

CHAPTER 2: LITERATURE REVIEW

INTRODUCTION

A goal of Healthy People 2000 was to reduce the prevalence of overweight adults to less than 20% by the year 2000 (33, 50). Contrary to this goal, the incidence of overweight and obese adults in the United States has risen markedly. The WHO estimates that over half of the US population is overweight and over one-fourth can be classified as obese (68). In addition, data from the third National Health and Nutrition Examination Survey (NHANES III) estimated that over 33% of adults are obese, an increase of 25% from NHANES II (35). Although variations in estimating the percentage of overweight and obese adults exist, it is apparent that a large and increasing proportion of the population can be classified as obese, resulting in a public health epidemic.

Indicators of Obesity

Most researchers have agreed that obesity is defined as an excessive accumulation of body fat (2, 27, 71). In 1959 the Metropolitan Life Insurance Company published the infamous height and weight tables. These tables were used to assess an individual's risk of premature death as denoted by weight increases above a desirable weight for height. The desirable weight was considered 126 lb. for a five foot four inch woman, and 154 lb. for a five foot ten inch man. These lean standards are now exceeded by about 80% of the population (68).

Today, one of the most commonly used measurements to assess obesity is BMI, where an individual's weight is divided by height squared (kg/m^2). A BMI greater than $25 \text{ kg}/\text{m}^2$ is considered overweight (5, 24), greater than $30 \text{ kg}/\text{m}^2$ is associated with being obese (5, 24), and greater than $40 \text{ kg}/\text{m}^2$ is regarded as severely obese (5, 49). An individual's WHR can be measured to determine the regional distribution of body fat. A WHR greater than 0.95 in men and 0.86 in women is indicative of android obesity, where fat accumulation is located in the

abdominal region as opposed to gynoid obesity where the fat accumulation is in the gluteal-femoral region (1). Recent findings have suggested that an individual's waist circumference may be a better indicator of central obesity than WHR (50). A waist circumference of greater than 99 cm (39 inches) is considered an indicator for central obesity (50).

Comorbidities Associated with Obesity

As an individual's degree of obesity increases, there is a concomitant increase in associated risks. Those individuals with a BMI greater than or equal to 27 kg/m² have over a 70 percent chance of developing obesity related diseases (45, 49, 52). In addition, those who display android obesity, typically men and postmenopausal women (9, 31), are also considered to be at an increased disease risk (49). Those diseases commonly associated with obesity include CHD, type 2 diabetes, hypertension (50, 59, 68), dyslipidemia, gall bladder disease, and some cancers (31, 68). Kanaley et al. (29) found that those subjects in a formal exercise program who exhibited weight losses of nine and ten percent of initial body weight also had improved blood cholesterol and triglyceride levels. This study agrees with the notion that weight loss of ten percent of body weight can aid in decreasing some obesity-related risks (29, 64). Simple as it sounds, achieving long-term weight loss is difficult, partly because of the complex etiology of obesity.

Factors Associated with the Development of Obesity

Genetic, physiological, and environmental factors have been implicated in the development of the obesity epidemic (24, 25). Comuzzie and Allison (11) reported that "an individual's risk of obesity is increased when he or she has relatives who are obese". Anywhere from 40-70% of the variability in the phenotypes related to obesity such as percent body fat (%BF), BMI, and leptin levels are considered heritable traits (11). Leptin, the protein product of

the *ob* gene, is synthesized and secreted by adipose tissue (38). It influences body fat by regulating both energy intake and metabolic rate (38). Through its action on the leptin receptor, leptin increases energy expenditure and decreases energy intake in animals (67). A deficiency in functional leptin due to a gene mutation can result in obesity, as is the case in the obese (*ob/ob*) mouse (17, 38). In humans, levels of leptin in the plasma positively correlate with BMI and %BF (17, 18), but a mutation in the leptin gene has not been observed, so researchers have suggested leptin resistance as a potential cause of obesity (17). Although genetic advances and the discovery of leptin have provided insight into an individual's predisposition to developing obesity, it is unlikely that genetics are the main culprit because there have not been dramatic gene changes in the population over the past two decades (18, 24, 25).

Total daily energy expenditure (24 h EE) consists of resting metabolic rate (RMR) which comprises about 60-75% of 24 h EE (54), thermic effect of food (TEF) that makes up about 10%, and the energy cost of activity with a varying contribution to 24 h EE (25, 27, 31, 67). The energy cost of activity, particularly exercise can vary daily in one individual and between individuals depending on the activity performed and performance frequency (27). Although there are variations in 24 h EE due mainly to the energy cost of activity, there is no evidence showing unexplainable decreases in RMR over an entire population. Therefore, it is difficult to correlate the increasing prevalence of obesity to physiological or metabolic alterations (24). Instead, a more likely factor is the reduction in energy expended due to activity.

