Journal of Strength and Conditioning Research, 2005, 19(3), 667–672

EFFECTS OF STRENGTH TRAINING ON BODY COMPOSITION AND BONE MINERAL CONTENT IN CHILDREN WHO ARE OBESE

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ABSTRACT. Yu, C.C.W., R.Y.T. Sung, R.C.H. So, K.-C. Lui, W. Lau, P.K.W. Lam, and E.M.C. Lau. Effects of strength training on body composition and bone mineral content in children who are obese. *J. Strength Cond. Res. 19(3):667–672. 2005.*—The purpose of this study was to test the hypothesis that strength training benefits diet-controlled obese children with respect to lean mass and bone mineral acquisition. Eighty-two Hong Kong school children (aged 10.4 ± 1.0 years, 70 in Tanner stage 1, 12 in stage 2) who were obese/overweight were randomly assigned to receive either a balanced low-energy (900–1200 cal) diet plus strength training (n = 41) (training group) or the diet alone (n = 41) (control group). The training group attended a 75-minute strength exercise program 3 times/week for 6 weeks (phase 1), after which they were offered and 22 children opted to continue a once-weekly program for a further 28 weeks (phase 2). All children were evaluated at baseline, after 6 weeks, and at the end of the 36-week study (including an intervening 2-week introduction to phase 2). Body composition and bone mineral content were measured by dual-energy X-ray absorptiometry, and diet was assessed by food-frequency questionnaire. The results showed that the exercise programs were well accepted, with good attendance at the exercise classes. After 6 weeks, the children in the training group showed significantly larger increases in lean body mass (+ 0.8 kg [2.4%] vs. +0.3 kg [1.0%], $p < 0.05$) and total bone mineral content (+46.9 g [3.9%] vs. +33.6 g [2.9%], $p < 0.05$) than those in the control group. At the end of the study, these trends were maintained in the continued-training subgroup, though no longer reaching statistical significance. We conclude that in diet-controlled prepubertal obese/overweight children, participation in an exercise program with emphasis on strength training resulted in improved lean mass and bone mineral accrual.

KEY WORDS. bone mineral density, resistance training, lean mass

INTRODUCTION

Bone mass generally correlates well with body weight both in adults and in children, but the relationship may not hold for obese children. Bone mineral density has been reported variously to be relatively higher (7) or to be comparable in obese prepubertal and early pubertal children (3, 11), but bone mineral content may be relatively lower (6, 26) than in the nonobese. Bone mineral status is of particular concern in childhood, which is a critical time for amassing bone mineral, and in relation to the potential consequences of dietary control, as is appropriate in obese children. In obese adults, it has been shown that total body bone mass and mineral density decrease after dietary weight reduction (1, 9). It is possible that dieting in obese children may also potentially prejudice the accrual of lean mass and bone minerals.

Adding strength (or resistance) training to a caloric restriction program in obese adults results in maintenance of lean body mass (5), but its effect on prevention of bone mineral loss has not been ascertained (1). Effects of strength training on obese children's body composition and bone mineral status have been little studied. It has been shown to increase lean body mass in one uncontrolled study of 15 obese children (22) and limited intra-abdominal fat accumulation in another controlled study of 11 girls (24). Strength training and increased lean body mass will be associated with increased muscle strength, and muscle strength correlates with bone density in adolescent children (19). Strength training in normal children and adults has been shown to increase their bone mineral density (10, 14, 16). Strength training is thus also likely to increase bone mass gain in obese children—a hypothesis which has not, to our knowledge, been tested.

The present study was accordingly undertaken to test the hypothesis that adding strength training in a dietary-control program for obese children may result in better lean mass and bone mineral accrual than a dietary-control program alone.

METHODS

Experimental Approach to the Problem

Overweight and obese children were recruited from 13 nearby primary schools and randomized into the dietary-control group (control group) or dietary-control plus strength-training group (training group). Hypocaloric diet was prescribed to both groups; strength training was given to the training group for 6 weeks during the summer vacation (phase 1). After 6 weeks, half of the children in the training group opted to continue their training for a further 28 weeks (phase 2). All children were maintained on diet control during the whole study period. Body composition and bone mineral content were measured, and dietary records of all children were assessed at the beginning, at 6 weeks, and at the end of the study.

