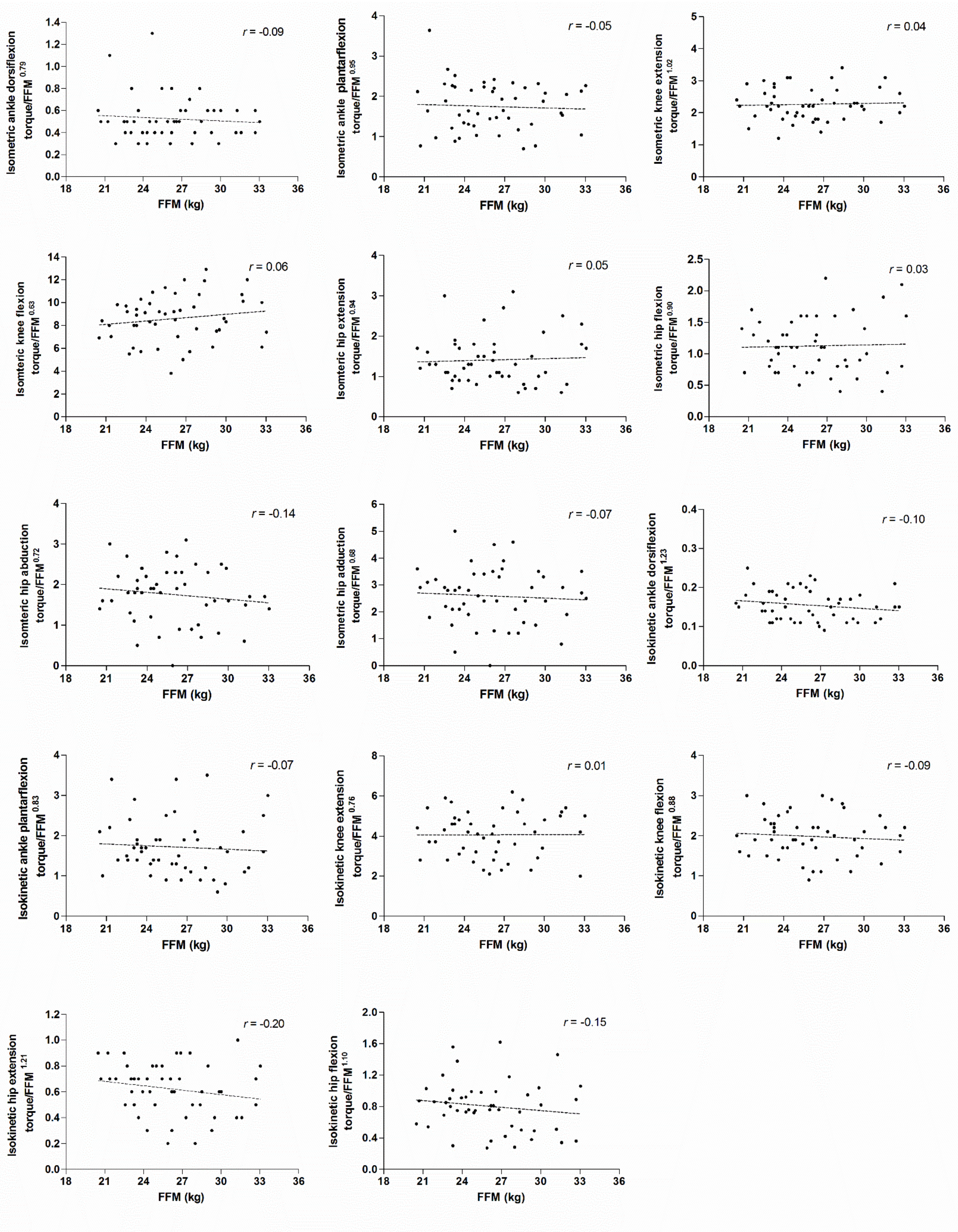

Figure 2. Correlations between body mass and isometric and isokinetic ankle, knee and hip torque allometrically scaled to FFM in OBW and TW children

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 one-way ANOVA's. The threshold for statistical significance was set at $p < 0.05$. 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.

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 to the TW group.

The results showed that children with OWB had significantly lower absolute isometric hip abduction torque compared to the TW group (ES = 0.54; mean difference: -3.59; 95% CI [-7.32-0.13]). 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 [-0.81-7.78]), and extensor torque (ES = -0.55; mean difference: 6.39; 95% CI [0.03-12.74]). Isokinetic ankle dorsiflexion torque was also significantly greater in the OWB compared to the TW group (ES = -0.50; mean difference: 0.78; 95% CI [-0.09-1.67]) (Table 2 and 3). There were no other absolute differences in ankle or hip strength between the groups.

Table 2. Isometric ankle, knee and hip torques between OWB and TW children, expressed in absolute terms and allometrically scaled to body mass^{b} (Nm·kg^{1b}) and FFM^{b} (Nm·kgFFM^{-1b}). Values are mean (standard deviation) (**p* < 0.05).