The development of obesity can be considered a response to an environment that promotes low energy expenditure and high energy intake (24). Although there has been an overall decrease in the percentage of fat from total calories consumed, fat intake in grams per day has remained the same (24). The decrease in overall percentage of calories from fat can be

attributed to an increase in the total amount of calories consumed. Since 1979 there has been a six percent increase in total energy intake (45). In addition, only 22% of adults engage in regular physical activity of at least 30 minutes per day, and about 24% are completely inactive. The remainder of the population participates in sporadic activities (48). As a result, the amount of fat stored in adipose tissue is the sum of the difference between energy intake and energy expenditure that accumulates over time (52).

Because obesity is such a tremendous health risk, it is necessary to identify treatment methods that have the potential to be lifelong lifestyle alterations to aid in both the prevention and treatment of the disease. The purpose of the following review is to examine the current treatment methods for obesity. Included will be a thorough review of diet and exercise regimens and the effects on body weight and composition, and possible fuels being utilized in various exercise protocols.

CURRENT TREATMENT STRATEGIES

Weight loss has become an obsession. One can conclude after visiting the “Health and Nutrition” section in a bookstore that the market for weight loss remedies is increasing. After a visit to the drug store, one can also conclude that a popular method of weight loss is through pharmaceuticals. In addition to the plethora of books written and available drugs, television and radio advertisements with celebrity testimonials of how phenomenal diet or weight loss programs have proven to be are commonplace.

Television programs and commercials rarely have overweight people in the “star” roles, possibly promoting the idea that both success and so-called “better lives” are associated with thinness. Additionally, Crandall et al. (13) reported that “fat Americans” are discriminated

against in society. One can fairly state that society is obsessed with the cosmetic ideal of thinness and will turn to the many available resources to achieve weight loss, thinness, and the desired better life.

It has been estimated that about 25% of men and 45% of women are trying to lose weight at any given time. To achieve this weight loss, Americans are spending more than \$33 billion on services and products to meet their weight loss goals (45). Recently, French et al. (19) completed a study examining the dieting behaviors of adults in the United States. This was a four year study in which the 1120 subjects were also part of the Pound of Prevention study, a weight gain prevention study. The subjects were assessed at baseline and annually for the following three years. The parameters examined were body weight, weight control behaviors, dieting status, dietary intake, physical activity, demographics, and smoking status. Treatment for the subjects consisted of monthly newsletters that emphasized at least one behavior modification for weight loss and/or maintenance. There was no direct mention of decreased energy intake in the monthly newsletters.

The subjects were mainly females about 35 years old, with a body weight of 76.5 kg and a BMI equal to 27.2 kg/m². In this subject pool, the most common weight loss behaviors were increased physical activity, reduced caloric intake, reduced fat intake, reduced amount of food eaten, and elimination of sweets for a median duration of 27.5, 20, 40, 24, and 18 weeks respectively from a possible 208 weeks total. The least common behaviors engaged in were fasting, purging, liquid diet supplements, and skipping meals for a median of zero, 2, 5, and 1 week respectively (19). Overall, the healthier weight control behaviors were engaged in for a longer duration than the unhealthy behaviors. French et al. (19) found that those subjects who engaged in weight loss procedures for a longer duration did not gain as much weight over the

four year period as their counterparts who incorporated the behaviors into their life for a shorter duration or not at all.

The authors concluded that weight loss behaviors are effective in a dose response manner to the duration of the behavior (19). This study provided insight into the behavioral alterations being done to achieve weight loss in a large subject pool. Because the subjects were not told what behaviors to adopt but were provided some basic literature, makes the study more adaptable to the general population who may rely on lay magazines and newspapers for weight loss tips. The subjects were mainly women, which makes it difficult to identify if a group consisting mainly of middle-aged men would engage in similar behaviors. Also, the possibility of the subjects providing false information about their lifestyles to the researchers exists.

Rosenbaum et al. (52) described the primary goal of weight loss to be a reduction in the morbidities that are commonly associated with obesity such as CHD, type 2 diabetes, hypertension, etc. Tremblay et al. (64) studied a group of obese women for 29 months performing exercise alone for 15 months and then for the remaining 14 months exercise in combination with diet modification. Overall, there was a 12% decrease in weight from 92.1 ± 19.2 kg to 81.1 ± 19.0 kg and body fat from 49 ± 6% to 41 ± 9% (p<0.05) from the beginning to the end of the study. In addition, there were significant improvements in glucose tolerance and insulin sensitivity. The area under the oral glucose tolerance curve changed from 25 mg/dl/180 min × 10⁻³ to 19 mg/dl/180 min × 10⁻³, and the area under the insulin resistance curve from 12.5 ± 7 U/ml/180 min × 10⁻³ to 6.5 ± 6 U/ml/180 min × 10⁻³ (p<0.05). The subjects' plasma lipid profile also improved after the study duration. Cholesterol levels decreased from 214.3 ± 14.9 mg/dl to 173.8 ± 19.5 mg/dl (p<0.05), low density lipoprotein cholesterol (LDL-C) levels decreased from

157.5 ± 20.9 mg/dl to 116.4 ± 22.7 mg/dl ($p < 0.05$) and high density lipoprotein cholesterol (HDL-C) levels increased slightly, although not significantly.

