DECREASED ABDOMINAL FAT AND IMPROVED BONE METABOLISM AFTER TAEKWONDO TRAINING IN OBESE ADOLESCENTS

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Abstract:

Accumulation of abdominal fat during adolescence is associated with early metabolic dysfunctions and interrupting bone metabolism. This study aimed at investigating the effects of taekwondo training on abdominal fat and bone metabolism in obese adolescents. Twenty male obese adolescents, with a body mass index above 95th percentile (BMI: 29.4±1.90 kg/m^2), aged 12-15 years, were assigned to the taekwondo training group (TKD, n=11) and control group (CON, n=9). Supervised taekwondo training was performed for 60 minutes/day, three times/week at 60-80% of participants' heart rate reserve for 16 weeks. Body composition and bone mineral density (BMD) were estimated by dual X-ray absorptiometry. A computerized tomography scan was applied to estimate total abdominal fat (TAF), abdominal visceral fat (AVF), abdominal subcutaneous fat (ASF), and AVF to ASF ratio (VSR). Blood samples were analyzed for adipocytokines (leptin and adiponectin) and bone turnover markers (osteocalcin – OC and C-terminal telopeptide – CTx). There were significant interaction effects between abdominal fat variables and training where TAF (p<.01) and AVF (p<.05) decreased in TKD group. Bone metabolism including bone formation (OC, p<.05) and resorption markers (CTx, p<.05) were significantly increased only in the TKD group. The present study suggests that taekwondo training can be an effective afterschool activity program for providing health benefits that include improving abdominal fat and bone metabolism in obese adolescents.

Key words: *abdominal fat, visceral fat, bone turnover markers, obese adolescent, taekwondo*

Introduction

Mounting evidence indicates that overweight and obesity continue to increase in adolescents (Ogden, et al., 2016). Obesity during adolescence is associated with cardiovascular disease, metabolic syndrome and premature death from endogenous causes (Batty, Calvin, Brett, Čukić, & Deary, 2016; Park, Falconer, Viner, & Kinra, 2012). Recent studies demonstrated that the location of accumulating fat tissue is important for dysmetabolic consequences during childhood and adolescence (Goran, Bergman, & Gower, 2001; Lawlor, et al., 2010; Slentz, Homard, & Kraus, 2009). Abdominal fat in particular plays a central role in increasing the risk of metabolic disease by up-regulating and secreting various inflammatory markers (Goran, et al., 2001). Furthermore, accumulation of abdominal fat adversely affects bone development in obese adolescents (Pollock, et al., 2010; Russell, et al., 2010). A previous study found that abdominal visceral fat is a negative predictor of whole-body and lumbar bone mineral density (BMD) in obese girls (Russell, et al., 2010). Another study of 140 overweight children showed that abdominal fat mass is inversely associated with bone mineral content, while fat mass shows positive relationships (Pollock, et al., 2010). It has been proposed that adipocytokines derived by adipose tissue, such as leptin or adiponectin, carry signals to bone, and abnormal status of these markers could disrupt bone metabolism (Cao, 2011). Plasma leptin concentration is a positive predictor of BMD, while adiponectin has the opposite effect (Russell, et al., 2010), but the results regarding these relationships are still unclear.

Physical activity (PA) and balanced nutritional intake play important role in managing fat deposits during adolescence (Lobstein, Baur, & Uauy, 2004). Increasing PA without energy restriction reduce whole body fat, but the information on the effect of PA on abdominal, especially visceral, fat is limited (Atlantis, Barnes, & Singh, 2006) despite increased accumulation of abdominal fat during adolescence (Jassen, Shields, Craig, & Tremblay, 2011; Mindell, Dinsdale, Ridler, & Rutter, 2012). Previous studies have reported that aerobic exercise reduces subcutaneous and visceral compartments of abdominal fat, while resistance exercise rarely provides such effects (Heijden, et al., 2010; Lee, et al., 2013). Recently, a combined exercise program (aerobic plus resistance exercise) has been introduced to reduce abdominal fat and increase BMD in obese adolescents (Campos, et al., 2013, 2014). However, it is important to note that exercise programs for obese adolescents should involve motivating factors (i.e., interest and pleasure), which enable them to carry exercise habits into adulthood. For this reason, adolescents readily participate in various sport-based activities, and the participation in these sports activities has resulted in fat loss and development of exercise habits (Basterfield, et al., 2015).

