CHANGES IN ENERGY EXPENDITURE ASSOCIATED WITH INGESTION OF HIGH PROTEIN, HIGH FAT VERSUS HIGH PROTEIN, LOW FAT MEALS AMONG UNDERWEIGHT, NORMAL WEIGHT, AND OVERWEIGHT FEMALES

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Amy Jo Riggs

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VITA

Amy Jo Riggs, daughter of Mike and Pam Riggs, was born January 25th, 1973 in Dayton, Ohio. Amy Jo graduated from Wando High School in Mount Pleasant, South Carolina, in 1991. She attended Indiana University where she received her Bachelor of Science degree in Nutrition and Food Science in May, 1997. In January 1999, she entered her internship at Ball State University and became a registered dietitian in November 1999. In August 2001, Amy Jo received her Master of Science degree in Nutrition and Food Science from Ball State University. Amy Jo worked as a clinical dietitian for four years at a Cancer Center in Columbus, Indiana. In August 2003, she entered the graduate program in the department of Nutrition and Food Science at Auburn University.

DISSERTATION ABSTRACT

CHANGES IN ENERGY EXPENDITURE ASSOCIATED WITH INGESTION OF HIGH PROTEIN, HIGH FAT VERSUS HIGH PROTEIN, LOW FAT MEALS AMONG UNDERWEIGHT, NORMAL WEIGHT, AND OVERWEIGHT FEMALES

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Changes in energy expenditure in response to ingestion of a high protein, high fat meal versus an isocaloric high protein, low fat meal were investigated in 21 females, aged 19-28 years. Subjects were classified based on body mass index (BMI) as underweight (<18.5 kg/m^2), normal weight (18.5-24.9 kg/m^2), or overweight (≥ 25.0 kg/m^2). Energy expenditure, measured using indirect calorimetry, was assessed before and every 30 minutes for 3.5 hours following consumption of the meals on two separate occasions. Height and weight were measured using standard techniques. Fat free mass (ffm) was measured using bioelectrical impedance analysis. No significant differences were found among the three groups in age, height, or fat free mass. BMI differed significantly among the three groups, and body weight and body fat were significantly higher in overweight subjects versus normal weight and underweight subjects. Significant positive correlations were found between BMI and baseline metabolic rate ($r^2 = 0.29$), between body weight and baseline metabolic rate ($r^2 = 0.32$), between BMI and average change in metabolic rate ($r^2 = 0.35$), and between body weight and average total change in metabolic rate ($r^2 = 0.22$). Changes in metabolic rate (kcal/min) from baseline rate did not significantly differ in the underweight (n=3) subjects or in the overweight subjects (n=5) following consumption of either eal at any of the measured times. Changes in metabolic rate (kcal/min) from baseline rate were significantly higher in the normal weight subjects (n=11) at 2, 3, and 3.5 hours following the consumption of the high protein, high fat meal versus the high protein, low fat meal. Significant differences in metabolic rate were observed among the overweight, normal weight, and underweight subjects following consumption of both meals at most of the times measured. However, when metabolic rate was calculated as kcal/min/kg ffm or as change in metabolic rate from the baseline rate, no significant difference were found among the groups at any of the times. In conclusion, changes in metabolic rate in response to high protein, high fat versus high protein, low fat meals do not differ in overweight and in underweight subjects and thus, there is no metabolic advantage in diet-induced thermogenesis between the two meals. In contrast, in normal weight subjects, ingestion of a high protein, high fat meal significantly increased metabolic rate (69.3 kcal/3.5 hr) versus consumption of a high protein, low fat meal and provides a short-term metabolic advantage.

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TABLE OF CONTENTS

LIST OF TABLES AND FIGURES………………………………………………... x

I. INTRODUCTION……………………………………………………... 1

II. LITERATURE REVIEW……………………………………………… 3

III. CHANGES IN ENERGY EXPENDITURE ASSOCIATED WITH INGESTION OF HIGH PROTEIN, HIGH FAT VERSUS HIGH PROTEIN, LOW FAT MEALS AMONG UNDERWEIGHT, NORMAL WEIGHT, AND OVERWEIGHT FEMALES…………………………… 50

IV. SUMMARY OF FINDINGS…………………………………………... 78

REFERENCES………………………………………………………………. 80

APPENDICES………………………………………………………………. 86

LIST OF TABLES AND FIGURES

Table 1 Mean (± SE) age, height, weight, body mass index (BMI), fat free mass, and body fat among overweight, normal weight, and underweight subjects…………………………………………………… 69

Table 2 Mean (± SE) baseline and postprandial metabolic rate (kcal/min) within and among overweight, normal weight, and underweight subjects before and following consumption of a high protein, high fat meal………………………………………………………………. 70

Table 3 Mean (± SE) baseline and postprandial metabolic rate (kcal/min) within and among overweight, normal weight, and underweight subjects before and following consumption of a high protein, low fat meal……………………………………………………………….. 71

Table 4 Mean (± SE) changes in metabolic (kcal/min) and mean (± SE) change in energy expended from baseline per kcal ingested (EE/I) in overweight, normal weight, and underweight subjects after consumption of a high protein, high fat (HPHF) meal versus a high protein, low fat (HPLF) meal………………………………………... 72

Figure 1 Mean (± SE) baseline and postprandial metabolic rate (kcal/min) among overweight, normal weight, and underweight subjects before and following consumption of a high protein, low fat (HPLF) meal…….……………………………………………………… 73

Figure 2 Mean (± SE) baseline and postprandial metabolic rate (kcal/min) among overweight, normal weight, and underweight subjects before and following consumption of a high protein, low fat (HPLF) meal.……………………………………………………………….. 74

Figure 3 Mean (± SE) baseline and postprandial metabolic rate (kcal/min) in overweight subjects after consumption of a high protein, high fat (HPHF) meal versus a high protein, low fat (HPLF) meal………….. 75

Figure 4 Mean (± SE) baseline and postprandial metabolic rate (kcal/min) in normal weight subjects after consumption of a high protein, high fat (HPHF) meal versus a high protein, low fat (HPLF) meal………….. 76

Figure 5 Mean (± SE) baseline and postprandial metabolic rate (kcal/min) in underweight subjects after consumption of a high protein, high fat (HPHF) meal versus a high protein, low fat (HPLF) meal………….. 77

CHAPTER 1

INTRODUCTION

Obesity is a growing epidemic. Nearly two-thirds of American adults (65%) are overweight with one-third being obese (30%) and this number continues to climb (Hedley and others 2004). Obesity accounts for thousands of deaths per year and on average costs $75 billion dollars per year in healthcare in the United States (Finkelstein and others 2004).

While the causes of obesity are multifactoral, weight gain ultimately results from an imbalance between energy intake and energy expenditure. The main components of energy expenditure by the body are basal/resting needs and physical activity. Diet induced thermogenesis (the rise in resting energy expenditure associated with food ingestion) is only a minor component representing on average about 10% of basal needs. Yet, the contribution of diet induced thermogenesis can be much higher if high protein diets are consumed. Metabolic rate may increase up to about 30% of basal needs after consumption of protein.

High protein diets, such as the Atkins diet and Zone diet, are popular for weight loss in the United States. For example, a 2002 Consumer's Report survey found that over 30% of dieters reported the use of the Atkins diet to help them lose weight (Anonymous 2002). Yet, while high protein diets provide good satiety and are popular with the public, health professionals are generally more cautious about such diets. High protein diets such as the Atkins diet often result in high fat consumption and may also promote increased calcium excretion and longer term problems such as an increased risk of heart disease, osteoporosis, and kidney problems (Eisenstein and others 2002).

Whether high protein diets offer a metabolic advantage through increased diet induced thermogenesis over other diets that are lower in protein is not clear, since the thermogenic response to food is only one small component of energy expenditure and thus weight balance. Also unclear is whether there are differences in the thermogenic response to different nutrients in individuals of various body sizes. Should differences in responses exist among individuals, these differences over time could promote weight gain or loss.

To date, most studies have examined differences in diet induced thermogenesis between normal weight and obese individuals with some studies showing no differences and others finding a diminished response in obese adults (De Palo and others 1989; Schutz and others 1984; Schwartz and others 1985; Westerterp-Plantenga and others 1997; Yerboeket-van de Venne and others 1996). Few studies, however, have included healthy underweight individuals (Casper and others 1991; Piers and others 1992; Scalfi and others 1992). Further, while the macronutrient composition has varied considerably between studies, no studies have used a macronutrient composition similar to those found in the Atkins and Zone high protein diets. Because the use of these fad diets is common for weight control, this study examined short-term changes in energy expenditure in response to ingestion of a high protein, high fat meal (designed by the Atkin's Company) versus an isocaloric high protein, low fat meal (designed by the makers of the Zone diet) among healthy underweight, normal weight, and overweight/obese females.

CHAPTER II

LITERATURE REVIEW

Obesity is a growing epidemic. Yet, the causes of its rising prevalence and effective means for treatment remain unclear. It is known that energy intake must equal energy expenditure in order to maintain weight. The unknown is what, if any, factors affecting specific components of energy expenditure differ and contribute to obesity among different individuals. The review of literature addresses the following: components of energy expenditure and factors affecting energy expenditure. In addition, studies comparing resting energy expenditure, diet-induced thermogenesis, and total daily energy expenditure among individuals with a range of body sizes and consuming a variety of diets are provided.

Components of Energy Expenditure

Energy expenditure consists of three major components including basal or resting energy expenditure, the thermic effect of exercise, and the thermic effect of food also known as diet-induced thermogenesis. Each component is described in the next three subsections.

Basal / Resting Energy Expenditure

Basal energy expenditure and resting energy expenditure are often used interchangeably; however, differences exist between the two terms. Basal energy expenditure is the energy expended and extrapolated for a 24-hour period by an individual physically and mentally at rest (i.e., lying down) in a thermoneutral environment, first thing in the morning, 12 to 18 hours after a meal, and having not engaged in physical activity. This represents the amount of energy used for involuntary activity over a 24-hour period. Basal energy expenditure includes energy expended for the maintenance of normal body functions and homeostasis including resting cardiovascular and pulmonary functions, the energy consumed by the central nervous system, cellular homeostasis, and other biochemical reactions involved in the maintenance of resting metabolism. Energy for basal needs accounts for about 60-70% of total energy needs.

Energy expenditure should be referred to as resting if any of the conditions for basal are not met. Typically, resting metabolic rate is measured first thing in the morning, after an eight hour fast, and in a thermoneutral environment. When resting metabolic rate is calculated for a 24-hour period, the term resting energy expenditure is used.

Thermic Effect of Exercise

Thermic effect of exercise is the energy expended above basal or resting energy expenditure. The thermic effect of exercise includes the energy expended through voluntary exercise including energy devoted to activity such as fidgeting and posture control.

Thermic Effect of Food / Diet-induced Thermogenesis

The thermic effect of food, also referred to as diet-induced thermogenesis, is the increase in energy expenditure, above basal or resting, associated with food ingestion. There are thought to be two components of diet-induced thermogenesis – obligatory and regulatory / facultative. The obligatory thermic effect of food includes the energy costs of nutrient absorption, transport, metabolism, and storage. The obligatory thermic effect of food varies between the different macronutrients, generally being highest after protein ingestion with a 20-30% increase, followed by carbohydrate and fat ingestion with up to about a 10% increase each. Regulatory or facultative thermogenesis is the increase in energy expenditure in excess of obligatory thermogenesis that occurs with food ingestion. This facultative thermogenesis results from the stimulation of the sympathetic nervous system that occurs with food ingestion. More specifically, it results from inefficiency in metabolism such as the uncoupling or loose regulation of oxidation to phosphorylation that is stimulated by increased sympathetic nervous system activity. Muscle is thought to be the main site of the facultative thermogenesis in man. Increased futile cycling is thought to result from sympathetic nervous system stimulated release of epinephrine, norepinephrine, glucagon, adrenal corticoids, and possibly prostacyclins (Sims and Danforth 1987).

Factors Affecting Resting Energy Expenditure

Age and gender, hormones and sympathetic nervous system activity, temperature, and body composition influence basal / resting metabolic rate. Each of these factors is addressed hereafter.

Age and Gender

Resting metabolic rate is typically highest in infants and young children due to rapid and extensive growth. In addition, metabolic rate also is relatively high again during the adolescent growth spurt. In adults, resting metabolic rate remains relatively stable and unchanged until about 30 years, whereby it starts to decrease on average 2-3%

per decade after age 30 years. The decrease is associated with a loss of both lean muscle mass and organ mass and function.

Gender differences in resting metabolic rate are thought to mainly result from differences in body composition and size, although men typically have slightly higher (up to about 10%) resting metabolic rates than women of the same height and weight. Six studies comparing resting metabolic rate between young versus older adults and/or between males and females are presented.