The phase 1 study was conducted to test the hypothesis that adding strength training in a dietary-control program for obese children may result in better lean mass and bone mineral accrual than a dietary control program

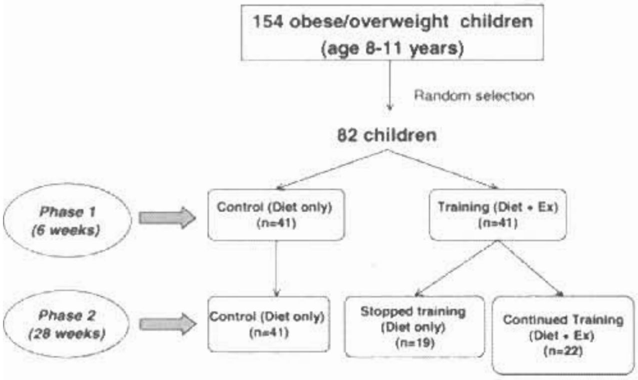

FIGURE 1. Trial profile.

alone. The phase 2 study was to determine the longer-term training effect and the results of detraining.

Subjects

Invitations were sent via schoolteachers to overweight or obese 8–11-year-old children in 13 local primary schools in Hong Kong. One hundred seventy children and their parents showed interest and underwent basic anthropometric measurements with an introductory explanation of the program. All children whose weight was greater than 120% median weight for height on a local growth chart (12) were further examined for medical conditions and sexual maturation by a pediatrician and a well-trained research assistant. Sexual development was assessed by using the Tanner staging of puberty, which included genital development for boys, breast development for girls, and growth of pubic hair for both sexes. Those with a history of renal or cardiovascular disease or steroid therapy and those whose sexual maturity status was more advanced than Tanner stage 2 were excluded. One hundred fifty-four children were eligible. Eighty-two were randomly selected for the study from a computer-generated list of numbers. Boys and girls, separately, were then randomized (by asking each child to select a sealed opaque envelope) into either the exercise training group (diet + strength training) or the control group (diet only) ($n = 41$ each). After 6 weeks (phase 1 of the study), the training group was divided into a (self-selected) continued-training subgroup ($n = 22$) and a stopped-training subgroup ($n = 19$) for a further 28 weeks (after an intervening 2-week introduction) (phase 2 of the study) (Figure 1). The study protocol was approved by the Ethics Committee of the Chinese University of Hong Kong. Informed consent forms were signed by of all participating children and their parents.

Measurement of Body Composition

Body weight was measured using an electronic body-weight scale (Seca Delta Model 707, Schmidt & Co., HK Ltd.) with subjects dressed in light T shirt and shorts. Height was measured using a Harpenden stadiometer (Holtain, United Kingdom). Body composition was determined by dual-energy x-ray absorptiometry (DXA; Hologic QDR-4500; Waltham, MA). A daily calibration test was performed before scanning the subjects according to the manufacturer's directions. Scans were performed with subjects in the supine position. The whole-body scan required 3–4 minutes using the fan beam model. It allowed for determination of total and regional (arms, trunk, and legs) lean tissue mass, fat tissue mass, bone mineral content (BMC), and bone mineral density (BMD). All measurements were conducted in the morning 2 hours postprandially. The coefficients of variation were 1, 0.6, and 1.5%, respectively, for total body, lumbar, and proximal femur BMC measurements. The coefficients of variation were 1 and 2.1, respectively, for lean tissue mass and fat mass measurements (13, 17). The same research staff performed all DXA scans at baseline, 6 weeks after training, and at the end of the program (36 weeks). After the scan was performed, the bone map was drawn manually and a standard data-analysis software (Hologic QDR-4500, version 9.80C) was used to process the data. We chose to use bone mineral content instead of bone mineral density as our primary outcome variable because as changes in bone density and geometry occur together in growing children, bone mineral content would better reflect the combined contribution of density and geometry to bone strength (4, 15).

Diet

All participating children were prescribed the same dietary educational program and scheduled to see the dietitian, who remained blinded to the randomization throughout the study. The diet prescribed was a balanced hypocaloric diet providing 900–1,200 kcals daily, low in fat (20–25%), and sufficient in protein (25–30%) to support growth (21). The prescribed menu was varied to suit each child's eating habits. The dietitian taught the parents and the child how to record food consumption. Portions were measured in terms of familiar volume and size and by reference to an atlas of local food portions. Dietary records of all children were assessed by a modified food questionnaire (25) at the beginning, at 6 weeks, and at 36 weeks of the program.