Given the nature of its training, taekwondo may be an appropriate exercise program for addressing the particular needs of obese adolescents. Taekwondo training is characterized by high-intensity intermittent training (Bridge, da Silva Santos, Chaabène, Pieter, & Franchini, 2014), which meets the exercise intensity guidelines recommended by the American College of Sports Medicine (Toskovic, Blessing, & Williford, 2002). It also involves various weight-bearing movements such as stepping, kicking, sparring, and self-defense, which generate relatively high ground-reaction forces that can lead to osteogenic activation. Taekwondo is a popular sport as well as a martial art in many countries, since it became an official Olympic event in 2000. It is marketed towards young children, especially in Korea. Several studies have focused on taekwondo training which enhances self-discipline, self-confidence and physical fitness (Fong & Ng, 2011; Kim, Stebbins, Chai, & Song, 2011; Lake, et al., 2013). However, health benefits of taekwondo training on abdominal fat and bone metabolism in obese adolescents are not well understood.

Therefore, the purpose of this study was to determine the effects of a 16-week controlled taekwondo training program on abdominal fat and bone metabolism in obese adolescents. Based on previous studies, we hypothesized that the 16-week taekwondo training would reduce abdominal fat and increase bone metabolism in obese adolescents.

Methods

Participants

The subjects of this study were recruited via a local advertisement. Thirty obese male adolescents with the body mass index above the 95th percentile referenced by the Center for Disease Control and Prevention (CDC, 2015), 12-15 years old, volunteered to participate in the study. Subjects were randomly divided into a taekwondo training group (TKD; n=15) and a control group (CON; n=15). Participants in TKD group completed 48 sessions of taekwondo training during the intervention period. Taekwondo training adherence exceeded 95%. However, ten subjects (four for TKD group and six for CON group) were excluded due to not meeting the completion criteria including personal reasons (two for TKD group; four for CON group), not completing the post-test (one for TKD group; two for CON group), or lack of interest (one for TKD group). Therefore, a total of 20 subjects (TKD, n=11; CON, n=9) participated in this study. All subjects had no metabolic disease and had no bone fractures during the past six months. They also did not participate in any other afterschool activity programs.

This study was conducted in accordance with the principals of the Declaration of Helsinki, and was approved by the Institutional Review Board at Kyung Hee University. Written informed consent was obtained from all subjects and their parents prior to participating in the study.

Study design

Subjects were randomly assigned to a TKD group or a CON group. The TKD group participated in their compulsory school physical education classes and three 60-minute periods per week of afterschool taekwondo training for 16 weeks. The control group only performed activities included in their physical education classes for the same period of time. Each subject was studied on two separate occasions: one week before the start of training program (baseline) and a week after the final taekwondo training session (post). Subjects were instructed to maintain a dietary pattern similar to what they followed prior to the study. All subjects limited their intense physical activity during the intervention.

Measurement

Physique and skeletal maturity

Standing height was measured to the nearest 0.1 cm using stadiometer (Takei, T.K.K., Japan), and body weight was measured to the nearest 0.1 kg using digital scale (Cas, 150A, Korea). Body mass index (BMI) was calculated as weight in kilograms divided by height in meters squared ($kg\cdot m^{-2}$). To assess skeletal maturity, X-rays were taken on their non-dominant hands and wrists by a portable X-ray (CORUS, Y. C., Growth Well), which was set at 56 kV at 1.5 mmAl for radiation dose. The Tanner-White method (TW3) was used to estimate skeletal maturity status of the 13 bones. Each bone was numbered and the radius-ulna-short bones (RUS) scores were calculated. The RUS score was converted into bone age according to Tanner, Healy, Goldstein, and Cameron (2001).