Fukagawa and others (1990) examined the relationship between fat free mass and resting metabolic rate in 24 young (18-33 years) and 24 elderly (69-89 years) men and 20 elderly (67-75 years) women with body mass indexes ranging from 22.6 to 25.2 kg/m^2. Resting metabolic rate (RMR) was measured for 45 minutes via indirect calorimetry after a 12- hour overnight fast. Fat free mass (FFM) was assessed via skinfold thickness measurements. Absolute RMR was significantly lower in the old men (1.04 ± 0.02 kcal/min) than in the young men (1.24 ± 0.03 kcal/min). After adjusting for FFM, RMR was still significantly lower in the old men (1.03 ± 0.02 kcal/min) than in the young men (1.13 ± 0.02 kcal/min). When comparing the old men with the old women, absolute RMR was significantly lower in the women (0.84 ± 0.02 kcal/min) than in the old men (1.04 ± 0.02 kcal/min). After adjusting for FFM; however, resting metabolic rate in the old men (1.03 ± 0.02 kcal/min) and women (0.99 ± 0.02 kcal/min) was not significantly different.

Visser and others (1995) investigated resting metabolic rate (RMR) between 56 young (27 women, 29 men; BMI range 19.7-24.8 kg/m^2) subjects aged 21-29 years and 103 elderly (71 women, 32 men; BMI range 22-29.6 kg/m^2) subjects aged 67-79 years. RMR was measured after an overnight fast on two nonconsecutive days within a week of each other. RMR, when expressed as absolute value as well as per kg of fat-free mass or body weight, was significantly lower in the elderly women (3.33 ± 0.39 kJ/min, 4.93 ± 0.60 kJ/h/kg FFM, 3.01 ± 0.37 kJ/h/kg body wt) and men (3.98 ± 0.46 kJ/min, 4.43 ± 0.53 kJ/h/kg FFM, 3.10 ± 0.46 kJ/h/kg body wt) than the younger women (4.08 ± 0.33 kJ/min, 5.38 ± 0.36 kJ/h/kg FFM, 3.87 ± 0.27 kJ/h/kg body wt) and men (5.29 ± 0.53 kJ/min, 4.77 ± 0.29 kJ/h/kg FFM, 4.14 ± 0.33 kJ/h/kg body wt).

Neuhauser-Berthold and others (2000) measured resting metabolic rate in 122 overweight (BMI 26.3 ± 3.6 kg/m^2) females aged 63–75 years and 82 overweight (BMI 26.0 ± 2.6 kg/m^2) males aged 64-74 years. Resting metabolic rate was measured for 25-35 minutes using indirect calorimetry following an overnight fast. Resting energy expenditure was significantly higher in the male subjects when expressed in absolute terms as well as per kg body weight (6745 ± 704 kJ/24 h and 87.2 ± 8.9 kJ/kg/24 h, respectively) than the female subjects (5421 ± 588 kJ/24 h and 81.7 ± 8.7 kJ/kg/24 h). However, when resting energy expenditure was expressed per kg of fat free mass (FFM), resting energy expenditure was significantly higher in the female subjects (146.8 ± 14.0 kJ/kg/24 h) than the male subjects (127.9 ± 12.6 kJ/kg/24 h).

Luhrmann and others (2001) examined resting metabolic rate in 164 women with a body mass index (BMI) ranging from 23 to 30 kg/m^2 aged 62-74 years and 98 men with a BMI ranging from 23 to 29 kg/m^2 aged 62-72 years. Resting metabolic rate was measured for 25-35 minutes at 1-minute intervals via a ventilated –hood system and bioelectrical impedance was used to measure body composition. Resting metabolic rate was significantly higher in the men than the women (6785 ± 747 kJ/d vs. 5502 ± 651 kJ/d, respectively). Resting metabolic rate was negatively correlated with age in the women (r = -0.16) and the men (r = -0.23). In contrast, resting metabolic rate was significantly positively correlated, in both genders, with BMI (women: r = 0.59; men: r = 0.53), fat-free mass (women: r = 0.73; men: r = 0.656), and fat mass (women: r = 0.63; men: r = 0.47).

Illner and others (2000) examined resting energy expenditure in 26 (13 females, 13 males) healthy adults (BMI for females 22.1 ± 2.47 kg/m^2; BMI for males 22.5 ± 1.82 kg/m^2) aged 23-28 years. Resting energy expenditure was measured by an open-circuit indirect calorimeter after a 12-hour overnight fast for a 40-mimute period. Body composition was measured by anthropometrics, bioelectrical impedance (BIA), and duel-energy X-ray absorptiometry (DEXA). Resting energy expenditure was significantly lower in the female subjects (5.74 ± 0.68 KJ/d) than the male subjects (7.28 ± 0.85 KJ/d). Male subjects had a significantly higher fat free mass (63.1 ± 6.9 kg; 87.2% body weight) than the female subjects (45.9 ± 4.7 kg; 73.1% body weight). Resting energy expenditure was significantly correlated with fat free mass when measured via bioelectrical impedance (r = 0.92) and muscle mass when measured via DEXA (r = 0.89).

Chong and others (1993) investigated the resting energy expenditure of 23 diabetic subjects aged 35-64 years. The subjects were divided into three groups based on their BMI classification: normal weight (BMI 20-24.9 kg/m^2) group (3 men, 5 women); overweight (BMI 25-29.9 kg/m^2) group (3 men, 2 female); and obese (BMI ≥ 30kg/m^2) group (2 men, 8 women). Resting energy expenditure (REE) was measured on all subjects for a 30-minute period after an overnight fast using indirect calorimetry. Overall, REE was significantly higher in the obese group (1785 ± 404 kcal/24 h) than in the normal weight group (1403 ± 256 kcal/24 h) and was significantly correlated with lean body mass (r = 0.8). However, when expressed per kg of lean body mass, no significant differences between the normal weight group (27 ± 9 kcal/24 h/ kg) and the obese group (26 ± 26 kcal/24/h/kg) were found. Male subjects had a significantly higher REE than the female subjects (1790 ± 174 kcal/24 h vs. 1307 ± 146 kcal/24 h, respectively).

In summary, in studies comparing men and women, over a wide age range, resting energy expenditure when expressed in absolute terms or per kg body weight is significantly greater in men than in women (Chong and others 1993; Illner and others 2000; Neuhauser-Berthold and others 2000). When expressed per kg fat free mass, one study found resting energy expenditure was significantly higher in women than men (Neuhauser-Berthold and others 2000). Young women and young men also have significantly higher resting energy expenditure, when expressed in absolute terms, per kg FFM, and per kg of body weight, than older women and older men, respectively (Fukagawa and others 1990; Visser and others 1995).

Hormones and Sympathetic Nervous System Activity

Hormones as well as nervous system activity influence metabolism. Hormones that tend to increase metabolic rate include those that are released with the stimulation of the sympathetic nervous system such as epinephrine, norepinephrine, and insulin. When the sympathetic nervous system is activated, the release of catecholamines directly increases oxygen consumption and cellular activities including the activities of multiple enzymes such as ATPases (Martin 1985). Similarly, thyroid hormones also increase oxygen consumption. Inhibition of the sympathetic nervous system with various agents has been shown to significantly lower concentrations of thyroid hormone to effect further reductions in metabolic rate.

Metabolic rate also varies with the menstrual cycle. Metabolic rate is typically at its lowest just before ovulation and after ovulation it begins to rise (Solomon and others 1982). Peak metabolic rate in premenopausal women occurs just prior to the start of menstruation. Changes in body temperature which occur throughout the month are thought to be associated with these changes in metabolic rate.

Temperature

Elevations in body temperature, as occur with fever, increase metabolic rate. Generally, metabolic rate increases about 7% for every one degree Fahrenheit or about 13% for every one degree Centigrade increase in body temperature above normal. Environmental temperature also has been shown to influence metabolism. Extremely cold temperatures increase metabolism, although the extent of the increase varies with body fat content and insulation. Extremely hot temperatures also increase metabolism about 5% to 20%, especially when associated with increased activity of the sweat glands (Butte and others 2006).

Body Composition

Lean mass, also referred to as fat free mass, is more metabolically active than fat mass. Resting metabolic rate is primarily related to lean body mass. Fat free mass (FFM) includes skeletal muscle, visceral organs, connective tissue, and myofibrillar proteins. Lean body mass is considered to be the best single predictor of resting energy expenditure (Ravussin and others 1982), and is thought to explain 70-80% of the variability in resting metabolic rate. Some of the 20-30% of the unaccounted variability in resting metabolic rate has been hypothesized to result from differences in the sizes or weights of different body organs. This hypothesis, however, has been rejected following a study by Sparti and others (1997) which found that the weight of internal organs were not a main determinant of resting metabolic rate. Correlations between resting metabolic rate and body weight and between resting metabolic rate and fat free mass vary among studies. Some studies have shown strong correlations, especially when male participants are included, while others show no or weaker correlations, especially with female participants (Kashiwazaki and others 1988; Ravussin and others 1982; Schutz and others 1984; Visser and others 1995).

The influence of body composition on resting energy expenditure is evident from studies comparing resting metabolic rate among individuals of different body sizes and composition as well as from studies examining the effects of dieting and weight loss in overweight / obese individuals. Three studies are presented which examine the effects of dieting and weight loss on resting energy metabolism. Following this section, studies examining resting energy expenditure among individuals of different body weights and fatness are given.

Resting Energy Expenditure after Dieting and Weight Loss

Barrows and others (1987) investigated the long-term effects (4-6 months) of a very-low calorie liquid diet (VLCD) and subsequent realimentation (reintroduction of food) on resting energy expenditure in 15 obese females (mean body fat 46.8%) aged 30-54 years. RMR was measured before the study protocol began, at the end of the modified fast, and after the 5-week realimentation period. After initial RMR was completed, subjects began the modified fast protocol. Subjects were instructed to consume five packets of Optifast-70/day, which provided a total of 420 kcal (54% protein, 23% carbohydrate, 2% fat). Aside from the experimental diet, subjects were allowed water, no more than 32 oz. of noncaloric beverages, and five sticks of sugarless gum per day. Subjects remained on the low calorie liquid diet for about four to six months. Following the liquid diet, subjects were gradually refed over a 5-week period a solid diet consisting of approximately 800 kcal/day. Initial resting metabolic rate was 70.0 ± 1.7 kcal/hr and significantly decreased following the VLCD to 55.6 ± 2.0 kcal/hr and remained lower after the re-feeding period (58.8 ± 2.2 kcal/hr). When RMR was expressed as kcal/kg LBM/height, RMR was significantly lower after the VLCD (1.40 ± 0.06) than before the VLCD (1.50 ± 0.03).

Stallings and others (1992) examined the effects of a low-calorie, high protein diet on resting energy metabolism in seven (2 men, 5 women) healthy obese (166% IBW) adolescents aged 11-15 years. Subjects were given a protein-sparing modified diet, which provided 2.0-2.5 g of protein/kg ideal body weight/day. Energy intake ranged from 800-850 kcal/day. At the end of the eight-week diet period, percent ideal body weight was significantly lower (166% to 142%). REE significantly decreased from 2034 ± 392 kcal/d to 1762 ± 453 kcal/d representing a 13.4% reduction in REE over the 8-week diet period. However, no significant differences were found when REE was expressed as kcal/kg body weight (initial 21.4 ± 2.8 vs. end 21.6 ± 4.5) or as kcal/kg FFM (initial 24.0 ± 6.1 vs. end 23.3 ± 4.2).

Hendler and others (1988) studied the effects of two weight loss diets on energy expenditure in 17 healthy obese (BMI 42 ± 50 kg/m^2) subjects aged 25-37 years. Subjects were initially placed on a weight-maintenance diet (50% carbohydrate, 30% protein, 20% fat) for 3-5 days and were then randomly assigned to either a very low calorie mixed diet providing 436 ± 2 kcal/d (41% protein, 55% carbohydrate, 4% fat) or a very low calorie high protein (HP) diet (439 ± 5 kcal/d, 95 ± 1% protein, 2 ± 1% carbohydrate, 3 ± 1% fat) for a 3-week period. Resting metabolic rate (RMR) was measured via indirect calorimetry for 45 minutes at baseline and once a week for the 3-week diet period. Nine subjects followed the mixed diet, and eight subjects followed the HP diet. RMR significantly decreased in the mixed diet group and the HP group from baseline to the end of the 3-week period (1.42 ± 0.08 vs. 1.20 ± 0.06 kcal/min and 1.30 ± 0.11 vs. 1.13 ± 0.11 kcal/min, respectively). However, no significant difference in REE was found between the two diet groups.

Resting Energy Expenditure among Individuals of Different Body Weights and Fatness

In the following paragraphs, nine studies are presented which have examined BMR, RMR, or REE among underweight, normal weight, and overweight / obese adults. Study data are presented in absolute terms as kcal/day and/or per kg body weight. When available, study data are expressed per kg fat free mass or lean body mass.

James and others (1978) examined resting energy expenditure among 72 obese subjects (11 men, 61 women) with body mass indexes (BMI) ranging from 29.1-44.3 kg/m^2 age 20-71 years and 26 (11 men, 15 women) aged-matched, normal weight (BMI range 19.1-24.4 kg/m^2) subjects. Obese subjects were found to have significantly higher resting energy expenditure (2410 kcal/day) than the normal weight subjects (1050 kcal/day).

Swaminathan and others (1985) investigated the differences in resting metabolic rate (RMR) between 11 (8 female, 3 male) normal weight (BMI 20.5 ± 0.6 kg/m^2) subjects aged 27-47 years and 11 (8 female, 3 male) obese (BMI 37.2 ± 2.4 kg/m^2) subjects aged 19-52 years. Resting metabolic rate was measured on all subjects for a 30-minute period after an overnight fast. RMR was significantly higher in the obese subjects (4.61 ± 0.22 kJ/min) than the normal weight subjects (3.56 ± 0.23 kJ/min).

