# TRANSITIONING YOUTH: THE CRISIS OF OBESITY & WHAT CAN BE DONE TO ADDRESS IT

By

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A Thesis Submitted to The Honors College

In Partial Fulfillment of the Bachelors degree
With Honors in

Physiology

THE UNIVERSITY OF ARIZONA

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ABSTRACT

Obesity is a silent killer that is the product of an inequality constructed through excessive caloric input and insufficient energy output. This imbalance is associated with multiple pathologies that slowly accumulate during their progression toward ensuring an early death. Most disturbing of all is the increasing presence of obesity establishing itself in younger generations, implying the possibility of its progression into the generations to come. In an attempt to provide a solution to the increasing prevalence of this preventable disease in youth, this literature review will examine the components of two physiologic entities that are heavily intertwined with obesity: the endocrine system and skeletal muscle. The normative and altered function due to obesity in both systems in youth transitioning through puberty are analyzed to create a foundational understanding of pubertal timing, various metabolisms, muscle development, and the effects of exercise throughout. Finally, various physically demanding strategies and possible work out regiments are presented to 1) address and hopefully reverse the dangerous implications of obesity in youth and 2) promote exercise regularity in the daily lives of adolescents during this impressionable phase of their development.

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*"Regular endurance exercise is beneficial as it prevents obesity, reduces the risk of cardiovascular disease and offers enhanced wellbeing during childhood. For these reasons, children and adolescents must be encouraged to practice regular endurance exercise adapted to their age, their level of sexual maturation and their emotional wishes."*

- Nathalie Boisseau & Paul Delamarche (2000)

# INTRODUCTION

## *Background*

Obesity has become one of the most urgent maladies present in modern day society due to its indirect lethality caused by the complications that manifest from it. A lifestyle that allows for obesity is dangerous, but what is even more alarming is the transmission of poor lifestyle choices from adults to future generations. Obese children have been proven to be more susceptible to growing up to be obese adults with increased probability of obtaining high blood pressure, high cholesterol (both factors that lead to cardiovascular disease), and prediabetes (or a high blood glucose content that is a precursor for type II diabetes) ("Childhood Obesity Facts" February 27, 2014). As obese adults, individuals increase their risk of procuring heart disease, bone/joint disorders, social and mental disorders, low self esteem, type II diabetes, stroke, and a plethora of different cancers ("Childhood Obesity Facts" February 27, 2014).

According to the Center for Disease Control and Prevention, one third of American youth were either overweight or obese in 2012 with the prominence of obesity reported from 2009-2010 as follows: 12.1% of children ages 2-5, 18% of youth ages 6-11, and 18.4% of adolescents ages 12-19 ("Obesity and Overweight" November 21, 2013). This statistic illustrates the dangerous downward spiral that children with unhealthy habits experience as they grow into adulthood; the older they become, the higher the probability of the child being overweight. Although these statistics are slightly dated, it shows both the current peril our younger generations are in and the drastic increase in weight gain among youth over the last 30 years – doubling in children and quadrupling in adolescence ("Childhood Obesity Facts" February 27, 2014). In the hopes of preventing both the immediate and permanent health hazards associated with being overweight/obese, it is at the point when youth start to gain independence by being allowed the freedom to make more of their own decisions while simultaneously experiencing drastic physical transformations during puberty that children (especially obese children) are most susceptible to change and should be targeted for healthy habit formation.

## *Purpose & Goals*

Obesity and being overweight is the product of “caloric imbalance”, a situation that occurs when an individual consumes more calories than they are expending, leading to variations of weight gain (the most severe being obesity) ("Childhood Obesity Facts" February 27, 2014). By altering diet one can alter caloric consumption, by altering exercise regiments one can alter caloric expenditure, and the alterations of both are leading factors in weight loss and healthy life styles. Although a critical component in the prevention of obesity, proper household nutrition is too personal and difficult a subject (due to its variability across household/school environments) to be addressed in this enterprise. Therefore, the goal of this proposed solution is to address the remaining component in obesity prevention: exercise in pubescent youth. Based on this premise, the following literature review will focus on how the skeletal muscle and endocrine systems, in conjunction with exercise, function in both non-obese and obese children as they transition from childhood to adolescence to adulthood.

Unfortunately, budget cuts across the nation have caused physical education to be one of the first subjects discontinued in many public schools. This will have, and undoubtedly has had, a profound impact on youth and their health. Therefore, in addition to analyzing the skeletal muscle and endocrine systems under the lens of obesity during a very specific age range, this thesis will also use the upcoming primary literature research to provide a solution to public education's diminishing physical education programs. This solution will consist of a contemporary work out regiment composed of several exercise techniques that have been analyzed, compared, and specifically tailored to benefit the physiological changes experienced by children transitioning through puberty. The exercise program is conceived in the hopes that instructors who are inexperienced with exercise science and work in an institution that has discontinued physical education programs from their curriculum will have a means with which to keep their students healthy and, hopefully, will help to insure that more of their students have a future devoid of health complications and premature death.

# SECTION ONE:

# REVIEW OF PRIMARY LITERATURE

## *The Effects of Obesity on the Timing of Puberty*

The effect of obesity on the timing of puberty appears to primarily depend on a child's gender. Literature agrees that childhood obesity tends to cause females to experience puberty at a younger age, but there is not as straightforward a conclusion regarding males. Some literature indicates that males experience puberty earlier if they are obese (similar to their female counterparts) while other literature suggests that obese males achieve puberty later than their leaner male peers. As a whole, there is far less research that has been conducted on the effects of obesity on the timing of puberty regarding males than there has been on females. More research must be done on obesity's influence on male pubertal timing in order for a stronger conclusion to be drawn.