Body composition and BMD

Body composition and BMD were estimated by dual X-ray absorptiometry (DXA: QDR-4500W, Hologic, USA). Each subject had one whole body DXA scan, as well as lumbar spine, proximal femur, and forearm scans completed. All scans required subjects to lie on the DXA table in the supine position or, for the radius scan, to place the forearm flat on the DXA table. All four scans required -15 minutes and were conducted by the same technician. The coefficient of variance of scanning was maintained at less than 1.5% as indicated by the manufacturer. The reliability of the repeated measurements assessed by the intra-class correlation coefficients (ICC) were .99 for four sites of bone mineral density. Percent body fat, fat mass, lean body mass, and four sites of BMD were assessed from this scan.

Computerized tomography (CT; ECLOS, Hitachi, Tokyo, Japan) images were obtained from L4-L5 intervertebral disc space to quantify abdominal fat. The mean value of all pixels was within the range of -150 to -50. Hounsfield units (HU) was determined using a software program (fatPointer, Hitachi). Abdominal visceral fat area (AVF) was measured within the muscle wall surrounding the abdominal cavity, and the abdominal subcutaneous fat area (ASF) was calculated by subtracting the AVF from the total abdominal fat area (TAF). The ratio of AVF to ASF (VSR) was also calculated. CT images were acquired by the certified hospital technician. The ICCs for the AVF and ASF areas computations were .95 and .97, respectively.

Blood variables

Blood samples were collected before and after the intervention period. Prior to the sample collection, subjects were instructed to complete 12 hours of fasting. Venous blood samples were taken at the antecubital vein and separated into serum separation tube. The clotted blood was separated using centrifugation at 3000 rpm for 10 min. The samples were stored at -80°C. Adipocytokines, including leptin and adiponectin, were measured by enzyme-linked immunosorbent assay (ELISA) methods using leptin kit (E07, Mediagnost, Aspenhaustre, Germany) and adiponectin kit (E09, Mediagnost, Aspenhaustre, Germany). An immunoradiometric assay (IRMA) method was used for analyzing osteocalcin (OC), a marker of bone formation, with OC kit (Osteo-Riact, CISbio international, Gif-Sur-Yvette, France) by Immulite (Immulite 2000, UK). Cross-linked C-telopeptides of Type I collagen (CTx) was analyzed with ELISA method using CTx-I kit (AC-02F1, Immunodiagnostic System Ltd, Boldon, UK), a marker of bone resorption, by Multiskan EX (Thermo, China). Blood variables were reported in ng/ml (leptin, OC, and CTx) and ug/ml (adiponectin). The inter- and intra-coefficients of variance were 7% and 3% for leptin, 7% and 5% for adiponectin, 3% and 5% for OC, and 3% and 3% for CTx, respectively.

Taekwondo training program

The taekwondo training program was scheduled for 60 minutes a session three times per week for 16 weeks. The program was designed for beginners and utilized basic taekwondo movements. Each training session was preceded by 10 minutes of warm-up (light jogging, static stretching and sports specific exercise), followed by 40 minutes of main exercise (stepping, basic kicking, target kicking, basic movement, form training, sparring and taekwondo aerobic), and 10 minutes of cool-down (static stretching and meditation). The exercise intensity level was designed to result in a heart rate corresponding to 60-80% of heart rate reserve (HRR). To assure that the desired heart rate was maintained for 40 minutes of main exercise each subject wore a heart rate monitor (Polar, 5610i, USA). All subjects had no experience with taekwondo training for at least two years. During the intervention period, all subjects in both TKD and CON groups took part in their physical education classes that included team sports (e.g., basketball and soccer) and track-and-field sports (e.g., running and throwing) two times a week.