Training program

Phase 1. The 6-week exercise program for the training group, comprising 3 sessions per week, was planned for practical reasons to take place during the summer vacation (Table 1). Each session lasted 75 minutes and included 10 minutes of warm-up, 30 minutes of strength training, 10 minutes of aerobic exercise, 10 minutes of agility training, and 5 minutes of cool-down, with short rests between stations. The exercise training program was in circuit style, and each child had to go through 9 stations for strength training, 1 station for agility training, and 1 for aerobic exercise at each session.

Strength-training items in 8 of the stations were fixed. A 10-repetition maximum (10RM)—defined as the maximum amount of resistance that can be actively overcome for 10 repetitions—was determined for biceps curl, shoulder press, bench press, triceps extension, quadriceps extension, straight-leg raise, handgrip, and squat with sand bags on the shoulders. Training intensity was initially set at 75% of the individually predetermined 10RM by a physiotherapist and gradually increased to 100% according to individual progress. Children were required to finish 1 set of 20 repetitions of biceps curl, shoulder press, bench press, triceps exercise, quadriceps exercise, straight-leg raise, squatting with weight, and grip strength for 30 repetitions during each session. In the ninth station for strength training, children performed 1

TABLE 1. Training program phase 1 (3 sessions per week for 6 weeks).

	Exercises	Sets	Repetitions	Intensity
Warm-up (10 min)	Stretching exercises			
Strength (30 min)	1. Biceps curl	1	20	Started at 75% of individual 10RM
	2. Shoulder press	1	20	
	3. Bench press	1	20	
	4. Triceps extension	1	20	
	5. Quadriceps extension	1	20	
	6. Straight-leg raise	1	20	
	7. Squatting with weight	1	20	
	8. Grip strength	1	20	
	9. Sit-up	1	20	
	Back extension	1	20	
	Push-up	1	10	
	(one of the above 3)			
Agility (10 min)	Squat thrust, star jump, Z-run, run over rubber rings (one of the above 4)	—	—	—
Aerobic (10 min)	Stepper, treadmill, cycling, aerobic dance, games (one of the above 5)	—	—	60–70% predicted maximum heart rate for 10 min
Cool-down (5 min)	Stretching exercises	—	—	—

TABLE 2. Training program phase 2 (1 session per week for 26 weeks).

	Exercises	Sets	Repetitions	Intensity
Warm-up (15 min)	Jogging and stretching exercises			
Strength (40 min)				
First 12 wk	1. Squat thrust	2–3	10–15	Individually adjusted
	2. Sit-up crunch (on floor)	2–3	10–15	
	3. Abdominal circuit (lying)	2–3	10–15	
	4. Lying spinal twist	2–3	10–15	
	5. Push-up (on knees)	2–3	10–20	
	6. Biceps curl	2–3	10–20	
	7. Shoulder press	2–3	10–20	
	8. Modified squat	2–3	(1 min)	
13–26 wk	1. Squat thrust	3–4	15–20	
	2. Sit-up crunch (on floor)	2–3	15–20	
	3. Back extension	2–3	15–20	
	4. Biceps curl	3	15–20	
	5. Shoulder press	3	15–20	
	6. Leg raise	3	15–20	
	7. Flat/incline dumbbell fly	3	15–20	
	8. Reverse lunges	3	10	
	9. Prone push hold	1	(1 min)	
Cool-down (5 min)	Stretching exercises			

set of 20 repetitions of sit-ups or of back extensions or 1 set of 10 repetitions of push ups, in rotation in successive sessions. To stimulate the interest of the children, 4 items included squat thrust, star jump, Z-run, and run over rubber rings for agility training, and aerobic exercises—stepper, treadmill, cycling, aerobic dance, and games—were incorporated at each session. The intensity of aerobic exercise was maintained at 60–70% predicted maximum heart rate (monitored by pulse oximetry) for 10 minutes.