What the literature does agree upon is the process of "normative" puberty in both genders. Puberty in both males and females starts with the hypothalamus dispensing gonadotropin-releasing hormone (GnRH). As the name implies, GnRH causes the release of gonadotropin in a pulse-like manner from the pituitary gland. The difference regarding gender is that males establish a steady amount of gonadotropin by the end of puberty, while females have more dynamic levels of gonadotropin which fluctuate monthly with their menstrual cycles (Solorzano, Burt, & McCartney, 2011). Gonadotropin is responsible for the production and secretion of sex hormones (testosterone, estrogen, and progesterone) as well as stimulating the development of ovarian follicles in females and the enlargement of the testis in males (Solorzano, Burt, & McCartney, 2011). Aside from sex hormones, there is a plethora of other hormones associated with puberty that could contribute to the deviations in obese children's pubertal timing. The following hormones are worth considering:

### *Aromatase and insulin*

As previously stated, available research favors differences in pubertal timing between obese females and leaner females. All studies that were evaluated agree that, as stated by Drum, Lipton, & Rosenfield (2009), females with higher BMI's tend to reach puberty at an earlier age than do their non-obese peers. Although the process of puberty is too ambiguous to find a single cause for the premature initiation of puberty in obese females, there are several theories regarding this phenomenon. With obesity comes a higher level of adiposity, or fat cells. Adipose tissue is fascinating because it can act as an endocrine organ, possessing the ability to increase the availability of sex hormones (like estradiol) in two ways: by increasing their production and by decreasing their degradation and removal from the body. Adipose tissue does this using aromatases (found in adipose tissue) which both convert androgens to estrogen while simultaneously decreasing estrogen elimination via digestion in the liver (Solorzano, Burt, & McCartney, 2011). Therefore, since aromatases are found in adipocytes, increasing fat mass increases aromatases, causing a spike in estrogen.

High insulin concentrations can also cause an increase in estrogen. High insulin availability occurs normally during puberty even in non-obese individuals, but can be enhanced/prolonged due to factors that cause obesity (i.e. poor diet and lack of exercise). This increase in insulin also increases the availability of estrogens by reducing the ability of estrogens to bind and be deactivated by sex hormone binding globulins (SHBG).

Obesity contributes to a dramatic increase in production and decrease in removal of estrogen via abnormally elevated concentrations of aromatases and insulin. In theory, this increased amount of estrogen will independently initiate premature puberty via the hypothalamic-pituitary pathway (which is why this occurrence is referred to as gonadotropin independent thelarche) (Solorzano, Burt, & McCartney, 2011).

*Leptin*

Another hormone theory that concerns pubertal timing involves the contribution of an important adipokine called Leptin. The fundamental roll of this hormone is to relay information regarding the body's fat storage (energy reserves) to the hypothalamus. For this reason, the concentration of leptin in the body has a direct correlation with fat mass, playing a critical role in instances such as decreasing appetite and controlling body temperature. In a study by Blum et al. (2013), the concentration of leptin was found to increase in females and decrease in males during the course of puberty. Additionally, it was found that increased BMI/body fat percent correlated with increases in concentration of leptin across both genders.

For females, the premature initiation of puberty from obesity can be described by the interaction between leptin and the central nervous system in regard to the "critical weight hypothesis". This theory suggests that increased levels of leptin signals the CNS, communicating that the body has enough energy reserved to allow the body to enter into the energy-intensive, time consuming process of puberty (Frisch, 1972). Logically, evolution would select for puberty to initiate in a female that has enough fat stored to survive their transition through puberty, and furthermore into childbearing, instead of a female that doesn't have enough energy stored to survive the process. In a female with normal

BMI/body fat percentage, it would take longer to accumulate the proper amount of leptin to promote puberty commencement. However, in obese female children, their abnormal increase in leptin concentration, correlated with their abnormal amount of fat mass, would signal the CNS for puberty earlier than it normally would.

Further evidence of leptin's significance in puberty is visible in individuals who have mutations that effect leptin production/leptin receptor accessibility. The main consequence of these mutations is the inability of the child to enter puberty without the aid of hormone therapy. In mouse models, it was found that leptin accelerated the pulse frequency of GnRH from the hypothalamus while also stimulating the release of luteinizing hormone (LH) and follicle stimulating hormone (FSH), all critical factors in the onset and progression of puberty (Solorzano, Burt, & McCartney, 2011).

Previously mentioned, obese males appear to experience the opposite phenomenon of pubertal initiation when compared to girls, beginning puberty later than males with normal fat mass. An observation referenced by Isidori et al. (2013) mentions that androgens, i.e. testosterone, appear to decrease in male rats as BMI increases. They propose that this decrease in testosterone is due to leptin obstructing a "leptin receptor isoform" that is responsible for testosterone production in Leydig cells. In a male with normal BMI/body fat percentage, leptin concentrations will continue to decrease through puberty, causing a decline in testosterone production interference. However, with increased obesity comes an increased presence of leptin and increased interference, providing a possible explanation for the delay in the onset of puberty in males.

