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GRADE / DEGREE

School of Human Kinetics

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**Body Composition, Cardiorespiratory and Musculoskeletal Fitness in
Obese Adolescents Aged 14 to 18 Years Old**

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**BODY COMPOSITION, CARDIORESPIRATORY AND MUSCULOSKELETAL
FITNESS IN OBESE ADOLESCENTS AGED 14 TO 18 YEARS OLD**

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Thesis submitted to the
Faculty of Graduate and Postdoctoral Studies
in partial fulfillment of the requirement for the degree of
Master's of Science in Human Kinetics

Faculty of Health Sciences, School of Human Kinetics

University of Ottawa, Ottawa, Canada

2008

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Ottawa ON K1A 0N4
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Your file *Votre référence*

ISBN: 978-0-494-46461-8

Our file *Notre référence*

ISBN: 978-0-494-46461-8

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ACKNOWLEDGEMENTS

This master's project would not have been possible without the help of some truly outstanding individuals I had the privilege of meeting along the way.

Firstly, I would like to thank Dr. Denis Prud'homme for introducing me to the HEARTY study. I've learned to strive for excellence through his rational and constructive comments he has provided me over the last two years.

I am forever grateful to Dr. Glen Kenny who provided me the opportunity to become involved in all aspects of the HEARTY study. His open-door policy, kindness and helpful demeanor have allowed me to accomplish several goals.

Although far away, Dr. Ron Sigal has helped tremendously with the realization of this project. Dr. Sigal's insightful suggestions do not go unrecognized and I am truly grateful for all the extra time and hard work he has contributed to my numerous research projects.

A big thanks to my knowledgeable committee members, Dr. Eric Doucet and Dr. Stasia Hadjiyannakis for their time and commitment in providing me with great advice and constructive feedback that have steered me in the right direction. Many thanks extend to the multidisciplinary HEARTY team, especially Penny Phillips, for her great organization, patience and endless hard work.

This experience would not have been the same without my fellow thermoregulation lab colleagues that have provided great friendship and support, always with a smile. I also want to thank Dr. Ollie Jay for always making time for some great 'stats chats' that have truly helped me along the way.

I must acknowledge a true inspiration of mine in my undergraduate years that motivated me to pursue research in the field of childhood obesity. I must admit that Dr. Joanna Komorowski's passion and strength of character are contagious, and I aspire to leave a mark as she has done in the future of my academic career.

Throughout the last two years, I was lucky enough to have my family and long-time best girlfriends offer me timely distractions and endless support from home. I would like to conclude by thanking my mom, dad and my sister Steph for their love and unprecedented support and encouragement throughout my studies and their understanding for being away from home for a little while to achieve my goals.

ABSTRACT

Background:

The short and long term consequences of childhood obesity are widespread, highlighting the necessity of designing effective interventions targeting the specific needs of obese adolescents. Obese children typically score lower on standardized fitness tests compared to their leaner peers. However, few studies have looked at the relationship between musculoskeletal fitness and obesity in adolescents. Sex differences in fitness and adiposity are important considerations that also warrant further investigation.

Objectives:

- 1) To compare the musculoskeletal fitness of obese adolescents in the Healthy Eating Aerobic and Resistance Training in Youth (HEARTY) trial to the norms of the Canadian population in the same age group. A secondary objective was to determine the sex differences in musculoskeletal fitness in the HEARTY study.
- 2) To determine the sex differences in abdominal adiposity and cardiorespiratory fitness in male and female participants in the HEARTY study. The secondary purpose was to examine the relationship between cardiorespiratory fitness and fatness in male and female obese adolescents.

Methods:

- 1) 134 female and 45 male participants were included in the analysis. Musculoskeletal fitness was assessed by the Canadian Physical Activity Fitness and Lifestyle Approach guidelines to assess muscular strength, endurance and power. Measures of grip strength, push-ups, curl-ups, sit and reach and vertical jump in the HEARTY study were compared to the Canadian Musculoskeletal norms in their age group.
- 2) 94 female and 30 male participants were included in the analysis. VO_2 peak was assessed using a maximal treadmill protocol until exhaustion and abdominal adiposity was quantified by one-single cross-sectional image at L4-L5 by Magnetic Resonance Imaging.

Results:

- 1) Obese adolescents ranked lower on most musculoskeletal fitness tests compared to their non-obese peers. However, obese females had greater grip strength compared to their non-obese female counterparts. Males in the HEARTY study had a higher grip strength and vertical jump whereas females had higher push-up, and sit and reach scores than males in the HEARTY study.
- 2) HEARTY males had a greater BMI, visceral adipose tissue and higher VO_2 peak compared to females. There was no difference in abdominal subcutaneous adipose tissue between sexes.

Conclusions:

- 1) Male and female obese adolescents have lower musculoskeletal fitness compared to their non-obese peers. Obese males also had a lower overall musculoskeletal fitness ranking compared to obese females in the HEARTY study.

2) Obese male adolescents have greater visceral fat and higher cardiorespiratory fitness than obese females. However, it appears that the negative relationship between cardiorespiratory fitness and fatness is similar between male and female obese adolescents.

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1. INTRODUCTION

1.1 General Problem

Pediatric obesity has become a great public health concern. With readily available energy dense fast foods and a relative increase in sedentary lifestyle, the incidence of obesity continues to increase at an inexorable rate. The prevalence of obesity has become more apparent in pediatric populations than in adults (Tremblay, Katzmarzyk and Willms, 2002). In the past 20 years, childhood obesity has reached worldwide epidemic proportions (Wang, 2001; James et al., 2001; James, 2004; Deghan, Akhtar-Danesh and Merchant, 2005). In 2005, approximately 20 million children worldwide under the age of five were considered overweight (World Health Organization, 2006). In 2004, Statistics Canada published the Canadian Community Health Survey reporting an increase of 11% in the prevalence of obesity from 1979 (15%) to 2004 (26%) (Shields, 2004). Furthermore, in 2004, 26% of children in Canada were considered overweight and 8% of which were classified as obese (Shields, 2004). Interestingly, this survey reports 26% of Canadian children are overweight compared to 27% of children in the United States in 2004 (Shields, 2004). In Canada, obesity rates are similar between boys (9%) and girls (7%) (Shields, 2004). A comprehensive review of international obesity rates also shows no sex predominance of obesity prevalence between sexes in children and adolescents (Sweeting, 2008). Given the multitude of factors involved in the etiology of obesity, obese children are constantly confronted with health issues and difficulties in treating their condition. Although several treatment options exist, the vicious cycle of pediatric obesity remains and interventions continue to be unsuccessful. While the prevalence of childhood obesity is comparable among boys and girls, there are sex differences that may

have important implications on exercise intervention outcomes within this younger population.

1.2 Specific Problem

The vicious cycle of childhood obesity (Malina, Bouchard, Bar-Or, 2004; Sothorn, Hunter, Suskind et al., 1999; Sothorn, Loftin, Suskind et al., 1999) prevents children from participating in physical activities due to their excess weight, perceived barriers (Zabinski et al., 2003) and decreased exercise tolerance when they engage in physical activity (Malina, Bouchard, Bar-Or, 2004; Sothorn, Loftin et al., 1999). It is assumed that less than 20% of obese children initiate treatment for their condition (Nemet et al., 2005). Developing efficient prevention and treatment strategies for obese adolescents is critical, and should begin in infancy and continue throughout the lifespan to alleviate more profound health consequences in adulthood (Daniels et al., 2005).

The problems encountered with adherence and compliance to exercise interventions can be ameliorated if exercise prescription is modified according to an obese child's strengths and perceived competence. Children will adhere to exercise programs that are varied (Sung et al., 2002; Faigenbaum et al., 2002) and fun (Daniels et al., 2005; Faigenbaum et al., 2002). Some studies also provided rewards for children to positively reinforce their participation in the exercise program (Sothorn, Loftin et al., 1999, Sothorn, Hunter et al., 1999; Ferguson, et al., 1999; Sung et al., 2002). Children will participate most in activities they enjoy, thus, an individualized exercise program should be based on a child's strength, size and maturity and needs to incorporate a multitude of exercises to alleviate the possibility of boredom in children (Faigenbaum and Kang, 2005).

It is evident that obese children experience more difficulties when exercising than their normal weight peers. Obese children typically score lower on standardized fitness tests compared to their leaner counterparts (Deforche et al., 2003). However, this observation has primarily been based on cardiorespiratory fitness, mostly in pre-pubertal populations (Kim et al., 2005). However, little is known about the musculoskeletal fitness of obese adolescents relative to the norms of the Canadian population within this age group. The association between musculoskeletal fitness and adiposity warrant further investigation in obese adolescents given the increased morbidity and mortality rates associated with poor musculoskeletal fitness in adults (FitzGerald et al., 2004). Information gathered on musculoskeletal fitness, especially sex comparisons, could help design exercise prescriptions tailored to the adolescents' strengths and weaknesses.

Obese children, especially girls, report more barriers to exercise than their non-obese counterparts (Zabinski et al., 2003). This creates a difficult obstacle when endorsing physical activity in overweight children (Zabinski et al., 2003) and further exacerbates the health problems associated with childhood obesity. To design appropriate exercise programs for children and adolescents, a sex comparison becomes an important consideration that may improve adherence and treatment outcomes. Little is known about the sex differences in adiposity distribution, musculoskeletal and cardiorespiratory fitness in obese adolescents.

To optimize positive exercise outcomes in obese adolescents, the need for large, randomized controlled trials examining the effects of different exercise modalities are crucial. By evaluating fitness and body composition of both male and female adolescents with weight problems, novel exercise programs could better cater to their needs to

increase exercise program compliance and beneficial results. Notably, a comprehensive literature review established that very few prevention and intervention programs exist targeting each sex separately, especially to meet the specific needs of boys (Flynn et al., 2006). Great successes of specific programs targeting adolescent girls only, such as ‘New Moves’ (Neumark-Sztainer et al., 2003) support the notion of designing sex-specific interventions to improve results during this vulnerable age. Epstein, Paluch and Raynor (2001) actually demonstrated that sex differences seen with intervention outcomes may be more prevalent in adolescence than in younger children.

1.3 Objectives

The primary objective of the **Healthy Eating Aerobic and Resistance Training in Youth (HEARTY)** randomized controlled trial is to evaluate the effects of resistance training, cardiorespiratory training, combined cardiorespiratory and resistance training on percent body fat in sedentary post-pubertal overweight or obese adolescents aged 14 to 18 years old. However, for the purpose of my thesis, two separate objectives were outlined for both articles written. For Article I, the purpose of my research was to compare musculoskeletal fitness in our sample of obese adolescents in the HEARTY study to the norms of the Canadian population in the same age group. We also examined sex differences in musculoskeletal fitness tests as designed by the Canadian Physical Activity Fitness and Lifestyle Approach for muscular strength, endurance and power (grip strength, push-up, sit and reach, partial curl-up and vertical jump) between the obese males and females of the HEARTY study. For Article II, we assessed sex differences in anthropometry (waist circumference and BMI), abdominal adiposity

(subcutaneous adipose tissue and visceral adipose tissue) and cardiorespiratory fitness ($\dot{V}O_{2peak}$) in the HEARTY participants.

1.4 Hypotheses

For Article I, we hypothesized that the HEARTY participants would rank lower in overall musculoskeletal fitness relative to the norms of the Canadian population, except in static strength in the same age category. We also hypothesized that males will score higher in most musculoskeletal fitness tests compared to females.

For Article II, we hypothesized that males would have greater visceral adiposity yet there will be no differences in cardiorespiratory fitness between males and females. However, we predicted that females will have greater subcutaneous fat compared to males, although the negative relationship between cardiorespiratory fitness and fatness will be similar in both sexes.

1.5 Relevance

This study will advance our understanding of musculoskeletal fitness in obese adolescents relative to normal weight adolescents. Most studies have focused on cardiorespiratory fitness, whereas very few studies have assessed musculoskeletal fitness in obese youth (Deforche et al., 2003; Prista et al., 2003; Kim et al., 2005; Malina et al., 1995). Furthermore, we will grasp a better understanding of the sex differences in fitness and adiposity and the relationship between cardiorespiratory fitness and fatness in obese male and female adolescents. The results of this study will help to identify the differences in cardiorespiratory and musculoskeletal fitness that can be used for proper design of exercise interventions catering to the needs and physical differences, if observed,

between sexes. This newly acquired knowledge could be disseminated to school boards and youth training centers to incorporate into their physical education curriculum and enforce different exercise modalities as beneficial programs in youth exercise training. This research can broaden the scope of more effective treatment options suited to younger obese populations, making adherence to exercise programs more appealing and worthwhile. Assessing the musculoskeletal fitness of our sample of obese adolescents is of clinical importance given that improvements in musculoskeletal fitness may attenuate age-related weight gain and obesity risk in adults (Mason et al., 2007). Information gathered on sex differences in musculoskeletal fitness and adiposity could contribute to design a more appropriate exercise protocol to target the areas that need improvement. Interestingly, Barbeau et al. (1999) studied pre-pubertal obese boys and girls aged 7-11 years and showed that more beneficial changes in body composition post-exercise intervention were associated with being a boy, higher compliance rates, lower dietary intake and more vigorous physical activity.

1.6 Limitations and Delimitations

The results of this study may not apply to lean and active children under the age of 14 years old (pre-pubescent children) or over the age of 18 years old (adults). Pre-pubertal and post-pubertal children differ significantly in pubertal maturation, growth and development and thus, in adiposity and physical fitness. Fitness gains and changes in body composition are more drastic in sedentary populations. In essence, results of this study will be limited to overweight and obese sedentary adolescents.

The data collection process for the HEARTY study began since the year 2005. For the purposes of my thesis, we included the first sample of participants that embarked

in the HEARTY trial that completed their baseline anthropometry, body composition, cardiorespiratory and musculoskeletal fitness tests for the present sub-study. Therefore, my thesis does not present results from a complete data set since the study is still ongoing.

2. LITERATURE REVIEW

2.1 Introduction to Childhood Obesity

As a result of wide ranging technological advancements, an underlying epidemic of sedentary lifestyle is claiming the health and vigor of our youth. Society has moved far away from prehistoric nomadic times into *obesogenic* environments favoring sedentary activities and energy dense foods (Gutin, Barbeau and Yin, 2004). Children are more apt to succumb to a sedentary lifestyle, increasing their risk of becoming overweight. An increasing number of reports demonstrate that the prevalence of childhood obesity is rising at an alarming rate. International health organizations recognize this crisis and seek interventions to successfully prevent and treat the obesity epidemic. Despite the increasing level of awareness, pediatric obesity remains, signaling the attention of researchers worldwide. The field of childhood obesity has received more attention in recent years with an exponential increase in the number of studies since the year 1995 (Goran, 2001), emphasizing its relevance to society today.