Hoffmans and others (1979) examined the resting energy expenditure of 28 females aged 20-30 years old. Based on body fat, the subjects were divided into either the obese group (n = 15; mean body fat = 33.6%) or normal weight group (n = 13; mean body fat = 20.4%). The mean resting energy expenditure of the obese group (1550 kcal/24 hrs) was significantly higher than that of the normal weight group (1421 kcal/24 hrs). Moreover, when expressed per kg fat-free mass, resting energy expenditure was also significantly higher in the obese group (32.9 kcal/kg FFM/24 hr) than the normal weight group (30.6 kcal/kg FFM/24hr). However, the resting energy expenditure in the obese group, when measured per kg body weight (21.8 kcal/kg body weight/24 hr), was significantly lower than the normal weight subjects (24.4 kcal/kg body weight/24 hr).

De Palo and others (1989) examined resting metabolic rate in 19 female and eight male subjects (12 obese and 15 normal weight) aged 22-34 years. Resting metabolic rate was measured for 15 minutes in a supine position after an overnight fast using indirect calorimetry. When expressed in absolute terms, resting metabolic rate (RMR) was significantly higher in the obese subjects (1.05 ± 0.16 kcal/min) than in the normal weight (0.61 ± 0.11 kcal/min) subjects. However, when expressed in relation to body weight, REE didn't significantly differ between the two groups (obese = 0.037 ± 0.004 kcal/min/kg vs. normal = 0.032 ± 0.005 kcal/min/kg).

Ravussin and others (1982) examined resting energy expenditure (REE) in 10 (5 men 5 women) normal weight (body fat 20.3 ± 1.1%) subjects, six (3 men, 3 women) moderately obese (body fat 29.8 ± 1.1%) subjects and 14 (6 men, 8 women) obese (body fat 36.1 ± 1.5%) subjects aged 22-32 years. REE was measured following a 10-hour overnight fast with a hood device for 1.5 hours in 5-minute intervals. Absolute REE was significantly higher in the obese subjects (1814 ± 84 kcal/d) compared to the normal weight subjects (1462 ± 97 kcal/d). However, when expressed on the basis of fat free mass, there were no significant differences found in REE among the normal weight (29.6 ± 0.72 kcal/kg FFM/d), moderately obese (29.4 ± 2.63 kcal/kg FFM/d), and obese (29.4 ± 0.96 kcal/kg FFM/d) subjects. REE was significantly correlated (r = 0.822) with fat free mass. The normal weight subjects had significantly higher resting respiratory quotients than the obese subjects (0.819 ± 0.006 vs. 0.792 ± 0.009, respectively).

Schutz and others (1984) evaluated the basal metabolic rate in 20 obese women and eight normal weight women aged 19 – 44 years. BMR was significantly greater in the obese group (1.18 ± 0.03 kcal/min) than the control group (0.88 ± 0.03 kcal/min) when expressed in absolute terms, but when expressed on the basis of fat free mass, BMR did not significantly differ between the obese group (1.2 kcal/kg FFM) and the normal weight group (1.3 kcal/kg FFM).

Kashiwazaki and others (1988) measured resting metabolic rate (RMR) in 36 normal weight (BMI 21.8 ± 1.9 kg/m^2) and 12 obese (BMI 27.3 ± 3.1 kg/m^2) males as well as in 23 normal weight (BMI 21.1 ± 1.8 kg/m^2) and 33 obese (BMI 26.1 ± 2.8 kg/m^2) females aged 20-71 years. RMR was obtained by measuring oxygen consumption and carbon dioxide production in a Douglas bag for 10 minutes. RMR, expressed in absolute values, was significantly higher in the obese men (1.30 ± 0.21 kcal/min) than in the normal weight men (1.09 ± 0.16 kcal/min). No significant differences were found between the normal weight and obese men in resting energy expenditure per kg fat free mass (FFM) (29.6 ± 4.1 kcal/kg FFM/d vs. 30.7 ± 3.8 kcal/kg FFM/d, respectively). When expressed per kg of body weight, no significant differences in resting energy expenditure were found between the normal weight subjects (25.9 ± 3.7 kcal/kg BW) and the obese subjects (23.8 ± 2.9 kcal/kg BW). As for the female subjects, no significant differences were found in absolute metabolic rate or in resting energy expenditure per kg FFM between the normal weight females (0.84 ± 0.13 kcal/min and 33.2 ± 5.0 kcal/kg FFM/day, respectively) and the obese females (0.88 ± 0.13 kcal/min and 33.2 ± 5.0 kcal/kg FFM/day, respectively). However, the resting energy expenditure per kg body weight was significantly higher in the normal weight women (25.5 ± 4.4 kcal/kg body weight/day) than the obese women (21.3 ± 3.3 kcal/kg body weight/day). In the male subjects, REE was strongly correlated with weight (r = 0.636) and FFM (r = 0.626), but REE was poorly correlated to weight (r = 0.356) and FFM (r = 0.349) in the female subjects. When male and female subjects were pooled together, REE was significantly correlated with FFM (r = 0.779), age (r = 0.481), height (r = 0.684) and fat percentage (r = -0.371).

Bosy-Westphal and others (2004) examined resting energy expenditure in 12 underweight females (BMI < 18.5 kg/m^2), 25 (12 female, 13 male) intermediate weight (BMI 19-28 kg/m^2) subjects and 18 (9 females, 9 males) obese subjects (BMI > 30 kg/m^2) aged 19-43 years. Resting metabolic rate was measured after an overnight fast for one hour using indirect calorimetry. Resting energy expenditure was significantly lower in the underweight group (978 ± 98 kcal/day) than the intermediate weight group (1637 ± 251 kcal/day) and the obese group (1699 ± 339 kcal/day). When REE was adjusted for FFM, no significant differences were found between underweight (1346 ± 143 kcal/d) and obese subjects (1436 ± 263 kcal/d) or between normal weight (1554 ± 120 kcal/d) and obese subjects (1436 ± 263 kcal/d). However, there was a significant difference in REE, when adjusted for FFM, between underweight (1346 ± 143 kcal/d) and normal weight subjects (1554 ± 120kcal/d).

Casper and others (1991) investigated basal metabolic rate in six anorexic female patients (mean BMI 15.7 kg/m^2) with secondary amenorrhea for 3 months or longer aged 17-32 years and six age and height-matched control female subjects. Basal metabolic rate was measured using open-circuit canopy system. Basal metabolic rate was significantly lower in the anorexic patients (997 kcal/d) than in the control subjects (1319 kcal/d). BMR and body weight were highly correlated in the patients ($r = 0.95$) and in the patients and control subjects combined ($r = 0.90$).

Astrup and others (1999) conducted a meta-analysis on past research studies focusing on resting metabolic rates between 124 post-obese subjects (62 females, 62 males) and 121 control (never been obese) subjects (61 females, 60 males) . The post-obese group had a significantly higher body fat mass (27.3 ± 5.6%) than the control group (24.8 ± 6.3%). The post-obese group had a 2.9% lower RMR that approached significance ($P = 0.09$) than the control group when adjusted for differences in fat free mass and fat mass. The post-obese group had a 4.1% significantly lower RMR than the control group when expressed per kg of fat free mass.

In summary, in studies examining differences in resting energy expenditure between obese men and women versus normal weight men and women over a wide age range, resting energy expenditure in the obese adults, when expressed in absolute terms, was significantly greater than normal weight adults (James and others 1978; Hoffmans and others 1979; Ravussin and others 1982; Schutz and others 1984; Swaminathan and others 1985; Kashiwazaki and others 1988; De Palo and others 1989). When resting energy expenditure is expressed per kg body weight, only two studies with women found significantly lower resting energy expenditure in obese women versus normal weight women (Hoffmans and others 1979; Kashiwazaki and others 1988). Moreover, in a study including both men and women and a study in only men no differences in resting energy expenditure when expressed per kg body weight were found (Kashiwazaki and others 1988; De Palo and others 1989). In most studies, no significant differences were found in resting energy expenditure when expressed per kg fat free mass between obese and normal weight subjects (Ravussin and others 1982; Schutz and others 1984; Kashiwazaki and others 1988). Only Hoffmans and others (1979) reported significantly higher resting energy expenditure per kg fat free mass in obese women versus normal weight women 20 to 30 years of age.

Other Possible Factors Influencing Resting Energy Expenditure

Whether habitual dietary intake affected resting energy expenditure was investigated by Cooling and Blundell (1998). These researchers investigated resting energy expenditure in 16 normal weight males aged 18-25 years. Of the 16 males, eight were habitual high fat consumers (44% of total energy from fat) and eight were habitual lower fat consumers (32% of total energy from fat). Resting energy expenditure was measured for 30 minutes using indirect calorimetry. REE, oxygen consumption, and heart rate were significantly higher in the habitual high fat consumer group (REE = 1624 ± 37 kcal/day; O_2 consumption = 3.2 ± 0.0095 mlO_2/kg/min; HR (bpm) = 66.1 ± 2.5) than the habitual lower fat consumer group (REE = 1455 ± 65 kcal/day; O_2 consumption = 2.9 ± 0.061 mlO_2/kg/min; HR (bpm) = 57.1 ± 2.5). The habitual high fat consumer group had a significantly lower resting RQ (0.84 ± 0.01) than the habitual low fat consumer group (0.89 ± 0.02).

Factors Affecting Diet-induced Thermogenesis

Food ingestion (as well as caffeine and nicotine) stimulates the sympathetic nervous system. Rapid increases in plasma norepinephrine and insulin have been shown to coincide with the initial thermogenic response to food ingestion, especially carbohydrates, in normal weight individuals (O’Dea and others 1982; LeBlanc and others 1985; Acheson 1993; Garrel and others 1994). Studies have found that when norepinephrine, the primary neurotransmitter of the sympathetic nervous system, is blocked with pharmaceutical drugs, the thermogenic response to food is blunted (Welle 1995). However, some studies investigating the thermic response to food ingestion in obese individuals have found a lowered or blunted sympathetic nervous system response

(Bazelmans and others 1985). Moreover, negative correlations have been demonstrated between body fat and plasma norepinephrine concentrations suggesting decreased sympathetic activity is associated with obesity (Spraul and others 1994).

Protein, Carbohydrate, and Fat Consumption and Total Energy Intake

Diet-induced thermogenesis varies in response to the composition of the food ingested as well as the amount of food (energy) ingested. Protein ingestion has been shown to produce the greatest changes in metabolism followed in descending order by carbohydrates and fat. Generally, protein intake can increase metabolism by as much as 30% while carbohydrate and fat produce rises of up to about 10%.

Flatt (1978) calculated the metabolic “costs” of nutrient ingestion as a percent of energy intake. Absorption of glucose requires about 1.3% or about 5 kcal to generate the ATP that was used to absorb 100 g of glucose. A similar amount is thought to be needed to absorb amino acids. The absorption of fatty acids is thought to require about 1.8%. Thus, absorption of 50 g of a fatty acid, such as palmitate, would require a little over 9 kcal. Conversion and storage of glucose to glycogen costs about 5.3%, and conversion and storage of glucose to lipids cost about 24%. Storage of fat into adipose tissue is thought to require about 2.3%. Conversion of amino acids into protein is thought to require about 24% of ingested energy. Thus, conversion of 50 g of amino acids into protein would require about 48 kcal.

Several studies have examined the thermic effects of varying amounts of foods (kcal intake) and of varying specific nutrients on energy expenditure. Some of these studies will be reviewed in this section of the literature review.

D'Alessio and others (1988) examined the effects of energy intake on the thermic effect of food in five normal weight men (mean BMI 22.5 kg/m^2) and five obese men (mean BMI 42.9 kg/m^2) aged 22-37 years. After measuring resting metabolic rate, subjects ingested 500 ml of water or mixed liquid meals (53% carbohydrate, 32% fat, 15% protein) with adjusted volumes to provide 8, 16, 24, or 32 kcal/kg fat-free mass. The five different meals were given to each subject over the 5-day study period in random order. Energy expenditure was measured before feeding and then for the first postprandial hour every 15 minutes. During the next 7 postprandial hours, energy expenditure was measured every 30 minutes. Weight, BMI, fat-free mass, fat mass, and resting metabolic rate were significantly higher in the obese men than the lean men. No statistical difference was found in resting metabolic rate over the 5-day period. The thermic effect of food was positively correlated ($r = 0.82$) with energy intake. The relationships between energy intake and thermic effect of food were not significantly different for the obese and normal weight men. Energy expenditure increased 30% with the largest energy intake and duration of thermic effect of food was highly correlated with energy intake. The time from meal consumption to peak thermogenesis was also significantly correlated ($r = 0.41$) to energy intake.

Sharief and others (1982) investigated the differences in dietary-induced thermogenesis following carbohydrate consumption in six normal weight (99% of ideal body weight) men and five overweight (157% of ideal body weight) men. Each subject was given either 5 grams of sucrose/kg ideal body weight or 5 grams of glucose/kg ideal body weight after an overnight fast in random order. Energy expenditure was measured 3 hours after ingestion of the test sugars. After ingestion of both carbohydrate meals, energy expenditure rose. The increase was greater after sucrose ingestion (normal weight men 0.191 kcal/min; overweight men 0.287 kcal/min) than after glucose ingestion (normal weight men 0.120 kcal/min, overweight men 0.215 kcal/min). The difference in diet-induced thermogenesis between sucrose and glucose ingestion was significant in the normal weight men, and was much less marked, and not significant, in the obese men.