With these results, Tremblay et al. (64) concluded that although the women remained obese it is possible that the weight loss achieved through diet and exercise normalized the women's risk for diabetes. Additionally, the improvements in the blood lipid profile may potentially decrease the subject's risk of developing CHD. This study provides evidence as well as the previously described study by Kanaley et al. (29) that small changes in weight can positively affect the health status of an individual even if obesity persists.

Ideally, weight management or the adoption of a healthy lifestyle filled with sensible eating and regular exercise patterns as described by the American Dietetic Association will not only initiate weight loss, but will aid in long term weight maintenance (45). There may be improvements in health status as disease risks are decreased as was demonstrated through positive alterations in glucose tolerance, insulin resistance, and improvements in blood cholesterol values (64). As stated previously, there are a wide variety of weight loss therapies available that can be categorized as pharmacotherapy, diet therapy, and exercise treatments. While drug therapies are a popular choice, it is beyond the discussion of this paper, therefore the focus will consist of the diet and exercise components of weight loss.

Dietary Treatments

Every so often a new diet emerges as the cure-all. In the past, diets containing foods with proposed miracle properties have emerged. These included the grapefruit diet, the ice cream diet, the bananas and milk diet (72) and more recently, the cabbage soup diet (47). Jenny Craig and Nutri-System, programs with prepackaged meals emerged but were deemed unrealistic for lifetime success because of the high cost to the consumer and the pressure to purchase and

consume the company's products (47). Each of the aforementioned diets provided little or no method of teaching healthy eating habits (12, 72). Instead, the diets were designed to provide a "quick fix", which typically resulted in a lack of adherence and weight regain equal to or sometimes greater than the amount initially lost (47).

McGuire et al. (37) examined the maintenance of lost weight in a group of individuals who initially lost weight through organized programs, liquid diets, or on their own. Overall, the 893 subjects surveyed were mainly Caucasian females around 45 years old. The results showed that those who lost weight on their own had less difficulty maintaining the lost weight than both the organized program and the liquid diet groups. Additionally, those who lost weight on their own had more difficulty in losing weight than maintaining weight, the opposite of the liquid diet group participants who easily lost weight, but were not able to maintain it as easily. Once the initial weight was lost the individuals in all three groups maintained their weight losses similarly through diet and exercise. The subjects all consumed low calorie (~1500 kcal/day) low fat diets (~25% kcal from fat) and participated in physical activity expending close to 2500 kcal per week.

Although different approaches to weight loss were taken, the individuals eventually developed similar lifestyle changes to maintain their weight loss. Although this study found positive methods of weight maintenance, it is possible that the general population will not respond the same way once initial weight loss is achieved. As was previously described in the study by French et al. (19), the subjects participated in weight loss activities for a maximum of 40 weeks out of a possible 208 demonstrating that individuals may not adhere to behaviors and/or programs for extended periods of time.

Evidence from the previously described studies demonstrates that achieving weight loss requires more out of a person than “going on a diet”. The individual must be willing alter their current behaviors to achieve dietary success and to also adopt an exercise regimen to aid in the promotion of weight loss.

THE EFFECTS OF DIET AND EXERCISE ON WEIGHT LOSS

Dietary restriction can promote an energy deficit on its own, but there is the undesirable risk of decreasing the amount of fat free mass (FFM) while decreasing weight and body fat. Aerobic exercise with and without dietary restriction can significantly decrease body fat and weight and maintain FFM (15, 21). Geliebter et al. (21) in a recent study comparing diet only, diet and aerobic training, and diet and strength training found that the diet only group had a decrease in the amount of FFM while decreasing weight and body fat. There were no such changes noted in the groups where diet and exercise were combined. Therefore, a combination of dietary restriction and increased energy expenditure through exercise is a potential modality to enhance body fat loss and weight loss while preserving FFM.