Phase 2. After this 6-week program, all children in the training group were offered a further 28-week training (continued training) but at the reduced frequency of once a week (Table 2). This second phase of training started 2 weeks after the end of the 6-week training program, to allow time for the interim assessment of body composition and physical fitness. Small groups of 4–6 children were supervised by a professional sports instructor and an assistant for a single 1-hour session per week. Each session started with 5 minutes of warm-up jogging and 10 minutes of stretching, and comprised 40 minutes of strength training, followed by 5 minutes of stretching exercises to cool down. Weights or repetitions loading were adjusted according to the children's individual abilities. The

TABLE 3. Body composition and bone mineral content (BMC) in control and training groups at baseline and changes at 6 weeks and 36 weeks relative to baseline.*

	Control			Training		
	Baseline ($n = 41$)	Change at 6 wk ($n = 41$)	Change at 36 wk ($n = 41$)	Baseline ($n = 41$)	Change at 6 wk ($n = 41$)	Change at 36 wk ($n = 22$)
Height (cm)	143.3 (6.5)	+1.8 (1.2)††	7.8 (2.6)††	146.0 (6.6)	+1.4 (1.0)††	+7.8 (1.7)††
Weight (kg)	51.0 (8.7)	−0.1 (2.2)	+5.3 (3.2)††	54.6 (9.2)	+0.6 (1.5)†	+6.1 (2.7)††
BMI	24.7 (3.0)	−0.6 (1.1)†	−0.1 (1.3)	25.5 (3.1)	−0.2 (0.8)	+0.1 (1.2)
Fat mass (kg)	19.3 (4.1)	+0.01 (0.9)	+1.5 (2.1)††	21.2 (5.3)	−0.03 (1.1)	+0.8 (2.4)
Lean mass (kg)	31.2 (4.9)	+0.3 (1.2)	+4.1 (2.4)††	33.0 (4.9)	+0.8 (1.1)††,*	+5.1 (2.4)††
% Fat mass	37.2 (3.3)	−0.2 (1.4)	−1.2 (2.9)†	38.0 (4.1)	−0.7 (1.5)†	−2.2 (3.0)†
BMC (g)						
Total	1,157 (202)	+33.6 (27.5)††	+202.7 (64.6)††	1,200 (195)	+46.9 (29.5)††,§	+236.2 (79.7)††
Hip	18.1 (3.9)	+0.4 (1.6)	+3.9 (2.5)††	19.0 (3.6)	+0.3 (1.6)	+3.7 (1.8)††
Lumbar	24.3 (7.4)	+0.7 (4.0)	+6.9 (4.7)††	25.5 (8.2)	+2.2 (3.5)††	+8.5 (5.9)††

* Values are mean (*SD*).

† $p < 0.05$.

†† $p < 0.001$ changes within groups compared with baseline.

§ $p < 0.05$ vs. control group.

strength-training exercises included 2–3 sets of 10–15 repetitions of squat thrusts, sit-up crunch (on floor), abdominal circuit (lying), and lying spinal twist, 2–3 sets of 10–20 repetitions of push-ups (on knees), biceps curls, and shoulder press, and 2–3 sets of 1-minute modified squat. After 12 weeks, the exercises were increased to 3–4 sets of 15–20 repetitions of squat thrust; 2–3 sets of 15–20 repetitions of sit-up and back extension; 3 sets of 15–20 repetitions of biceps curl shoulder press, leg raise, and flat/incline dumbbell fly; 3 sets of 10 repetitions on each side of reverse lunges; and a 1-minute prone push hold.

Statistical Analyses

Statistical analyses were performed using SPSS software (SPSS 10.0 for Windows; SPSS, Inc., Chicago, IL). Histograms were produced for all variables to exclude any skew in the presence of which the data would be transformed before comparing group differences. Baseline features were compared between control and training group by using Student's *t*-test. Paired *t*-test was used to compare the variables in each group at baseline with those after the 6-week intervention period and those at 36 weeks. The changes between different time points were again compared between the control and the training groups using the Student's *t*-test. Baseline data and changes at 6 weeks were compared between the continued-training subgroup and stopped-training subgroup to exclude potential selection bias in comparing outcomes. A value of $p \leq 0.05$ was considered to be statistically significant.

RESULTS

The 41 children in each group were generally well matched at baseline, each with 14 girls and with mean age 10.3 ± 1.0 and 10.5 ± 1.0 year in the control and the training groups, respectively. There were no significant differences in body weight, body composition, and bone mineral content at baseline (Table 3). Seventy children were in Tanner stage 1 and 12 were in stage 2.

Phase 1. None of the subjects dropped out during the 6-week summer training program. Mean overall attendance to the training sessions of each child was 83 ± 17%, and each session was attended by a mean of 83 ± 7% of children. Reasons for absence were mainly family traveling abroad or minor illness.