2.2 Childhood Obesity Classification

Childhood obesity is characterized as having a Body Mass Index (BMI), a measure normalizing body weight for height, of greater than the 95th percentile for age and sex. Overweight is defined as having a BMI between the 85th and 95th percentiles for age and sex. Growth curves are used as reference tools to depict percentiles for a child's BMI progression from birth to adulthood respective to age, sex and height. The National Center for Chronic Disease Prevention and Health Promotion in collaboration with the National Center for Health Statistics have developed growth charts based on U.S.

children for age and sex (National Center for Health Statistics and National Center for Chronic Disease Prevention and Health Promotion, 2006). Despite the known limitations associated with the use of BMI, it is the most commonly used tool to assess and monitor childhood obesity prevalence worldwide (Goran, 2001; Malina, Bouchard and Bar-Or, 2004; Neovius et al, 2004). An internationally standardized reference index for obesity and overweight is needed (Neovius et al., 2004; Bellizi and Dietz, 1999) and remains a challenge. As of 2006, the World Health Organization (WHO) is developing a worldwide growth reference index for children and adolescents (WHO, 2006).

Sothorn and colleagues (1999, 1999, 2000, 2000, 2003) have also consistently used a percentage of Ideal Body Weight (% IBW) to categorize classes of obesity among children for what is recommended for their age and sex. Children are considered to be mildly obese if they range from 120% to 149% IBW, moderately obese 150% to 199% IBW and severely obese as any value greater than 200% IBW. According to these criteria, if a child has a %IBW of 175%, his or her body weight is 75% greater than the ideal reference norm for his or her age and sex and would be classified as moderately obese.

2.3 Etiology

Pediatric obesity cannot be explicated by a single causing factor. Obesity can be defined as an energy imbalance, influenced by several etiological agents that alter the equilibrium. The causes behind childhood obesity are multifactorial, suggesting a link between a genetic basis for disease and contributing environmental factors.

2.3.1 Energy Imbalance

Obesity is the result of an energy imbalance between energy intake and energy expenditure (Malina, Bouchard and Bar-Or, 2004; Maffeis, 2000). The sustained positive energy balance from either diet (high carbohydrates, and/or high fat) and/or low physical activity is associated with a gradual increase in adipose tissue leading to weight gain (Maffeis, 2000). If a negative energy balance is maintained from either increased energy expenditure (physical activity, thermic effect of food and resting metabolic rate) and/or low caloric intake, the body subsequently loses weight. It has been suggested, that the increased prevalence in childhood obesity and weight gain is not caused by a decreased metabolic rate in the population (Goran and Weinsier, 2000). The authors further identify “the need to focus on what metabolic, genetic, environmental, and behavioral factors lead to a mismatch between energy expenditure and energy intake” in children and adolescent obese populations. Another study also showed resting metabolic rate or total energy expenditure cannot completely explain excess adiposity in growing children (Goran et al., 1998). In essence, the energy balance is influenced by a multitude of factors leading to the development of childhood obesity (Yanovski and Yanovski, 2003).

2.3.2 Environmental Influences

It has been proposed that approximately 80% of the causes of obesity are a result of environmental influences (Sothorn and Gordon, 2003). Poor diet, physical inactivity and a sedentary lifestyle are implicated in the development of childhood obesity (Malina, Bouchard and Bar-Or, 2004; Maffeis, 2000; Must and Tybor, 2005). Increased physical activity provides protection while screen time spent in front of a computer or television, is a risk factor of obesity (Must and Tybor, 2005; Tremblay and Willms, 2003). Children are more enthused with the emergence of new technology such as video games,

computers, Internet and watching television than ever before, with a concomitant decrease in physical activity (Must and Tybor, 2005). It has been shown that there is a strong correlation between daily hours of screen time and childhood BMI (Shields, 2004). These results suggest that children that engage in more than two hours of screen time a day have a higher risk of becoming overweight than those who do less than two hours per day. Eliakim et al. (2002) also showed a significant positive correlation between BMI and hours of television and computer playing.

It has also been shown that there are sex differences in sedentary behavior. Males typically watch more television and play more video games than females. A recent systematic literature review including children of all ages under 18 years found that 30% of males and 7% of females played video games more than four hours per week (Marshall, Gorely and Biddle, 2006). In addition, 30% of males and 25% of females also watch TV for more than 4 hours per day (Marshall, et al., 2006).

2.3.3 Genetic Basis

The possibility of a genetic cause has also been established. Friedman (2003) contends that obesity can be explained by our genetic makeup and its interaction with the environment. Parental obesity (Sothorn et al., 2003), and extremely rare cases of leptin deficiency or resistance (Friedman, 2003) may also have a profound influence on the development of obesity.

The Bogalusa Heart Study demonstrated the persistence of childhood obesity into adulthood (Freedman et al., 2003; Freedman et al., 2005). Childhood BMI is related to adulthood BMI and overweight children have a greater risk of becoming obese adults (Goran, 2001). Freedman et al. (2005) found that 2 to 5 year old overweight children

were at 4 times greater risk of becoming overweight adults. One study showed that childhood BMI was a stronger predictor of becoming an overweight adult than birth weight or adult lifestyle habits (Guo et al., 2000). Parent-child associations of obesity and physical activity showed that parental inactivity also predicts childhood inactivity (Fogelhom et al., 1999). Notably, obese children that have obese parents tend to lose less weight compared to obese children without parental obesity in a combined twice-weekly cardiorespiratory training and diet intervention study (Eliakim et al., 2002).

2.4 Risk Factors

Other risk factors such as having a lower socioeconomic status, low birth weight and formula feeding instead of breast-feeding can contribute to the development of childhood obesity (Sothorn et al., 2003). However, controversy exists in the birth weight hypotheses (Malina, Bouchard and Bar-Or, 2004). Normal and high birth weights have also been associated with a greater likelihood of obesity (Johannsson et al., 2006; Ong, 2006).

2.4.1 Critical Periods

Dietz (1997) identified three critical periods, defined as the developmental stages where physiological alterations increase the risk of becoming obese. The first period is the intrauterine environment where the mother's nutritional status and feeding may affect the development of the fetus. Breastfeeding may have a protective effect on the development of obesity although the precise mechanism is unknown (Owen et al., 2005; Grummer-Strawn and Mei, 2004). However, other studies have not shown that breastfeeding decreases the risk of obesity later in life (Burdette et al., 2006; Hediger et

al., 2001). It has also been proposed that an early age of 'catch-up growth' from a low birth weight (small for gestational age) to an accelerated rate of fat storage, 'catch-up fat', in infancy is associated with central adiposity and consequent insulin resistance syndrome (Ibanez et al., 2006; Dulloo, 2006).

The second phase, known as 'adiposity rebound' takes place between the ages of 4 to 6 years old (Dietz, 1997). Adiposity rebound is characterized by an increase in BMI into adulthood after a previous rise in infancy and subsequent decline from 1 to 4 years old (Dietz, 1998). It is hypothesized that the earlier a child experiences this rebound, the more likely the child will be obese (Malina, Bouchard and Bar-Or, 2004; Wang, 2004).

The adolescent phase, characterized by a change in location and quantity of body fat may also predispose a child to obesity (Dietz, 1997; Daniels et al., 2005). Moreover, few longitudinal studies have looked at tracking of obesity from infancy to adulthood. Although Guo et al. (2000) developed a reasonable explanation of the interplay of the critical stages in obesity development: "The earlier the child is 'fat', the earlier a child will be fat at a later age. The fatter a child is at one age, the fatter that child will be at a later age".

2.5 Pubertal Maturation

Freedman et al. (2003) also showed that obese girls mature earlier and attain menarche at an earlier age than leaner girls. Earlier growth is associated with a greater risk of becoming overweight or obese (Malina, Bouchard and Bar-Or, 2004; Mitchell, et al., 2002). One study showed that girls born with a light birth weight and larger height obtained menarche at an earlier age (<11.5 years) and had greater central adiposity in childhood (Tam, C.S., de Zegher, Garnett et al., 2006). Children that mature earlier

generally have a greater height, weight and more adiposity than those that are delayed in biological maturity (Malina et al., 2004). The Penn State Young Women's Health Study showed that healthy white adolescent females aged 11-18 years experienced peak velocities for height, weight, total body fat and lean body mass at 11.5-12 years where most tissues reached maximal growth at age 17.5 years (Lloyd et al., 1998).

Obesity has been associated with earlier puberty especially in girls, which has also been linked to an increased breast cancer risk, although explanations for this occurrence warrant further investigation (Stoll, 1998). Conversely, the evidence is less clear on the relationship between the onset of puberty in males, although some studies have linked obesity with later maturation in males (Wang, 2004; Slyper, 2006). In fact, males typically attain puberty approximately two years later than females (Rowland, 2005). Furthermore, in a study with normal, overweight and obese British children, Benfield et al. (2008) found that girls (13.5 ± 0.5 years) were at later stages of sexual maturation than boys at a mean age of 13.4 ± 0.4 years. However, there were no differences in adipose tissue distribution between pubertal groups in this age category.

2.6 Body Composition

Obese children differ significantly from their non-obese counterparts in terms of body composition, physical fitness, developmental maturation and perceived barriers to exercise.

Obese children and adolescents tend to be taller (Malina, Bouchard and Bar-Or, 2004; Deforche et al., 2003; Wells et al., 2006), have higher BMIs, greater percentage of body fat and greater muscle mass compared to leaner children matched for age and sex

(Deforche et al., 2003; Norman et al. 2005; Eliakim et al., 2006; Nagai and Noritani 2004; Wells et al., 2006).

Subcutaneous adipose tissue (SAT) and Visceral (VAT) and are also higher in overweight and obese girls and boys when they are compared to normal weight children the same age and sex (Benfield et al., 2008). It has been suggested that race and sex should be taken into consideration when assessing anthropometry and obesity-related health risks (Lee et al., 2008). Goran et al. (1999) also summarized key factors that may influence VAT in children and adolescents which include ethnicity, pubertal maturation, diet and physical activity.

2.6.1 Sex Differences in Adiposity

Most studies in adulthood reveal that adult males have more VAT, although females have more total body fat and SAT than males (Demerath et al., 2007). Demerath et al. (2007) studied 18-88 year old males and females and found that males had consistently greater VAT as measured by MRI, especially in the higher abdominal MRI scans than females. It has been proposed that perhaps these sex differences seen in adults are only apparent once pubertal maturity is maintained through adulthood (Brambilla et al., 2006) given that sexual maturation does affect body fat as well as abdominal fat distribution and patterning in youth. However, the evidence on sex differences in adiposity distribution is less clear in youth.

A recent study by Lee et al. (2008) found that for a given BMI, boys aged 12-14 years have a higher waist circumference and VAT than girls in the same age group (Lee et al. 2008). Although BMI has limitations, it is the most commonly used index of weight-for-stature in children and is a useful marker for chronic disease risk (Nieman,

1999). In a large sample of British children aged 5-18 years, it was found that girls have more %body fat than boys as early as 5 years old (22.6% vs. 18.8% respectively) and this trend persisted until 18 years of age (girls 33.4% and boys 20.5%) even when adjusted for body weight (Shaw et al., 2007).

A 3-5 year longitudinal study of 8 year old children examined patterns of growth in abdominal adiposity and found no sex differences in growth rates of total body fat, SAT and VAT (Huang, 2001). However, in pubescent children, there was evidence that boys already deposited more visceral fat whereas girls accumulated more total body fat and subcutaneous fat from 11.5 to 13.7 years (Fox et al., 2000) showing a pattern similar to the one seen in adults. These findings agree with Lee et al. (2008) demonstrating that males aged 12-14 years had greater visceral fat than their female peers.

Conversely, a recent study discovered that younger adolescent normal, overweight and obese boys aged 13.4 ± 0.4 years had lower SAT and VAT volume than females in the same age category (Benfield et al., 2008). However, males in this study had a greater VAT/SAT ratio, suggesting a preferential accumulation of intra-abdominal adipose tissue in comparison to subcutaneous fat. This study also provided insight into the adolescent patterns of fat deposition which seem different from that seen in adults. In essence, in this study, 90% of adipose tissue was deposited in the subcutaneous compartment (Benfield, 2008) suggesting the amount of VAT accumulated during this sexual maturation stage is small compared to that seen in adults (Benfield, 2008; Fox et al., 2000).

It has been shown that sex differences in visceral fat between males and females are not seen in pre-pubertal years (Goran et al., 1997). Thus, sex hormones may be

implicated in body fat distribution observed at puberty. In fact, Wang (2004) suggests that sexual maturation plays a more important role in determining the level of fatness than fatness has on sexual maturation. It has been stated that males increase SAT in the trunk during adolescence whereas females accumulate more SAT in the mid thigh during this developmental period (Pietrobelli, Boner and Tato, 2005).

Race and sex differences in adiposity have received more attention in recent years. A study by Lee et al. (2008) found that African American boys and girls aged 12-14 years had greater SAT than their Caucasian peers. Moreover, this study also showed that VAT was lower in Caucasian boys compared to black boys whereas no such relationship was seen in girls. However, in adults, Caucasians had greater VAT than African Americans (Demerath et al., 2007). Lastly, South Asian girls and boys in a large sample of British school children aged 5-7 years had the highest percentage body fat compared to African-Caribbean and White (Shaw et al., 2007).

2.6.2 Diet, Energy Expenditure, Physical Activity and Adiposity

Previous studies in children have shown conflicting results on the relationship between dietary intake and adipose tissue accumulation. Some studies have shown relationships between fat intake and body fatness in samples of pre-pubertal children (McGloin et al., 2002; Tucker et al, 1997) and have demonstrated that obese children aged 8-11 years consume more dietary fat than their non-obese peers (Maffeis, 1996). However, other studies have shown no relationship between dietary intake of fat, carbohydrate, protein and % body fat in preschool children (Atkin and Davies, 2000). In a longitudinal study of 8 year old children, the researchers did not observe any

relationships between total energy intake, macronutrient intake, amount of physical activity and change in BMI over a 4 year period (Maffeis, Talamini and Tato, 1998).