Resistance exercise has been recognized as a potential method of exercise for weight loss and improvements in body composition in obese women who were also on a modest calorie restriction (54). Ryan et al. (54) examined the effects of resistance exercise on body composition in 15 women. Seven women were obese, $BMI \geq 27 \text{ kg/m}^2$ and eight were not obese, $BMI < 27 \text{ kg/m}^2$. The subjects performed a circuit of 14 resistance exercises three times per week for 16 weeks. The subjects began exercising at a resistance of 90% of a three repetition maximum for the first few repetitions and then the weight was decreased to allow the subjects to perform 15 repetitions. The resistance level was monitored weekly and changed to accommodate for

individual strength gains as needed. The obese women were also placed on modest caloric restriction to promote half to one pound of weight loss weekly. In the weight loss group there were significant reductions in body weight, fat mass (FM), and %BF (78.7 ± 2.1 kg to 74.0 ± 2.0 kg, 33.3 ± 1.9 kg to 28.2 ± 1.7 kg, and $43.0 \pm 1.2\%$ to $38.9 \pm 1.3\%$, $p < 0.001$). The nonobese women reduced their body weight, fat mass, and %BF although not significantly. Overall, there was a significant increase in FFM for the groups combined, but not for each individual group. This study demonstrated those women on a weight loss plan of caloric restriction and resistance exercise can positively alter their body weight and body composition. However, the same conclusion can not be made for normal weight women performing resistance exercise. Although positive results were found with this diet and exercise regimen, the effect of RT in a weight loss program when compared to groups devoid of RT when other parameters are controlled is not as clear.

Kraemer et al. (33) incorporated RT into a weight loss program consisting of diet and aerobic exercise. Thirty-one overweight premenopausal women were divided into four groups matched by BMI. There was a control group, a diet group (D), a diet group which performed aerobic exercise three days per week (DA), and a diet group which performed aerobic exercise combined with RT three days per week (DAR). The treatment lasted for 12 weeks, and measurements were taken pretreatment, at week six, and after week 12. The diets were high in fiber and modest dietary restriction was designed to promote 0.5 to 1 kg weight loss per week. The subjects attended weekly nutrition education sessions to promote healthy well-balanced eating and behavior modification techniques. The subjects performing aerobic exercise did a variety of cross-training activities beginning at 30 minutes per session and increasing to 50 minutes per session with intensity and duration increasing according to each individual's

improvement in the exercise. The subjects exercised at a target heart rate of 70-80% their functional capacity. The RT training consisted of exercises incorporating each of the major muscle groups.

Kraemer et al. (33) found that the subjects in the three treatment groups had similar nutrient intakes throughout the experimental period. Body weight was reduced in each group at week 6 and by week 12 there was a 6.2 kg, 6.8 kg, and 7.0 kg ($p<0.05$) reduction in weight for the D, DA, and DAR groups respectively from the initial weight. FM and %BF decreased at week 6 in D and DA and by week 12 there were significant reductions of 5.8%, 8.0% and 4.3% in body fat and 6.0 kg, 8.3 kg, and 5.5 kg ($p<0.05$) in fat mass in the D, DA, and DAR groups respectively, as compared to the initial values. There were no significant changes in FFM in any of the groups. Contrary to the previously described studies by Geliebter et al. (21) and Tremblay et al. (64) this study did not provide evidence that exercise, whether aerobic or resistance in nature incorporated into a weight loss program based on modest dietary restriction preserved FFM more than diet restriction alone. Additionally, this present study was 12 weeks in duration compared to the 29 months that the study by Tremblay et al. (64) took place.

The study by Kraemer et al. (33) did not have matched caloric expenditure between the exercise groups or between individuals, which may have affected the outcome. In addition, the researchers provided the subjects with some of the foods, which may have affected subject compliance to the dietary protocol.

A majority of the weight loss studies examined were done in women. Although these studies are able to provide a foundation for the current study, they cannot be directly compared to studies in which men are subjects. Ross et al. (53) examined the effects of diet and exercise on adipose tissue in an 18 week study. The subjects were 33 obese men ($BMI>27 \text{ kg/m}^2$,

WHR>0.95) divided into three groups of 11 for the different protocols to allow for similar BMI, WHR, lean tissue (LT) and adipose tissue (AT) among the groups. The groups were diet only (DO), diet and aerobic exercise (DA), and diet and resistance exercise (DR). Diet restriction consisted of reducing energy intake by 1000 kcal/day. The subjects' needs were calculated based on the Harris-Benedict equation and multiplied by an activity factor of 1.5. The subjects were on a weight maintenance diet for one week and then a weight reduction diet for 16 weeks. After 16 weeks, the subjects energy needs were recalculated and they were then placed on a second maintenance diet. The subjects chose their own foods and kept daily food diaries. The subjects also attended weekly group diet sessions.

Aerobic exercise consisted of an initial duration of 15 minutes increasing to 60 minutes 5 days/week. The exercise was performed on a cycle ergometer, treadmill (walking), or on a stair stepper. The exercise was performed at 77% of the maximum heart rate. The resistance exercise program consisted of multiple lifts with the workload set at 8 repetitions and increasing once 12 repetitions were achieved. The energy expenditure was estimated at 120 kcal/session. Waist-to-hip measurements were taken prior to and after the training period. A MRI was also performed to determine the amount of visceral and subcutaneous adipose tissue (VAT and SAT).