Pittet and others (1976) examined the thermic effect of a glucose load in 21 females (11 obese and 10 normal weight) aged 22-32 years. After measurement of resting energy expenditure, subjects were fed an oral dose of 50 grams glucose. Energy expenditure was measured for 150 minutes. Metabolic rate, following the glucose load, increased significantly in both groups over the 150-minute period. However, this increase in metabolic rate compared to the baseline value was significantly higher in the normal weight group (13.0%) than in the obese group (5.2%).

Nair and others (1983) examined thermic response to ingestion of isoenergetic meals of protein, carbohydrate, and fat in five (4 women, 1 man) normal weight (mean 60.1 ± 4.9 kg) and five (4 women, 1 man) obese (mean 100.6 ± 17.5 kg) subjects aged 21-51 years. After measuring resting energy expenditure, one of the following four meals was given to the subjects: carbohydrate (AnalaR glucose, 300 kcal); protein (Maxiprot, 300 kcal); fat (double cream, 300 kcal), or control solution (fruit flavor with artificial sweetener, 0 kcal). Energy expenditure was measured continuously for about 2.5 hours via indirect calorimetry. In both groups, when expressed as a percentage of the energy value of the meal, the thermic response to the protein meal was 15 ± 4% and significantly greater than that of the carbohydrate (6 ± 2%) and fat meal (7 ± 3%).

Swaminathan and others (1985) studied the effects of isocaloric amounts of carbohydrate, protein, fat, and mixed meal on postprandial metabolic rate in 11 (8 female, 3 male) normal weight (mean BMI 20.5 ± 0.55 kg/m^2) subjects aged 27-47 years and 11 (8 female, 3 male) obese (mean BMI 37.2 ± 2.39 kg/m^2) subjects aged 19-52 years. Following the resting metabolic rate measurement, subjects ingested, in random order, each of the following meals on 4 separate days: 400 kcal of glucose (100 g crystalline glucose) dissolved in low-calorie lemon juice, 400 kcal of fat (as 38 g corn oil and 70 g pure tomato juice), 400 kcal of protein (as 114 g of Maxipro), or 400 kcal mixed meal (cheese, cream cracker, grapefruit juice, and sugar). Energy expenditure was measured continuously for 120 minutes. Ingestion of all the meals tested in the normal weight subjects produced a significant increase in absolute metabolic rate during the study period (carbohydrate meal: 0.523 ± 0.094 kJ/min, fat meal: 0.485 ± 0.102 kJ/min, protein meal: 0.742 ± 1.33 kJ/min, and mixed meal: 0.856 ± 0.162 kJ/min). In the obese subjects, the carbohydrate, protein, and mixed meals produced a significant increase in absolute metabolic rate (0.544 ± 0.147 kJ/min, 0.873 ± 0.172 kJ/min, and 0.585 ± 0.099 kJ/min, respectively), but there was no significant change in absolute energy expenditure following the fat meal. When changes in energy expenditure in lean and obese subjects were compared, the response to the fat meal was significantly less in the obese, expressed in absolute terms (-0.049 ± 0.099 kJ/min) or as a percentage (-0.9 ± 2.0%), than the lean (0.485 ± 0.102 kJ/min and 14.4 ± 3.4%) subjects. The obese group had a significantly lower response to the mixed meal, when expressed as a percentage, than the lean subjects (12.9 ± 2.3% vs. 25.0 ± 4.8%, respectively).

In summary, while studies clearly show that the greatest rise in metabolic rate occurs following protein intake, the response to fat and carbohydrate intake varies more markedly among studies. Some studies show no significant difference in the metabolic response between the two nutrients (Raben and others 2003), while other studies suggest carbohydrate intake results in a slightly higher rise than fat (Nair and others 1983; Schwartz and others 1985; Swaminathan and others 1985).

Effects of Different Diet Compositions

Studies in Normal Weight Individuals

Several studies have examined the effects of consumption of meals or diets of varying composition on diet-induced thermogenesis in individuals of different body sizes. Some of the studies examining differences in diet-induced thermogenesis in normal weight individuals are presented in this section.

Yerboeket-van de Venne and Westerterp (1996) examined the short-term effects of dietary fat and carbohydrate exchange on energy expenditure in 12 normal weight women. All subjects were fed three different, isocaloric diets including low fat, high carbohydrate (15% protein, 10% fat, 75% carbohydrate), high fat, low carbohydrate (15% protein, 50% fat, 35% carbohydrate), and mixed diet (15% protein, 30% fat, 55% carbohydrate), for 3 days with a 4-day washout period between each diet. On the last day of each diet, energy expenditure was measured in a respiratory chamber. The DIT was highest on the low fat, high carbohydrate diet (1.23 MJ/d) and lowest on the high fat, low carbohydrate diet (0.99 MJ/d), but the difference was not significant.

Raben and others (2003) investigated the effects of ingestion of meals rich in alcohol, protein, carbohydrate, or fat on energy expenditure in 19 (nine female, 10 male) healthy normal weight subjects aged 20-30 years. Four different meals were tested in random order. Dietary fiber and energy content were the same in all four diets (2500 kJ for females, 3000 kJ for males). Composition of the four different diets was as follows: protein-rich meal: 31.8% protein, 37.2% carbohydrate, 31.1% fat, and 0% alcohol; carbohydrate-rich meal: 12.2% protein, 65.4% carbohydrate, 23.7% fat, and 0% alcohol; fat-rich meal: 11.6% protein, 23.9% carbohydrate, 64.6% fat, and 0% alcohol; alcohol-rich meal: 0% protein, 0% carbohydrate, 0% fat, and 23% alcohol. Resting metabolic rate was measured initially. In addition, after meals were ingested, energy expenditure was measured for 5 hours during the postprandial phase using an open-air circuit, ventilated hood system. Although not significant, diet-induced thermogenesis was 17% higher after the protein-rich meal than after the carbohydrate-rich or fat-rich meals. Diet-induced thermogenesis was 27% higher, a significant difference, after the alcohol-rich meal than after the carbohydrate-rich and fat-rich meals. When expressed as a percentage of energy intake, diet-induced thermogenesis averaged 9% after the ingestion of the alcohol-rich meal, 8.3% after protein-rich meal, and 7.1% after both carbohydrate-rich and fat-rich meals.

Johnston and others (2002) compared the effects of two diets with different macronutrient compositions on diet-induced thermogenesis in 10 females 19-22 years of age with normal body weight. All subjects consumed two experimental diets equal in energy (1763 kcal/d) for one day in a randomized fashion. The two diets included: mixed diet (50% complex carbohydrate, 10% simple sugar, 15% protein, and 25% fat), and high protein (HP) diet (30% complex carbohydrate, 10% simple sugar, 30% protein, and 30% fat). Postprandial energy expenditure was 8 kcal/hour higher at 2.5 hours following the breakfast meal and the lunch meal on the HP diet compared to the mixed diet. Postprandial energy expenditure was 14 kcal/hour higher on the HP diet than the mixed diet 2.5 hours after the dinner meal. Postprandial energy expenditure rose rapidly and was sustained for as long as 4-5 hours following a HP diet, but was more modest and fell rapidly 1-2 hours after the mixed diet.

Flatt and others (1985) examined the effect of dietary fat on postprandial substrate utilization and nutrient balance in seven men (body fat 16 ± 3%) aged 21-26 years. After baseline measurements, subjects ingested, in random order, either a low fat meal (482 kcal, 62% carbohydrate, 27% protein, 11% fat), a high fat, long-chain triglyceride rich meal (858 kcal, 35% carbohydrate, 15% protein, 50% fat), or a medium-chain triglyceride rich meal (856 kcal, 35% carbohydrate, 15% protein, 9% long-chain triglyceride, and 41% medium-chain triglyceride). There was at least one week in between the ingestion of the different meals. The three test meals were given within a 5-week period. Energy expenditure was measured for a continuous nine-hour period. Energy expenditure rose after ingestion of all three meals reaching a peak at approximately 60 minutes. Energy expenditure was significantly higher after the high fat, long chain triglyceride meal (96 ± 11 kcal/9 hr) and the medium-chain triglyceride meal (105 ± 13 kcal/9 hr) than the low fat meal (76 ± 10 kcal/9 hr). However, when expressed as a percentage of energy content of the meals, the thermic effect was not significantly different between the low fat meal (15.8 ± 2.1%), high fat, long-chain triglyceride meal (11.2 ± 1.3%) or the high fat, medium-chain triglyceride meal (12.3 ± 1.5%).

Robinson and others (1990) examined thermogenesis in response to three different feedings in seven normal weight men (body fat 13.4 ± 1.3%) aged 24-26 years.

All subjects were randomly assigned to three different test meals on three separate days with a one-week washout period between the three test meals. The test meals included a high carbohydrate meal (25 kcal/kg body weight, 70% carbohydrate, 15% protein, 15% fat), a high protein meal (25 kcal/kg body weight, 70% protein, 15% carbohydrate, 15% fat), and an acaloric meal (0 kcal flavored water). Each test day included a measurement of resting metabolic rate and 2 hours after ingesting the meal, energy expenditure was measured for a nine-hour period via indirect calorimetry. Energy expenditure was significantly higher 2 hours after all three meals were ingested compared to baseline resting metabolic rate (acaloric 1.12 ± 0.05 kcal/min vs. 1.23 ± 0.08 kcal/min; high carbohydrate 1.15 ± 0.05 kcal/min vs. 1.40 ± 0.08 kcal/min; high protein 1.16 ± 0.05 kcal/min vs. 1.52 ± 0.08 kcal/min). The increase above resting metabolic rate was significantly higher after the high carbohydrate meal (21.6 ± 2.3%) and the high protein meal (31.2 ± 2.0%) than after the acaloric meal (9.7 ± 2.6%). The mean rise in energy expenditure from five to nine hours postprandial was significantly higher after the high protein meal (9.6 ± 0.68%) than after the high carbohydrate meal (5.7 ± 0.4%).

In summary, in normal weight adults, diet-induced thermogenesis was typically significantly higher after consumption of isocaloric meals rich in protein and lower in carbohydrate (30% protein, 40% carbohydrate and 70% protein, 15% carbohydrate) versus those lower in protein and higher in carbohydrate (15% protein, 60% carbohydrate and 15% protein, 70% carbohydrate) (Robinson and others 1990; Johnston and others 2002). In contrast, in studies where the protein content of the meal was kept consistent and percent of calories from fat and carbohydrate were varied, no significant differences in diet-induced thermogenesis were reported (Yerboeket-van de Venne and others 1996).

Changes in the structures of fat given did not significantly alter diet-induced thermogenesis (Flatt and others 1985). Consumption of isocaloric diets containing higher amounts of protein (32% protein, 31% and 37% of fat and carbohydrate, respectively) versus lower amount of protein (12% protein with 24% carbohydrate and 65% fat or 12% protein, 24% fat and 65% carbohydrate) resulted in no significant difference in diet-induced thermogenesis between meals but a trend toward a higher diet-induced thermogenesis after consumption of the higher protein diet (Raben and others 2003).

Studies in Normal Weight, and Overweight / Obese Individuals

Several studies have examined the effects of consumption of meals or diets of varying composition on diet-induced thermogenesis in individuals of different body sizes. These studies are presented hereafter.

Marques-Lopes and others (2001) assessed the postprandial energy expenditure induced by consumption of a high carbohydrate, low fat meal in six normal and seven overweight men age 20-22 years. Subjects ingested an isoenergetic diet (55% carbohydrate, 15% protein, and 30% fat) during a 3-day baseline period. After initial resting energy expenditure measurement, subjects ingested a high carbohydrate meal (80% carbohydrate, 17% protein, and 3% fat) in liquid form. Post meal energy expenditure was measured every 30 minutes for 4 hours. No significant difference was found between the normal weight and overweight men in energy expenditure during the baseline period. However, four hours after eating, diet-induced thermogenesis, when expressed as kJ/kg fat free mass, was significantly higher in the overweight men (29.8 ± 1.2 kJ/kg FFM) than the normal weight men (24.9 ± 0.3 kJ/kg FFM).

De Palo and others (1989) examined postprandial thermogenesis induced by ingestion of a mixed meal and a carbohydrate rich meal in 19 females and eight males (12 obese and 15 normal weight) aged 22-34 years. Following resting energy expenditure measurements, 15 subjects (6 obese and 9 normal weight) were fed a mixed meal (750 kcal; 52% carbohydrate, 19% protein, 24% fat, 4% alcohol) and 12 subjects (6 obese and 6 normal weight) were fed a carbohydrate rich meal (288 kcal; 3% dextrose, 7% disaccharides, 5% trisaccharides, 6% tetrasaccharides, 7% pentasaccharides, 11% hexasaccharides, 61% heptasaccharides and saccharides). Indirect calorimetry was conducted at 30-minute intervals for 2 hours. After the mixed meal consumption, energy expenditure significantly increased in the normal weight subjects (48 ± 22%) but not in the obese subjects (-0.8 ± 12%). After consumption of the carbohydrate rich meal, energy expenditure increased significantly in both groups but the increase appeared 60 minutes later and was less evident in the obese group than in the normal weight subjects. The carbohydrate-induced thermogenesis was slightly, but not significantly, higher in the normal weight subjects (159 ± 66%) than the obese subjects (98 ± 46%).