Resting metabolic rate accounts for ~65-75% of daily energy expenditure in most adults (Prentice, 2007). Resting energy expenditure has been shown to be lower in normal weight 5 year old girls compared to boys in the same age group (Kirkby et al., 2004) as well as in obese female children and adolescents aged 5-17 years compared to their male peers even when adjusted for body composition (Tershakovec et al., 2002). Older obese adolescents also had lower relative resting energy expenditure compared to the younger obese children after adjustment for body composition, sex and ethnicity, demonstrating age-related decreases in resting energy expenditure (Tershakovec et al., 2002). The authors also found that increasing age, girls and African American obese children and adolescents have been associated with a lower resting energy expenditure relative to younger children, boys and Caucasians respectively.

Increases in physical activity are generally associated with decreases in adiposity in children and adolescents. Previously sedentary obese adolescents that underwent an 8-month intervention including moderate or high intensity cardiorespiratory exercise twice weekly combined with lifestyle intervention had significant improvements in total percent body fat and VAT (Gutin et al., 2002). A combined cardiorespiratory and resistance exercise training program with obese boys aged 9-12 years also significantly decreased percent body fat (10%) after a 12-week intervention. Saelens et al. (2007) found that 8 year old children that had greater accelerometer- measured physical activity levels had lower VAT as measured by MRI. The European Youth Heart Study also found that accelerometer- measured vigorous and not moderate or total physical activity was

associated with lower percent body fat in children aged 9-10 years (Ruiz et al., 2006). Furthermore, Berkey et al. (2003) provided evidence to support the association between increased participation in recreational physical activity, reduced sedentary activity and decreases in adiposity in adolescents aged 10-15 years old.

2.6.3 Adiposity and Risk of Chronic Disease

There have also been several associations made between adiposity and risk of chronic disease in childhood and adolescence. An approximate 20-fold increase in the incidence of type 2 diabetes in obese children has been shown over the past 2 decades (Cruz et al., 2005). The increased prevalence of the Metabolic Syndrome in youth which is characterized by insulin resistance, dyslipidemia, and high blood pressure (Cruz et al., 2005) has also been associated with body fat mass, especially an increase in abdominal fat (Ball, Marshall and McCargar, 2003) and particularly with an increase in VAT (Caprio et al., 1995; Syme et al., 2008). In fact, Asayama et al. (2002) found that VAT was the single best predictor of metabolic risk in obese Japanese boys aged 6-14 years. Furthermore, their study established that obese boys with a VAT area $>58.0 \text{ cm}^2$ measured by computed tomography are at an increased risk of acquiring cardiovascular disease which is less than the one reported for adults (130 cm^2) (Lemieux et al., 1996). As reported in adults, one study observed no association between the metabolic markers and VAT area in obese adolescents but did see a relationship with SAT area (Karlsson et al., 2006). Moreover, the relationship between the prevalence of the metabolic syndrome and cardiorespiratory fitness in obese children and adolescents is less clear than with the obese adults and warrants further investigation (Eisenmann, 2007; Shaibi et al., 2005; Mesa et al., 2006; Torok et al., 2001).

2.7 Fitness

Excess weight generally has a negative effect on cardiorespiratory fitness tests in children (Malina, Bouchard and Bar-Or, 2004). A study conducted in school-age children and adolescents found that overweight children had lower overall fitness scores compared to normal and underweight children when the scores were adjusted for age, socioeconomic status and pubertal maturational stage (Prista et al., 2003).

2.7.1 Fitness and Adiposity

Gutin et al. (2002) found that cardiorespiratory fitness in obese adolescents was significantly correlated to free-living vigorous physical activity but inversely correlated with percentage of body fat. The results of the study suggest that the adolescents that were not able to achieve their maximal oxygen uptake ($\dot{V}O_{2max}$) were heavier compared to those who achieved their maximal levels (Gutin et al., 2002). The authors defined achieving $\dot{V}O_{2max}$ as meeting one of the following criteria: an oxygen plateau, respiratory exchange ratio >1.0 or maximal heart rate >200 bpm. The 'Quebec En Forme' project also showed a negative correlation between waist circumference, BMI and physical fitness, which became more pronounced with age (Brunet et al., 2006). Furthermore, several studies found inverse correlations between body fat and running speed and endurance (Minck et al., 2000; Deforche et al., 2003). An earlier study in girls aged 7-17 years concluded that the girls with higher adiposity had lower levels of cardiorespiratory fitness as assessed by a step test (Malina et al, 1995).

It is important to investigate if fitness and adiposity in obese adolescents could predict future weight gain and the risk of chronic disease. The Aerobics Center

Longitudinal Study showed that cardiorespiratory fitness, waist circumference, BMI and % body fat track strongly from adolescence into adulthood (Eisenmann et al., 2005). Another longitudinal study showed that children aged 4-11 years with higher cardiorespiratory fitness gain less adipose tissue during 3 to 5 years follow-up than children with a lower cardiorespiratory fitness (Johnson et al., 2000). Furthermore, Eisenmann et al. (2007) studied a large sample of children aged 9-15 years and found that high cardiorespiratory fitness has a protective effect on the prevalence of cardiovascular risk factors even in children with a high level of adiposity. Notably, this study found that the low fit- high fat group had the highest cardiovascular risk.

Lastly, a study found that total and central adiposity were lower in overweight and obese Greek children aged 6-13 years with high cardiorespiratory fitness (Nassis, Psarra and Sidossis, 2005). This study gives further support to adult studies that have shown the protective effect of cardiorespiratory fitness on mortality even in men with high abdominal adiposity (Lee et al., 1999).

2.7.2 Cardiorespiratory Fitness

Due to the obese child's excess weight and the weight-bearing nature of most aerobic exercise, the obese child experiences an increased workload during these exercises. Part of this metabolic cost is likely attributable to the obese child's decreased mechanical efficiency, lower exercise tolerance and decreased motor performance, although more extensive research is needed to further understand the consequences of obesity on musculoskeletal form ((Norman et al., 2005; Malina, Bouchard and Bar-Or, 2004; Gallisti et al., 2001). Aerobic weight-bearing exercise interventions may result in injury and non-compliance from straining the obese child's immature musculoskeletal

system (Sothorn, Loftin et al., 1999). Nantel, Brochu and Prince (2006) showed that obese children aged 8-13 years demonstrated altered hip motor patterns early on in their walking cycle compared to non-obese children. In similar aerobic activities, obese children have to use 50% more energy than non-obese children to achieve the same work rates (Maffeis et al. 1993). Obese children tend to consume more oxygen during submaximal exercise such as walking displaying their greater metabolic cost of locomotion (Bar-Or and Rowland, 2004). Weight bearing exercises can cause frustration amongst obese children, preventing them from adhering to aerobic exercise interventions (Cruz et al., 2005; DeStefano et al., 2000; Sung et al., 2002). Due to the excess weight carried, and the burden on the cardiovascular and respiratory systems, less weight bearing activities are recommended for this special population (Sothorn, Loftin et al., 1999).

Norman et al. (2005) conducted cycle ergometry tests on obese adolescents aged 12-18 years old and showed that they had higher resting heart rates, greater oxygen consumption during unloaded cycling and lower maximal heart rates than their non-obese peers. The results suggest that due to the excess weight constraints, obese children must consume more oxygen to sustain workloads compared to leaner children. These obese adolescents had lower $\dot{V}O_{2\max}$ compared to non-obese adolescents even when lean body mass and fat mass were considered. The authors concluded that the greater the BMI, the greater the functional impairment.

A large-scale study of Swedish obese children and adolescents aged 8-16 years found that obese children had significantly lower relative $\dot{V}O_{2\max}$ (ml/kg/min) but their absolute $\dot{V}O_{2\max}$ (L/min) was higher than the age-matched reference group representative of the general Swedish population. Furthermore, the authors report that

their higher absolute $\dot{V}O_2\text{max}$ is attributed to the increased lean body mass observed in obese compared to normal weight children.

Conversely, Goran et al., (2000) demonstrated that $\dot{V}O_2\text{max}$ was not different between obese and non-obese pre-pubertal children when cardiorespiratory capacity was expressed relative to fat free mass. Submaximal cardiorespiratory capacity and time to exhaustion were significantly lower whereas maximal heart rate was higher in the obese group. Their findings suggest that children's difficulties with aerobic weight-bearing exercise is linked to their reduced submaximal exercise capacity.

2.7.3 Sex Differences in Physical Activity and Cardiorespiratory Fitness

Even if most studies combine results for boys and girls, sex differences in physical activity and fitness can play an important role in determining exercise outcomes. An international review of physical activity levels between the ages of 10 and 17 years showed yearly declines of 2.7% among boys and a much greater 7.4% decrease in physical activity among girls during that time period (Molnar and Livingstone, 2000). Brunet and colleagues (2006) discovered that physical fitness declined substantially in children aged 7 to 10 years especially in girls based on the Canadian Fitness Survey in 1981 and the results of their study performed in 2006. Girls tend to participate less in physical education classes during adolescence (National Center for Chronic Disease Prevention and Health Promotion; 1996). A review focusing on the relationship between physical activity and overweight and obesity in children and adolescents concluded that boys are more active than girls while decreases in physical activity with age are more pronounced in girls than in boys (Molnar and Livingstone, 2000).

However, a large-scale Swedish study found that 34% of obese girls and 24% of obese boys aged 14 -16 years old participated in organized physical activity (Berndtsson et al., 2007). Both obese Swedish girls and boys in this sample were still participating in much less organized physical activity than the reference group (45% girls, 57% boys). Deforche et al. (2003) have also shown that leisure-time physical activity (excluding sport) is not different between obese and non-obese adolescents. The authors have also reported that obese boys aged 12-18 years had a lower sport index compared to their leaner male peers although there was no difference between obese and non-obese females. The results of this study suggest the need to perform further investigation to determine if a low participation in structured physical activity is a consequence or a cause of childhood obesity.

In young adults, males typically have 20-25% greater cardiorespiratory fitness compared to females (Rowland, 2005) due primarily to increased lean body mass and other sex-related differences. As children grow up, absolute $\dot{V}O_2\text{max}$ increases at the same rate until age 12 years and continues to increase substantially until age 17-18 years in boys but remains relatively stable from age 14-18 years in girls (Bar-Or and Rowland, 2004). These sex differences are commonly seen in normal weight children especially between the ages of 11-13 years and 14-16 years (Berndtsson et al., 2007). However, Berndtsson and colleagues (2007) did not find significant sex differences in relative $\dot{V}O_2\text{max}$ between male and female obese adolescents. The authors attributed this lack of sex difference to the high non-participation of obese boys in vigorous physical activity.

In pre-pubertal children, it has been shown that boys have 12-15% higher $\dot{V}O_2\text{max}$ than girls in the same age group with a greater difference seen after the age of

12 years (Rowland, 2005). Furthermore, pre-pubertal boys aged 12 ± 0.4 years had a relative $\dot{V}O_{2\max}$ 16.8% higher than girls the same age. When $\dot{V}O_{2\max}$ was expressed relative to fat free mass, the sex differences were reduced to 6.2% but remained statistically significant (Rowland et al., 2000). The authors suggest that body composition accounted for 2/3 of the differences in $\dot{V}O_{2\max}$ between sexes such that boys had 20% whereas the girls had 26% body fat.

2.7.4 Musculoskeletal Fitness

Generally, obese children score lower on standardized fitness tests than their non-obese peers (Deforche et al., 2003; Gutin et al., 2002; Shaibi et al., 2006; Prista et al., 2003). Few studies have looked at the relationship between musculoskeletal fitness and obesity in children and adolescents (Deforche et al. 2003; Prista et al., 2003; Kim et al., 2005; Malina et al., 1995) whereas it has been extensively studied in adults. Overall musculoskeletal fitness typically decreases throughout adulthood from ages 20-69 years (Fortier et al., 2001). Adult studies have shown that poor musculoskeletal fitness, particularly lower scores on the abdominal muscular endurance sit-up test, is linked to lower health status (Payne, Gledhill, Katzmarzyk, Jamnik and Ferguson, 2000; Warburton, Gledhill and Quinney, 2001) and an increased risk of mortality (Katzmarzyk and Craig, 2001; FitzGerald, Barlow and Kampert, 2004).

A large-scale study of middle aged men and women found significant relationships between poor musculoskeletal fitness and adverse blood test results among men only (Fujita et al., 1995). The longitudinal Amsterdam Growth and Health Study examined body fatness and musculoskeletal fitness from 13-27 years of age in males and

females and they found that low physical fitness predicted fatness in adulthood even after controlling for baseline physical activity and total body fat (Minck et al., 2000).

Obese children experience particular difficulty in weight-bearing musculoskeletal fitness tests compared to normal weight children. In fact, Deforche and colleagues (2003) compared musculoskeletal fitness in obese and non-obese Flemish youth aged 12-18 years using the Eurofit test battery and found that obese children scored lower on the balance test, vertical jump, sit-ups, bent-arm hang, endurance shuttle run, and speed shuttle run tests than leaner children. The authors attributed this difference to the burden of carrying the excess weight, the greater energy cost associated with moving their larger mass and their lack of experience with weight-bearing exercise compared to leaner children. Thus, it is plausible to assume that the obese child versus the normal weight child do not differ in underlying muscle contractile properties that determine their lower performance in weight-bearing tasks (Bar-Or and Rowland, 2004).

Women generally have better flexibility as measured by the sit and reach test than men (Fortier et al., 2001). However, there is no clear evidence on the influence of adiposity on flexibility in the hips and lower back between obese and non-obese children. Kim et al. (2005) reported that weight status did not affect flexibility test scores in all weight categories, which agrees with one study (Deforche, 2003), but not all findings in youth (Prista et al., 2003; Malina et al., 1995; Minck et al., 2000). Fortier et al. (2001) demonstrated that trunk flexibility stability fluctuates during childhood for females but remains highly stable in adulthood, whereas males maintain high stability throughout the lifespan.

Muscular endurance as measured by the push-up and sit-up tests are known to be adversely affected by increasing adiposity. Girls aged 7-17 years with higher levels of adiposity had lower scores on the sit-ups, leg-lifts and flexed arm hang compared to leaner girls (Malina et al., 1995). Obese boys and girls aged 12-18 years also scored lower on all test requiring lifting their body mass including the standing-broad jump, sit-ups and bent-arm hang (Deforche et al., 2003) which is in agreement with the results of a longitudinal study of males and females 13-27 years (Minck et al., 2000). Similarly, Kim et al. (2005) showed that underweight and healthy children had similar fitness levels whereas a very small percentage of overweight children passed endurance and strength-related fitness tests.

Grip strength typically increases in normal weight males and females during the ages of 11-19 years whereas sit-ups decline during that time period (Fortier et al., 2001). Given obese children have greater static strength than their non-obese peers, this suggests that obese youth may have more muscle mass than normal weight children (Deforche et al., 2003; Prista et al., 2003). In fact, these observations may advocate a fundamental predisposition to pursue resistance training in obese children.