The WHR decreased in each group with no significant difference between the three groups. Overall, total body VAT was reduced more than total body SAT. However, there was a greater reduction in abdominal SAT than gluteal-femoral SAT in both the DA and DR groups. This study suggested that dietary restriction in combination with aerobic or resistance exercise was effective in decreasing abdominal SAT and VAT (53).

The reviewed studies consistently indicated that modest dietary restriction and aerobic exercise is a combination that promotes weight loss and favorable improvements in body

composition and body fat distribution in obese subjects. The subjects in these studies performed various exercises ranging from walking to cycling to stair stepping at varying intensities.

Although the intensities varied from one study to the next, the subjects were maintained at an intensity that could be considered moderate.

There is some evidence suggesting that exercising at a high intensity may be more beneficial as a weight loss regime. Further discussion of HIT versus MIT is warranted as the optimal exercise program for weight loss and maintenance is sought after.

HIGH INTENSITY EXERCISE VERSUS MODERATE AND LOW INTENSITY EXERCISES

Alterations in Body Composition

Changes in body composition, primarily a decrease in body fat may occur with exercise. Previously, moderate constant intensity exercise has been employed to achieve high energy expenditure and fat usage in the obese population (2). A 14 month study by Depres et al. (16) demonstrated a significant reduction in %BF, fat mass, and weight, and no change in FFM upon completion of the study. The subjects exercised four to five times per week for 90 minutes per session. The work intensity was approximately 55% VO_2 max. There was no dietary intervention. Upon completion of the program, the subjects significantly reduced their body weight, BMI, %BF, and FM from 90.0 ± 11.8 to 86.3 ± 9.6 kg ($p < 0.05$), 34.5 ± 4.3 to 33.1 ± 3.6 kg/m² ($p < 0.05$), 47.0 ± 5.5 to $43.7 \pm 4.8\%$ ($p < 0.01$), and 42.6 ± 9.4 to 38.0 ± 7.3 kg ($p < 0.01$) respectively. This study demonstrated that when a moderate intensity exercise program without dietary intervention is adhered to for duration of time that there could be significant and favorable alterations in both body weight and body composition (16).

More recent evidence has suggested that HIE may be more beneficial in optimizing body fat loss (63). A survey of 2500 people by Tremblay et al. (63) suggested that individuals who exercised at a higher intensity were more likely to have a lower percentage of body fat than those who did not exercise at the high intensity.

A follow-up study by Tremblay et al. (65) examined the effects of a 15 week HIIT versus a 20 week MIT program on body composition and skeletal muscle metabolism. The 27 subjects (14 women and 13 men) in the study were healthy and of normal weight. The MIT protocol consisted of exercising 4 times a week increasing to 5 times a week. Each session began at 30 minutes and increased to 45 minutes. The intensity of the MIT protocol began at 60% and increased to 80% of the maximal heart rate reserve over the 20 weeks. The HIIT protocol began at 30 minutes per session at 70% maximum heart rate reserve. High intensity intervals were incorporated into the exercise session. Short interval duration began at 10 and increased to 15 bouts for 15 seconds, which increased to 30 seconds duration. The long interval consisted of 4-5 bouts of 60 seconds increasing to 90 seconds in duration. The intensity of the short interval was set at 60% of maximal output for 10 seconds for the short interval, and at 70% of maximal work output for 90 seconds for the long interval. The intensity was increased 5% every 3 weeks.

Overall, the MIT protocol elicited a 120.4 ± 31.0 MJ energy expenditure whereas the HIIT protocol only provided 57.9 ± 14.4 MJ of energy expended ($p < 0.01$). There tended to be a greater reduction in the sum of the six skinfolds in the HIIT group (94.2 ± 37.7 to 80.3 ± 36.0 mm) than the MIT group (79.2 ± 35.1 to 74.7 ± 34.2 mm). Expressing the decrease in sum of the six skinfolds per total energy expenditure resulted in the subcutaneous fat loss being nine times greater in the HIIT group (65). This suggests that a HIIT protocol significantly reduces body fat to a greater extent than does a constant intensity MIT protocol. The results of this study were for

all 27 subjects combined; it would be of interest to know if men and women responded differently to the two protocols.

Bryner et al. (7) compared the effects of HIE and LIT on changes in body composition in 15 normal weight women of average fitness level. LIT exercised at 60-70% maximal heart rate 40-45 minutes per day, 4 days per week, and the HIE at 80-90% maximal heart rate 40-45 minutes per day, 4 days per week for 10 weeks. Each exercise session began at the desired intensity for 20 minutes per session in the first week; this increased by 10 minutes each week, so that by the fourth week the subjects were at the desired exercise duration. Beginning with week five until week 15, the subjects were considered in the experimental period, the first four weeks were considered control period. There were no dietary alterations made. There were no changes in body weight in either group, but there was a significant 13.5% decrease in percent body fat in the HIE group over the duration of the study. When analyzed within group, the LIT group did not change their body composition. It is important to note that the caloric expenditure in the two exercise groups was not matched in the study. It is hard to determine whether the HIE would have caused superior body fat loss if the same amount of energy was expended as the LIT group.