Schutz and others (1984) evaluated the thermogenic response to three meals each providing 15% protein, 40% fat, and 45% carbohydrates in 20 obese and eight normal weight women aged 19-44 years. Each subject received a total energy content to maintain body weight. Basal metabolic rate (BMR) was measured after a 13-hour fast and diet-induced thermogenesis was measured every 30 minutes for four hours after eating each meal. Diet-induced thermogenesis was significantly greater in the normal weight group (14.8 ± 1.1%) compared to the obese group (8.7 ± 0.8%). Thermogenic response was negatively correlated with body weight (r = -0.552) and with body fat percentage (r = -0.613).

Kaplan and Leveille (1976) examined the response to a semisynthetic high protein test meal in four obese (44.4 ± 1.6% body fat) and four nonobese (32.4 ± 0.6% body fat) women age 19 to 31 years that had a history of childhood onset obesity. After resting energy expenditure was measured, subjects ingested a high protein test meal (823 kcal; 166 grams of casein, 3 grams of soy oil, and 33 grams of sucrose). Oxygen consumption was measured for five hours. Oxygen consumption, when corrected for body weight (L/hr/body weight) and fat free mass (L/hr/kg FFM), was significantly lower in the obese group (0.031 ± 0.025 L/hr/ kg body weight; 0.045 ± 0.036 L/hr/kg FFM) than in the nonobese subjects (0.134 ± 0.034 L/hr/ kg body weight; 0.178 ± 0.047 L/hr/FFM).

Nagai and others (2005) examined the thermic effect of food in 10 obese (29.7% body fat) and 13 normal weight (18.8% body fat) boys aged 6-11 years. Resting energy expenditure as well as postprandial energy expenditure for a 3-hour period were measured. Subjects were fed two different meals on two separate days in random order. The energy content of the meal was calculated to provide approximately one-third of each subject’s daily energy requirements. The two meals included a high carbohydrate meal (70% carbohydrate, 20% fat, 10% protein) and a high fat meal (20% carbohydrate, 70% fat, 10% protein). The thermic effect of food, expressed as % energy intake, was significantly lower in the obese group (3.7% energy intake) than the normal weight group (5.2% energy intake) after the high carbohydrate meal. In contrast, no significant difference was observed after the high fat meal between the obese group (3.9% energy intake) and the normal weight group (4.5% energy intake) in diet-induced thermogenesis.

Schwartz and others (1985) examined the thermic effect of feeding after a high carbohydrate meal and a high fat meal in eight obese (mean IBW= 145%; 3 men, 5 women) and eight normal weight (mean IBW = 99%, 4 men, 4 women) subjects aged 18-39 years. Resting metabolic rate was measured for 60 minutes prior to meal ingestion. The order of the meals was randomly assigned and both meals contained 800 kcal in a volume of 400 mL. The high carbohydrate (HC) meal consisted of 85% dextrose polymer and 15% protein hydrolysate and the high fat (HF) diet contained 85% lipid emulsion and 15% protein hydrolysate. Energy expenditure was assessed using indirect calorimetry for 6 hours following meal ingestion. The resting metabolic rate in the obese group was significantly greater than in the normal weight group (1.33 ± 0.14 vs. 1.15 ± 0.19 kcal/min, respectively). There was a significant increase in energy expenditure in both groups over baseline after each meal. The absolute thermic effect of the HC meal was significantly greater in both groups when compared to the HF meal (0.26 ± 0.07 vs. 0.18 ± 0.11 kcal/min, respectively). The absolute thermic effect to the high fat meal did not significantly differ between the normal weight and obese subjects. The absolute thermic effect to the HC meal was not significantly larger in the normal weight subjects versus the obese subjects (0.29 ± .06 vs. 0.23 ± .08 kcal/min). No statistically significant difference was observed in the mean 6-hour response to the meals between the two groups. During the first 3 hours of the postprandial period, the thermic response to the HC diet was greater in the normal weight subjects than the obese group (0.30 ± .07 vs. 0.22 ± .09 kcal/min) while the responses were similar in the normal weight (0.26 ± .05 kcal/min) and obese (0.25 ± .08 kcal/min) group during the last 3 hours of the study. Six hours postprandial, the absolute energy expenditure was significantly increased over baseline in the normal weight group (HC: 6-hour: 1.38 ± 0.21 vs. baseline: 1.14 ± 0.21 kcal/min, HF: 6-hour: 1.35 ± 0.21 vs. baseline 1.16 ± 0.19 kcal/min) and the obese group (HC: 6-hour: 1.56 ± 0.18 vs. baseline: 1.33 ±0.16 kcal/min, HF: 6-hour: 1.48 ± 0.20 vs. baseline: 1.33 ± 0.13 kcal/min).

Westerterp-Plantenga and others (1997) investigated diet-induced thermogenesis in 32 subjects (15 men, aged 39-51 years, BMI 26 ± 2 kg/m^2; 17 women, aged 38-52 years, BMI 25 ± 2 kg/m^2). Diet-induced thermogenesis was measured 3 times on 3 different occasions after consuming meals of different nutrient compositions. The 3 different meals included a full fat-lunch (15% protein, 41% fat, 44% carbohydrate), a reduced-fat, reduced-energy lunch (15% protein, 26% fat, 58% carbohydrate), and an isoenergetic reduced fat lunch (15% protein, 26% fat, 59% carbohydrate). The full fat lunch and the isoenergetic reduced fat lunch provided 3 MJ for men and 2.3 MJ for women and the reduced fat, reduced energy lunch was 65% of that of the full-fat lunch for both genders. On each measurement day, subjects were instructed to eat a subject-specific breakfast (20% of their calculated energy requirements) an hour before arriving to the department. Metabolic rate was measured for one hour after subjects rested for 3 hours. Next, the subjects ingested their assigned lunch and energy expenditure was then measured for 3.25 hours continuously. Resting metabolic rate differed significantly between the men and women (men: 5.6 ± 0.6 kJ/min; women: 4.3 ± 0.5 kJ/min). The degree of diet-induced thermogenesis differed among the 3 diets. The reduced fat, reduced energy lunch (0.6 ± 0.02 kJ/min) had a significantly smaller absolute increase in metabolic rate than the full fat lunch (0.7 ± 0.02 kJ/min). However, the metabolic absolute increase in the reduced fat, isoenergetic lunch was not significantly different than the full fat lunch (0.8 ± 0.02 kJ/min vs. 0.7 ± 0.02 kJ/min). There also was no significant difference in the relative increase in energy expenditure (percentage of energy intake during lunch) between the isoenergetic reduced fat lunch (6.1 ± 1.8%) and the full fat lunch (5.2 ± 1.8%). There was, however, a significantly larger increase in diet-induced thermogenesis in the reduced fat, reduced energy lunch (6.7 ± 2%) compared to the full fat lunch (5.2 ± 1.8%).

Shetty and others (1981) examined postprandial thermogenesis in five normal weight (BMI 18.99± 0.68 kg/m^2), five obese (BMI 32.48 ± 2.37 kg/m^2), and five postobese (23.0 ± 0.7 kg/m^2) women aged 26-67 years. Resting metabolic rate was measured in all subjects after a 12-hour fast. Energy expenditure was measured after the test meal of Carnation Instant Breakfast mixed with milk for a continuous 60-minute period as well as for two 15-minute intervals between 75-90 minutes and 105-120 minutes after the meal was ingested. Subjects ingested 9.8 kcal/kg ideal body weight. Normal weight ingested 582 kcal, obese 559 kcal, and postobese 576 kcal. No significant differences were found at baseline in resting metabolic rate between the three groups (normal weight: 3.701 ± 0.097 kJ/min, obese: 4.489 ± 0.329 kJ/min, postobese: 3.934 ± 0.244 kJ/min). There was a marked and sustained rise in metabolic rate after the test meal consumption in the normal weight group, reaching the maximum at 45 minutes (0.741 ± 0.083 kJ/min) and then slowly decreasing. In contrast, the response was significantly reduced in the obese (0.481 ± 0.124 kJ/min) and postobese (0.443 ± 0.063 kJ/min) groups with the maximum response being seen at 45 minutes. Significant differences in postprandial energy expenditure were observed at 90 minute and 120 minute postmeal in the obese (90 min: 0.206 ± 0.119 kJ/min; 120 min: 0.189 ± 0.167 kJ/min) and postobese (90 min: 0.272 ± 0.100 kJ/min; 120 min: 0.270 ± 0.061 kJ/min) groups versus in the normal weight (90 min: 0.662 ± 0.086 kJ/min; 120 min: 0.594 ± 0.055 kJ/min) group. In summary, both the obese and postobese groups had a significantly smaller thermogenic response than the normal weight group.

De Peuter and others (1992) examined energy expenditure in eight post-obese (BMI 24.7 kg/m^2) women aged 30-46 years and eight normal weight (BMI 22.9 kg/m^2) women aged 22-44 years. After resting metabolic rate was measured, subjects ingested a liquid meal of Ensure Plus (12 kcal/kg fat free mass, 53% carbohydrate, 32% fat, 15% protein). Energy expenditure was measured at 30-minute intervals for the next 4.5 hours via indirect calorimetry. No significant differences were observed in postprandial energy expenditure between the post-obese (23.36 ± 0.42 kcal/min/kg FFM) and normal weight (24.41 ± 0.68 kcal/min/kg FFM) subjects. The thermogenic response of the post-obese group was significantly lower after meal ingestion (5.91 ± 0.69 % meal energy) than the normal weight group (7.07 ± 0.66 % meal energy).

Bukkens and others (1991) studied the thermic response to a normal mixed meal (energy intake calculated individually to maintain weight; 55% carbohydrate, 14.5% protein, 30.5% fat) in six post-obese women (BMI 24.0 ± 0.6 kg/m^2) aged 37-47 years and six women (control group) who had never been obese (BMI 24.8 ± 0.6 kg/m^2) aged 34-44 years. Subjects remained in the residential building during the entire two-week study period and postprandial thermogenesis was assessed on two different occasions.

Resting metabolic rate was measured after a 12-hour overnight fast. Next, the meal was ingested and energy expenditure was measured for a continuous 245-minute period via indirect calorimetry. The mean baseline and mean postprandial energy expenditure were not significantly different between the post-obese women (3.65 ± 0.22 kJ/min and 4.50 ± 0.25, respectively) and the controls (3.73 ± 0.17 kJ/min and 4.61 ± 0.18 kJ/min, respectively). Significant increases in energy expenditure after meal ingestion compared to baseline measurements were found in both the post-obese (23.5 ± 1.4% increase) and the control (24.1 ±1.6% increases) subjects. No significant difference in this increase was found between the two groups.

Golay and others (1982) studied the thermogenic response to an oral glucose load in 55 obese (28 females, 27 males) and 30 healthy control (6 young females, 11 young males, 9 elderly females, 4 elderly males) subjects. The obese subjects were divided into four groups according to the severity of their diabetes and to insulin response to 100 grams of oral glucose. Group A consisted of 13 obese subjects (6 female, 7 male) with normal plasma glucose concentrations, group B consisted of 13 obese subjects (10 females, 3 males) with impaired glucose tolerance, group C consisted of 16 obese diabetics (7 females, 9 males) with increased insulin response to the oral glucose load when compared to the control groups, and group D consisted of 13 obese diabetics (5 female, 6 males) with overt diabetes that had a lower insulin response to the glucose load when compared to the control groups. After an overnight fast, subjects ingested a 100-g glucose load in 400 ml lemon-flavored water and measurements were taken for a 3-hour period via indirect calorimetry. Energy expenditure was significantly elevated in all groups following the glucose ingestion. The magnitude, however, varied greatly among the different groups. When expressed as percent increase over the pre-meal baseline, energy expenditure rose significantly higher in the young control group (15.1 ± 1.0%) than in the elderly control group (11 ± 1%). Group A and group B showed a significantly lower glucose-induced thermogenesis (Group A: 9.9 ± 1.0% and Group B: 11.3 ± 1.3%) than the young control group when expressed as percent increase over the pre-meal baseline (15.1 ± 1.0%). Group C and group D also had significantly reduced glucose-induced thermogenesis (Group C: 5.4 ± 0.91%, Group D: 3.3 ± 1.7%) when compared to age-matched elderly control group (11 ± 1.0%). Significant differences were also observed in the young control group and the elderly control group When glucose-induced thermogenesis was related to the energy content of the glucose load given, the young control group had a significantly greater response (8.6 ± 0.7%) than the elderly control group (5.8 ± 0.3%). Groups A and B had a significantly lower thermogenic response (6.6 ± 0.9% and 6.4 ± 0.6%, respectively) than the young control group (8.6 ± 0.7%) when expressed in relation to energy content of the glucose load. Glucose-induced thermogenesis values also were significantly lower in group C (3.7 ± 0.7%) and group D (2.2 ± 0.4%) when compared to the elderly control group (5.8 ± 0.3%).