Thus, resistance training, if used as a weight-supporting exercise regime, can have several potential health benefits with obese children. Resistance training is a rapidly evolving research area showing promising results that focus on the obese child's fundamental confidence in static strength. In 2006, the Council on Sports Medicine emphasized the following: "Because of their added body mass, overweight participants also tend to be stronger than their peers, giving them a relative psychological advantage" (Council on Sports Medicine, 2006). Major health organizations such as the American

Academy of Pediatrics (2001), the American College of Sports Medicine (Committee on Sports Medicine, 1990) and the National Strength and Conditioning Association (Krotish et al., 2005) recognize the benefits of resistance training in youth. Strength training can also increase self-confidence and increase participation in other physical activities (Givler, 2000). Most people, especially children, generally have high exercise outcome expectations. Obese children prefer strength training as opposed to aerobic training because of its weight-supporting nature and its rapid physiological results that can be seen in 2 to 3 weeks after the start of the exercise program (Cruz et al., 2005; Council on Sports Medicine and Fitness and Council on School Health, 2006). Strength gains in prepubescent children can be explained by neuromuscular adaptations due to increased firing rate and motor unit recruitment, whereas hypertrophy is seen in adolescents once they have reached puberty (Benjamin et al., 2003).

2.8 Perceived Barriers to Physical Activity

Obese children, especially girls, report more barriers to exercise than their non-obese counterparts (Kang et al. 2002). Obese children restrict themselves from physical activity because they perceive environmental and personal barriers such as the weather, a lack of interest, and body issues that prevent them from pursuing physical activity (Zabinski et al., 2003). This creates a difficult obstacle when endorsing physical activity in overweight children (Zabinski et al., 2003) and further exacerbates the health problems associated with childhood obesity.

Girls also tend to experience heightened body image issues and increased susceptibility to develop eating disorders during adolescence (Nemark-Sztainer et al., 2002). Extreme dieting behaviors including usage of diet pills, laxatives, diuretics and

vomiting were significantly higher in obese adolescent girls compared to boys (18% vs. 6% respectively) (Neumark-Sztainer, 2002). However, obese males may be stigmatized due to the socially constructed ideal of the larger male form and may not be perceived as negatively as females by their peers, although these findings require further investigation (Sweeting, 2008).

2.9 Consequences of Childhood Obesity

2.9.1 Short Term

Most co-morbidities associated with obesity are prevalent in adulthood. However, the most widespread immediate morbidities experienced in children are psychosocial problems (Dietz, 1998). Overweight children are socially isolated and least preferred by their peers in terms of friendship nominations (Dietz, 1998; Strauss and Pollack, 2003). In fact, overweight children score lower on psychosocial wellbeing, self-esteem, parental emotional wellbeing and physical functioning than children with normal weight (Friedlander et al., 2003). The Canadian Community Health Survey found that the percentage of obese adolescents aged 12-17 years was lowest in reports of very good to excellent health compared to normal and overweight groups (Shields, 2004). However, Swallen et al. (2005) did not find a relationship between health related quality of life and an increased BMI in adolescents (Swallen et al., 2005).

Obese children already show risk factors for the Metabolic Syndrome characterized by dyslipidemia, hypertension and hyperinsulinemia (Ornstein and Jacobson, 2006; American Diabetes Association, 2000). A study conducted by Cruz et al. (2004) demonstrated that 90% of overweight and obese Hispanic adolescents had at least one component of the metabolic syndrome (Cruz et al., 2004). Insulin resistance is

considered to be a major contributing risk factor in the development of Type 2 Diabetes, previously known as adult-onset Diabetes but is now emerging in pediatric populations (Ornstein et al., 2006). In fact, the prevalence of Type 2 Diabetes in youth has increased worldwide (ADA, 2000) suggesting a 20-fold increase in the past 20 years (Cruz et al., 2005). Obese children are also showing other cardiovascular risk factors such as increased overall body fat, subcutaneous and visceral abdominal adipose tissue (Goran et al., 2003; Owens et al., 1998). It is evident that prevention of cardiovascular disease should begin in childhood especially if cardiovascular risk factors are already present in obese children (Kavey et al., 2003).

A skin disorder, known as acanthosis nigricans, is also associated with childhood obesity and Type 2 Diabetes (ADA, 2000). Obese females are at a higher risk of acquiring menstrual irregularities that may lead to polycystic ovarian syndrome which can cause infertility (ADA, 2000). Liver problems such as steatohepatitis (Rashid and Roberts, 2000; Fishbein et al., 2003) and pseudomotor cerebri defined as an increased intracranial pressure of the cerebrospinal fluid, are more prevalent among obese individuals (Daniels, 2005; Dietz, 1998; Deckelbaum and Williams 2001).

Obesity is associated with a decreased mechanical efficiency in energy transfer that may lead to orthopedic problems because of the weight overload on the musculoskeletal system and joints (Nantel et al., 2006). Blount's disease (Dietz, 1998; Wills, 2004) characterized by a bowing tibia and overgrowth of the proximal tibial metaphysis and slipped capital femoral epiphysis, a hip disorder (Wills, 2004), is more prevalent in children with weight problems. Excess weight may also burden a child's respiratory system and may lead to sleep apnea (Dietz, 1998).

2.9.2 Long Term

The long term health consequences of childhood obesity are widespread. The most serious consequence an obese child will experience is to become an obese adult. It has been shown that up to 80% of obese adolescents will become obese adults (Daniels et al., 2005). Male obese adolescents may actually have a higher risk of mortality as adults than female obese adolescents (Dietz, 1998, 1998). Obesity in adulthood increases the risk of coronary artery disease, atherosclerosis, arteriosclerosis, colon cancer and gout (Yanovski, 2001).

2.10 Conclusion

It is clear that continued growth of pediatric obesity has become an important public health concern. With the multifactorial etiology of obesity and the widespread morbidities associated with its progression, childhood obesity prevention strategies and treatment interventions need to be further developed and studied. In fact, it has been shown that adherence and compliance to exercise interventions can be ameliorated if the exercise prescription is modified according to an obese child's strengths and perceived competence.

To date, most of the research done on sex differences in fitness and adiposity has centered on adults and pre-pubertal populations. It has been shown in adults that males typically have more visceral fat, whereas females have more total body and subcutaneous fat. These sex-related differences are less clear in children and adolescents given their differences in growth and maturation. Generally, obese children differ significantly from normal weight children. Obese children are taller, heavier, have more total adiposity, subcutaneous and visceral fat, engage less in competitive sports, have lower self-esteem

and perceive more barriers to exercise compared to their leaner peers. The significant differences between obese and non-obese children exacerbate the difficulties associated with designing appropriate interventions for this vulnerable population. It is also evident that there is a lack of research in the area of musculoskeletal fitness with respect to obese adolescents. The significance of musculoskeletal fitness in obese adolescents bears great importance considering the increased morbidity and mortality risk associated with poor physical fitness in addition to the increased risk of chronic disease associated with obesity. Nevertheless, there is a lack of research on sex differences on abdominal adiposity, musculoskeletal and cardiorespiratory fitness in obese adolescents. Collectively, the results from the present study could provide useful insight for the development of efficient treatment options for obese adolescents.

4. METHODS & RESULTS

ARTICLE I:

Musculoskeletal fitness in obese adolescents: a HEARTY study

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ABSTRACT

Background: Obese children tend to score lower on fitness tests than their non-obese peers. Sex differences in musculoskeletal fitness also warrant further investigation in obese adolescents. **Objectives:** To compare the musculoskeletal fitness of our cohort of obese adolescents to the Canadian Musculoskeletal Fitness Norms (CMFN) as measured by the widely used Canadian Physical Activity, Fitness and Lifestyle Approach (CPAFLA). A secondary aim was to determine the sex differences in musculoskeletal fitness in obese adolescents. **Methods:** 179 obese adolescents (45 Male, 134 Female, mean BMI= $34.4 \pm 4.4 \text{ kg/m}^2$) that volunteered to participate in the Healthy Eating Aerobic and Resistance Training in Youth (HEARTY) randomized controlled trial study. Sedentary obese adolescents aged 14-18 years were included in the study if they had a baseline BMI $>95^{\text{th}}$ percentile for their age, sex, and height, or $>85^{\text{th}}$ percentile +additional diabetes risk factors. Musculoskeletal fitness (hand grip, push-ups, curl-ups, sit and reach and vertical jump) was assessed by following the CPAFLA guidelines that were designed by the Canadian Society for Exercise Physiology. The HEARTY participants' mean scores were compared to the CMFN for males and females aged 15-19 years old. **Results:** HEARTY males scored lower on all musculoskeletal fitness tests compared to the Canadian norms. Although HEARTY females had lower curl-up, push-up, sit and reach and vertical jump than their leaner peers, they had greater grip strength. Males in the HEARTY study had greater hand grip strength and vertical jump than females. However, HEARTY females scored higher on push-ups and sit and reach tests than males. **Conclusions:** Based on the Canadian Musculoskeletal Fitness Norms, obese male and female adolescents scored lower on most musculoskeletal fitness tests

compared to their leaner Canadian peers. Poor musculoskeletal fitness in obese adolescents could have adverse health implications when they reach adulthood.

Key words: musculoskeletal fitness, flexibility, muscular endurance, muscular strength, muscular power, obese adolescents, sex differences

INTRODUCTION

Generally, obese children score lower on standardized fitness tests than their non-obese peers (Malina et al., 1995; Prista et al., 2003; Kim et al., 2005). Musculoskeletal fitness is an important testing parameter to assess muscular strength, muscular endurance, muscular power and flexibility (Heyward, 2002), which all play a role in maintaining good health in activities of daily living. It has been previously shown that poor musculoskeletal fitness is linked to lower health status (Warburton, Gledhill and Quinney, 2001) and an increased risk of mortality in adulthood (FitzGerald et al., 2004). Few studies have compared musculoskeletal fitness between non-obese and obese adolescents (Deforche et al., 2003; Prista et al., 2003; Kim et al., 2005). Muscular endurance, as measured by the push-up and sit-up tests, is known to be adversely affected by increasing adiposity. Girls aged 7-17 years with higher levels of adiposity had lower scores on the sit-ups, leg-lifts and flexed arm hang compared to leaner girls (Malina et al., 1995). Deforche et al. (2003) reported that Flemish obese adolescents aged 12-18 years scored lower on weight bearing tests such as the balance test, standing-broad jump, sit-ups, bent-arm hang, endurance shuttle run and speed shuttle run compared to their leaner counterparts for the same age and sex which is in agreement with the results of a longitudinal study of males and females aged 13-27 years (Minck et al., 2000). Similarly, Kim et al. (2005) showed that underweight and healthy children had similar fitness levels whereas a very small percentage of overweight children passed endurance and strength-related fitness tests. Although the relationship between adiposity and trunk flexibility does not yield consistent findings (Malina et al., 1995; Minck et al., 2000; Deforche et al., 2003; Prista et al., 2003; Kim et al., 2005), obese children demonstrate a greater

handgrip strength than their non-obese counterparts (Deforche et al., 2003; Prista et al., 2003). The relationship between obesity and musculoskeletal fitness has yet to be examined in Canadian obese adolescents.

Sex differences in musculoskeletal fitness have been extensively studied in adults although the relationships are less clear in obese adolescents. In adults, males have typically greater grip strength and vertical jump but lower sit and reach scores than females (Payne et al., 2000; 2001; Fortier et al., 2001). However, abdominal muscular endurance appears to be similar between male and female adults.

The purpose of this study was to compare musculoskeletal fitness scores of obese adolescents in the Healthy Eating Aerobic and Resistance Training in Youth (HEARTY) study to the Canadian Musculoskeletal Fitness Norms (Payne et al., 2000) as measured by the Canadian Physical Activity, Fitness and Lifestyle Approach (CPAFLA) (Canadian Society for Exercise Physiology (CSEP), 2003). A secondary aim was to determine the sex differences in musculoskeletal fitness in HEARTY males and females. We hypothesize that HEARTY obese adolescents will score lower on all musculoskeletal fitness tests except for grip strength when compared to the Canadian Musculoskeletal Fitness Norms.

METHODS

Participants

The pre-randomized sample of this sub-study comes from the first participants (N=179; 45 Males, 134 Females) aged 14-18 years old that completed baseline musculoskeletal fitness tests for the larger ongoing HEARTY study. This study is a

randomized, controlled trial with a parallel group design. Recruitment began in April 2005 and is currently in progress. Several recruitment methods were used to attract participants; family doctor referrals, posters, school board advertisements, bus campaigns and radio station advertisements. The bus campaigns proved to be the most successful in recruiting the majority of the participants. Adolescents showing interest in the study were first screened by the research coordinator to determine if they fit the inclusion and exclusion criteria of the HEARTY study.

Inclusion Criteria

Male and female sedentary post-pubertal adolescents aged 14 to 18 years old of Tanner Stage IV or above in developmental maturity with a baseline BMI >95th percentile for their age, sex, and height, or >85th percentile plus additional diabetes risk factors were eligible to participate in the study. The diabetes risk factors include: Fasting glucose ≥ 6.0 mmol/L, 2-hour plasma glucose 7.8-11 mmol/L after 75g oral glucose (impaired glucose tolerance), fasting triglycerides >1.7 mmol/L, fasting plasma insulin >105 mmol/L, HDL-C <0.9 mmol/L, LDL-C >3.0 mmol/L, total cholesterol/HDL-C >90th percentile, or first-degree relative with type 2 diabetes, and waist circumference $\geq 75^{\text{th}}$ percentile for their age and sex. The participants underwent all baseline testing before entering in the 4-week run-in period, designed to test for compliance.

Exclusion Criteria

Participants were excluded if they: 1) engaged in a regular exercise program or any physical aerobic activity more than 2 times per week for a minimum of 20 minutes per session within 4 months of beginning the HEARTY study, 2) showed signs of an

eating disorder and/or experienced a significant weight change in the 2 months prior to enrollment in the study, 3) were using performance-enhancing medication or any other medication likely affecting body composition, 4) have diabetes, uncontrolled hypertension, and/or any other illness rendering physical activity inadvisable, 5) were unwilling to attend exercise and/or dietary sessions, 6) were unable to speak French or English and/or have significant cognitive deficits. Participants weighing more than 159 kg and/or a BMI greater than 45 kg/m^2 were not considered because their physical size exceeds the capacity of the MRI (Sigma, General Electric, Milwaukee, WI). Lastly, if participants and/or their parents or guardians were unwilling to sign the informed consent, they were not permitted to participate in the study. The Ottawa Hospital Research Ethics Board approved all methods and procedures and all participants provided written informed consent.