Questionnaires

Physical activity was assessed before and after the intervention period using the Physical Activity Questionnaire for adolescents (PAQ-A) (Kowalski, Crocker, & Donen, 2004). The questionnaire is a self-administered 7-day recall instrument, consisting of nine items with a 5-point Likert scale (1 = low, 5 = high). The mean score of these nine items represented the subjects' overall physical activity. Subjects also provided a 3-day dietary recall log before and after the intervention period. All data were analyzed using software program (CAN Pro 4.0, Korean Nutrition Society, Korea).

Statistical analysis

Statistical analyses of the data were computed using SPSS version 24.0 (SPSS Inc., Chicago, Illinois). All data were presented as means and standard deviations, or standard errors. 2 × 2 (group × time) repeated-measures ANOVAs were applied to examine the interaction effects. Analysis of covariance (ANCOVA) adjusted for height, body mass, physical activity level, and total energy intake as covariates was applied for bone parameters. Independent and paired *t*-tests were applied if any significant interaction or main effects were detected. Pearson's correlation analysis was applied to analyze the relationship between the percent changes of abdominal fat and BMD. A statistically significant level was defined as .05. Partial eta-squared (η^2p) was used to examine effect size. The effect size value indicated small (<.06), medium (.06-.14) and large (<.14) size (Cohen, 1988).

Results

Physique and skeletal maturity

At the baseline, there were no significant differences between the TKD and CON in the variables of interest, including bone age, body height, body weight, and BMI. Subjects' average bone age was a year in advance compared to their chronological age. There were significant interaction effects (group x time) for body weight (F=9.159, p=.007, =.34) and BMI (F=9.588, p=.006, η^2p=.35), where the TKD group decreased body weight and BMI from pre- to post-tests. There was a significant time effect for body height (F=58.254, p=.000, η^2p=.76) where both groups increased during the intervention period. The changes of physique and skeletal maturity are presented in Table 1.

Body composition and abdominal fat

There were significant interaction effects (group × time) for fat mass (F=6.681, p=.019, η^2p=.27) and lean body mass (F=6.288, p=.022, η^2p=.26) during the intervention period. A significant reduction in fat mass (F=14.139, p=.001, η^2p=.44) was observed only in the TKD group, while lean body mass increased only in the CON group. Percent body fat significantly decreased in both the TKD and CON groups (F=19.742, p=.001, η^2p=.50). In relation to abdominal fat, there were significant interaction effects (group x time) for TAF (F=8.385, p=.01, η^2p=.32) and AVF (F=5.063, p=.037, η^2p=.22). AVF and other variables (TAF and ASF) significantly decreased in the TKD group as well, whereas these variables did not significantly change in the CON group. The changes of body composition and abdominal fat are described in Table 2.

Bone mineral density

Analysis of covariance adjusted with body height, body mass, total energy intake and physical

Table 1. The changes of physique and skeletal maturity between pre- and post-tests in obese adolescents

	TKD		CON		F-value		
	Pre (M±SD)	Post (M±SD)	Pre (M±SD)	Post (M±SD)	Group	Time	G x T
Age (years)	13.9±0.94		13.9±0.60				
Bone age (years)	14.9±1.00		15.1±0.78				
Height (cm)	172.2±7.40	173.7±6.88**	168.7±7.18	170.4±6.60**	1.161	58.254††	0.190
Bodyweight (kg)	86.8±12.38	82.6±13.95**	84.6±8.89	85.7±7.88	0.008	3.148	9.159††
BMI (kg/m^2)	29.1±2.32	27.2±3.06**	29.7±1.29	29.5±1.31	2.196	14.658††	9.588††

Note. BMI: body mass index, G x T: group x time; *p<.05, **p<.01, a significant difference within group (pre- and post-test); †p<.05, ††p<.01, significant main or interaction effects