In summary, the majority of studies have demonstrated that when comparing diet-induced thermogenesis in normal weight individuals versus overweight/obese individuals, diet-induced thermogenesis is typically significantly higher in normal weight versus overweight/obese individuals (Kaplan and others 1976; Shetty and others 1981; Schutz and others 1984; De Palo and others 1989; Nagai and others 2005). In contrast, one study reported significantly higher diet-induced thermogenesis in overweight versus normal weight adults (Marques-Lopes and others 2001). Moreover, two studies found no difference in diet-induced thermogenesis in normal weight versus obese individuals after consuming a meal providing 85% of calories as carbohydrate and 15% of calories as protein (Schwartz and others 1985) and after consuming a meal providing 20% of calories as carbohydrate, 70% fat and 10% protein (Nagai and others 2005). Similar findings were reported in normal weight versus post obese adults (Bukkens and others 1991).

Studies in Normal Weight and Underweight Individuals

Few studies have examined differences in diet-induced thermogenesis in underweight individuals versus normal weight individuals. Studies in underweight individuals often include those with eating disorders. Two studies are presented with varying outcomes, which have investigated diet-induced thermogenesis in underweight adults.

Scalfi and others (1992) investigated postprandial thermogenesis after consumption of a mixed meal (16% protein, 50% carbohydrate, 34% fat) in seven anorectic women (BMI 15.3± 0.8 kg/m^2), seven nonpathological underweight women (BMI 16.8 ± 0.3 kg/m^2), and eight control women (BMI 22.5 ± 0.9 kg/m^2) aged 20-30 years. Resting energy expenditure was measured on all subjects for 40 minutes before ingesting the mixed meal. After meal ingestion providing 850 kcal, energy expenditure was measured for a 4-hour period. Resting energy expenditure did not significantly differ between the underweight group (4,790 ± 283 kJ/d) and the control group (5,199 ± 206 kJ/d), but was significantly reduced in the anorectic group (3,713 ± 194 kJ/d). Resting energy expenditure was significantly correlated with body weight when grouping all the subjects (r = 0.778) and in the control group (r = 0.896), but was not as strongly correlated in the anorectic group (r = 0.56) and in the underweight group (r = 0.37). Energy expenditure increased in all subjects after meal ingestion, but the postprandial thermogenesis peak occurred in the anorectic group at 60 minutes when compared to 30 minutes in the other two groups. During the first 120 minutes and throughout the whole postprandial measurement, integrated postprandial thermogenesis (above resting energy expenditure) was significantly reduced in the underweight group (3.9 ± 0.6%) when compared to the anorectic group (5.2 ± 0.3%) and the control group (5.6 ± 0.5%). Energy expenditure was higher than baseline values at the end of the 240-minute experimental period in all subjects.

Casper and others (1991) investigated diet-induced thermogenesis in six anorexic patients (mean BMI 15.7 kg/m^2) aged 17-32 years with secondary amenorrhea for at least 3 months and six age and height-matched control subjects. After measuring basal metabolic rate, subjects consumed a liquid meal (Ensure Plus) and energy expenditure was measured for a period of four hours. The thermic effect of the meal on metabolism did not significantly differ between the patients (87 MJ/d) and control subjects (77 MJ/d).

Other Factors Influencing Diet-induced Thermogenesis

Other than the effects of differences in body weight / composition, few studies have examined factors influencing diet-induced thermogenesis. Visser and others (1995) compared diet-induced thermogenesis (DIT) in 56 young (27 women, 29 men; BMI range 19.7-24.8 kg/m^2) adults aged 21-29 years and 103 elderly (71 women, 32 men; BMI range 22-29.6 kg/m^2) subjects aged 67-79 years. After measurement of resting metabolic rate, subjects ingested a liquid test meal (1.33 MJ, 14% protein, 34% fat, 52%

carbohydrate) on two occasions. Energy expenditure was measured for 3 hours after eating. The absolute DIT as well as the percent of the energy of the test meal (DIT%) was significantly higher in the young men(154 ± 34 kJ/180 min and 12 ± 3 % of energy of meal) than the elderly men (126 ± 27 kJ/180 min and 9 ± 2% of energy of meal). No significant differences in absolute DIT or DIT% were found between the young and elderly women. DIT was negatively associated (r = -0.07) with body composition (% body fat and fat mass) only in the elderly men.

Hendler and others (1988) examined diet-induced thermogenesis in 17 healthy obese (BMI 42 ± 50 kg/m^2) subjects aged 25-37 years after being randomly assigned to either a very low calorie mixed diet (436 ± 2 kcal/d, 41% protein, 55% carbohydrate, 4% fat) or a very low calorie, high protein diet (439 ± 5 kcal/d, 95 ± 1% protein, 2 ± 1% carbohydrate, 3 ± 1% fat) for a 3-week period. Diet-induced thermogenesis was assessed initially as well as on the 21st day of the diet period. Subjects were fed a test meal providing 618 kcal (15% protein, 54% carbohydrate, 31% fat) and after consumption of the test meal, energy expenditure was measured for a continuous 3-hour period via indirect calorimetry. While significant decreases in resting metabolic rate were found after 3 weeks in both the group that had received the low calorie diet (15.3 ± 2.8%) and the group that had received the high protein diet (13.0 ± 5.2%), no significant effects on diet-induced thermogenesis were observed. In other words, diet-induced thermogenesis did not appear to be affected by weight loss.

Mechanisms Thought to be Responsible for Differences in Diet-Induced Energy Expenditure

Reasons for observed differences in diet-induced thermogenesis between individuals of varying body sizes remain unknown; however, multiple, interrelated factors are thought to be involved. Differences in obligatory thermogenesis - the absorption, transport, metabolism, and /or storage of any one nutrient - may occur among individuals of varying body sizes to affect postprandial metabolic rate. Any difference that exists in this obligatory thermogenesis, however, may be the result of factors affecting facultative thermogenesis. For example, diminished norepinephrine release (indicative of sympathetic nervous system activity) may diminish insulin secretion and in turn diminish cellular nutrient uptake and metabolism (obligatory thermogenic responses). Differences in sympathetic nervous system activity (measured by plasma norepinephrine concentrations) have been shown in response to ingestion of meals varying in nutrient composition. For example, significant increases in plasma norepinephrine concentrations have been found in response to ingestion of carbohydrate, but not protein or fat (Welle and others 1981). Other studies, however, have not observed this finding (Schwartz and others 1985). Since increased plasma insulin is associated with increased plasma norepinephrine, blunted insulin secretion, as may occur in some individuals who are obese or overweight, may be associated with diminished sympathetic nervous system activity, and thus thermogenic response (Ravussin and others 1983; Rowe and others 1981). Some, but not all studies, have shown decreased thermogenic responses to high carbohydrate meals in obese individuals with glucose intolerance and to high fat meals in obese individuals (Golay and others 1982; Swaminathan and others

1985; De Palo and others 1989; Spraul and other 1994; Welle 1995; Marques-Lopes and others 2001; Nagai and others 2005).

Lack of significant rises in body temperature (internal and skin) or diminished total heat production, indicators of thermogenesis, also have been found in obese versus lean individuals (Pittet and others 1976). The diminished diet-induced energy expenditure found in obese individuals has been attributed to inefficient stimulation of thermogenesis. The decreased dietary-induced thermic effect also has been suggested as a cause of altered glucose oxidation which has been demonstrated in obese individuals (Pittet and others 1975).

Total Energy Expenditure and the Effects of Consumption of Different Diet Compositions

Several studies have examined the effects of consumption of diets varying in macronutrient composition on total daily energy expenditure. The findings of 10 studies will be presented.

Yerboeket-van de Venne and Westerterp (1996) examined the short-term effects of dietary fat and carbohydrate exchange on energy metabolism in 12 healthy, normal weight women. All subjects were fed three different, isocaloric diets including high carbohydrate, low fat (15% protein, 10% fat, 75% carbohydrate), low carbohydrate, high-fat (15% protein, 50% fat, 35% carbohydrate), and mixed diet (15% protein, 30% fat, 55% carbohydrate), for 3 days with a 4-day washout period between each diet. On the last day of each diet, energy expenditure was measured in a respiratory chamber. No significant differences in 24-hour energy expenditure were observed in the subjects while consuming the three different diets.

Westerterp and others (1999) studied the effect of diet composition on energy expenditure over 24 hours in a respiration chamber in eight healthy, normal weight (body mass index 23 ± 3 kg/m^2) females aged 27 ± 3 years. Subjects spent two 36-hour periods in a respiration chamber, consuming a low fat, high protein diet (61% carbohydrate, 10% fat, 29% protein) and a low carbohydrate, high fat diet (30% carbohydrate, 61% fat, 9% protein) in random order. Both diets were similar in calories and volume. Twenty-four hour energy expenditure did not significantly differ after consumption of the two diets.

Wilhelmine and others (1994) investigated the metabolic responses to dietary fat and carbohydrate in 14 healthy young females (7 restrained eaters and 7 unrestrained eaters) aged 19-24 years. Subjects ingested a low-fat (LF) diet (15% protein, 10% fat, 75% carbohydrate) and a high fat (HF) diet (15% protein, 50% fat, 35% carbohydrate) over 3-day intervals in randomized order. In addition, 12 subjects ingested a mixed (M) diet (15% protein, 30% fat, 55% carbohydrate) for a 3-day period. There was a 4-day washout period between the experimental periods. During the last day of each experimental diet, subjects spent the day in a respiratory chamber to measure energy expenditure. No significant differences in 24-hour energy expenditure between the restrained-eating and unrestrained-eating women were observed on the LF (8,525 kJ/d vs. 8,698 kJ/d, respectively) diet, M (8,179 kJ/d vs. 8,649 kJ/d, respectively) diet or HF (8,209 kJ/d vs. 8,604 kJ/d, respectively) diet.

Hill and others (1991) investigated the effects of three different diets varying in nutrient composition on energy expenditure in eight (3 men, 5 women) moderately obese (BMI range 27- 32 kg/m^2) individuals aged 28-43 years. The three diets consisted 20% protein, 60% carbohydrate, and 20% fat (diet A); diet B consisted of 20% protein, 20%

carbohydrate, and 60% fat; and diet C consisted of 20% protein, 35% carbohydrate, and 45% fat. The total energy intake varied among the subjects based on their individual energy requirements. All eight subjects were randomly assigned to either diet A or diet B for 7 days and then after a 7 day washout period, the subjects were assigned to the diet that they did not eat during the first 7-day experimental period. After another 7-day washout period, six of the subjects (3 men and 3 women) were studied for an additional 7-day period on Diet C. Total energy expenditure was not significantly different during periods of consumption of the different diets.

Roust and others (1994) investigated the effects of isoenergetic, low fat diets on energy expenditure in 15 moderately obese (8 upper body obesity and 7 lower body obesity) women aged 33-40 years and eight nonobese aged-matched women. During the 2-week baseline period, all subjects consumed a diet that consisted of 40-45% fat, 30-35% carbohydrate, and 20% protein. Prior to switching diets, subjects consumed a dinner consisting of 30% fat, 50% carbohydrate, and 20% protein. Subjects then consumed for four weeks an isoenergetic diet providing 27% fat, 53% carbohydrate, 20% protein. Energy intake of these diets was for each individual to maintain their current weight. No significant change was seen in overnight energy expenditure between the upper body obese group (4.14 ±0.24 MJ/14 h), the lower body obese group (3.94 ± 0.14 MJ/14 h), or the nonobese group (3.37 ±0.30 MJ/14 h). Total daily energy expenditure among the 3 groups did not significantly differ.

Ravussin and others (1982) examined 24-hour energy expenditure in 10 (5 men 5 women) normal weight (body fat 20.3 ± 1.1%) control subjects, six (3 men, 3 women) moderately obese (body fat 29.8 ± 1.1%) subjects and 14 (6 mean, 8 women) obese (body fat 36.1 ± 1.5%) subjects aged 22-32 years. Subjects lived in a respiration chamber for 24 consecutive hours. Three standardized meals and one snack providing 2490 kcal/day (15% protein, 39% fat, 46% carbohydrate) were fed to all subjects while in the respiration chamber. Mean 24-hour energy expenditure (kJ/day) differed significantly among all three groups (control: 8439 ± 432 kJ/d; moderately obese: 9599 ± 277 kJ/d; obese: 10043 ± 363 kJ/d). However, when expressed as kJ//kg fat free mass/day, mean 24-hour energy expenditure did not significantly differ among the three groups (control: 173 ± 4 kJ/day/kg FFM; moderately obese: 176 ± 11 kJ/day/kg FFM; obese: 163 ± 4 kJ/day/kg FFM). Significant differences in mean RQ were found between the moderately obese group (0.839 ± 0.008) and the obese group (0.808 ± 0.006). Total 24-hour energy expenditure was highly correlated with resting metabolic rate ($r = 0.888$) and fat free mass ($r = 0.886$).

