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Original Article

Muscle force and power in obese and overweight children

R. Rauch[1], L-N. Veilleux[2], F. Rauch[2], D. Bock[1], E. Welisch[1], G. Filler[1], T. Robinson[1], E. Burrill[1], K. Norozi[1,3]

[1]University of Western Ontario, Department of Paediatrics, London, Ontario, Canada; [2]Shriners Hospital for Children, Montreal, Quebec, Canada; [3]Department of Paediatric Cardiology and Intensive Care Medicine, Medical School Hannover, Hannover, Germany

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Abstract

The study investigated differences in skeletal muscle function between obese and non-obese children using a force platform. Forty obese children and adolescents (age range 8 to 18 years; 21 girls) and 40 age- and sex-matched controls performed two tests: (1) single two-legged jump, a countermovement jump for maximal height; (2) multiple one-legged hopping on the forefoot, a test of maximal force. In the single two-legged jump, obese subjects had higher absolute peak force (1.62 kN vs 1.09 kN) and peak power (2.46 kW vs 2.06 kW), but lower body weight-related peak force (2.10 vs 2.33) and lower peak power per body mass (30.9 W/kg vs 41.6 W/kg). Jump height (29.3 cm vs 37.5 cm) and maximal vertical velocity (1.92 ms^{-1} vs 2.31 ms^{-1}) were reduced in obese children. In multiple one-legged hopping, obese subjects had 72% and 84% higher absolute peak force on the left and right foot, respectively. However, forces relative to body weight were 24% and 23% lower in the obese group than in the control group. In conclusion, obese children and adolescents have increased muscle force and power. This partly compensates for the effect of high body weight on muscle performance.

Keywords: Children, Obesity, Skeletal Muscle, Mechanography

Introduction

In Canada and in the United States, the prevalence of childhood obesity has tripled in the last two decades[1,2]. In obese children, skeletal muscle alterations are observed, such as increased muscle lipid content, raising concerns about the development of muscle function[3].

Even though changes in muscle function are among the key characteristics of physical development, its evaluation in the clinical context is typically limited to isometric muscle tests (e.g., grip force tests). Studies on muscle function in obese children are scarce. One study using an exercise ergometer (a sledge dynamometer), requiring a two-legged movement found that the generation of muscle power per unit of fat free mass was similar between obese and non-obese children[4]. A study on lower limb maximal power observed that obese children had increased power[5]. This was surprising given the previous finding by the same authors that muscle power development during jumping was impaired in obese individuals[6].

These tests, however, evaluated movements with which test subjects were not previously familiar, thus necessitating familiarization with equipment[4]. Muscle power, but not muscle force was evaluated[6]. In addition, none of the previous studies addressed the question whether the differences in muscle function observed between groups simply reflected a response to the larger inertia that a higher body weight opposes to the movement. We addressed these issues using a portable force platform that allowed measurements not only of muscle power but also of muscle force in everyday movements in tests that yield reproducible results in healthy children and adults and patients with chronic illnesses[7-10].

Patients and Methods

This is a cross-sectional study on 40 obese (body mass index, BMI, >95th percentile) and overweight (BMI between 85th and 95th percentile) subjects aged 8 to 18 years (19 male, 21 female) who had been referred to the Department of Paediatrics, University of Western Ontario, Canada, to enter a 12-months in-

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The authors have no conflict of interest.

Corresponding author: Frank Rauch, Genetics Unit, Shriners Hospital for Children, 1529 Cedar Avenue, Montreal, Quebec, Canada H3G 1A6
E-mail: frauch@shriners.mcgill.ca