Table 2. The changes of body composition and abdominal fat between pre- and post-tests in obese adolescents

	TKD		CON		F-value		
	Pre (M±SD)	Post (M±SD)	Pre (M±SD)	Post (M±SD)	Group	Time	G x T
% body fat (%)	33.4±3.92	30.1±5.68**	35.7±4.94	34.3±4.77*	2.377	19.742††	2.538
Fat tissue (kg)	28.4±4.34	24.8±6.52**	29.4±2.68	28.7±3.19	1.626	14.139††	6.681†
Lean tissue (kg)	54.6±9.18	54.3±9.03	51.4±8.82	53.3±7.70**	0.294	3.335	6.288†
BMC(kg)	2.3±0.30	2.4±0.30**	2.2±0.38	2.3±0.37**	0.372	225.950††	0.153
Abdominal fat							
TAF (cm^2)	350.1±59.64	298.9±84.36**	352.0±42.78	354.9±35.70	1.270	6.687†	8.385††
AVF (cm^2)	47.7±15.05	41.6±16.34**	45.7±12.03	52.3±18.64	0.455	0.009	5.063†
ASF (cm^2)	298.3±48.22	256.4±74.18*	306.3±41.90	300.1±44.49	1.311	6.139†	3.381
VSR (ratio)	0.16±0.05	0.17±0.05	0.15±0.05	0.18±0.09	0.009	2.799	1.625

Note. ASF: abdominal subcutaneous fat; AVF: abdominal visceral fat; BMC: bone mineral content; G x T: group x time, TAF: total abdominal fat; VSR: AVF/ASF; *p<.05, **p<.01, a significant difference within group (pre- and post-test); †p<.05, ††p<.01, significant main or interaction effects

Table 3. Changes in bone mineral density (BMD) between pre- and post-tests in obese adolescents

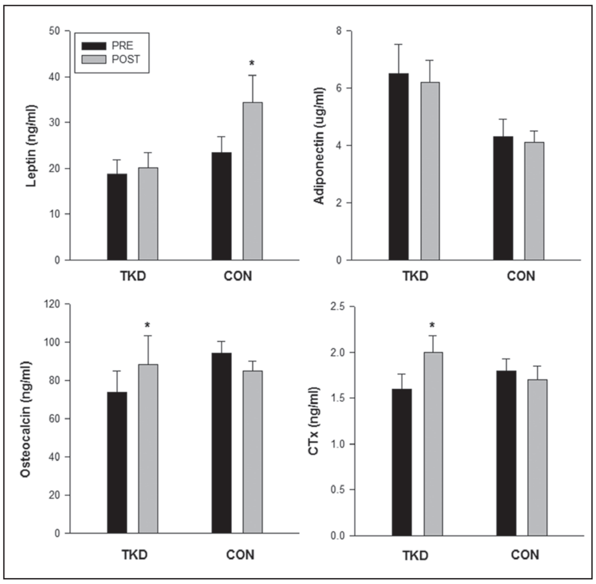
	TKD		CON		F-value		
	Pre (M±SE)	Post (M±SE)	Pre (M±SE)	Post (M±SE)	Group	Time	G x T
Total body BMD (g/cm^2)	1.04±0.03	1.08±0.03**	1.01±0.03	1.06±0.03**	0.288	108.529††	0.115
Lumbar BMD (g/cm^2)	0.89±0.03	0.93±0.03**	0.85±0.03	0.87±0.03	1.085	25.561††	0.940
Femur BMD (g/cm^2)	0.99±0.03	0.98±0.02	0.93±0.03	0.95±0.03	1.443	0.169	1.482
Forearm BMD (g/cm^2)	0.48±0.02	0.49±0.02	0.48±0.02	0.49±0.02	0.009	8.982††	0.002