*Ghrelin*

Another factor responsible for the indication of energy stores is ghrelin. This substance is a ligand associated with food intake (elevated ghrelin concentrations result from insufficient energy intake) and the regulation of growth hormones (Fernandez-Fernandez et al., 2004). As described by Fernandez-Fernandez et al. (2004), the effect of ghrelin on males is much more pronounced than its effect on females, inhibiting luteinizing hormone (LH) in male prepubescent rats but not markedly hindering follicle-stimulating hormone (FSH) in females. LH is responsible for the production of testosterone in the Leydig cells of males (Jabbour, 2012). These findings can be interpreted one of two ways: 1) the male child's diet is hypercaloric but devoid of nutritional value, thus increasing ghrelin, decreasing testosterone, and ultimately hindering puberty from starting, or 2) the male subject is consuming excessive calories with sufficient nutritional value, thus causing a decrease in ghrelin and not supporting the original premise of postponed puberty in obese males. If nutritional value isn't a factor and we assume obesity to be associated with sufficient energy intake, ghrelin could be a protective mechanism in males. Similar to leptin in females, ghrelin may act to prevent males from undergoing their transition into adulthood without enough energy stored away to ensure their survival.

Whatever the cause(s) may be, altering the timing of puberty can have significant consequences on the health of pubertal youth. Early puberty, defined as nine years old or younger for males and younger than six to eight years old for females, can cause physical implications such as decreased adult height (the result of accelerated skeletal muscle development), development of female genital tract cancers, breast cancer, testicular cancer in males, and psychological ramifications such as premature sexual encounters and misconduct (Golub et al., 2008). Classified as any time after the age of 14 years old for males and 13 years old for females, the belated onset of puberty can be equally as dangerous. The difference between early and late puberty onset is that the early start of puberty increases ones risk for different pathologies/behaviors whereas delayed puberty is more indicative of disorders that are already present. Therefore, delayed puberty is a sign that a child may have insufficient amounts of gonadotropin, sex-steroids, growth hormone, thyroid hormone, or any of the other intermediates throughout the pathway responsible for the inception of puberty (Argente, 2004). In summary, obesity's influence on the timing of puberty can increase ones risk of certain illnesses or can be the event of an issue that requires diagnosis and treatment.

### *Metabolic Regulation during Puberty and the Influence of Exercise*

There are three different forms of substrate utilization that provide humans with energy: lypolysis, glycolysis, and proteolysis. These pathways are determined by several factors, from substrate availability to the ability of the substrate to be translocated and metabolized. During puberty, a multitude of studies have found that it is normal for adolescents to experience insulin-resistance. In a study performed by Hannon, Janosky, & Arslanian (2006), insulin sensitivity decreased by 50% and the resulting compensatory hyperinsulinemia doubled insulin secretion in pubertal youth. The temporarily diminished response to insulin, insulin dependent glucose uptake, and glucose oxidation during puberty is associated with higher levels of lipolysis/fat oxidation. Prepubescent children experience progressively reduced glycolytic activity and decreased reliance on carbohydrates until mid-puberty when this process reverses itself, gravitating toward increased glycolytic activity and decreased fat oxidation characteristic of adults. These events provide evidence that the baseline amount of energy produced by glycolysis depends heavily upon age (Boisseau & Delamarche, 2000). Further evidence for this can be found in a study by Boisseau & Delamarche (2000), who found that children experienced a relatively slight decrease in intramuscular pH when compared with untrained adults after partaking in high intensity exercise. This failure to decrease in pH during high intensity exercise, characteristic of low glycolytic metabolism, in addition to finding that adolescents possess more oxidative muscle fibers than adults do, reveal that the preferred method of substrate utilization in pubescent children is lipolysis rather than glycolysis.

One explanation for this pubertal decrease in insulin-sensitivity is found in a longitudinal study by Arslanian & Suprasongsin (1997). Unfortunately, this study was conducted exclusively on males, but a similar explanation may also exist for females. Testosterone was administered in low doses to males experiencing delayed puberty. The results were an increase in height and weight (more specifically in fat-free mass) and a decrease in fat mass, percent of fat, plasma cholesterol, HDL's, LDL's, and leptin. There was also a decrease in protein oxidation, but not in protein synthesis. These results suggest that the steady release of the proper amount of testosterone during puberty in males might promote fat utilization in favor of protein metabolism. This increases the availability of protein substrate and eventually more fat-free mass. In a separate study, glycolysis (or carbohydrate oxidation) was found to be inversely associated with testosterone concentration. This presents a potential cause for pubertal hyperinsulinemia, decreased insulin sensitivity, and high blood glucose: increased testosterone during puberty associates with a decrease in glycolysis (Timmons, Bar-Or, & Riddell, 2007).

Could the increased presence of insulin that results from compensatory hyperinsulinemia have a function as well? Amiel et al. (1991) make an interesting proposal, stating that the increased amount of insulin magnifies insulin's ability to metabolize amino acids, the products of which can be used as substrates in synthesizing new proteins that would be used to build muscle and increase fat-free mass (an observation that seen with the addition of testosterone in the study by Arslanian & Suprasongsin (1997)).

The emphasis of fat oxidation in pubertal individuals is not altered by obesity. Resting energy expenditure was found to rely solely upon adolescent fat-free mass, regardless of the amount of fat mass (Tounian et al., 2003). However, fat mass (especially excessive fat mass) plays a significant and detrimental role in the efficiency of metabolism in pubertal systems (Zunquin et al., 2009).