Musculoskeletal Fitness Testing

Before beginning the HEARTY study, participants' baseline musculoskeletal fitness was assessed according to the five well-documented musculoskeletal fitness tests from the Canadian Physical Activity, Fitness and Lifestyle Approach (CPAFLA) designed by the Canadian Society for Exercise Physiology (CSEP, 2003). Musculoskeletal fitness assesses muscular strength, muscular endurance, muscular power and flexibility (Heyward, 2002), which all play a key role in maintaining good health and physical functioning. The tests were conducted in the following consecutive order for each participant to standardize testing procedures: grip strength, push-up, sit and reach, partial curl-up and vertical jump. All the results obtained from the multiple fitness tests were recorded and ranked according to the CPAFLA norms (Table 1).

Grip strength was assessed using a hand grip dynamometer (Baseline Hydraulic Hand Dynamometer, #OC-3054-02, OrthoCanada). The participants were instructed to grasp the dynamometer, one hand at a time and to exhale during exertion, with one hand at a time. The device is held at the level of the thigh away from the body and squeezed to maximal force. Both hands were measured alternately starting with the right hand, completing two trials per hand, rounding the strength value to the nearest kilogram. To obtain a total score, the maximum score for each hand were combined together and recorded in kilograms.

The push-up test was modified according to sex; males used their toes while females used their knees as their pivot point. Participants were asked to complete as many consecutive push-ups as possible while respecting proper form and technique. However, if two consecutive push-ups were not maintained in proper form and the participants appeared to be straining themselves forcibly, the repetitions were not counted.

The sit and reach test was used as an indicator of flexibility and provides a measure of the range of motion in the hips and lower back. The participants' feet were placed against the backboard of the flexometer, at the 23-cm mark, with legs fully extended and feet were placed 6 inches apart. The participants were required to stretch out their arms and hands in front of them in the direction of their feet while pushing a sliding marker forward along the horizontal scale. Subjects were required to maintain full knee extension at all times. Once they achieved maximal hip flexion, they were required to hold the position for 2 seconds. Two trials were taken and the distance reached from the fingertips was recorded to the nearest 0.5 cm.

Subjects were then required to perform partial curl-ups over a 1-minute period at a set cadence. The partial curl-up exercise was conducted to evaluate muscular endurance. The exercise targeted the abdominal and hip flexor muscles. A metronome, set at a rate of 50 beats per minute, (1 beat for the up-phase and 1 beat for the down-phase), was used as an audio tool to set the pace for the partial curl-up exercise. The participant had to complete consecutive curl-ups to the beat of the metronome and must have reached the 10 cm mark with their fingertips before returning to the start position. The test lasted a maximum of 1 minute allowing a maximum total of 25 repetitions to be achieved. If the participants could not maintain the pace of the metronome or perform proper curl-up technique, the test was terminated. The number of successful curl-ups was counted and a weighted score was recorded according to Table 1.

A vertical jump test was then performed to assess muscular power. Prior to the jump, the height of the middle fingertip was marked and recorded as the Stand and Reach Height to the nearest 0.5 cm. Subjects performed the vertical jump from a semi-squatting position. A total of 3 trials were conducted with a 15 second rest period in between each jump. The difference between the Stand and Reach Height and the three trials of peak jump height was recorded. The trial with the maximum difference was recorded as the measure of vertical jump.

All tests were conducted by two highly trained exercise specialists to ensure consistency in measurement. Generally, fitness tests have high reliability and high objectivity (coefficients greater than 0.90) especially when exercise specialists are well trained and strictly follow standardized fitness testing protocols (Heyward, 2002).

The HEARTY participants' results for the five musculoskeletal fitness tests described above were ranked according to the CPAFLA Healthy Musculoskeletal Fitness Norms and Health Benefit Zones that are shown in Table 1. Our sample of participants aged 14-18 years old were ranked according to the 15-19 years age category in the CPAFLA. The purpose of the scoring tables was to rank the HEARTY results from 'needing improvement' to 'excellent' health benefit rating. The results of the five musculoskeletal tests from the HEARTY study were compared to the age- and sex-specific Canadian Musculoskeletal Fitness Norms written by Payne et al. (2000). The representativeness of the Payne et al. (2000) Canadian Musculoskeletal Fitness Norms was verified by comparing to the Canada Fitness Survey of 1981 and the Campbell's Survey of 1988. The 15 to 19 year old age category from the Canadian Musculoskeletal Fitness Norms comprised 59 females (BMI: $22.2 \pm 0.4 \text{ kg/m}^2$) and 54 males (BMI: $23.1 \pm 0.5 \text{ kg/m}^2$). The musculoskeletal fitness mean scores from the HEARTY participants were compared to the average values provided by the Canadian norms of males and females aged 15 to 19 years old that have been reported elsewhere (Payne et al., 2000). Thus, we did not compare our results to the raw data set from the Canadian Musculoskeletal Fitness Norms, but only to the results from the published study (mean \pm SD).

Pedometer logs

Habitual physical activity was assessed using Step Count pedometers. Although methods used to measure physical activity patterns in children are controversial (Ruiz, Rizzo and Hurtig-Wennlof, 2006), pedometers are regarded as valid tools to assess quantity of physical activity (Troost, 2001; Sirard and Pate, 2001). By self-report,

participants were asked to write down the number of steps taken at the start and finish of their day for a period of 7 consecutive days. The information gathered from the pedometer logs was used to compare physical activity levels between males and females in the HEARTY study.

STATISTICAL ANALYSIS

One-sample t-tests were conducted to determine if the HEARTY participants mean scores differed significantly from the set values from the Canadian Musculoskeletal Fitness Norms. Each musculoskeletal fitness test variable was analyzed separately by sex for the one-sample t-tests. For the purpose of this paper, HEARTY participants aged 14 years were treated as 15 year olds in order to compare them to the reference norms aged 15-19 years. To satisfy this claim, a separate analysis was conducted without the results of the 14 year old HEARTY participants and similar results were found. In essence, inclusion or exclusion of the younger 14 year old participants did not change the results that were found when comparing the HEARTY participants to the reference norms. Independent sample t-tests were also conducted to determine the difference in physical activity and musculoskeletal fitness between male and female participants in the HEARTY study. Data were analyzed using SPSS v. 16.0 with significance was set at a p-value of <0.05 .

RESULTS

Baseline characteristics for the 179 participants included in the analyses are displayed in Table 2. Males and females in the HEARTY study did not differ significantly in age (Males 15.7 ± 1.2 y, Females 15.9 ± 1.4 y; $p= 0.429$) but males had a greater BMI ($P < 0.05$).

Health Benefit Ratings for HEARTY participants

The overall CPAFLA health benefit rating was calculated for all HEARTY participants by sex. The health benefit ratings range from lowest 'Needs Improvement', 'Fair', 'Good', 'Very Good' to the highest rating 'Excellent'. Males had a lower mean cumulative musculoskeletal composite score of 'Fair' (1.42 ± 0.62) whereas females scored 'Good' (2.04 ± 0.77). Notably, 50% of the female participants fall into the 'good' category while 51% of the males fall into the 'fair' health benefit rating zone as shown in Figure 1.

HEARTY Males vs. HEARTY Females

A sub-sample of completed pedometer logs (N=87) were compared between males (N=20) and females (N= 67) in the HEARTY study. There were no differences ($p = .856$) in total step count between males (57456 ± 23311 steps) and females (56133 ± 29959 steps).

Musculoskeletal fitness tests were compared between males and females in the HEARTY study (Table 2). The males had significantly higher grip strength and vertical jump whereas females had higher push-up and sit and reach results (all $P < 0.01$). There was no difference between males and females in curl-ups ($p = 0.229$). A supplementary ANCOVA was performed to determine if sex differences persist when accounting for BMI. The ANCOVA results showed that grip strength, push-up, sit and reach and vertical jump remained significantly different between sexes when BMI was a covariate ($p < 0.01$).

Figure 2 presents the differences in musculoskeletal fitness between males and females across the different age categories. It is apparent that there is an increasing trend

in grip strength in males from age 14-18 years. There also seems to be a decreasing age trend in partial curl-ups for females.

HEARTY vs. Canadian Musculoskeletal Fitness Norms

Data collected from the HEARTY study participants for each CPAFLA musculoskeletal fitness test were compared by sex to the scores obtained in the 2000 Canadian Musculoskeletal Fitness Norms (Payne et al., 2000) (Table 2). For males, grip strength, push-up, sit and reach, curl-up and vertical jump tests were significantly lower (all $P < 0.01$) in HEARTY males compared to the males aged 15-19 years old in the Canadian Musculoskeletal Fitness Norms.

The females in the HEARTY study had significantly lower push-up, sit and reach, curl-up and vertical jump test scores compared to the females from Canadian Musculoskeletal Fitness Norms (all $P < 0.01$). However, grip strength was significantly greater in HEARTY females (62 ± 11 vs. 56 ± 2 kg, $P < 0.01$) compared to that of Canadian norms for females.

DISCUSSION

Obese HEARTY vs. non-obese Canadian Musculoskeletal Fitness Norms

The main finding of this study showed that our sample of obese adolescents aged 14-18 years old had lower scores on weight-bearing musculoskeletal fitness tests including push-ups, curl-ups and vertical jump compared to their leaner peers aged 15-19 years old. This finding agrees with previous studies (Deforche et al., 2003; Prista et al., 2003; Minck et al., 2000; Kim et al., 2005).

Although the obese child's increased weight may have favorable effects on lower body strength by the increased resistance, exercises involving propulsion and/or lifting of their own body weight are hindered (Deforche et al., 2003; Malina et al., 2004). In fact, Dao et al. (2004) showed that fat mass was the only factor that determined the increase in vertical jump height after weight loss in male and female obese adolescents aged 9-17 years. Furthermore, we can ascertain that the increased fat mass in our sample of obese adolescents impeded their performance on the weight bearing musculoskeletal fitness tasks compared to the norms. The lower scores on the push-up, sit-up and vertical jump tests from the HEARTY participants compared to the Canadian Musculoskeletal Fitness Norms is not surprising given their significantly higher BMI.

As expected, it appears as though HEARTY obese female adolescents have greater static strength compared to their leaner female peers. This finding is consistent with other studies that also compared hand grip strength between obese and non-obese children (Deforche et al., 2003; Prista et al., 2003). However, this trend was not apparent in the obese males in the present study. It has already been shown that muscle mass increases with adiposity (Goran et al., 2000) to accommodate the excess weight experienced by obese children. Katzmarzyk et al. (2002) also found that BMI was positively correlated with grip strength and negatively correlated with all other CPAFLA musculoskeletal fitness tests in the 1981 Canadian Fitness Survey. Thus, it is plausible that our sample of obese adolescents have more muscle mass than the leaner sample of adolescents, which may be accounting for this difference seen in grip strength.

The present study also showed that flexibility in obese youth is lower than their leaner peers in the same age group. Our findings agree with some studies (Minck et al.,

2000; Prista et al., 2003) but not all (Malina et al., 1995; Deforche et al., 2003; Kim et al., 2005).

Although pubertal maturity was assessed by Tanner Stages in our sample of HEARTY participants, no such evidence is provided for the children of the same age group in the Canadian Musculoskeletal Fitness Norms. It is known that overweight children mature earlier than normal weight children (Adair and Gordon-Larsen, 2001; Kanbur, Derman and Kinik, 2002; Freedman et al., 2003). Furthermore, children that mature earlier may have greater height, weight and more adiposity than those that are delayed in biological maturity (Malina, Bouchard and Bar-Or, 2004). Paradoxically, since older children have hormonal and developmental differences compared to their younger peers, it is possible that the older lean males (and possibly more advanced in maturation) from the Canadian Musculoskeletal Fitness Norms may have more circulating testosterone levels and muscle mass than their obese peers in the HEARTY study. This may account for the leaner males' greater scores on the hand grip strength, push-up, curl-up, sit and reach and vertical jump tests compared to the HEARTY males.

Unfortunately, spontaneous physical activity and physical activity lifestyle patterns were not provided in the Canadian Musculoskeletal Fitness Norms sample of adolescents aged 15-19 years old. Therefore, we cannot preclude that our samples had different physical activity patterns that explain the differences seen in musculoskeletal fitness. Notably, Deforche et al. (2003) demonstrated that both obese and normal weight children in the same age group did not differ in leisure-time physical activity. However, studies have shown that obese children participate less in competitive sports (Deforche et al., 2003; Berkey et al., 2003) that require more sport-specific skills like agility and

coordination, than leaner children. The higher participation in sport may explain the higher overall musculoskeletal fitness in the normal weight reference sample. In addition, obesity is associated with an altered motor coordination, decreased mechanical efficiency (Norman et al., 2005; Nantel et al., 2006), and decreased exercise tolerance (Goran et al., 2000, Norman et al., 2005). The HEARTY obese adolescents may experience more difficulty performing the musculoskeletal fitness tests designed by the CPAFLA helping to explain their lower scores relative to the Canadian Musculoskeletal Fitness Norms.

Sex differences in musculoskeletal fitness in obese HEARTY participants

The sex-related differences observed in push-ups are likely due to differences in the measurement techniques used in the CPAFLA for males versus females. For example, males scored significantly lower than females in their push-up scores possibly because males have to use their toes as their pivot point which may be more difficult than using their knees like the females were instructed to do. The most obvious explanation for the greater number of push-ups that the obese females achieved is their significantly lower weight and BMI compared to males for this weight-bearing task. However, the lack of difference in the sit-up test between sexes in the present study may be due to the CPAFLA measurement of partial curl-ups to assess abdominal muscular endurance. We speculate that the partial curl and 1-minute duration as opposed to using a complete curl or longer duration, respectively, may mask the differences between sexes for the curl-up test.

Even though HEARTY males scored lower on grip strength than males from the Canadian Musculoskeletal Fitness Norms, they still had significantly higher grip strength

than the females in the HEARTY study. Other studies with obese adolescents agree with the findings of the present study and have consistently shown that males have higher grip strength and vertical jump than females (Dao et al., 2004). Our results also agree with other studies that have shown higher flexibility with sit and reach scores in adult females compared to males (Payne et al., 2000; Fortier et al., 2001) and obese female adolescents compared to obese males (Deforche et al., 2003). Furthermore, it has been shown that sex differences are important predictors of mortality (Payne et al., 2000; Payne et al., 2000). Payne et al. (2000) showed that muscular strength and endurance were significant predictors of mortality for males while grip strength and trunk forward flexion were predictors for females.