Note. Adjusted with height, body mass, physical activity level, and total energy intake as covariates.
G x T: group x time; $^{*}p<.05$, $^{**}p<.01$; between pre- and post-test; $^{\dagger}p<.05$, $^{\dagger\dagger}p<.01$, significant main or interaction effects

activity level as covariates was applied to establish bone parameters. There were no significant interaction effects (group × time) for total body, lumbar, femur and forearm BMD during the intervention period. However, significant time effects for total body (F=108.529, p=.000, η^2p=.89), lumbar (F=25.561, p=.000, η^2p=.70), and forearm BMD (F=8.982, p=.010, η^2p=.41) were observed. Total body BMD increased significantly in both TKD and CON groups, while lumbar BMD significantly increased only in the TKD group. The changes of bone mineral density are shown in Table 3.

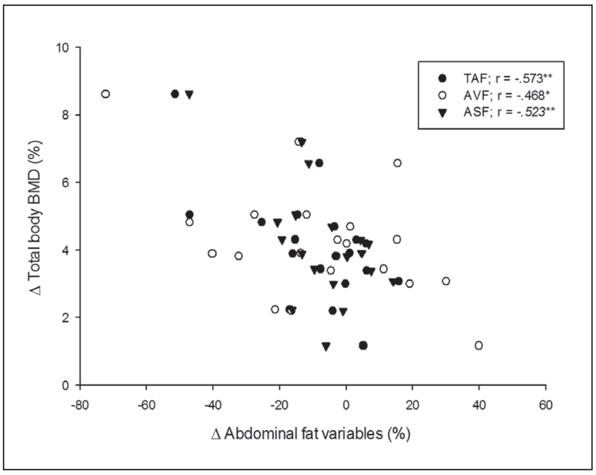
Adipocytokines and bone metabolism

The changes of adipocytokines and bone turnover markers are described in Figure 1. There was a significant interaction effect for plasma leptin level (F=6.203, p=.023, η^2p=.26) where the CON group increased greater than the TKD group. However, there was no significant interaction effect on plasma adiponectin level. In relation to bone metabolism, there were significant interaction effects (group x time) for osteocalcin (F=6.909, p=.02, η^2p=.28) and CTx (F=8.255, p=.01, η^2p=.31). Osteocalcin and CTx were significantly increased in the TKD group, whereas these variables did not significantly change in the CON group.



Note. $^{*}p<.05$; between pre- and post-tests

Figure 1. Changes in adipocytokines (leptin, adiponectin) and bone turnover markers (osteocalcin and CTx) between pre- and post-tests in obese adolescents.



Note. ASF: abdominal subcutaneous fat; AVF: abdominal visceral fat; TAF: total abdominal fat; $^{*}p<.05$, $^{**}p<.01$, significant correlations between the variables

Figure 2. Correlations between percent changes of abdominal fat variables as a function of total body BMD in obese adolescents.

Relation between abdominal fat and BMD

There were inverse relations between percent changes of abdominal fat variables (TAF; p<.01, AVF; p<.05, ASF; p<.05) and total body BMD (Figure 2). However, no significant relations between adipocytokines and bone turnover markers were observed in this study.

Discussion and conclusions

This study was designed to determine the effects of taekwondo training on abdominal fat and bone metabolism. To the best of our knowledge, this is the first approach that applied taekwondo training to obese adolescents for the investigation of abdominal fat and bone metabolism. The major findings of this study were that taekwondo training reduced abdominal, especially visceral, fat and increased bone turnover markers.

Bone age commonly provide the information of skeletal maturity during childhood or adolescence (Tanner, et al., 2001). Early maturity is defined when a child possesses a bone age of three or more months in advance of their chronological age (Van Lenthe, Kemper, & Van Mechelen, 1996). The average bone age of our subjects was almost a year in advance compared to their chronological age.