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Parameter	Obese (n=40)	Controls (n=40)	p
Age (y)	12.5 (3.1)	12.3 (3.2)	0.67
Height (cm)	153.6 (3.1)	151.1 (2.4)	0.11
Weight (kg)	78.3 (17.8)	48.2 (28.6)	<0.001
BMI (kg/m^2)	32.1 (3.9)	20.3 (6.9)	<0.001
Single Two-Legged Jump			
Peak Force (kN)	1.62 (0.61)	1.09 (0.39)	<0.001
Peak Power (kW)	2.46 (1.01)	2.06 (0.94)	<0.001
Jump Height (cm)	29.3 (6.7)	37.5 (8.5)	<0.001
Peak Velocity (m/s)	1.92 (0.25)	2.31 (0.30)	<0.001
Peak Force per body weight	2.10 (0.27)	2.33 (0.36)	<0.001
Peak Power per body mass (W/kg)	30.9 (6.2)	41.6 (8.3)	<0.001
Multiple One-Legged Hopping			
Peak Force left leg (kN)	2.42 (0.35)	1.41 (0.58)	<0.001
Peak Force right leg (kN)	2.50 (0.29)	1.36 (0.51)	<0.001
Peak Force left leg per body weight	2.30 (0.63)	3.04 (0.59)	<0.001
Peak Force right leg per body weight	2.29 (0.73)	2.96 (0.52)	<0.001
Results are expressed as mean (SD).			

Table 1. Anthropometric and mechanographic data.

terventional program (diet and physical activity) for weight reduction through lifestyle changes. As a control group we recruited 40 age- and sex-matched healthy normal weight children and adolescents among children of hospital staff at the Shriners Hospital for Children in Montreal. An additional 10 healthy subjects (age: 8 to 18 years; mean 11.8 years) were recruited among children of UWO hospital staff to elaborate on the results obtained in the main study cohort (see Results section). Informed consent was obtained from all participants or their caregivers.

The mechanography measurement device (Leonardo® Ground Reaction Force Platform, Novotec Medical Inc, Pforzheim, Germany) is a quadratic platform with a side length of 66 cm and a height of 7 cm[9]. The platform is divided into two sections and can measure the applied forces from the right and left lower limb separately. Only the vertical component of the force is taken into account. The signal from the sensors is recorded by a portable computer. Data were analyzed using the Leonardo Mechanography GRFP Research Edition® software, version 4.2-b05.53-RES. The software uses the force and time data to calculate velocity of the movement, power, and jump height using the approach established by Cavagna[11].

The various maneuvers were explained to the participants in a standardized fashion. Each participant performed two different tests, as described in detail elsewhere[9]: A) Single two-leg jump: Individuals were asked to jump as high as possible using both legs in a counter-movement jump with freely moving arms. This evaluates a concentric contraction in the context of a stretch shortening cycle. B) Multiple one-legged hopping: This test consisted of 6 to 10 hops on one forefoot without hitting the ground with the heels. This results in an eccentric contraction of the calf muscles (muscles are lengthening while contracting during the downward movement). This stores the energy of the downward movement and creates larger forces than concentric or isometric contractions[9].

Statistical analysis was performed with the PASW Statistics software version 18.0 (SPSS Inc., Chicago, Illinois, USA), using the 2-tailed paired t-test. A $p<0.05$ was regarded as significant.

Results

Two of 40 participants of the study group were excluded as they were unable to perform the tests. 38 completed the study, as did all participants of the control group. The obese and the control groups differed in weight and BMI but not in age or height (Table 1). In the single two-legged jump, results for peak force and peak power were 49% and 19% higher, respectively, in obese subjects than in controls (Table 1). Nevertheless, obese children jumped on average 22% less high than controls, and their maximal vertical velocity during the take-off phase of the jump was 17% lower. Weight-related peak force and power in obese subjects were 10% and 26% lower, respectively, than in controls.

In multiple one-legged hopping, peak force on the left and right side were 72% and 84% higher in the obese group than in controls (Table 1). However, relative to body weight, these forces were 24% and 23% lower in the obese group than in the control group.

Next, we investigated whether the increased peak force during the multiple one-legged hopping in obese subjects was simply the result of the larger inertia that a larger body weight opposes to the movement. Multiple one-legged hopping was

Parameter	Without extra weight	With extra weight	p
Force left leg (kN)	1.15 (0.39)	1.19 (0.40)	0.44
Force right leg (kN)	1.21 (0.41)	1.20 (0.41)	0.72
Force left leg per total weight	2.72 (0.33)	2.47 (0.45)	0.02
Force right leg per total weight	2.83 (0.41)	2.45 (0.26)	0.002

Results are expressed as mean (SD).