The two previous studies suggest a benefit of HIE on body fat loss. However, both studies used lean subjects. It is important to test the effect of different exercise intensities on obese individuals, to determine if these regimens should be recommended as a means of weight loss.

Slightly overweight women were studied for changes in body composition in low and high intensity exercise by Grediagin et al. (22). There were 18 women with an average BMI between 23.8 and 26.2 kg/m² for the HIE and LIT groups. The HIE group exercised at 80% VO₂max and LIT group at 50% VO₂max. The subjects exercised on a treadmill four times a

week for 12 weeks. The duration of each exercise session was long enough for the subjects to expend 300 kcal per session. There were no dietary alterations. The HIE group lost less weight than the LIT group, 0.7 ± 2.6 lb. compared to 3.3 ± 2.6 lb., but this difference was not significant. As was determined by the hydrostatic weighing technique, both the LIT and HIE groups lost five pounds of FM, but the HIE group gained more FFM than did the LIT group, 4.3 ± 5.4 lb. versus 1.8 ± 5.0 lb. This change in the gain of FFM, possibly muscle mass may be the reason for the lower body weight loss of the HIE group. This gain in lean tissue might lead to an increase in RMR and in turn lead to an improvement in long-term weight control (22). The women who served as subjects in this study do not adequately represent an overweight and/or obese population. Since increased health risks are identified in those with a BMI > 27 kg/m² (52) it would be beneficial to examine a group that can more appropriately be considered at risk.

In another study by Ballor et al. (3), 27 obese females participated in an eight week body mass loss study. The subjects presented with an average BMI of 28.0 kg/m². All of the subjects were placed on a 1200 kcal per day diet with 52% carbohydrate, 20% protein, and 28% fat. The subjects were then divided into two groups based on the exercise protocols. The exercise protocols consisted of the LIT group working at 42.5% VO₂max for 50 minutes per session, and the HIE group at 85% VO₂max for 25 minutes per session. The differences in exercise duration were made to give equal caloric expenditure between the groups. Both groups exercised 3 days per week. There were no significant differences between the body mass, FFM, FM, %BF, or the sum of the skinfold measurements after the exercise training between the two groups. With this result, the researchers concluded that the intensity of the exercise does not affect body composition or the rate of body mass loss. It may be that the exercise training program was not long enough to give measurable differences in body composition between the two groups when

the subjects were placed on a restricted calorie diet. The previously mentioned studies continued training for at least 10 weeks.

In summary, some studies show more fat loss in individuals who exercise at higher as compared to lower intensities. The studies by Tremblay et al. (65) and Bryner et al. (7), used only normal weight subjects, so it is unknown whether or not the same results would apply to an obese population. The two studies in which overweight and obese women were studied gave conflicting results; more research is required to compare the value of HIE for obese individuals in improving body composition. Additionally, only one study compared interval exercises, it is possible that HIE performed at a constant intensity is less effective than HIIT in decreasing body fat. Another important aspect that may be affecting the amount of body fat lost with exercise are the fuels being utilized during and after exercise.

Exercise and Sources of Energy

Adenosine triphosphate (ATP) is the major source of energy in the body (28). The amount of ATP stored in the body is limited, and could be quickly utilized. To prevent the stored ATP from being depleted, there are three energy systems, the creatine-phosphate (CP) system, anaerobic glycolysis, and aerobic metabolism capable of providing ATP (23, 46). Briefly, the CP system consists of the phosphate group of CP being transferred to adenosine diphosphate (ADP) to produce ATP and creatine. This reaction is catalyzed by the enzyme creatine kinase (28). Anaerobic glycolysis occurs in the absence of oxygen and consists of the breakdown of glucose to lactate through a series of reactions. The glucose is derived from muscle glycogen and glucose in the circulation (23). Lastly, aerobic metabolism consists of the complete oxidation of fats, carbohydrates, and proteins to carbon dioxide and water (23).

At rest, a majority of the energy needs are met by the aerobic metabolism of fat (23). However, when exercise is performed, ATP is provided through a combination of the above systems based on the intensity and duration of the exercise (23). The CP system is capable of providing ATP at a rapid rate upon initiating extremely intense exercise bouts (20, 55, 70). The CP system is only able to produce adequate ATP for the first few seconds of exercise (20, 55). Continued exercise at a high intensity will then have an increased reliance upon anaerobic glycolysis and aerobic metabolism.