Over the last several years, accumulation of abdominal fat during childhood and adolescence has attracted attention, because abdominal fat, and especially visceral fat, was proposed to be associated with early metabolic dysfunction (Goran, et al., 2001; Lawlor, et al., 2010; Slentz, et al., 2009). Exercise has been introduced as a preventative and non-pharmacological treatment for adolescents with abdominal obesity. Recently, combined exercise (aerobic plus resistance) and high-intensity interval exercise have been introduced as a progressive strategy to control obesity in adolescents (Campos, et al., 2013, 2014; Dâmaso, et al., 2014; De Mello, et al., 2011). In the present study, application of taekwondo training for 16 weeks led to a significant reduction in visceral fat (-12.3%) as well as in overall fat variables (percent body fat, fat mass, total abdominal fat). Taekwondo training was conducted in the current study at a relatively high intensity with intermittent movements (60-80% of HRR), including various stepping, kicking, punching, and sparring movements. Taekwondo consists of various kicking skills such as front, side, and roundhouse kicks performed by a twisting motion between upper and lower body. The movements require high energy due to the usage of large muscle groups with explosive movements. We assumed that these intense movements would enhance the acceleration of fat burning, especially abdominal fat. According to the Compendium of Physical Activities, moderate pace of taekwondo training represents a vigorous activity (10.3 METs), and the activity level was greater than in other sports activities including basketball games (8 METs), soccer games (10 METs), tennis training (7.3 METs), and volleyball games (6 METs) (Ainsworth, et al., 2011). There was no significant change in lean body mass in the TKD group, while it significantly increased in the CON group (4.3%). Although it is known that resistance training elicits substantial gains in lean body mass even in young people, taekwondo training has previously been shown not to promote comparable lean body mass gains in obese adolescents (Kim, et al., 2011). Moreover, adolescence is a critical period during growth which involves an increased role of sex hormones for body height and body composition (Malina, Bouchard & Bar-Or, 2004). A previous study reported that body fat decreased and lean body mass increased in sedentary obese boys during puberty (Brufani, et al., 2009). In addition, energy expenditure in the TKD group may have reduced calories for lean body mass and utilized calories for fat mass. This could possibly explain why lean body mass increased and percent body fat decreased in the current CON group during the intervention period. Although, the present study did not observe the persistence of training-induced adaptation, we assume that intense taekwondo training may be beneficial for maintaining stable condition of fat mass. A previous study reported that both moderate and high intensity resistance training decreased BMI and sum of skinfold thickness, but the training-induced adaptations only remained in the high intensity training group after 24 weeks of detraining (Fatourous, et al., 2005).

Adipose tissue secretes various adipocytokines such as leptin and adiponectin, and it plays an important role in energy metabolism (Meier & Gressner, 2004). The current study did not show any positive change in plasma leptin level in the TKD group, while this value greatly increased in the CON group (56.1%). Weight loss programs by various exercises and caloric restrictions have been shown to decrease serum leptin levels (Ackel-D'Elia, et al., 2014; Elloumi, et al., 2009b; Kim, et al., 2007). Moreover, a significant elevation in serum leptin levels often occurs from the prepubertal years into early puberty (Clayton, et al., 1997). Adiponectin concentration did not change in either the TKD or CON group after 16 weeks of the intervention. Adiponectin concentration has not been changed by weight loss with exercise training despite a significant reduction in fat tissue and improvement in insulin sensitivity (Hulver, et al., 2002; Bodou, Sobngwi, Mauvais-Jarvis, Vexiau, & Gautier, 2003; Chae, et al., 2013; Nassis et al., 2005).

Bone mass increases during the first two decades of growth period and reaches a peak in the late-teens and early adulthood (Baxter-Jones, Faulkner, Forwood, Mirwald, & Baley, 2011). Accelerating bone turnover markers during adolescence have a positive effect on BMD (Jürimäe, Mäestu, & Jürimäe, 2011), whereas they have an inverse effect during middle-aged adults (Hinton, et al., 2012). The current study found that bone turnover markers (OC: 19.7%, CTx: 25.4%) increased after 16 weeks of taekwondo training in obese adolescents. A previous review study summarized that early pubertal children could increase bone mass up to 3.9% by engaging in weight-bearing exercise over a 6-month period (Hind & Burrows, 2007).