Phase 2. After the summer program, all children in the training group were invited to attend a continuing weekly training program. Nineteen (46%) declined the invitation, citing clash with school schedules as their main reason. Mean overall attendance of each child was 79 ± 11%, and each training session was attended by a mean of 78 ± 14% of children. Reasons for absence were mainly school-term examinations or minor illness. One boy in the control group broke his tibia while running down stairs during the study period. No children in the training groups sustained any injury during the study.

Body Composition and Bone Mineral Content

Height and weight increased with time, but body mass index and fat mass altered little (Table 3). Lean body mass increased more in the training than the control group at 6 weeks (+0.8 kg [2.4%] vs. +0.3 kg [1.0%], $p <$ 0.05). Total bone mineral content increased with time in both groups but slightly more in the training group at 6 weeks (+46.9 g [3.9%] vs. +33.6 g [2.9%], $p < 0.05$). No significant differences of the lean mass and bone mineral accrual between the 2 groups were observed at 36 weeks (Table 3).

Comparability of the Two Subgroups in Phase 2

The data suggest that self-selection of participants in the 2 subgroups might have contributed a small bias to the training effects of this second part of the study. There were no statistical significant differences in height, weight, or BMI between the continued-training and the stopped-training subgroups either at baseline or 6 weeks, but in those who discontinued the training, the percentage of body fat was significantly higher and percentage of lean mass significantly lower, both at baseline and after the 6-week intervention, than in those who continued training (all $p < 0.01$) (Figure 2). The changes of percentage body fat and lean mass between baseline and 6 weeks in the 2 subgroups did not differ from each other. There was no difference in attendance rate at the 6-week training classes.

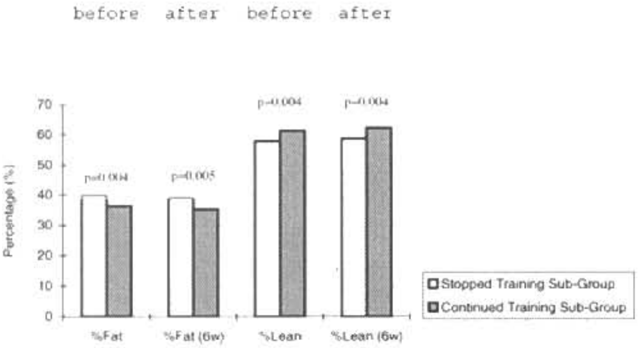

FIGURE 2. Percentage fat mass and lean mass in stopped-training and continued-training subgroup before and after the initial 6-week intervention of dietary control and exercise training.

Dietary Intake

The food-frequency questionnaire confirmed that dietary intake did not differ between the training and the control groups at the start of the study nor after 6 or 36 weeks. Calorie, carbohydrate, protein, and fat intake were all reduced relative to baseline after 6 weeks of the balanced low-energy diet of the study in both groups. By the end of the study, however, the intake of all these components except fat had risen to baseline levels in both groups (Table 4).

DISCUSSION

Our previous study showed that obese children perceived themselves to have poorer coordination, sports competence, physical flexibility and endurance, but greater strength (8). To increase their confidence and encourage them to participate in the exercise program, we put the emphasis on strength training and took advantage of the summer vacation to mount a special exercise regime. The good attendance at the exercise classes during the first 6 weeks showed that the program is workable. After the 6-week summer program, however, only 54% of obese children in the training group agreed to further training. Time commitments were cited as the main reason for declining to continue, but some self-selection relating to motivation may have contributed—a possibility supported by the finding that children in the continued-training group had less body fat at baseline and 6 weeks than those in the stopped-training group.

The hypothesis of this study is that strength training is beneficial to dieting overweight/obese children in terms of lean mass and bone mineral accrual. This hypothesis has been supported by our key findings: (a) a 6-week mixed exercise training program with predominant strength training resulted in a modest, but significantly greater, increase in lean mass and total bone mineral content than in the control group, who had diet control alone; and (b) these trends were maintained following a further 28 weeks of less-intensive strength training, though the differences were no longer statistically significant. The latter finding is not surprising, considering the limited training frequency during the phase 2 study.