Although a seemingly beneficial resource to have for a system fueled by lipids, obesity is damaging to children and adolescents. Even though puberty can help to eliminate some of the "baby fat" commonly seen in chubby children entering puberty, excessive fat-free mass can actually impede fat oxidation effectiveness in youth during exercise (Zunquin et al., 2009). When testing the ability of obese and lean males to utilize fat at different intensity levels, Zunquin et al. found that both groups maintained similar fat oxidation rates at low exercise intensities. However, when tested during moderate intensities (from 40-60% maximum oxygen consumption), lean males had a much higher fat oxidation rate. Therefore, to increase obese males efficiency (assumedly females as well) at utilizing fat more effectively, lower exercise intensities must be employed first before progressing to exercising at higher intensities (Zunquin et al., 2009).

In addition to hindering lipolysis efficiency, the presence of altered glucose metabolism and glucose intolerance caused by obesity in prepubescent and pubescent children can cause prolonged harm to the body's metabolism later on in life (Weiss & Caprio, 2005). Although hyperinsulinemia and decreased glucose tolerance is expected during puberty, it is apparent that maintaining these phenotypes after puberty would more than likely cause damage to insulin receptors, islets of langerhans, and/or any component of the body that is involved in the metabolic syndrome. If obese adolescent lifestyles are not altered at an early enough stage of their development, their metabolisms may not be able to take advantage of the "plasticity" of their immature tissues ability to transition back to a healthy level of metabolic functionality (Aucouturier, Duche, & Timmons, 2011).

This perilous risk of altered metabolic efficiency throughout life can be combated by exercise. During this growth period of high fat utilization, increasing the adolescent body's energy output allows for improvement of lipid oxidation (Brandou et al., 2003). An extremely metabolic and diverse tissue most effectively engaged by physical activity, skeletal muscle is the most critical organ relating substrate utilization and obesity to exercise. In the next block, the components, functions, and interactions of skeletal muscle, in addition to the types of physical activities that are most beneficial, will be compared and analyzed.

### *Skeletal Muscle Content & Transitions During Puberty*

Skeletal muscle is composed of three basic types of fibers: slow oxidative fibers (type I), fast oxidative-glycolytic fibers (type IIa), and fast glycolytic fibers (type IIb). Type I and type IIb fibers have opposing oxidative and glycolytic enzyme content, with type I being composed of oxidative enzymes, high lipid content, and low levels of glycolytic enzymes. Type IIb fibers have high glycolytic and low oxidative enzyme content in addition to low lipid content. Type IIa has intermediate levels of both types of enzymes and moderate lipid content. Twitch speed, or rate of force production, is quickest in type IIb, moderate in type IIa, and slowest in type I fibers. Endurance is maintained most effectively in type I fibers, with type IIb being the most fatigable and type IIa being fatigue-resistant (Keen, 2013, *Lecture 14*).

One topic of interest is the possibility of fiber types to switch their identity during puberty (i.e. type IIb becoming type I) independent of training or environmental factors. For example, could the transition from mainly fat oxidation metabolism to carbohydrate metabolism observed in normal adolescence be caused by slow oxidative fibers transforming into fast oxidative glycolytic or fast glycolytic fibers? The switching of metabolic identity of muscle fibers appears to be mainly environmental and primarily training oriented. According to Staron (1997), the location and distribution of fast and slow muscle fibers is determined shortly after birth, but this is not always a permanent assignment; skeletal muscle is able to slightly alter its composition based upon factors such as training, changes in training, circulating hormones, diet, etc. Additionally, it was stated that every skeletal muscle group throughout the entire body is composed of all fiber types, but to varying degrees. For example, although the soleus is mainly composed of slow oxidative fibers (because it is utilized in endurance activities such as walking, standing, etc. for extended periods of time), it still contains fast-twitch fibers for activities like sprinting or calf raises (Keen, 2013). Even though the soleus may slightly alter its aerobic fiber content, it will still be predominantly a slow oxidative muscle due to its main function (maintaining posture) and predisposition at birth.

If not the muscle fiber identity, then what aspects of skeletal muscle are altered during puberty? When examining muscles in the forearm, Neu et al. (2002) analyzed the changes in grip force and cross sectional area of the muscle group of each gender in relation to their pubertal stage. As is customary with our species, males had larger muscle and more grip force than females both before and throughout puberty. Cross sectional area in females stopped increasing at the end of puberty, but grip force continued to increase. Males continued to increase both grip force and cross sectional area throughout and after puberty. It was found that specific tension, or the amount of grip force per cross sectional area, increased relatively in both males and females by 50% during puberty. This study illustrates the significant amount of skeletal muscle growth and increase in power for both genders during puberty.

Testing the effects of different gender-specified hormones on skeletal muscle could explain muscle development and growth through puberty. Men with low amounts of testosterone were treated with dosages of the male sex hormone (the amount of which was determined by their skeletal muscle content) to see its effect on muscle fibers. Skeletal muscle was shown to hypertrophy due to increases in the number of satellite cells, mitochondrial content, and nuclei per muscle fiber with a decline in cytoplasm to nuclei ratio in the myocyte (Sinha-Hikim et al., 2003). Female rats injected with testosterone displayed similar results, their skeletal muscle hypertrophying from fiber growth caused by increased satellite cell mitosis as well as increased myonuclei (Joubert & Tobin, 1989). This shows that testosterone, regardless of gender, influences skeletal muscle growth.