Thomas and others (1992) examined total 24-hour energy expenditure during ad libitum feeding of high fat (HF) (13% protein, 35% carbohydrate, 52% fat) and high carbohydrate (HC) (13% protein, 62% carbohydrate, 26% fat) diets in 11 (6 men, 5 women) normal weight (BMI 20 - 25 kg/m^2) subjects aged 22-29 years and 10 (5 men, 5 women) obese (BMI 29-33 kg/m^2) subjects aged 25-29 years. Subjects followed a baseline diet (14% protein, 48% carbohydrate, 38% fat) one week prior to the experimental diets. Subjects were then randomly assigned to either the HC or HF diet for 1 week and after a 1-month washout period (subjects ate ad libitum), subjects were fed the remaining experimental diet for 1 week. Total 24-hour energy expenditure was measured with a whole-room indirect calorimeter on day 7 of the baseline diet as well as on day 7 of both of the experimental diets. Changes in diet composition did not produce significant changes in total daily energy expenditure in any of the subjects. However, energy expenditure, when expressed as kcal/day, was significantly higher in the male subjects than the female subjects as well as significantly higher in the obese subjects than the lean subjects. 24-hour RQ values were significantly higher on day 7 of the HC diet (0.920 ± 0.0223) than it was on day 7 of the HF diet (0.838 ± 0.0125) for all subjects.

Lean and James (1987) investigated the effects of feeding isoenergetic diets varying in fat and carbohydrate in six normal weight (body mass index 20.0 ± 2.4 kg/m^2), seven post-obese (body mass index 24.8 ± 2.4 kg/m^2), and ten obese (body mass index 37.0 ± 5.1 kg/m^2) women aged 27-57 years. All subjects were fed a standard meal (2.6 MJ, 50% carbohydrate, 35% fat, 15% protein) the night before each study day. All subjects were fed three different diets on three separate occasions in random order including a fasting diet, a low fat diet (6 MJ, 83% carbohydrate, 2% fat, 15% protein), and a high fat diet (6 MJ, 45% carbohydrate, 40% fat, 15% protein). Significant differences in 24-hour energy expenditure were found among all three groups between the fasting period and the low fat diet period (normal weight 1.88 ± 0.05 kg FFM vs. 1.98 ± 0.04 kg FFM; post-obese 1.69 ± 0.06 kg FFM vs. 1.82 ± 0.08 kg FFM; obese 1.75 ± 0.05 kg FFM vs. 1.85 ± 0.05 kg FFM). A significant decrease in 24-hour energy expenditure was observed in the post-obese group from the low fat diet and high fat diet (1.82 ± 0.06 kg FFM vs. 1.74 ± 0.08 kg FFM). When expressed per kg of fat free mass, 24-hour energy expenditure was significantly lower in the obese group under all feeding conditions (fasting 1.75 ± 0.05 kg FFM; low-fat 1.85 ± 0.05 kg FFM; high fat 1.82 ± 0.05 kg FFM) than the control group (fasting 1.88 ± 0.05 kg FFM; low fat 1.98 ± 0.04 kg

FFM; high fat 1.95 ± 0.04 kg FFM). When expressed per kg fat free mass, the post-obese group had a significantly lower 24-hour energy expenditure than the control group after the fasting regimen (post-obese: 1.69 ± 0.06 kg FFM; control: 1.95 ± 0.04 kg FFM) and the high fat meal (post-obese: 1.74 ± 0.08 kg FFM; control: 1.95 ± 0.04 kg FFM).

Abbott and others (1989) examined energy expenditure in 14 (12 male, 2 female) non-diabetic and six (4 male, 2 female) diabetic Pima Indians aged 21-57 years. All subjects were fed, in random order, a high fat diet (43% carbohydrate, 42% fat, 15% protein) and a high carbohydrate diet (65% carbohydrate, 20% fat, 15% protein) providing appropriate energy intake to maintain weight. Energy expenditure was measured in a closed-circuit indirect calorimetry chamber after an overnight fast. Subjects were fed their assigned meals in the chamber. No significant difference in 24-hour energy expenditure was found in the non-diabetic subjects after consuming the high fat diet (2,435 ± 103 kcal/d) and the high carbohydrate diet (2,359 ± 82 kcal/d). Likewise, no significant difference was observed in 24-hour energy expenditure in the diabetic subjects after consuming the high fat diet (2,169 ± 207 kcal/d) and the high carbohydrate diet (2,128 ± 185 kcal/d).

Bessard and others (1983) examined 24-hour energy expenditure and postprandial thermogenesis in six obese (body fat 39.1 ± 1.1%) women aged 25-29 years and six gender-matched controls (body fat 24.2 ± 0.7%) aged 22-26 years. In addition, the obese women were studied again following substantial weight loss in order to observe whether the thermogenic response was affected by this weight loss. During the 24-hour period in the respiratory chamber, all subjects were fed a standard mixed diet (45% carbohydrate, 40% fat, 15% protein) providing appropriate energy for their individual requirements. The obese subjects were brought back at a later time (once target weight loss was met) to re-measure energy expenditure after weight loss. When expressed in absolute terms, 24-hour energy expenditure was significantly greater in both obese before weight loss 2208 ± 105 kcal/24 h and the obese after weight loss 2009 ± 99 kcal/24 h than in the control group (1746 ± 61 kcal/24 h). However, when expressed per kg of fat free mass (FFM), the 24-hour energy expenditure did not significantly differ among the three groups (obese before weight loss 42.7 ± 1.0 kcal/ kg FFM/24 h; obese after weight loss 41.1 ± 1.0 kcal/kg FFM/24 h; control 42.0 ± 1.6 kcal/kg FFM/24 h). Absolute 24-hour energy expenditure significantly dropped an average of 10% after weight loss, but still remained significantly higher than the 24-hour energy expenditure seen in the control group.

In summary, most studies in normal weight and overweight/obese men and women suggest that consumption of diets that vary in macronutrient composition results in no significant difference in total daily energy expenditure (Ravussin and others 1982; Lean and James 1987; Abbott and others 1989; Hill and others 1991; Roust and others 1994; Wilhelmine and others 1994; Venne and Westerterp 1996; Westerterp and others 1999). Studies comparing total daily energy expenditure between subjects varying in body mass index when expressed in absolute terms, kcal/day, but not kcal/kg FFM/day, show obese individuals have a significantly higher total daily energy expenditure than normal weight adults (Bessard and others 1983; Thomas and others 1992). In contrast, another study found that obese adults had significantly lower total energy expenditure (kcal/kg/day) than controls (Lean and James 1987).

Justification and Purpose

The thermogenic response to food consumption is one component of energy expenditure and thus weight balance. Differences in responses among individuals could over time promote weight gain or loss; however, examination of longer term responses would be needed. Because the use of fad diets is common for weight control, this study used two of the more common fad diets practiced, the Atkins' Diet and the Zone Diet. The purpose of this study was to determine short-term changes in energy expenditure in response to ingesting two different meals (one similar to a popular high protein, low carbohydrate, high fat diet and one similar to a high protein, low carbohydrate, low fat diet) among underweight, normal weight, and overweight/obese college females.

Limitations

Because this study was limited to females aged 19-28 years living in the Auburn area (southeastern United States), the results may not be generalized to other populations. The timing of the resting energy expenditure measurements varied between about 6:30 am and 10:00 am among individuals. Sample size was smaller, especially in the underweight and overweight/obese groups, which could make it more difficult to identify differences. In addition, subjects may not have complied with the required conditions prior to the testing day and the researcher relied on the subjects to be honest about the required protocol.

Null Hypotheses

1. There will be no significant differences in change in metabolic rate from baseline after ingestion of a high protein, high fat meal among overweight, normal weight, and underweight females.

2. There will be no significant differences in change in metabolic rate from baseline after ingestion of a high protein, low fat meal among overweight, normal weight, and underweight females.
3. There will be no significant difference in metabolic response to ingestion of a high protein, high fat meal versus a high protein, low fat meal among overweight females.
4. There will be no significant difference in metabolic response to ingestion of a high protein, high fat meal versus a high protein, low fat meal among normal weight females.
5. There will be no significant difference in metabolic response to ingestion of a high protein, high fat meal versus a high protein, low fat meal among underweight females
6. Following consumption of a meal, metabolic rate will rise significantly above baseline at least one time during the measurement period among the overweight females.
7. Following consumption of a meal, metabolic rate will rise significantly above baseline at least one time during the measurement period among the normal weight females.
8. Following consumption of a meal, metabolic rate will rise significantly above baseline at least one time during the measurement period among the underweight females.

CHAPTER III

CHANGES IN ENERGY EXPENDITURE ASSOCIATED WITH INGESTION OF HIGH PROTEIN, HIGH FAT VERSUS HIGH PROTEIN, LOW FAT MEALS AMONG UNDERWEIGHT, NORMAL WEIGHT, AND OVERWEIGHT FEMALES

ABSTRACT

Changes in energy expenditure in response to ingestion of a high protein, high fat meal versus an isocaloric high protein, low fat meal were investigated in 21 females, aged 19-28 years. Subjects were classified based on body mass index (BMI) as underweight (<18.5 kg/m^2), normal weight (18.5-24.9 kg/m^2), or overweight (≥ 25.0 kg/m^2). Energy expenditure, measured using indirect calorimetry, was assessed before and every 30 minutes for 3.5 hours following consumption of the meals on two separate occasions. Height and weight were measured using standard techniques. Fat free mass (ffm) was measured using bioelectrical impedance analysis. No significant differences were found among the three groups in age, height, or fat free mass. BMI differed significantly among the three groups, and body weight and body fat were significantly higher in overweight subjects versus normal weight and underweight subjects. Significant positive correlations were found between BMI and baseline metabolic rate ($r^2=0.29$), between body weight and baseline metabolic rate ($r^2=0.32$), between BMI and average total change in metabolic rate ($r^2=0.35$), and between body weight and average total change in metabolic rate (r^2=0.22). Changes in metabolic rate (kcal/min) from the baseline rate did not significantly differ in the underweight (n=3) subjects or in the overweight subjects (n=5) following consumption of either meal at any of the measured times. Changes in metabolic rate (kcal/min) from the baseline rate were significantly higher in normal weight subjects (n=11) at 2, 3, and 3.5 hours following consumption of the high protein, high fat meal versus the high protein, low fat meal. Significant differences in metabolic rate were observed among the overweight, normal weight, and underweight subjects following consumption of both meals at most of the times measured. However, when metabolic rate was calculated as kcal/min/kg ffm or as change in metabolic rate from the baseline rate, no significant differences were found among the groups at any of the times. In conclusion, changes in metabolic rate in response to high protein, high fat versus high protein, low fat meals do not differ in overweight and in underweight subjects and thus, there is no metabolic advantage in diet-induced thermogenesis between the two meals. In contrast, in normal weight subjects, ingestion of a high protein, high fat meal significantly increases metabolic rate (69.3 kcal/3.5 hr) versus consumption of a high protein, low fat meal and provides a short term metabolic advantage.

Key words: thermogenesis, energy expenditure, obesity, underweight, diet

INTRODUCTION

Obesity is a growing epidemic. Nearly two-thirds of American adults (65%) are overweight with one-third being obese (30%) and this number continues to climb (Hedley and others 2004). Obesity accounts for thousands of deaths per year and on average costs $75 billion dollars per year in healthcare in the United States (Finkelstein and others 2004).

While the causes of obesity are multifactoral, weight gain ultimately results from an imbalance between energy intake and energy expenditure. The main components of energy expenditure are basal/resting needs and physical activity. Diet-induced thermogenesis (the rise in resting energy expenditure associated with food ingestion) is only a minor component representing on average about 10% of basal needs. Yet, the contribution of diet-induced thermogenesis can be much higher if high protein diets are consumed. Metabolic rate may increase up to about 30% of basal needs after consumption of protein.

High protein diets, such as the Atkins diet and Zone diet, are popular for weight loss in the United States. For example, a 2002 Consumer's Report survey found that over 30% of dieters reported the use of the Atkins diet to help them lose weight (Anonymous 2002). Yet, while high protein diets provide good satiety and are popular with the public, health professionals are generally more cautious about such diets. High protein diets such as the Atkins diet often result in high fat consumption and may also promote increased calcium excretion and longer term problems such as an increased risk of heart disease, osteoporosis, and kidney problems (Eisenstein and others 2002).

Whether high protein diets offer a metabolic advantage through increased diet-induced thermogenesis over other diets that are lower in protein is not clear, since the thermogenic response to food is only one small component of energy expenditure and thus weight balance. Also unclear is whether there are differences in the thermogenic response to different nutrients in individuals of various body sizes. Should differences in responses exist among individuals, these differences over time could promote weight gain or loss.

To date, most studies have examined differences in diet-induced thermogenesis between normal weight and obese individuals with some studies showing no differences and others finding a diminished response in obese adults (Schutz and others 1984; Schwartz and others 1985; De Palo and others 1989; Yerboeket-van de Venne and others 1996; Westerterp-Plantenga and others 1997). Few studies, however, have included healthy underweight individuals (Caper and others 1991; Piers and others 1992; Scalfi and others 1992). Further, while the macronutrient composition has varied considerably between studies, no studies have used a macronutrient composition similar to those found in the Atkins and Zone high protein diets. Because the use of these fad diets is common for weight control, this study examined short-term changes in energy expenditure in response to ingestion of a high protein, high fat meal (designed by the Atkin's Company) versus an isocaloric high protein, low fat meal (designed by the makers of the Zone diet) among healthy underweight, normal weight, and overweight/obese females. The purpose of this study was to determine the changes in energy expenditure in response to ingesting a high protein, high fat meal versus a high protein, low fat meal among underweight, normal weight, and overweight females.