Previous studies on strength training in children have been scanty. It has been generally believed that strength training does not increase the muscle mass in prepubertal children, and the strength gain after training has been attributed to neuromuscular adaptation (18). A few recent studies, however, showed some evidence that muscle mass may increase in response to strength training in prepubertal children (20, 23). Schwingshandl et al (20). showed that a group of 14 dieting boys and girls with a mean age of 11.0 years gained significantly more fat-free mass than their slightly older diet-only control group (12.2 years) after 12 weeks of strength training . Suman and colleagues also showed that a 12-week strength training exercise program increased muscle strength and mass in both preadolescent and adolescent children with burn injuries (23). We show a modest increase in total lean mass of 0.8 kg (2.4%) in the training group, which agrees with the previous 2 studies.

Even fewer previous studies investigated the effects of strength training on bone mineral content in children and adolescents. Blimkie et al. showed that there was a transient increase in lumbar spine bone mineral in a group of 16 adolescent females after the first half of a 26-week resistance training program (2). Nichols et al. showed that femoral neck bone mineral density increased significantly in the training group after 15 months of strength training. In their study, however, more than half of the girls dropped out from the exercise and control group (16). Morris et al. reported that a 10-month exercise program, which consisted of aerobic and strength training, significantly increased total-body bone mineral density by 3.5% in 38 normal-weight preadolescent girls (14). In our study, we showed a significant increase, 46.9 g (3.9%), in total bone mineral content in the training group at 6 weeks, which is in line with Morris's study. There is also a trend of more increase in total and lumbar bone mineral content and total and regional bone mineral density at the end of the study in the continued-training subgroup.

A major limitation that must be addressed regarding

TABLE 4. Daily dietary intake in control and training groups at baseline and changes at 6 weeks and 36 weeks relative to baseline.*

	Control			Training		
	Baseline (n = 41)	Change at 6 wk (n = 41)	Change at 36 wk (n = 41)	Baseline (n = 41)	Change at 6 wk (n = 41)	Change at 36 wk (n = 22)
Calories (Kcal/d)	1,675 (586)	−378 (656)†	+85.3 (796)	1,702 (684)	−242 (824)	+74.6 (660)
Carbohydrate (g/d)	232.9 (76.9)	−32.7 (87.3)	+39.6 (117.6)†	236.9 (81.7)	+1.5 (128.4)	+40.8 (102.7)
Protein (g/d)	73.3 (27.6)	−18.8 (29.6)‡	+6.4 (40.1)	76.0 (35.7)	−14.5 (33.2)†	+6.2 (35.8)
Fat (g/d)	50.5 (23.0)	−19.0 (27.5)‡	−10.6 (28.4)†	50.5 (29.5)	−20.3 (30.9)‡	−12.6 (21.3)†

* Values are mean (*SD*).

† $p < 0.05$.

‡ $p < 0.001$ changes within groups compared with baseline.

our study is that, for practical reasons, we did not have a group without any intervention to compare with the diet alone and diet plus strength-training groups. It is therefore impossible to draw a conclusion on the effect of dietary control on muscle mass and bone mineral in obese/overweight children. A second limitation is that our children did not reach the goal of reduced caloric intake of 900–1,200 cal in the first 6 weeks of study. The compliance to the diet was even poorer in the second phase of the study and hence there was no significant reduction in BMI. Nevertheless, it is encouraging that even with such a short study period there was a significantly greater increase in lean mass and a trend of decreasing percentage of body fat in the training group. Because oxygen consumption increases with increased lean mass, it is likely that obese children who receive strength training will burn more calories and decrease their body fat in the long run. There were multiple reasons for the suboptimal compliance to the diet; one important factor could be the inadequate reinforcement from the dietitian in our program (twice weekly for 6 weeks and twice only in the second phase). More stringent dietary control is necessary in further studies so that the effects of reducing diet on lean body mass and BMC in obese children could be better demonstrated.

In conclusion, our relatively short-term study showed that an exercise program with emphasis on strength training can have a modest, but significant, beneficial effect on lean mass and bone mineral accrual in prepubertal obese children.

PRACTICAL APPLICATIONS

This study provides evidence that strength training benefits preadolescent children who are obese/overweight in respect to lean mass and bone mineral accrual. Further research with more stringent dietary control and higher frequency of training over a longer term are necessary to confirm the effects of strength training on body composition and bone mineral change in dieting obese children.

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Acknowledgments

This project was supported by a grant from the Research Grants Council of the Hong Kong Special Administrative Region (project CUHK 4060/00M). We are most grateful to Professor Andrew Henderson for his critical review and constructive suggestions.

The study was conducted at the Bone Health Laboratory, School of Public Health, The Chinese University of Hong Kong.

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