Additional interactions between hormones and different skeletal muscle fiber types were analyzed in a study by Kobori & Yamamuro (1989) through multiple gonadectomy procedures in male and female rats. By examining hormonal effects on the soleus and the caudofemoralis, all three types of muscle fiber were present for analysis. Performing an ovariectomy caused an increase in the diameter of all three types of muscle fibers but most prominently in type IIa fibers. To see the effect of the removal of the male gonads, an orchiectomy was performed and resulted in a decrease in the size (diameter) of type IIb fibers without effecting type I or IIa fibers. It was noted that the administration of these procedures affected only the diameter and not the amount or the composition of skeletal muscle fibers. This experiment suggests that gender, or more specifically the hormones associated with the different sexes, influences skeletal muscle growth.

Referring back to the Neu et al. experiment, increased testosterone during puberty and post-puberty more than likely contributed to the drastic increase in specific grip force and increased muscle cross sectional area in males. Following this logic, an increasing presence of estrogen would likely cause skeletal muscle cross sectional area and grip force to stop increasing, possibly even cause it to decrease, during and after puberty. However, these findings were not confirmed by the study conducted by Neu et al. (2002). One possible explanation is that females experience a high enough elevation of testosterone during puberty to counteract the effects of estrogen, condoning increased muscular growth and strength. As always, another explanation is that there are a multitude of other factors aside from sex hormones that may contribute to skeletal muscle growth and maturation during and after puberty.

Abnormally high adiposity influences skeletal muscle greatly, its effects on slow oxidative fibers being the most pronounced. With increased obesity comes a decreased percentage of type I fibers found in skeletal muscle (Hickey et al., 1995). As mentioned previously, metabolism of fats is greatly affected by obesity and skeletal muscle tissue is no exception. Type I fibers are the most oxidative muscle fiber and contain the most aerobic enzymes and lipid content. Lipid can be stored in skeletal muscle to an extent, but when lipid content reaches a certain point, utilization and regulation of fat and glucose metabolism is disrupted in both children and adult skeletal muscle (Goodpaster & Wolf, 2004). The powerhouses for metabolism in type I fibers, responsible for housing aerobic enzymes and substrates, are the mitochondria. Obese individuals have smaller mitochondria when compared to non-obese subjects (Kelley et al., 2002). The importance of physical activity on mitochondria is apparent in a study by Koves at al. (2008). Lack of exercise resulted in the inactivation of the tricarboxylic acid cycle in mitochondria. This altered functioning and caused a chain of reactions that resulted in the depletion of intermediates and the buildup of metabolites (e.g. acyl-carnitine, acyl-CoA, and acytl-CoA). This dysfunction causes incomplete oxidation of fats in the mitochondria, minimal to no beta-oxidation, and abnormal amounts of stress to be placed on the organelle itself. If not treated with increased physical activity, the mitochondria will eventually fail.

The effects of weight loss on skeletal muscle metabolism are a current topic of deliberation among exercise scientists. Several studies suggest that exercising, even without decreases in BMI, can improve fat and glucose metabolism. Other studies suggest that the weight loss itself is what improves muscular metabolism. Although a combined effort of both a restricted diet *and* exercise, weight loss has been shown to increase fatty acid metabolism in addition to increasing glucose metabolism by about 50% in skeletal muscle (Goodpaster & Wolf, 2004). A decrease in the amount of lipid stored in muscle and adipocytes would be responsible for the decrease in body weight, which would provide an explanation for the increase in metabolic efficiency of skeletal muscle (Goodpaster & Wolf, 2004).

Dietary factors aside, exercise alone has the ability to cease and repair the damaging effects of obesity in youth, adulthood, and adolescence. Specific types of aerobic, anaerobic, and combined exercises will be evaluated and modified based on how they pertain to our target age group, their interactions with skeletal muscle and adipose tissue, and their ability to incite maximum benefits for obese and non-obese adolescents.

## SECTION TWO:

## EXERCISE REGIMENT

### *What We Have to Work With*

Regular physical activity is the most efficient way to counteract the effects of obesity through the elimination of unhealthy excess fat reserves, the removal of free fatty acids from the blood, and the sparing of carbohydrates and glycogen utilization through increased fat oxidation (Keen, 2013). By removing excess adiposity through exercise, the goal is to also eliminate the negative consequences associated with excess fat from adolescent skeletal muscle metabolism and hormonal development.

Three different forms of skeletal muscle fibers were previously discussed: one that effectively processes fat aerobically, one that is fueled by glucose and glycogen anaerobically, and one that can moderately utilize both types of substrate. Ideally, increasing the activity of muscles composed of mainly slow oxidative fibers would be the main purpose of the workout regiment (due to the pronounced lipid metabolism in pubertal youth) with intermittent activities intended to stimulate anaerobic muscles. However, one type of fiber seldom dominates an entire muscle; instead, a muscle can be comprised of 40-70% of either type I or type II fibers. Muscles such as the deltoid, biceps brachii, gastrocnemius, rectus femoris, and vastus lateralis generally have a 50/50 aerobic to anaerobic fiber ratio in individuals who are neither endurance nor sprint trained (Johnson et al., 1973). Therefore, rather than try to stimulate specific muscles exclusively in the hopes of engaging primarily type I fibers, any form of exercise should theoretically cause oxidative fibers to work to some extent. Aside from muscle fiber targeting, there are two adjustable independent factors of exercise that determine which muscle fiber is utilized the most during physical activity: intensity and duration. Combining variations of these two elements will allow us to emphasize slow twitch fiber activation in any muscle.