		Absolute		**Allometrically scaled to body mass**			**Allometrically scaled to FFM**		
		Torque (Nm)	***p* value**	**BM^{b}**	**Torque/body mass (Nm·kg^{-1b})**	***p* value**	**FFM^{b}**	**Torque/FFM (Nm·kgFFM^{-1b})**	***p* value**
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 plantarflexion	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)	

Table 3. Isokinetic ankle, knee and hip torque between OWB and TW children, expressed in absolute terms and allometrically scaled to body mass x leg length^b (Nm·kg^{-2b}) and to FFM x leg length^b (Nm·kgFFM^{-2b}). Values are mean (standard deviation) (*p < 0.05).

		Absolute		Allometrically scaled to body mass x leg length			Allometrically scaled to FFM x leg length		
		Torque (Nm)	***p* value**	**BM^b**	**Torque/body mass x leg length (Nm·kg^{-2b})**	***p* value**	**FFM^b**	**Torque/FFM x leg length (Nm·kgFFM^{-2b})**	***p* value**
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 plantarflexion	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)	

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 [-0.396-0.004]) and isokinetic ankle dorsiflexion (ES = 0.63; mean difference: -0.05; 95% CI [-0.097-0.007] and isometric (ES = 0.48; mean difference: -0.29; 95% CI [-0.63-0.04]) and isokinetic knee extension (ES = 0.52; mean difference: -0.32; 95% CI [-0.66-0.01]), isokinetic hip flexion ES = 0.75; mean difference: -1.01; 95% CI [-1.72- -0.29]), and extension (ES = 0.69; mean difference: -1.64; 95% CI [-2.92- -0.36]), and isometric ankle plantarflexion (ES = 0.53; mean difference: -0.056; 95% CI [-1.14-0.02]), and hip abduction (ES = 0.51; mean difference: -3.84; 95% CI [-8.05-0.36]) (Table 2 and 3).

Torque scaled to FFM

When torque data were allometrically scaled to FFM, isometric hip abduction (ES = 0.78; mean difference: -0.53; 95% CI [-0.90- -0.16]), isokinetic hip extension (ES = 0.75; mean difference: -0.15; 95% CI [-0.25- -0.04]) and flexion (ES = 0.57; mean difference: -0.18; 95% CI [-0.365-0.07]) remained significantly lower in the group with OWB. However, isometric knee flexion (ES = -0.48; mean difference: 0.52; 95% CI [-0.08-1.14]) and extension (ES = -0.50; mean difference: 0.25; 95% CI [-0.02-0.54]) allometrically scaled to FFM were significantly greater in the OWB compared to TW group (Table 2 and 3).

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: 1) Absolute isokinetic ankle dorsiflexion and isometric and isokinetic knee flexor and extensor torque were significantly greater in the OWB group compared to the TW group, whilst isometric hip abduction was significantly lower; 2) When torque was allometrically scaled to body mass, children with OWB were significantly weaker in isometric plantarflexion 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; 3) 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 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 to 19% found in this study. To the 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 to 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 weight 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 to the TW group. Shultz et al. (37)

observed that OWB children spend considerably more time in an adducted position during gait, whilst TW children spent more time in hip abduction. This shift to a greater activation of the hip adductors may minimise the work of the abductors during gait in the OWB group and explain the observed weakness of the hip abductor muscles. This weakness may prevent stabilisation 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 were 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 weight. Children with OWB have been reported to walk with a straighter knee (less knee flexion) throughout stance phase (30). Some authors have suggested this is to allow adequate toe clearance when the contralateral hip joint centre drops (22), whilst 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 plantarflexor), has been reported to contract near-isometrically during much of the single support phase of stance, which minimises mechanical work and contributes to an efficient pattern of locomotion (15). Children with OWB have been shown to require greater power generation of the plantarflexors during walking, and coupled with lower relative strength, would mean the plantarflexors 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 minimise the metabolic cost of walking. Therefore, children with OWB may compensate for relatively weaker ankle plantarflexors by altering gait mechanics, thus reducing metabolic cost at the detriment of physical performance.

During gait, ankle dorsiflexors are active prior to 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 plantarflexion (5,7). Obese individuals present greater plantarflexion during gait, as 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 are 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 body weight and controlling hip extension (8). Gait analysis has shown that, during stance, children with obesity moved into hip extension earlier than typical weight 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 weight.

Hip flexor muscle activity is important during the pre-swing part of the gait cycle, when the leg is accelerated as a biarticular pendulum that progresses the swing limb during swing (4). Gait analysis of pediatric cohorts with OWB have demonstrated greater hip external extension moments in mid- to late stance (27,30). Weaker hip flexors may contribute to greater external hip extensor moments effecting 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 the present 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%), 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 favourable 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, was much higher in adults with obesity compared to typical weight 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 suggests 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 to 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 muscle-specific 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 two 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.

Whilst 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 modelling (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 APPLICATION

The findings highlight the need for strength training programmes in children with OWB, to focus not only the knee, but also training for the hip and ankle. 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 maximise strength gains and reduce the risk of injury associated with muscle weakness, OWB children would benefit from resistance training at lower training intensities then gradually progressing intensity, volume, or both whilst maintaining optimal technique.

Training-induced strength gain in children are 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 programmes 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 participant in lower limb strength programmes (in clinics, clubs and schools) to promote motor performance and physical activity whilst reducing the health comorbidities associated with obesity in adulthood.

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Competing Interests

The authors declare no competing financial interests in relation to this work

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