Serresse et al. (55) studied 25 males performing three different maximal effort tests to determine the energy contribution from the three systems. The tests were 10, 30, and 90 seconds in duration. Results from the 10 second exercise bout revealed that 53% of the energy was derived from the CP system, 44% from anaerobic glycolysis, and 3% from aerobic metabolism. In the 30 second test, the energy contributions were 23%, 49%, and 28% for the CP system, anaerobic glycolysis, and aerobic metabolism, respectively. Lastly, during the 90 second bout, 12% of energy was from the CP system, 42% from anaerobic glycolysis, and 46% from aerobic metabolism. Closer inspection revealed that during the 90 second test, the maximal contribution of each energy system was during 0-15 seconds for the CP system, 16-30 seconds for anaerobic glycolysis, and 61-75 seconds for aerobic metabolism. Additionally, a study by Yamamoto and Kanehisa (70) demonstrated a similar finding in that aerobic metabolism is the main contributor of energy after 60 seconds of supramaximal cycling.

Brooks and Mercier (6) proposed a model to explain the contribution of carbohydrate and fat to energy production during exercise, better known as the crossover concept. It has been reported that as exercise intensity increases there is a concomitant increase in the utilization of carbohydrate as a fuel source and a decrease in the utilization of fat. The crossover concept

implies that there is a crossover point at a particular exercise power output where ATP formation from carbohydrate is greater than that of fat (6). At power outputs above the crossover point, there are subsequent increases in carbohydrate utilization and decreases in fat utilization. As a result of training, there is an increased reliance on fat as a fuel source at rest up to and including moderate exercise intensities (6, 32, 56), however at higher intensities the crossover to carbohydrate utilization continues to occur (6).

Romijn et al. (51) studied five endurance trained athletes performing exercise at 25, 65, and 85% VO_2max on consecutive days. The exercises at 25 and 65% VO_2max were performed for 120 minutes, whereas the exercise at 85% VO_2max was performed for 30 minutes. Indirect calorimetry and stable isotope tracers were utilized to identify carbohydrate and fat metabolism at the different exercise intensities. Adipose tissue lipolysis was significantly higher during exercise at 25% VO_2max compared to that at 65 and 85% VO_2max (25.8 ± 2.6 versus 22.8 ± 2.7 and 17.0 ± 3.4 $\mu\text{mol/kg/min}$, respectively ($p < 0.05$)). Total fat oxidation was significantly higher at 65% VO_2max (42.8 ± 3.7 $\mu\text{mol/kg/min}$) compared to 25 and 85% VO_2max (26.8 ± 1.5 and 29.6 ± 4.3 $\mu\text{mol/kg/min}$) ($p < 0.05$). As lipolysis decreased there was an increase in glucose turnover, with increasing exercise intensity. This study is consistent with the crossover concept previously discussed, in that as exercise intensity increases there is a decrease in the use of fat as a fuel source and an increase in the use of glucose (carbohydrate).

Several other studies have compared the utilization of fat and carbohydrate at different exercise intensities and have found results similar to and different than those of Romijn et al. (51). Thompson et al. (62) examined the effects of exercises of varying intensities on substrate oxidation. Ten healthy and active male subjects were used for the study. The subjects performed two submaximal exercise tests, one at 33% VO_2 max for 90 minutes and another at

66% VO_2 max for 45 minutes. The exercises were designed for equal caloric expenditure. Oxygen uptake and carbon dioxide outputs were measured during the exercise bouts and during the post-exercise period via indirect calorimetry. The subjects oxidized a greater amount of CHO during the moderate intensity exercise than the low intensity exercise (188.8 vs. 142.5 g, $p < 0.05$). During LIT the subjects oxidized 42.4 g fat and 24.0 g during MIT ($p < 0.05$). There were no significant differences in the post exercise substrate oxidation for the two exercise groups.

Overall, the authors demonstrated that LIT promoted fat oxidation to a greater extent than did MIT contrary to that found by Romijn et al. (51), which may have occurred due to the different subjects used. Romijn et al. (51) used endurance trained subjects and Thompson et al. (62) used active subjects. The effect of trained individuals utilizing a greater amount of fat as fuel at rest and up to and including moderate intensity exercise may have caused the difference in the two studies. Although this study does not agree with that of Romijn et al. (51), it however, provide a basis for LIT for weight loss, which may be the mode of exercise obese individuals prefer.

The effect of exercise protocols of varying intensities on substrate oxidation using indirect calorimetry was studied by Phelain et al. (43). Comparisons of HIE to LIT, and no exercise in 8 nonobese women was performed. The HIE group cycled at 75% of maximal oxygen uptake (VO_2max) and LIT group at 50% of VO_2 max for as long as it took to expend 500 kcal per session (about 65-90 min). The protocols were separated by 3 days. The measurements of oxygen uptake (VO_2) and carbon dioxide output (VCO_2) were used to compute the R value, an indicator of fat and carbohydrate oxidation. The metabolic measurement revealed that there was a greater amount of carbohydrate oxidation during HIE and a greater total fat oxidation during

LIT. However, at the end of a 3 hour recovery period there was a 23.8% higher rate of fat oxidation for the HIE as compared to the LIT protocol. These findings suggest that although fat oxidation is lower during HIE, the rise in fat oxidation during recovery may play an important role in reducing body fat in those who perform higher intensity exercise.