The most successful way to work slow oxidative muscle fibers is with long durations and low to moderate intensity exercises. These fibers are best employed in endurance activities that require the maintenance of small to medium amounts of force for extended periods of time. Energy is obtained primarily from anaerobic pathways within the first minute of exercising. After that initial oxygen independent contribution, aerobic metabolism takes over to meet the energy demands of the body for the duration of the workout. At submaximal moderate intensities, this aerobic metabolism begins to decrease its use of carbohydrates as its main fuel source by increasing fat utilization. As time progresses, the source for this increased use of lipids in fat oxidation then shifts from intramuscular stores of triglycerides to free fatty acids that have been liberated from the target tissue: adipocytes (Keen, 2013).

The skeletal muscles with the highest slow twitch muscle fiber content, referred to as "tonic" muscles, are found in the legs and are responsible for postural support (Johnson et al., 1973). Examples of these skeletal muscles include the soleus and tibialis anterior (Keen, 2013). Therefore, the majority of endurance exercises should involve some form of leg movement such as jogging, walking, biking, etc.

Glycolytic skeletal muscle fibers produce significantly more force than slow oxidative muscle fibers, but are easily fatigable. Type IIb fibers are active and most effective at the beginning of high intensity physical activities that last for short durations of time. Increasing exercise intensity results in carbohydrate/glucose and glycogen utilization, with more fast twitch muscle fibers being recruited as resistance rises (Keen, 2013). There are fewer type IIb dominated "phasic" muscles in the body, most of which are found in the arm (the most notable being the tricep brachii) and are responsible for quick movements and high velocities (Johnson et al., 1973). Due to their high force production and fatigability, resistance training is the most effective way to promote activation of type IIb muscle fibers.

### *Suggested Workout Regiment*

The United States Department of Health and Human Services recommend that individuals 6-17 years of age, so pubescent aged adolescents, exercise for a minimum of 60 minutes every day ("Adolescence and School Health" March 12, 2014). As far as in-school physical activity is concerned, this amount of time can be unrealistic. Depending upon how class times are divvied up throughout the day, the allotted amount of time for a class may not be enough to comply with the suggested amount of time to spend exercising. This of course is assuming that the entire class period can be dedicated to physical activity (i.e. in a physical education class). If attempting to introduce physical activity as an extracurricular endeavor for the benefit of students during a class unrelated to exercise, any time that is allocated for working out is simultaneously removing time from curriculum-based content (a risky practice to partake in with an education system that bases its level of accomplishment on the ability of students to regurgitate information on standardized tests). However, the fact is that any amount of physical activity, no matter how brief, is better than none at all. Exercise at any intensity for any duration will be more beneficial for students than sedentary classroom inaction.

A concept that should be noted before moving on to exercise approaches is the importance of orchestrating these physical activities in a way that does not segregate the less physically proficient/obese students from their peers while also encouraging leaner, more active participants to reach their peak physical potential. It has been shown that a "fitness oriented curriculum" in schools benefit both obese and non-obese students by improving insulin sensitivity, cardiovascular functioning, and inflammatory markers across all subjects (Carrel et al., 2009). By not grouping participants based on appearance, all students can improve their health and athletic abilities without any added sense of insecurity.

There are several strategies concerning weight loss seen within scientific literature. The following programs have been suggested, analyzed, and compared with one another. Below is a list and brief description of each type of weight loss scheme:

- Multidisciplinary Approach (MTG): involves a combination of dieting, progressive exercises with variable intensities, and behavior modification (i.e. educational support) (Sothern et al., 1999).
- Aerobic Interval Training (AIT): aerobic exercises that are divided into intervals of vigorous intensity (90% max heart rate) that are broken up by intervals of moderate intensity (70% max heart rate). There is no mandatory duration, but experiments tend to limit interval time from one to five minutes due to exercise intensities (Tjønna, 2008).
- Continuous Moderate Exercise (CME): moderate intensity exercise (~70% max heart rate) is maintained for the duration of the workout (Tjønna, 2008).
- Circuit Training (CT): multiple plyometric exercises of various intensities are set up in a circuit, making it a combined anaerobic-aerobic approach to exercise. Each exercise is a "station". Participants spend a predetermined and identical amount of time at each station. At the end of each time period, participants will rotate in a uniform direction to the next station (Duncan et al., 2009).
- Progressive Resistance Training (PRT): with high intensity and isolated muscle contractions, this exercise approach is mainly anaerobic. Any combination of sets and repetitions can be implemented, but less than 5 sets of 10 or fewer repetitions should be appropriate (weight/resistance should be fairly challenging). Types of lifts vary, but can be any combination of upper body, lower body, core, and back workouts. Choosing a beneficial amount of weight has been accomplished through a combination of The Borg Scale of Perceived Exertion and a participant's one repetition maximum (Benson, Torode, & Singh, 2008). The aforementioned scale ranges from 6-20 with 6 being no exertion and 20 being very, very high exertion (The Borg Perceived Scale of Exertion).

Although a promising concept with promising results, MTG is not a reasonable option for the scope of this review because it involves diet and behavior therapy: diet being too difficult to target from the classroom and behavior therapy requiring even more time (something that is usually in short supply).

Between the two aerobically driven exercises, AIT is by far the superior approach to exercising. As discussed by Tjønna et al. (2008), both AIT and CME were successful at decreasing fat, overall weight, and mean arterial pressure, but AIT was also able to improve signaling in both fat and skeletal muscle, aide in skeletal muscle biosynthesis, lower blood glucose the greatest, increase change in $VO_2$ max, and decrease lipogenesis in adipose tissue. Therefore, although both regiments are aerobically effective, interval training generates the most health benefits.