In the present study, a greater increase in lumbar BMD (3.8%) was observed after 16 weeks of taekwondo training. This is partly due to the characteristics of taekwondo training. Taekwondo training is performed with weight-bearing movements that stimulate the bone anabolic response during adolescence (Shin, Jung, & Kang, 2011). A greater mechanical loading by taekwondo training during adolescence seems to stimulate lumbar bone mineral density more than any other site of BMD in the present study. A previous study on high-school girls who trained taekwondo for over five years showed higher BMD than a control group (Shin, et al., 2011) supports our results. Another study demonstrated that football athletes who experienced high impact on bones showed higher BMD and bone metabolism (OC and CTx) than their counterparts (Elloumi, et al., 2009a). It should be noted that the increase in OC following weight loss may reflect the endocrine response of bone to changes in energy balance. We therefore suggest that taekwondo training increases osteogenic activity, which affects fine regulation of bone metabolism during adolescence.

The present study revealed that percent changes of abdominal fat variables were inversely related with BMD in obese adolescents. Previous studies support the current results that accumulation of abdominal fat was inversely related with BMD during adolescence (Campos, et al., 2013; Pollock, et al., 2010; Russell, et al., 2010). The mechanism underlying these relations have been known to relate with fat-bone metabolic signaling. It is believed that adipocytokines derived from fat tissue influence the regulation of bone metabolism (Cao, 2011). However, the present study did not show any relation between adipocytokines and bone turnover markers. In support of the current research, a recent study showed that plasma leptin and adiponectin levels were not associated with bone mineral parameters (OC and CTx) in both active and non-active pubertal boys (Vaitkeviciute, et al., 2016).

The lack of direct measurement of physical activity level and nutrition intake could be seen as a limitation of our study. However, PAQ-A and dietary records were collected between pre- and post-tests to monitor the environmental factors, which could have effected subjects' total energy expenditure. Although the physical activity level (TKD: pre=1.7±0.33 pt, post=1.9±0.30 pt; CON: pre=1.8±0.40 pt, post=1.7±0.55 pt) and total energy intake (TKD: pre=1708.5±202.90 kcal, post=1735.2±209.73 kcal; CON: pre=1618.2±82.00 kcal, post=1664.6±108.83 kcal) did not vary between groups, and the potential influence of dietary intake or physical activity level could be dismissed. Another limitation of this study was the fact that lean body mass significantly increased in CON group but not in TKD group between pre- and post-tests. One possible reason for this inconsistency might be differences in skeletal maturity level between the two groups. Several studies demonstrated that early-maturing adolescent boys have larger measurements of muscle and fat than late-maturing adolescent boys (Malina, Bouchard, & Bar-Or, 2004). As such, it is unclear if the changes in body composition that we observed could be maintained over a longer period of time.

In conclusion, the present study revealed that a 16-week taekwondo training program reduced abdominal fat, particularly visceral fat, and increased bone metabolism in obese male adolescents. We believe that our findings suggest a taekwondo afterschool activity program could be effective in improving abdominal fat and osteogenic activities in obese adolescents.

Practical applications

Increasing evidences indicate that prevalence of obesity with accumulation of abdominal fat during adolescence has increased worldwide (Jassen, et al., 2011; Mindell, et al., 2012). Recent studies reported that the accumulation of abdominal fat creates severe health problems, inducing metabolic dysfunction and bone fractures during adolescence (Pollock, Bernard, Gutin, Davis, Zhu, & Dong, 2011). The present study showed positive effects of taekwondo training (60 minutes/session, three times a week, 60-80% HRR) on reducing abdominal fat and increasing bone metabolism. With current level of evidence, we believe taekwondo training could be an optimal afterschool activity program for obese adolescents.

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