Table 2. Multiple one-legged hopping in 10 normal-weight healthy children with and without the addition of external weight.

performed in 10 healthy children and adolescents with normal body weight who performed the test with and without the addition of a backpack that was tightly tied to their chest and that contained weights corresponding to 15% of the subjects' body mass. The addition of this external weight did not change the absolute peak force that these subjects could generate (Table 2).

Discussion

In this study, muscle performance of obese children and adolescents was evaluated using simple jumping and hopping tests that closely mimic everyday movements. The main findings are that obese children and adolescents have higher peak muscle force (unit: Newton, N) and peak power (unit: Watt, W) than normal-weight controls. Nevertheless, obese study participants achieved lower body weight-related peak force and power, and consequently had lower results for maximal velocity and jump height.

Results for peak power in the single-two legged jump resemble those of an earlier study where subjects were asked to accelerate their body upward on a tilted platform[4]. In that study as well as in the present one, obese children and adolescents had 19% higher absolute power than controls.

Given their higher absolute power and force results, why did obese study participants achieve lower peak velocity and jumping height than controls? The reason for this apparent discrepancy is that peak velocity and jumping height depend on the action of muscle against the resistance of body weight. The speed at take-off (and therefore jump height) depends on the acceleration of the body during the upward movement while the feet are pushing against the ground. Acceleration corresponds to the ratio between force and mass. A subject with higher mass therefore needs to produce a proportionately higher force to achieve the same acceleration. However, in our study, the obese and normal-weight groups differed more in body mass than in absolute force and power. Therefore, weight-related force and power and, consequently, peak velocity and jumping height, were lower in the obese group.

The second test performed in our study, multiple one-legged hopping, resulted in much higher absolute forces than the single two-legged jump. For example, the obese group generated an average of 2.50 kN while hopping on the right leg, but only 1.62 kN (both legs combined) during the single two-legged jump. The explanation for this difference is that muscles are able to generate much higher forces during eccentric contraction (such as landing on the forefoot during hopping, when muscle fibers are elongating) than during concentric contraction (such as during the take-off phase of the single two-legged jump, when muscle fibers are shortening)[12].

It is noteworthy that the absolute peak force during one-legged hopping was much higher in obese subjects than in controls. It appears unlikely that this was simply caused by the passive effect of the larger inertia that a larger body weight opposes to the movement. Indeed, our study demonstrated that normal-weight children and adolescents are not able to increase their peak force during multiple one-legged hopping when they are loaded with an extra weight. This suggests that the hopping test achieves the maximal force that an individual can generate with the lower extremities[9,13]. What is limiting the force output in this test can not be determined on the basis of the present data. One possibility is that a protective negative feedback mechanism (e.g., through force sensors in tendons) protects the system from generating forces that might cause tissue damage.

The observation that obese subjects were able to produce higher absolute forces in the one-legged hopping test therefore suggests that some biological adaptation had taken place in the obese subjects. The nature of such an adaptive process can not be examined in a cross-sectional study such as the present one, but it is well established that obese children and adolescents not only have higher fat mass but also higher fat free body mass than normal-weight controls[4,14]. Whether childhood obesity is also related to changes in tendon properties is unknown at present.

Whatever the mechanism of the putative adaptive mechanism, our results indicate that this adaptation only partly compensates for the effect of increased body weight on whole-body performance measures, such as jump velocity and jumping height. Our data do not allow answering the question why the musculoskeletal system of our obese subjects was not entirely adapted to the increased body weight. It is possible that the continuously increasing body weight simply exceeds the adaptive capacity of the musculoskeletal system. An alternative explanation is that our obese cohort was physically less active than controls.

In summary, our data demonstrate that obese children and adolescents have increased muscle force and power. This partly compensates for the effect of high body weight on muscle performance. Longitudinal and more detailed studies are required to elucidate the nature of this compensation mechanism and its determinants.

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