Similar to aerobic exercises, the effectiveness of CT and PRT is determined by their intensities and their volume of training (Marx et al., 2001). CT is much more characteristic of AIT in the sense that they are both divided into repeating intervals. Although there is no significant evidence in the literature that suggests either CT or PRT is better than the other, it's safe to propose that they accomplish different forms of anaerobic exercise, the success of which can only be gauged based on the goals of the individual. PRT is ideal for targeting specific muscles and burning skeletal muscle fat stores. CT is composed of plyometrics, defined as exercise that produces repeated bursts of maximum force as quickly as possible, thus creating a mixture of aerobic oxidation from continuous whole body movement and anaerobic metabolism from quick, high intensity movement (Merriam-Webster).

With these considerations in mind, AIT should be conducted as often as possible. Running activities are suggested, but they should be disguised. Relay races, games like tag, and obstacle courses are a few examples of ways to camouflage difficult interval training as something that can be fun and competitive. A good test to determine whether students are reaching the appropriate level of intensity for this regiment is as follows: if they can speak nearly complete sentences but are breathing fairly heavy then they are exercising at a moderate level, if they can't talk or can only manage to say a few words at a time then they are exercising at a vigorous intensity level (our target intensity) (President's Council on Fitness, Sports & Nutrition). Although not as effective, CME is a good way to keep students moving without having to disguise the activity as exercise due to the decreased intensity requirement. CME is also a way to recover from a particularly challenging workout from the day before. Workouts such as playing basketball, soccer, baseball, kickball, etc. are good ways to keep moderately active for an extended amount of time.

Access to the appropriate equipment (i.e. dumbbells, bars, etc.) determines whether or not a class can participate in PRT. If the materials required are present, PRT should be performed 2-3 days a week (in an effort to avoid overworking/straining adolescent muscle) and should focus on arm, leg, abdominal, and back exercises. Lifting patterns are based on personal preference, some possible suggestions being 1) one type of lift representing each body region during one session and then a different type of lift representing each region the next session (varying the type of lift that corresponds with a muscle region every session) or 2) focusing on two different body regions per session (varying the region of the body trained every session). These approaches are a good way to prevent any one muscle from getting overworked by allowing for proper recovery while also benefiting the entire body by the end of every week or so. Lower weight and higher repetitions should be the theme with PTR at this age level due to the declined capacity for anaerobic activity in adolescents and the fact that their musculoskeletal system is still developing; 2-3 sets of 15-20 reps with a fairly challenging weight (enough to cause labored breathing) should suffice.

CT is a more feasible workout plan than PTR due to its relatively minimal equipment requirements and for its more interactive, entertaining structure of exercise for puberty-aged children. Some ideas for plyometric activities for circuit stations include jumping rope, crunches, burpees, sprints, medicine ball drills, ladders, stairs, push-ups, resistance bands, jumping jacks, etc. Due to the large variety of plyometrics to choose from, CT allows the instructor the freedom of customizing their regiment based upon their class's characteristics and equipment/environmental limitations. Finally, by combining diverse exercises into one CT session, a nice variety of aerobic- *and* anaerobic-related activities can benefit the entire body and all muscle types rather than only one or two specific regions.

Even with these promising exercise routines listed above, it can be challenging to find an activity that will promote amusement and participation from this awkward "in-between" age group; awkward in the sense that adolescents are no longer children but aren't teens yet either. Contemplating whether an activity like tag is too juvenile a game for these students who watch MTV and start wearing make-up when they're 10 or 11 years old starts to become a real concern when trying to encourage group involvement. On the other hand, how many adolescents would be willing to run laps with no foreseeable reward other than being told "it's good for you"? When asked questions such as these, a professor who has taught K-12 PE and adaptive PE since 1976 and is now teaching physical education related topics at the collegiate level had a few pieces of advice to share (M. Jenks, personal communication, April 30, 2014):

1. Regardless of what the activity is, it is all in the presentation. Be creative; if the activity is conveyed in a dry and uneventful way, adolescents will be less willing to participate.
2. Give the students options. Even if they don't really have much choice in what activity you have planned for the day, give them the illusion that they have the freedom to choose whichever activity it is you want them to do. Try being spontaneous: let your participants exercise however they want, just make sure it involves movement.
3. Let students participate to whatever capacity they feel comfortable at. Unable to do a complete push-up? Do a push-up on your knees. Unable to do a push up on your knees? Do a push-up against the wall. As long as adolescents are moving and trying their best, they're making progress.
4. Try to break barriers with team building and competition among groups. Mix students up, make teams diverse, and never let any single member or entire group feel isolated or singled out.
5. Lastly, empowering students and recognizing their successes is the best form of motivation. Doing this causes adolescents to want to keep up their hard work and will hopefully make them want to incorporate regular physical activity into their adult lives.

In summary, there isn't a wrong approach to helping adolescents become more physically active. As previously iterated, any exercise is better than the alternative: no exercise. These different variations of workouts are models that have been shown to significantly improve important health markers. It is no one's responsibility to try and force a teen to either exercise or want to be healthy to avoid health complications later on in life. Educating students, giving them exercise opportunities, letting them feel like they have some control over their physical activities, and commending them on their efforts/progress is the best way to try to instill good health habits in adolescents growing up in a sedentary, high caloric, high fat environment.