The pedometer logs used for the HEARTY study did not show any differences in step count between sexes. Although the limitations of pedometers are well-documented in previous studies (Troost, 2001; Sirard and Pate, 2001), we can ascertain that the males and females in our sample had similar physical activity levels. However, the type and duration of physical activity performed could not be estimated with the use of self-reported pedometer logs. In addition, the smaller sample of adolescents that completed the pedometer logs (N= 87) compared to the total sample (N= 179) of participants that completed their musculoskeletal fitness testing may have affected the results.

Trends in obesity prevalence and age-associated changes in musculoskeletal fitness

The trends in obesity rates may limit our findings given the HEARTY and Canadian Musculoskeletal Fitness Norms samples were tested at different time periods and regions in Canada. For instance, secular trends in physical fitness and obesity in the European Youth Heart Study showed that younger boys had lower physical fitness and

greater adiposity in 1997-98 compared to 1985-86 data (Wedderkopp et al., 2004). The 2006 'Quebec En Forme' project also showed lower fitness levels especially in girls in their cohort, compared to the documented reference values of the Canada Fitness Survey in 1981 (Brunet et al., 2006). These studies suggest that even in younger populations, there are increasing trends in obesity rates across time. The latter Quebec study also found that the prevalence of overweight children has increased in the 25 year period, with girls having the highest prevalence close to 30% compared to boys (20%). However, Fortier et al. (2001) concluded that indicators of musculoskeletal fitness are moderately stable over a 7 year period from 1981-88 in a representative sample of the Canadian population aged 11-18 and 19-69 years.

Our study shows that grip strength and push-up test results are greater in older adolescents. This is consistent with previous findings showing increasing strength with age (Fortier et al., 2001; Dao et al., 2004) whereas the females in our study did not demonstrate this pattern in strength across the different age categories. In addition, our results for female sit-up scores agree with another study showing a decreasing trend in sit-ups for females with age (Fortier et al., 2001) although this is not apparent in the males in our study.

Limitations

The findings of this study must be interpreted by taking into account its limitations. For the purposes of our study, the musculoskeletal fitness results from the HEARTY participants aged 14-18 years were compared to the slightly older reference group (15-19 year olds) in the Canadian Musculoskeletal Fitness Norms which may have affected the results. However, a supplementary analysis excluding our younger

participants aged 14 years yielded consistent results with the complete sample including the 14 year olds in our comparative analysis to the Canadian norms. Fitness testing inter-rater reliability issues may also limit the interpretation of the results from the HEARTY study compared to the means scores obtained from the Canadian reference norms. In addition, the mean age is not provided by the Canadian Musculoskeletal Fitness Norms so significant age differences between both samples could not be assessed to determine if age is a covariate. In this regard, Brunet et al. (2006) showed that the negative relationship between BMI, waist circumference and fitness indices (particularly the sit-up score) is greater in older children and is increasing over time.

In summary, we show that obese adolescents aged 14-18 years scored lower on most musculoskeletal fitness tests compared to the representative reference norms of the Canadian population in the same age group. We also showed that obese males have higher grip strength and vertical jump than obese females although females have higher sit and reach and push-up scores than males. Furthermore, we also showed that obese males in the HEARTY study had a lower overall musculoskeletal fitness ranking compared to obese females in the HEARTY study. Prevention strategies targeted at improving physical fitness should be implemented at an early age in children to reduce the onset of decreased physical functioning and poor health status associated with poor musculoskeletal fitness seen in obese adolescents.

ACKNOWLEDGEMENTS

This study was supported by the Canadian Institutes of Health Research (CIHR).

Table 1. Canadian Physical Activity, Fitness & Lifestyle Approach (CPAFLA) Healthy Musculoskeletal Fitness Norms and Health Benefit Zones

Norms and Health Benefit Zones

MALE

Age (yr 15-19)	Grip Strength (kg)	Weighted score	Pushups (#)	Weighted score	Sit and Reach (cm)	Weighted score	Partial Curl-ups (#)	Leg Power (Watts)	Weighted score
Excellent	≥108	8	≥39	8	≥39	4	25	≥4644	4
Very Good	98-107	6	29-38	6	34-38	3	23-24	4185-4643	3
Good	90-97	4	23-28	4	29-33	2	21-22	3858-4184	2
Fair	79-89	2	18-22	2	24-28	1	16-20	3323-3857	1
Needs Improvement	≥78	0	≤17	0	≤23	0	≤15	≤3322	0

FEMALE

Age (yr 15-19)	Grip Strength (kg)	Weighted score	Pushups (#)	Weighted score	Sit and Reach (cm)	Weighted score	Partial Curl-ups (#)	Leg Power (Watts)	Weighted score
Excellent	≥68	8	≥33	4	≥43	8	25	≥3167	4
Very Good	60-67	6	25-32	3	38-42	6	22-24	2795-3166	3
Good	53-59	4	18-24	2	34-37	4	17-21	2399-2794	2
Fair	48-52	2	12-17	1	29-33	2	12-16	2156-2398	1
Needs Improvement	≥47	0	≤11	0	≤28	0	≤11	≤2155	0

Total Weighted Scores Achieved

28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	
4	4	4	4	3	3	3	3	3	3	3	2	2	2	2	2	2	2	1	1	1	1	1	1	1	0	0	0	0	0

Conversion Between Health Benefit Ratings and Scores

Health Benefit Rating	Symbol	Score
Excellent	E	4
Very Good	VG	3
Good	G	2
Fair	F	1
Needs Improvement	NI	0

Adapted from: Canadian Society for Exercise Physiology. The Canadian physical activity, fitness & lifestyle approach, 3rd Edition. 2003, CSEP; Ottawa, p. 7-36 to 7-57.

Table 2. Baseline subject characteristics and measurements of musculoskeletal fitness by sex in HEARTY versus the Canadian Musculoskeletal Fitness Norms.

	HEARTY		CMFN	
	Males	Females	Males	Females
N	45	134	54	59
Age (years)	14-18	14-18	15-19	15-19
BMI (kg/m ²)	36.1 ± 3.7*‡	33.9 ± 4.4‡	23.1 ± 0.5	22.2 ± 0.4
Grip strength (kg)	87 ± 16**	62 ± 11‡	94 ± 2‡	56 ± 2
Push-ups (#)	6 ± 6	10 ± 7*	27 ± 2‡	20 ± 1‡
Curl-ups (#)	20 ± 8	18 ± 8	25 ± 0‡	22 ± 1‡
Trunk flexion (cm)	20.1 ± 9.8	26.6 ± 10.8*	34.0 ± 1.0‡	37.5 ± 1.0‡
Vertical jump (cm)	33 ± 7**	27 ± 7	48 ± 1‡	34 ± 1‡

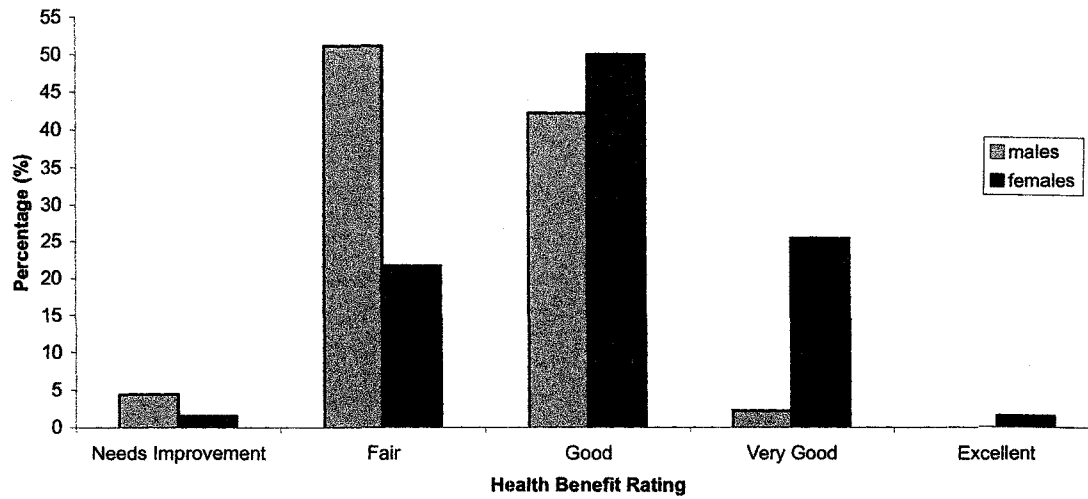
Values are mean ± SD.

* p<0.05; **p<0.01 significantly different between HEARTY males and females,

‡ p<0.01 HEARTY males and females significantly different from CMFN

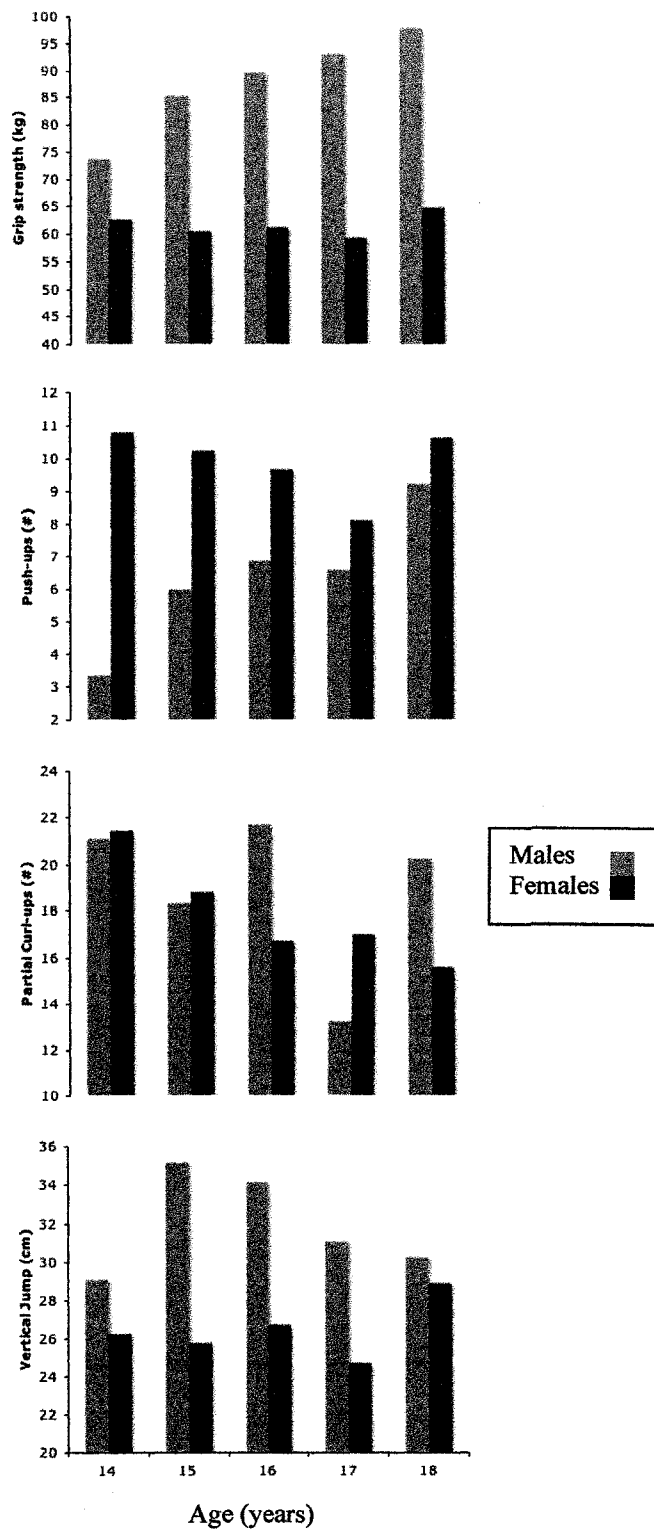
Abbreviations: HEARTY, Healthy Eating Aerobic and Resistance Training in Youth; CMFN, Canadian Musculoskeletal Fitness Norms [*Adapted from: Payne, N., Gledhill, N., Katzmarzyk, P.T., Jamnik, V.K., Keir, P.J. (2000). Canadian Musculoskeletal fitness norms. Canadian Journal of Applied Physiology, 25, 430-442, with copy permission.*]

Figure 1. Overall Health Benefit Rating of HEARTY participants by sex



Abbreviations: HEARTY, Healthy Eating Aerobic and Resistance Training in Youth Ratings as established by the Canadian Society for Exercise Physiology. The Canadian physical activity, fitness & lifestyle approach. 3rd Edition. 2003, CSEP: Ottawa, p. 7-36 to 7-57.

Figure 2. Musculoskeletal fitness scores for strength and endurance tests of HEARTY males and females across different age groups



ARTICLE II:***Sex differences in abdominal adiposity and cardiorespiratory fitness in obese adolescents: a HEARTY study***

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ABSTRACT

Background: Poor cardiorespiratory fitness and increased abdominal fat are strongly associated with an increased risk of the metabolic syndrome, which has been studied primarily in adults. **Objectives:** To investigate the sex differences in the relationships between BMI, waist circumference (WC), subcutaneous adipose tissue (SAT), visceral adipose tissue (VAT), and peak oxygen uptake ($\dot{V}O_{2peak}$) in obese adolescents. **Methods:** Sedentary obese adolescents aged 14-18 years (N= 124: 30 Males and 94 Females) that volunteered to participate in the Healthy Eating Aerobic and Resistance Training in Youth (HEARTY) randomized controlled trial. Participants were included if they had a baseline BMI >95th percentile for their age, sex, and height, or >85th percentile +additional diabetes risk factors. SAT and VAT at the L4-L5 level were quantified using Magnetic Resonance Imaging (MRI). An incremental treadmill test was used to assess $\dot{V}O_{2peak}$. **Results:** The results show that males had greater BMI, WC, VAT, VAT/SAT ratio and $\dot{V}O_{2peak}$ than females ($P < 0.05$). However, males and females did not differ significantly in step count, total energy intake and SAT ($P > 0.05$). Correlations between fitness and fatness indices were similar between sexes. Waist circumference was significantly correlated with SAT and VAT ($0.59 > r < 0.79$; $p < 0.01$) in both sexes. Waist circumference, SAT and VAT were also negatively correlated ($-0.37 > r < -0.55$; $p < 0.05$) with $\dot{V}O_{2peak}$. **Discussion:** These results suggest that there are sex differences in cardiorespiratory fitness and abdominal adiposity in obese adolescents. This study also shows that cardiorespiratory fitness is inversely related to both subcutaneous and visceral

adipose tissue in both sexes. Finally, waist circumference is a good proxy of abdominal adiposity measured by magnetic resonance imaging in obese adolescents.