The previously discussed studies compared a variety of exercise intensities and protocols. Those protocols in which constant intensity exercise was performed generally demonstrated that lower intensity exercises utilized more fat as a fuel and higher intensity exercises utilized more carbohydrate as fuel during the exercise. However, the combined high and low intensity interval sprint protocols demonstrated that fat is an important source of fuel during the exercise. The utilization of fat during the interval protocols may make this exercise method better at promoting decreases in body fat than constant intensity exercises at low, moderate, or high intensities.

Exercise Intensity and Enzymatic Alterations

Several physiological and biochemical changes occur in skeletal muscle as a result of exercise training which may influence the fuels being utilized during an exercise bout. Holloszy and Coyle (26) reported that some of these changes include an increase in the mitochondrial content in skeletal muscle and an increased oxidative capacity, which includes increased levels of enzyme markers, especially those involved in fatty acid oxidation. Keeping these physiological and biochemical changes in mind, one would expect an increase in the activity of HADH, an enzyme marker of the β -oxidation of fatty acids with exercise training.

The effects of varying exercise training intensities on fatty acid oxidation has been looked at by a few studies. Tremblay et al. (65) examined the enzymatic adaptations of skeletal muscle to the different exercise programs previously described. Muscle biopsies performed

before and after the training programs showed that the enzyme activity of HADH, increased more in the HIIT program as compared to the MIT program (3.49 ± 0.76 to 5.59 ± 1.65 U/g versus 3.61 ± 1.10 to 4.26 ± 1.20 U/g respectively, $p < 0.001$). Alterations in activities were observed for the glycolytic enzymes hexokinase (HK) and, phosphofructokinase (PFK), and an oxidative enzyme malate dehydrogenase (MDH) upon completion of the training period. MIT resulted in a significant decrease in HK, a decrease in PFK although not significant, and a significant increase in MDH. HIIT resulted in significant increases in HK, PFK, and MDH.

The alterations noted in the glycolytic enzymes are in accordance with the activities performed, typically MIT will not rely strongly on these enzymes and HIIT will since the primary energy systems used during HIIT include CP and anaerobic glycolysis. The increase in MDH exhibited by both training protocols suggests an increased reliance on oxidative metabolism during each of the groups as a result of training. The increase in HADH observed in the HIIT protocol suggests an increase in fatty acid oxidation potential within the muscle.

MacDougall et al. (36) studied adaptations in enzymes to sprint interval exercise training. The subjects were 12 healthy and highly active males. The subjects exercised three days per week for seven weeks total. The exercise protocol consisted of a maximum effort for 30 seconds with four minutes of recovery between the sprints beginning with four intervals and increasing to ten intervals per session. Muscle biopsies were obtained for biochemical analyses. There was an increase in HADH from 2.99 ± 1.25 to 4.15 ± 2.04 mol/kg protein/hr, although this increase was not significant. Several other oxidative enzymes, citrate synthase (CS), MDH, and succinate dehydrogenase (SDH) increased significantly after the training period. The authors concluded that sprint training could potentially be a training method to increase the activity of oxidative

enzymes. Additional work needs to be done to assess the potential role that sprint training may have in the beta-oxidation of fatty acids.

Phillips et al. (44) studied seven inactive but otherwise healthy males in an endurance training study. The subjects exercised for two hours on five consecutive days at 59% VO_2peak . The training lasted for 31 days. HADH activity increased after 31 days of training from 6.3 ± 0.3 to 7.8 ± 0.4 mol/kg protein/hr ($p < 0.01$). Additionally, there were significant increases in other oxidative enzymes upon completion of the training period. The amount of intramuscular triglycerides depleted with exercise was measured and showed a 56% increase in the amount depleted compared to the initial values ($p < 0.01$). This suggests that the training improved muscle oxidative capacity and potentially the ability to better oxidize fat. This study demonstrated the potential benefits of a moderate intensity exercise, but it is unknown if a training program of this magnitude at either a low or high intensity would be as beneficial in improving fat oxidation and possibly decreasing body fat.

Increases in the activity of HADH may correspond to an increased rate of fatty acid oxidation and a decrease in body fat. A decrease in body fat is a desirable outcome in the treatment of obesity. Evidence suggesting how obese individuals respond to exercises of varying intensities would be beneficial in determining an exercise prescription for decreasing body fat and body weight in this population.