## SECTION THREE:

## WRAPPING UP LOOSE ENDS

*Ethical Dilemmas Concerning Pubertal-Aged Research*

In most social instances, the topic of puberty is considered taboo. However, add to this the sensitive nature of childhood with its aura of innocence and the result is an ethical dilemma dense enough to cut with a knife. Although a social rather than a scientific construct, the gravity and level of awkwardness surrounding these tricky issues give them the ability to hinder science's ability to conduct proper, diversified studies. Granted, gonadectomies should not be performed on a model any higher up the food chain than a rat, but just because parents are in denial of the fact that their cherished little daughter will one day become a grown, sexually active woman should not stop them from allowing science the opportunity to utilize her brief but critical transition into adulthood for the benefit of future children and more in depth study.

Additional elements provide added dimensions of complexity to this already questionable combination of topics, the first of which is the different procedures implemented to arrive at the conclusions which provided the foundation for this review and accompanying exercise routine. Invasive protocol is mandatory to gauge relevant factors that either contribute to or are influenced by muscle and endocrine function, obesity, and exercise. Such procedures, such as muscle biopsies, withdrawing blood, hormone injections, etc. are problematic due to the age range of this studies targeted demographic. Is it ethically and morally acceptable for a parent to allow their 8 year old, prepubescent daughter or son to undergo these uncomfortable and sometimes painful procedures? What if there is monetary compensation involved? Do the ends justify the means? These types of ethical considerations are extensive.

The other major ingredient in this recipe of complications is the social discomfort associated with obesity. Being overweight is a lifestyle characteristic that is viewed in a negative context within our society, not because of the health implications it causes, but because it is assumed to represent laziness and is considered unaesthetic. Altering societies current perception of obesity is crucial – possessing more than a healthy amount of fat should be viewed as an illness rather than a means with which to categorize and judge individuals. Until that happens, singling out children and adolescents who are obese for these experiments instills the idea that they are different than other children, that something is wrong with them, and that they need to be fixed. Is that justifiable? Necessary? Ethical? You get the point.

*Further Considerations & Suggestions*

First and foremost, the primary literature that existed for this topic significantly lacked diversity. This shortcoming of the literature can be seen both in the subject as a whole and also on an individual study basis. The most obvious reoccurring flaw, which is noticeable throughout the entire review, is the lack of representation of both genders in testing for certain factors. For example, there was an abundant amount of information regarding pubertal timing in females, but conclusions regarding the alteration in the timing of puberty in males were open for interpretation based on the interaction between testosterone and various other factors that could possibly influence the start of puberty. This lack of equal gender testing was not one sided. In other areas of pubertal analysis, such as experiments that analyze the benefits of weightlifting in adolescents, males were the primary focus with little attention geared towards females. Although some results from the literature regarding sex-independent factors may be able to be applied to both genders, the complexity and magnitude of components/interactions present during puberty in both genders make this a risky practice. Comparable representation of both genders during experimentation is a must in order to reach acceptable conclusions.

Another problematic aspect of the primary literature that also concerned diversity was race. Although race was not mentioned in this review, it is an important factor to consider when scrutinizing subject matter such as metabolism and exercise. From an evolutionary standpoint, differences in genomes due to prehistoric spreading and independent evolution of gene pools that are responsible for different races may explain how different ethnicities have different physiological processes and responses to environmental factors. Unfortunately, these studies were primarily composed of testing on "healthy Caucasian ______ (males/females)" with only a few studies that analyzed either African American or Hispanic adolescents.

This lack of uniform representation among pubertal youth regarding differences such as gender and race hinder the accuracy of any conclusions that may be drawn due to bias towards Caucasians, or females, or Caucasian females, etc. This becomes problematic in instances of diagnosis, treatment, and the devising of further studies. More diversity in the representation of subjects in individual studies, as well as diversity in the variation of experiments conducted regarding puberty and obesity, must be accomplished in order to make studies such as this one more effective in its mission to treat the effects of obesity in pubescent teens.

## CONCLUSION:

## THE IMPORTANCE OF PREVENTION

The purpose of this review was to provide a way to incorporate age-specific exercise into the daily life of children going through puberty in the hopes of decreasing the occurrence of health defects associated with obesity in youth. However, exercise is not the most effective way to see this decrease in adolescent health concerns, but is second only to one other approach to treating obesity, that approach being prevention.

Prevention is such a simple and straightforward solution to obesity that it can easily be overlooked. What better way to fix a problem than to never have the problem, or the associated complications, exist in the first place? Unfortunately, prevention is limited because it cannot address the problem once obesity is obtained. Whether from diet, lack of exercise, or genetics, once an individual becomes obese they must address their weight by other means. Diet is one option, but it is not always effective. This is especially true for minors because they may not be able to choose what types of food they consume – it is chosen for them while they are living at home.

Unlike diet, physical activity is a fantastic option for anyone because it is independent of age and environmental factors, it is never in short supply, it is free, and most importantly it is associated with multiple physiological benefits. In the context of this paper, the physiological payoffs of exercise were only examined in two systems: skeletal muscle and the endocrine system. Both with and without the initial presence of obesity, substrate utilization and overall performance improved; aerobic skeletal muscle fibers were repaired; hormones such as insulin, testosterone, and estrogen were returned to normal levels and function; and markers for risk factors indicative of various fatal diseases were restored to their appropriate contexts. If exercise was able to induce all of these favorable changes in only two body systems, imagine the body-wide benefits it provides when it comes to the cardiovascular system, or the neurological system, etc. With that in mind, exercise is the best strategy in counteracting the deadly high caloric density and low activity environment that has been created for youth. When implemented at the right time of development and in an age appropriate way, exercise is the most effective approach to guarantee the longevity, prosperity, and continued improvement of our future generations.

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