Keywords: abdominal adiposity, MRI, sex differences, obese adolescents, cardiorespiratory fitness

INTRODUCTION

Adolescence is known to be one of the critical periods associated with an increased risk of developing adulthood obesity (Dietz, 1997). It has been shown that up to 80% of obese adolescents become obese adults (Daniels et al., 2005). The relationship between cardiorespiratory fitness and body fatness has gathered much attention in recent studies in obese youth (Goran et al., 2000; Nassis et al., 2005). In adults, cardiorespiratory fitness appears to have a protective effect on the relationship between increased central adiposity and mortality. In fact, Lee et al. (1999) showed that men and women with higher maximal oxygen uptake ($\dot{V}O_2 \text{ max}$) and greater central adiposity had a 2.5-fold lower risk of mortality than men and women with lower cardiorespiratory fitness with the same abdominal adiposity. In a large sample of youth aged 9-15 years, high cardiorespiratory fitness reduced the prevalence of cardiovascular disease (CVD) risk factors in children with high % body fat (Eisenmann et al., 2007). Moreover, Canadian adolescents with lower cardiorespiratory fitness have been shown to have more CVD risk factors relative to total % body fat and BMI (Flouris et al., 2007).

Adult studies have also shown a higher prevalence of metabolic disorders in overweight adults with greater abdominal adiposity. Generally, men typically have more visceral adipose tissue (VAT) than women, whereas women have more total body fat and subcutaneous adipose tissue (SAT) than men (Demerath et al., 2007). Conversely, a recent study showed that adolescent males (13.4 ± 0.4 years) had lower SAT and VAT volume than females (13.5 ± 0.4 years) (Benfield et al., 2008). Sex-related differences were also observed in a sample of British school children as early as 5 years old, however, the most significant differences were seen in older adolescents (Shaw et al.,

2007). This study showed that 18-year-old females had 12.9% greater body fat than the males for the same age even when adjusted for weight (Shaw et al., 2007).

Sex differences in adiposity and cardiorespiratory fitness in obese adolescents are less clear and require further investigation. Sex differences are important to consider for the evaluation of health risks and to determine appropriate cutoffs for obesity diagnosis and treatment among youth (Lee et al., 2008). Brambilla et al. (2006) also mentioned that sex and pubertal status should be taken under consideration when assessing abdominal adiposity. Furthermore, validation of anthropometric measurements of abdominal adiposity by magnetic resonance imaging (MRI) is limited in obese youth.

The objective of this study was to investigate sex differences in abdominal adiposity and peak oxygen uptake ($\dot{V}O_{2peak}$) and their relationships in obese adolescents.

METHODS

Participants

The pre-randomized sample of this sub-study comes from the first participants (N=124; 30 Males, 94 females) aged 14-18 years old that completed baseline anthropometry, body composition by MRI and cardiorespiratory fitness tests for the larger ongoing HEARTY study. The HEARTY study is a randomized, controlled trial with a parallel group design. Recruitment began in April 2005 and is currently in progress. Several recruitment methods were initiated to attract participants; family doctor referrals, posters, school board advertisements, bus campaigns and radio station advertisements. The bus campaigns proved to be the most successful in recruiting the

majority of the participants. Adolescents showing interest in the study were first screened by the research coordinator to determine if they fit the inclusion and exclusion criteria of the HEARTY study. The Ottawa Hospital Research Ethics Board approved all methods and procedures and all participants provided written informed consent.

Inclusion Criteria

Male and female sedentary post-pubertal adolescents aged 14 to 18 years old of Tanner Stage IV or above in developmental maturity with a baseline BMI $>95^{\text{th}}$ percentile for their age, sex, and height, or $>85^{\text{th}}$ percentile plus additional diabetes risk factors were eligible to participate in the study. The diabetes risk factors include: fasting glucose ≥ 6.0 mmol/L, 2-hour plasma glucose 7.8-11 mmol/L after 75g oral glucose (impaired glucose tolerance), fasting triglycerides > 1.7 mmol/L, fasting plasma insulin >105 mmol/L, HDL-C <0.9 mmol/L, LDL-C >3.0 mmol/L, total cholesterol/HDL-C $>90^{\text{th}}$ percentile, or first-degree relative with type 2 diabetes and waist circumference $\geq 75^{\text{th}}$ percentile for their age and sex. The participants underwent all baseline testing before entering in the 4-week run-in period, designed to test for compliance.

Exclusion Criteria

Participants were excluded if they: 1) engaged in a regular exercise program or any physical cardiorespiratory activity more than 2 times per week for a minimum of 20 minutes per session within 4 months of beginning the HEARTY study, 2) showed signs of an eating disorder and/or experienced a significant weight change in the 2 months prior to enrollment in the study, 3) were using performance-enhancing medication or any other medication likely affecting body composition, 4) have diabetes, uncontrolled

hypertension, and/or any other illness rendering physical activity inadvisable, 5) were unwilling to attend exercise and/or dietary sessions, 6) were unable to speak French or English and/or have significant cognitive deficits. Participants weighing more than 159 kg and/or a BMI greater than 45 kg/m^2 were not considered because their physical size exceeds the capacity of the MRI (Sigma, General Electric, Milwaukee, WI). Lastly, if participants and/or their parents or guardians were unwilling to sign the informed consent, they were not permitted to participate in the study. The Ottawa Hospital Research Ethics Board approved all methods and procedures and all participants provided written informed consent.

Anthropometry

Upon first visit, the research coordinator nurse practitioner assessed medical history and conducted a physical exam including the anthropometric measurements of body weight, height and waist circumference. The participants' weight was quantified in kilograms using a Health O Meter manual scale and height was assessed using a stadiometer. Waist circumference (WC) was measured at the middle distance between the last floating rib and the iliac crest at the end of expiration. WC is considered a good predictor of intra-abdominal adipose tissue in children (Goran, 1998; Brambilla et al., 2006).

Abdominal Adiposity

Magnetic Resonance Imaging scans were performed at the Children's Hospital of Eastern Ontario using a 1.5-T scanner, version signa 11 with echo speed gradients (Sigma, General Electric, Milwaukee, WI). Participants were asked to lie still for 30

minutes while whole-body cross-sectional images were acquired in 5mm thick images with a 10mm skip using established protocols (Lee, Janssen and Ross, 2004; Ross et al., 1992). For the purposes of this sub-study, one-single cross-sectional image at L4-L5 was analyzed to quantify abdominal adiposity. An interactive slice-editor program, Sliceomatic v. 4.3 (Tomovision, Montreal, Canada) was used to quantify the area of subcutaneous and visceral adipose tissue at the level of L4-L5. Different color codes were assigned to segment the separate regions of interest: muscle, intramuscular adipose tissue, bone, SAT and VAT. One single investigator analyzed all the images and was blinded to the participant's sex to ensure consistency and reduce bias of the results. A single slice at L4-L5 is commonly used as a valid measure of the area of central adiposity and is strongly predictive of adiposity volume in humans (Ross et al., 1992). MRI is a relatively new method for the measurement of body composition in pediatric populations. This method was chosen due to its high accuracy and very low dose of radiation emitted throughout the scanning process and is considered safe for all populations, especially for children and adolescents (Pietrobelli et al., 2005; Nieman, 1999; Mattsson and Thomas, 2006).

Cardiorespiratory Fitness

All participants arrived in a 12-hr fasted state at the University of Ottawa laboratory for their maximal aerobic fitness test. $\dot{V}O_2$ peak was assessed using a walking modified Balke & Ware (1959) incremental treadmill protocol. The treadmill speed was predetermined during a practice session and was held constant throughout the entire test. Three different continuous ramp protocols (slow: <3.0, average: 3.0, fast: 3.5) were used based on the perceived ability of the participant. The test began with 1-minute resting

blood pressure measurement and a 1-minute warm-up period where the participant walked at 2 miles per hour (mph) at a 0% incline. The walking speed was increased to the predetermined pace and remained the same throughout the entire duration of test. Grades were progressively increased by 2% every minute until the participants experienced volitional exhaustion.

Indirect calorimetry with the open circuit technique was used to collect expired gas samples drawn from a 6-litre mixing chamber. Expired gas was analyzed using electrochemical gas analyzers (AMETEK Models S-3A/1 and CD 3A; Applied Electrochemistry, Pittsburg, PA) and were calibrated prior to every testing session. Each trial used gas mixtures of 4% CO₂ and 17%O₂ and a balance of N₂ for calibration. The turbine ventilometer was also calibrated using a 3-litre syringe. Data was collected in 10-second averaging intervals for the duration of the stress test. Criteria for $\dot{V}O_{2\max}$ test termination included a plateau in VO₂ despite an increase in work rate, respiratory equivalent quotient (RER) > 1.1, and/or participant wishes to stop. The highest relative $\dot{V}O_2$ (mlO₂/kg/min) achieved was considered to be the $\dot{V}O_{2\text{peak}}$ for the participant. Relative $\dot{V}O_{2\text{peak}}$ to total body mass ($\dot{V}O_{2\text{peak}}$ expressed in ml O₂/kg/min) was used as our measure of cardiorespiratory fitness.

Physical activity & dietary intake

Physical activity was tracked using Step Count pedometers. Although methods used to measure physical activity patterns in children are controversial (Ruiz, Rizzo and Hurtig-Wennlof, 2006; Goran, 1998), pedometers are regarded as valid tools to assess the quantity of physical activity (Troost, 2001; Sirard and Pate, 2001). In fact, Eston,

Rowlands and Ingledeu (1998) reported a good correlation between pedometer step counts and maximal oxygen uptake in children. By self-report, the participants in our study were asked to write down the number of steps taken at the end of their day for a period of 7 consecutive days.

Dietary intake was assessed using 3-day recall dietary food logs. Participants were taught to provide dietary specifications for 2 week days and 1 day on the weekend prior to commencing the study. Once the participants submitted their 3-day food records, data was tabulated by the dietician and analyzed using a food composition software (the food processor SQL, ESHA Research, Salem, OR) to determine separate macronutrient intake for carbohydrate, protein and fat for each participant.

Statistical Analysis

An independent samples t-test was conducted to determine if there were mean differences in dietary intake, physical activity, age, Tanner Stage, anthropometry (weight, height, BMI and waist circumference), abdominal adiposity (SAT, VAT and VAT/SAT) and cardiorespiratory fitness ($\dot{V}O_{2peak}$) between males and females. Pearson's correlation was performed to determine the relationship between SAT, VAT, and $\dot{V}O_{2peak}$ in males and females. All data were analyzed using SPSS software v.16.0 with significance set at $P < 0.05$.

RESULTS

Body composition

The mean baseline subject characteristics are presented in Table 1. There were no differences in age, SAT and treadmill time between males and females in our sample ($P >$

0.05). However, males had greater weight, height, BMI, WC, VAT, and VAT/SAT ratio than females ($P < 0.05$). Males also performed more work and had a higher $\dot{V}O_{2peak}$ than females ($P < 0.05$). Males also had a lower mean Tanner Stage (Males: 4.50 ± 0.5 ; Females: 4.89 ± 0.31 ; $p < 0.01$). A supplementary ANCOVA was performed to determine if sex differences persist when accounting for BMI. The ANCOVA results showed that SAT, VAT/SAT, WC, $\dot{V}O_{2peak}$ and treadmill time remained significantly different between sexes when BMI was a covariate ($p < 0.01$).

Pearson correlation coefficients for the relationships between relative $\dot{V}O_{2peak}$ and fatness are presented in Table 2. Cardiorespiratory fitness and abdominal measures of abdominal adiposity were moderately correlated among males ($-0.37 > r < -0.55$; $p < 0.05$) and females ($-0.42 > r < -0.51$; $p < 0.01$). There were also relationships between WC, SAT and VAT among males ($0.42 > r > 0.76$; $p < 0.05$) and females ($0.51 > r < 0.79$; $p < 0.01$).

Dietary Intake and Physical Activity

The dietary intake for males and females is presented in Table 3. Because of the lack of completed dietary logs, a sub-sample of data ($N=116$) was used to determine patterns of dietary intake in males ($N=28$) and females ($N= 88$). Total caloric intake ($p= 0.146$), intake of carbohydrate ($p = 0.499$) and fat intake ($p= 0.589$) did not differ between males and females. However, males ate significantly more protein than females (94 vs 74 g; $P < 0.01$).

Total step count did not differ between a sub-sample of completed pedometer logs for males (56595 ± 20314 , $N=14$) and females (58593 ± 31686 , $N=52$) ($p= 0.824$).

DISCUSSION

Body composition

Magnetic Resonance Imaging is renowned for its reproducibility and suitability for comparing body composition in individuals especially in long term studies (Heymsfield et al., 2005). One study validated MRI and CT measurements of skeletal muscle and adipose tissue using cadavers. Mitsiopoulos et al. (1998) concluded that both CT and MRI had a ~2% reproducibility of estimating SAT, suggesting both methods accurately quantify adipose tissue distribution in vivo. MRI is considered a sophisticated technique in measuring amount and distribution of body fat. It can be used to distinguish VAT (fat surrounding the organs) from SAT (fat located underneath the skin) (Pietrobelli et al., 2005) to increase our knowledge on the intricate relationship between body composition and chronic disease (Ross, 2003). Distribution of body fat is as equally important as measuring total body fat (Goran, 1998).

We did not observe differences between males and females in abdominal SAT levels. Our findings do not agree with a recent study performed in a large cohort of younger British adolescents (12-14 years old), with a wide range of BMIs, that reported males having lower SAT volumes than females (Benfield et al., 2008). However, the latter study included adolescents varying in Tanner Stages of pubertal maturity that may have affected the sex comparisons.

Studies in adult populations report that men tend to deposit more adipose tissue surrounding the abdominal viscera than women (Demerath et al., 2007). We also observed greater levels of VAT and VAT/SAT ratio in our sample of adolescent males compared to females, which may suggest a similar fat patterning accumulation as that

seen in adults. Our findings agree with Lee et al. (2008) that showed younger African American and Caucasian adolescent males aged 12-14 years had a greater VAT than females for a given BMI and WC. However, these findings do not agree with Benfield et al. (2008) that found that adolescent males (13.4 ± 0.4 years) had less SAT and VAT than females (13.5 ± 0.5 years). It is possible that the differences in body fat distribution observed between these studies may be due to differences in the measurement technique employed to determine body composition, i.e. quantifying adipose tissue area versus volume by MRI. In fact, Demerath et al. (2007) findings in adults suggest that the adipose tissue volume is a more precise and representative estimate of abdominal adiposity than quantifying cross-sectional adipose tissue area by MRI from one single image at the L4-L5 level. However, Lee et al. (2004) suggest that single images used to quantify area at different abdominal measurement sites are comparable. In fact, Siegel et al. (2007) found, a very small coefficient of variance (3.79%) for L4-L5 adipose tissue area measurements, when MRI analysis was performed by an experienced observer in overweight children and adolescents. A more recent study has shown that 5 to 10 cm above L4-L5 might be a preferable marker for abdominal fat distribution instead of L4-L5 since a selected lower image in the abdomen could misrepresent sex differences in VAT in adults (Demerath et al., 2007). Future studies should examine adipose tissue distribution differences between sexes across various measurement sites in children and adolescents.

The feasibility of measurement of waist circumference is of clinical importance because of the quick estimation of abdominal adiposity and is considered a valid tool for early prevention and treatment of consequent chronic diseases associated with increased abdominal adiposity (Nieman, 1999). A greater waist circumference is often associated

with a greater amount of abdominal adipose tissue and several adverse health consequences (Nieman, 1999) especially an increased cardiovascular risk (Goran, 1998). The significant correlations observed between WC, SAT and VAT in our cohort, demonstrate that WC is a good indicator of abdominal adiposity as measured by MRI in this sample of male and female obese adolescents. MRI is also considered one of the best reference tools to assess the accuracy of anthropometry (Tothill and Stewart, 2002). Our findings agree with a recently published study that assessed and cross-validated the relationship between anthropometry and MRI measurements of abdominal adipose tissue in the largest pediatric sample thus far (Brambilla et al., 2006). Our study agrees with their findings that waist circumference was a strong predictor of abdominal adiposity in relationship to the MRI measurement of visceral adipose tissue.

Cardiorespiratory Fitness

Comparisons of cardiorespiratory fitness using relative $\dot{V}O_{2\text{peak}}$ suggest that obese males have greater cardiorespiratory fitness than obese females. A recent study found that absolute measurements of $\dot{V}O_{2\text{peak}}$ are also significantly higher in adolescent males despite no difference in body weight between sexes (Knopfli et al., 2008). Goran et al. (2000) recommends expressing $\dot{V}O_{2\text{max}}$ per kilogram of fat free mass ($\dot{V}O_{2\text{max}}$ mlO₂/kgFFM/min) to determine the muscle tissue's ability to consume oxygen. The results of their study demonstrated that obese pre-pubertal children did not differ significantly in $\dot{V}O_{2\text{max}}$ when expressed relative to fat free mass compared to their leaner counterparts (Goran et al., 2000). However, these findings can only be generalizable to pre-pubertal children since differences in growth and development are

evident between both populations. Since fat free mass was not quantified in our sample of obese adolescents, this comparison could not be performed although males typically have more muscle mass than females, whereas females have greater total fat mass due to an increased number and size of adipocytes (Malina and Bouchard, 1991). It is evident that our study shows that the differences in body composition may explain differences in cardiorespiratory capacity. In order to better understand these differences, it is perhaps best to express cardiorespiratory capacity (oxidative ability of muscle tissue) as the amount of oxygen that can be consumed per kg of fat free mass.

Interestingly, according to the relative $\dot{V}O_2\text{max}$ norms established by Shvartz (1990) by sex, both males and females in this study fall within the 'very poor' to 'poor' cardiorespiratory fitness levels for their respective age group. This suggests that our sample of obese adolescent males and females have a lower cardiorespiratory fitness compared to leaner peers that may have negative health implications in adulthood.

Growth and development

It has been shown that puberty influences improvements in cardiorespiratory fitness in children. It has also been proposed that sex differences in adiposity seen in adults are only apparent once pubertal maturity is maintained through adulthood (Brambilla et al., 2006) given that sexual maturation does affect abdominal fat distribution and patterning in youth. In fact, sex differences in VAT between males and females are not seen in pre-pubertal years (Goran et al., 1997). Reports suggest that males mainly increase SAT in the trunk during adolescence whereas females accumulate more SAT in the mid-thigh during this developmental period (Pietrobelli et al., 2005). Perhaps the females in our study had proportionally less muscle mass in their lower limbs

compared to the males that could have impeded their performance on the weight-bearing nature of the treadmill exercise.

Even though all participants included in the study had to be in Tanner Stage 4 or above, and there were no significant age differences between sexes, it is possible that our males were less developmentally mature than our females. In fact, it has been shown that males mature later than females given males attain puberty approximately 2 years later than girls (Rowland, 2005). Future studies should look at sex differences in fat free mass especially regional distribution of adipose tissue and its relationship to $\dot{V}O_2$ peak particularly in adolescents. It is possible that lower limb adiposity and muscle mass is more predictive of performance in weight bearing tasks in obese female versus male adolescents.

Diet

Although there was no difference in total caloric, carbohydrate and fat intake between males and females in this study, males generally consumed more protein than females. The slightly greater but non-significant dietary intake may be due to the increased demands from the males' greater fat free mass that is acquired after puberty (Sweeting, 2008). Our results may also have been confounded by the known under-reporting of dietary intake that is especially prevalent amongst older girls (Sweeting, 2008). However, the lack of dietary intake data and completed pedometer logs available to compare males and females in this study may limit the interpretation of our results.

Previous studies in children have shown conflicting results on the relationship between dietary intake and adipose tissue distribution. Some studies have shown relationships between fat intake and body fatness in samples of pre-pubertal children

varying in percent body fat (McGloin et al., 2002; Tucker et al., 1997) and have shown that obese children aged 8-11 years consume more dietary fat than their non-obese peers (Maffeis, 1996). However, other studies have shown no relationship between dietary intake of fat, carbohydrate, protein and percent body fat in pre-school children (Atkin et al., 2000). A longitudinal study of 8-year-old children did not observe any relationships between total energy intake, macronutrient intake, amount of physical activity and change in BMI over a 4-year period (Maffeis et al., 1998). Interestingly, according to the U.S. recommendations for children aged 14-18 years old, the males in our study are eating less than the recommended 2,600 kcal while the females are eating slightly more than 2,000 kcal according to the standards set by the Dietary Guidelines for Americans in 2005 (U.S. Department of Health and Human Services).

Limitations

The smaller sub-sample of completed dietary and physical activity logs included in the analysis between sexes may have affected the results. Furthermore, the male sample was considerably smaller than the number of female participants which may also have influenced the sex differences found in our study.

In summary, the findings of this study suggest that there are sex differences in abdominal adiposity and cardiorespiratory fitness in obese adolescents aged 14-18 years old. It appears that obese males have greater abdominal visceral fat than females that may put them at an increased risk of developing associated metabolic disorders (Nieman, 1999; Goran, 1998). Conversely, although obese males had a significantly higher cardiorespiratory fitness level than the females in our study, both sexes are still classified in the lower fitness level range according to reference norms for their age groups. It is

important that prevention strategies include exercise programs that target improving cardiorespiratory fitness in obese adolescents and properly design sex-specific interventions to decrease the relative risk of metabolic disorders and cardiovascular disease in adulthood.

ACKNOWLEDGEMENTS

This study was supported by the Canadian Institutes of Health Research (CIHR)

TABLES & FIGURES

Table 1. Characteristics of male and female HEARTY participants

	Males N= 30	Females N= 94
Age (years)	15.8 ± 1.2	16.0 ± 1.4
Weight (kg)	108 ± 15 **	92 ± 14
Height (kg)	174 ± 8 **	165 ± 5
BMI (kg/m²)	35.5 ± 3.4 *	33.6 ± 4.3
WC (cm)	103 ± 8 **	93 ± 10
SAT (cm²)	465 ± 104	457 ± 129
VAT (cm²)	86 ± 27 *	72 ± 25
VAT/SAT	0.19 ± 0.053 *	0.16 ± 0.05
$\dot{V}O_2$peak (mlO₂/kg/min)	32.85 ± 3.59 **	29.06 ± 3.47
Treadmill time (min)	10.22 ± 1.35	9.63 ± 1.56
Work (watts)	177 ± 39 **	148 ± 31

Values are given as mean ± SD

Abbreviations: HEARTY, Healthy Eating Aerobic and Resistance Training in Youth; SAT, subcutaneous adipose tissue; VAT, visceral adipose tissue; VAT/ SAT, ratio of visceral adipose tissue to subcutaneous adipose tissue; WC, waist circumference; $\dot{V}O_2$ peak, peak oxygen uptake. Significant difference between males and females: * P < 0.05, ** P < 0.01.

Table 2. Pearson correlation coefficients between $\dot{V}O_2\text{peak}$ and abdominal adiposity in male and female HEARTY participants

	Males	Females
SAT x VAT	.42 *	.51 **
SAT x WC	.76 **	.79 **
VAT x WC	.59 **	.73 **
SAT x $\dot{V}O_2\text{peak}$	-.41 *	-.51**
VAT x $\dot{V}O_2\text{peak}$	-.55 **	-.42 **
WC x $\dot{V}O_2\text{peak}$	-.37 *	-.51 **

Abbreviations: HEARTY, Healthy Eating Aerobic and Resistance Training in Youth; SAT, subcutaneous adipose tissue; VAT, visceral adipose tissue; WC, waist circumference; $\dot{V}O_2\text{peak}$, peak oxygen uptake.

Correlation reached significance: * $P < 0.05$, ** $P < 0.01$.

Table 3. Dietary intake in male and female HEARTY participants

	Males N= 28	Females N= 88
Total energy intake (kcal)	2271 ± 553	2075 ± 635
Protein intake (g)	94 ± 28	76 ± 27 ‡
Carbohydrate intake (g)	282 ± 81	269 ± 93
Fat intake (g)	81 ± 23	78 ± 28

Abbreviations: HEARTY, Healthy Eating Aerobic and Resistance Training in Youth.

Values are given as mean ± SD.

Significant difference between males and females ‡ P < 0.01.

5. GENERAL CONCLUSIONS

The primary purpose of the first article was to compare the musculoskeletal fitness of our cohort of obese adolescents aged 14-18 years old to the norms of the Canadian population in their age group. A second objective was to determine the sex differences in musculoskeletal fitness in obese adolescents. The results of our study demonstrate that our sample of obese adolescents scored lower on most musculoskeletal fitness tests relative to their Canadian normal weight peers. However, the obese females in our study did show superior scores in grip strength compared to the reference group. This important finding should be incorporated into the design of future exercise interventions, by including a component of resistance training exercise to benefit the perceived competence and adherence to exercise in obese youth. Furthermore, exercise interventions should be targeted at improving the weaknesses in musculoskeletal fitness components of obese males (push-ups and sit and reach) and obese females (grip strength and vertical jump).

The objective of the second article was to compare abdominal adiposity and cardiorespiratory fitness in our sample of obese adolescents. It was found that males had greater abdominal adiposity especially in the visceral area but also had greater cardiorespiratory fitness as compared to their female peers.

Interestingly, although the prevalence of obesity is comparable between sexes in Canada, 75% of the present sample consisted of females. It is plausible to speculate that females may initiate treatment more readily than males. The results of this study clearly indicate that there are sex differences in adiposity, cardiorespiratory and musculoskeletal fitness in obese adolescents aged 14-18 years old that may play a role in determining

subsequent outcomes in exercise interventions. It is clear that prevention and treatment programs should target males and females separately. There should be more of an emphasis on targeting male participation in weight loss interventions given their significantly greater adiposity and lower overall musculoskeletal fitness rating compared to their female counterparts. A review by Sweeting (2008) emphasizes that males and females may respond differently to treatment programs and that sex differences in intervention outcomes may be more apparent in adolescence than in younger children. Our results support the recommendation by Flynn et al. (2006) which underlines the need for more effective sex-specific interventions with obese youth, especially in males. The results obtained from this research project provide useful insight into the differences between obese and non-obese youth in terms of musculoskeletal fitness and underlines the differences between males and females in body composition and cardiorespiratory fitness. While our cross-sectional study cannot preclude the most appropriate exercise program that will cater to the needs of obese male and female adolescents, we can conclude that sex-specific interventions may be a worthwhile consideration for this vulnerable population in the future.

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Overweight children's barriers to and support for physical activity. Obesity

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APPENDIX

CPAFLA fitness testing record sheet (Part 1 of 2)

Name: _____

Date: _____

Visit: _____

Age: _____

	Trial 1	Trial 2
Grip Strength R		
Grip Strength L		

	Number Completed
Push up (M / F)	

	Trial 1	Trial 2
Sit and Reach		

	Number Completed
Partial Curl-Up	

Distance reached if none completed: cm

	Trial 1	Trial 2	Trial 3
Stand and Reach			
Vertical Jump			
Jump Height (difference)			

CPAFLA fitness testing record sheet (Part 2 of 2)

Healthy Musculoskeletal Fitness – Composite Scoring

Name: _____

Date: _____

Visit: _____

Age: _____

Appraisal Items	Measurement	Rating (NI, Fair, etc.)	Weighted Score	Maximum Attainable Weighted Scores	
				Male	Female
Grip Strength (kg)					
Push-up					
Sit and Reach (cm)					
Partial Curl-ups					
Let Power (watts)					

Total Maximum Attainable Weighted Score: /28 /28

Total Weighted Score Achieved: _____

Composite Musculoskeletal Fitness Score: _____ (out of 4)

Composite Musculoskeletal Rating:

NI F G VG E

*Leg Power (W) = [60.7 x jump height (cm)] + [45.3 x body mass (kg)] – 2055

HEARTY VO₂peak Protocol

Patient's Name: _____

Date: _____

Visit: _____ M

Protocol: slow tmt regular tmt fast tmt (circle one)

	Grade	Speed	BP
	(%)	(mph)	(mmHg)
rest	0	0	___/___
0:00	0		-
1:00	0		-
1:30	0		-
2:00	0		-
2:30	0		-
3:00	1.5		-
3:30	1.5		___/___
4:00	3		-
4:30	3		-
5:00	4.5		-
5:30	4.5		___/___
6:00	6		-
6:30	6		-
7:00	7.5		-
7:30	7.5		___/___
8:00	9		-
8:30	9		-
9:00	10.5		-
9:30	10.5		___/___
10:00	12		-
10:30	12		-
11:00	13.5		-
11:30	13.5		___/___
12:00	15		-
12:30	15		-
13:00	16.5		-
13:30	16.5		___/___
14:00			-
14:30			-
15:00			

Time Recovery started: _____

	BP
Recovery	(mmHg)
0:30	___/___
2:00	___/___
3:00	___/___

Terminated b/c: _____