SUBJECTS AND METHODS

Subjects

Subjects, recruited through flyers posted around Auburn University campus and oral announcements in nutrition and food science classes, consisted of 21 females aged 19-28 years. Subjects had to be healthy, free from nut and chocolate allergies, and have regular menstrual cycles to participate. The study was approved by the Auburn University Institutional Review Board for the Use of Human Subjects in Research.

Methods

Subject participation required three visits to the nutrition lab. On the first visit, height and weight were measured using a stadiometer and calibrated beam scale (Detecto Medical Scale, Webb City, MO). From the height and weight measurements, each subject's body mass index (BMI) was calculated, and each subject was classified as underweight (<18.5 kg/m^2), normal weight (18.5-24.9 kg/m^2), or overweight (≥ 25.0 kg/m^2) based on Center for Disease Control (CDC) criteria. Body composition (fat free mass and body fat) was measured using bioelectrical impedance analysis (Bodystat Ltd., Tampa, FL). Subjects completed a consent form and medical questionnaire, and received a menstrual cycle log to track the first and last day of their menstrual cycle.

Subjects reported for the second and third visits at the same time of the month based on their menstrual cycle In addition, subjects must have refrained from eating or drinking (except water) for 12 hours, refrained from caffeine use and exercise for at least 12 hours, and refrained from smoking the morning of their trial. The term baseline rather than resting is being used since subjects drove to the testing site. Energy expenditure, assessed using indirect calorimetry (MedGem, Healthetech, Golden, CO), was measured at baseline between about 7 and 8 am after subjects sat quietly for 10 minutes. Energy expenditure measurements took about 10 minutes/measurement and were conducted with subjects in a seated position in a darkened room with a room temperature of 72ºF. Subjects were then given 15-20 minutes to consume a high protein (34% kcal), high fat (43% kcal) meal (2 Atkins Advantage bars, Atkins Nutritionals, Inc., Ronkonkoma, NY) or a high protein (28% kcal), low fat (24% kcal) meal (2 OmegaZone bars, Sears Labs, Inc., Marblehead, MA). Following consumption, energy expenditure was measured every

30 minutes for 3.5 hours. Consumption of two Atkins Advantage bars provided 440 kcal, 37 g protein, 21.2 g fat, and 43 g carbohydrate. Consumption of two OmegaZone bars provided 440 kcal, 30.8 g protein, 11.8 g fat, and 49 g carbohydrate. Subjects received the two different meals in random order on two different occasions, and the researcher was blinded to what bars the subjects received on each of the two visits. During the time period following meal consumption and in between energy expenditure measurements, subjects were allowed to read or study in a seated position, were allowed one bathroom break per hour, and were allowed to drink water as desired.

Statistical Analysis

Statistical analyses were conducted using InStat (GraphPad Software, San Diego, CA) and JMP IN (SAS Institute, Thomson Learning, Belmont, CA) programs. Analysis of variance (ANOVA) and repeated measures ANOVA were used to assess mean differences for metabolic rate among groups and across times, respectively. ANOVA also was used to assess differences in age, height, weight, BMI, fat free mass, body fat, and energy expended per kcal ingested among the three groups. When ANOVA results were significant, $p < 0.05$, identification of significant differences between groups or times was based on Tukeys multiple comparisons test. Paired t-tests were used to examine mean differences in change in metabolic rate from baseline in subjects within a BMI class at each of the times after consumption of the high protein, high fat meal versus the high protein, low fat meal. Pearson correlations were used to assess the relationships between BMI and energy expenditure, and between body weight and energy expenditure. Because the order in which the subjects ingested the two meals varied, determination of any potential order effects was tested using the Wilcoxon Signed Rank test.

RESULTS

Twenty-one females (1 Asian, 2 African Americans, and 18 Caucasians) aged 19-28 years participated in the study. Two subjects, however, only completed one trial each. Four other subjects completed body composition measurements in the initial visit, but failed to return. The main reason cited for not completing the study was the lack of time to commit to the study. In addition, a few underweight subjects would or could not participate due to abnormal menstrual cycles and/or disordered eating.

Mean (± SE) age, height, weight, body mass index (BMI), dry fat free mass (not including body water), and body fat for all subjects are shown in Table 1. Of the 21 participants, six were overweight, 12 were normal weight, and three were underweight. BMI of the subjects ranged from 17.7 to 31.4 kg/m^2. No significant differences were found among the three groups in age, height, or fat free mass. BMI differed significantly among the three groups, and body weight and body fat were significantly higher in the overweight subjects versus normal weight and underweight subjects. Subjects completed the high protein, high fat meal on day 14.2 $\pm$ 0.7 of their menstrual cycle and completed the high protein, low fat meal on day 14.5 $\pm$ 0.9 of their menstrual cycle counting as day one the first day after completion of the menstrual cycle. The average number of days between consumption of the two meals was 15 $\pm$ 5 days. No order effects were found.

Table 2 and Figure 1 present mean (± SE) baseline and postprandial metabolic rate (kcal/min) within and among overweight, normal weight, and underweight subjects before and following consumption of a high protein, high fat meal. Postprandial metabolic rate was significantly higher than baseline in both normal and overweight subjects at 30, 60, 90, 120, and 150 minutes following consumption of a high protein, high fat meal. In normal weight subjects, this significant difference persisted at 180 and 210 minutes. No significant differences were found between baseline and postprandial metabolic rates in underweight subjects after consumption of a high protein, high fat meal. Baseline metabolic rate did not differ among overweight, normal, and underweight subjects prior to consumption of the high protein, high fat meal (Table 2). Baseline metabolic rate also did not significantly differ between subjects prior to consumption of the high protein, high fat meal versus prior to consumption of the high protein, low fat meal (Tables 2 and 3). Significant differences in postprandial metabolic rates after consumption of the high protein, high fat meal were found among the three groups at 30, 60, 120, and 180 minutes. At each time, metabolic rate was highest in overweight subjects, followed by normal weight, and then underweight subjects. At 90 and 150 minutes, metabolic rates of overweight subjects were significantly higher than those of normal and underweight subjects (Table 2). At 210 minutes, metabolic rate was significantly higher in the overweight subjects versus underweight subjects (Table 2). However, when metabolic rate was calculated per kg fat free mass, no significant differences were found among the three groups at any of the times (data not shown). In addition, no interaction was found between BMI classification and time after consumption of the high protein, high fat meal.

Table 3 and Figure 2 present mean (± SE) baseline and postprandial metabolic rate (kcal/min) within and among overweight, normal weight, and underweight subjects before and following consumption of a high protein, low fat meal. Postprandial metabolic rate was significantly higher than baseline in both normal and overweight subjects at 30, 60, 90, 120, and 150 minutes following consumption of a high protein, low fat meal. In overweight subjects this significant difference persisted at 180 and 210 minutes. No significant differences were found between baseline and postprandial metabolic rates in underweight subjects after consumption of a high protein, low fat meal. Baseline metabolic rate was significantly higher in overweight versus underweight subjects. Significant differences in postprandial metabolic rates were found among the three groups at 60, 90, 120, and 150 minutes after consumption of a high protein, low fat meal. At each time, metabolic rate was highest in overweight subjects, followed by normal weight and then underweight subjects. At 30 minutes, overweight and normal weight subjects had a significantly higher metabolic rate than underweight subjects. At 180 and 210 minutes, postprandial metabolic rate was significantly higher in overweight subjects than in the normal and underweight subjects. However, no significant differences were found in metabolic rate among the three groups when metabolic rate was expressed per kg fat free mass (data not shown). In addition, no interaction was found between BMI classification and time after consumption of the high protein, low fat meal.

Significant positive correlations were found between BMI and baseline metabolic rate (r^2=0.29), and between body weight and baseline metabolic rate (r^2=0.32). Significant positive correlations also were found between BMI and average total change in metabolic rate (r^2=0.35), and between body weight and average total change in metabolic rate (r^2=0.22).

Table 4 and Figures 3-5 report mean (± SE) changes in metabolic rate among overweight, normal weight, and underweight subjects after consumption of high protein, high fat and high protein, low fat meals. Data are also reported as mean percent energy expended per kcal ingested. No significant differences in mean change in metabolic rate were found among the three groups at any of the times after consumption of the high protein, high fat meal or after consumption of the high protein, low fat meal. No significant difference in mean percent energy expended per kcal ingested was found among the three groups after consumption of the high protein, high fat meal or after consumption of the high protein, low fat meal. No significant differences in mean change in metabolic rate were found at any time in overweight subjects after consumption of the high protein, high fat meal versus the high protein, low fat meal. No significant differences in mean change in metabolic rate were found at any time in underweight subjects after consumption of high protein, high fat meal versus high protein, low fat meal. In contrast, mean change in metabolic rate was significantly higher after consumption of the high protein, high fat meal than after consumption of the high protein, low fat meal at 120, 180, and 210 minutes and approached significance at 150 minutes in normal weight subjects. The difference in the increase in metabolic rate after consumption of the high protein, high fat meal versus the high protein, low fat meal in the normal weight subjects represents about 69.3 kcal per 3.5 hours (1.20 – 0.87 kcal/min X 210 min = 69.3 kcal).

DISCUSSION

High protein diets remain a popular choice for dieting among Americans. Yet, while high protein foods appeal to the taste buds of many individuals and can be part of a weight loss diet, high protein diets can vary tremendously in fat and carbohydrate contents and can be extremely unhealthy if excessively high in fat or extremely low in carbohydrate. These variations in the macronutrient composition of diets may influence diet-induced thermogenesis. Diet-induced thermogenesis also has been shown to differ among individuals of different body sizes. These thermogenic differences over time could lead to changes in energy balance and thus body weight. This study examined short-term changes in energy expenditure among overweight, normal weight, and underweight females after consumption of a high protein, high fat meal versus high protein, low fat meal.

Baseline Energy Expenditure

Baseline metabolic rate per kg fat free mass did not significantly differ among overweight, normal weight, and underweight subjects prior to the high protein, high fat or the high protein, low fat meals. Absolute baseline metabolic rate (kcal/min) also did not significantly differ between subjects before the two meals or among overweight, normal weight, and underweight subjects prior to the high protein, high fat meal, but was significantly higher in overweight versus underweight subjects prior to the high protein, low fat meal. Several studies have examined differences in resting metabolic rate among individuals of different sizes. Similar to the present findings, James and others (1978), Hoffmans and others (1979), Ravussin and others (1982), and De Palo and others (1989) found absolute resting metabolic rates were significantly higher in obese individuals versus normal weight individuals. Bosy-Westphal and others (2004) demonstrated that an underweight group of subjects had a significantly lower absolute metabolic rate than an intermediate weight group and an obese group. Moreover, also similar to the current study, most studies that have calculated metabolic rate per kg fat free mass have shown no significant differences (Ravussin and others 1982; Schutz and others 1984; Kashiwazaki and others 1988; de Peuter and others 1992). Significant correlations in the present study were found between baseline metabolic rate and both BMI and body weight. These findings also are consistent with other studies which have examined relationships between resting metabolic rate and body weight (Ravussin and others 1982; Kashiwazaki and others 1988).

Postprandial Thermogenic Responses to the High Protein, High Fat Meal and the High Protein, Low Fat Meal among and within Groups

The increases in metabolic rate that occurred after overweight, normal weight, and underweight subjects consumed the high protein, high fat and the high protein, low fat meals are consistent with changes in metabolic rate associated with diet induced thermogenesis. However, while increases in metabolic rate were exhibited among all groups, the rise was not significantly different from baseline in the underweight subjects. Only one study has examined postprandial changes in metabolic rate in healthy, underweight females. While differences between baseline and postprandial measurements were not published, Scalfi and others (1992) reported that underweight females had a significantly reduced postprandial thermogenesis versus normal weight females.

The significant differences in postprandial metabolic rate among the three groups at the various times after consumption of the high protein, high fat meal and the high protein, low fat meal may be due to: (a) the initial differences in baseline metabolic rate, (b) the differences in response to the meals or, (c) a combination of the two. No differences in postprandial metabolic rate were found among the groups when calculated as kcal/min per kg fat free mass. Moreover, no significant differences were found in change in metabolic rate from baseline among the overweight, normal weight, and underweight groups after consumption of the high protein, high fat meal. Similar findings were observed after the consumption of the high protein, low fat meal.

Two studies have reported findings similar to the present study. Schwartz and others (1985) reported no significant differences in diet-induced thermogenesis between normal weight and obese adults after consumption of a meal providing 85% of energy as carbohydrates and 15% protein. Secondly, in a study conducted in boys aged six to 11 years, Nagai and others (2005) demonstrated no significant difference in postprandial energy expenditure between obese and normal weight boys after consumption of a high fat meal (70% fat, 20% carbohydrate, 10% protein).

In contrast to the present study, several studies in which subjects received mixed meals found that diet-induced thermogenesis was significantly higher as a percent of resting energy expenditure or as absolute metabolic rate in normal weight versus overweight/obese individuals (Kaplan and others 1976; Shetty and others 1981; Schutz and others 1984; De Palo and others 1989). However, due to the differences in how the data were expressed it is possible that the findings of these studies are similar to the findings of the present study. Conversely, one study found significantly higher diet-induced thermogenesis, when expressed per kg fat free mass, in overweight versus normal weight adults (Marques-Lopes and others 2001). Differences in findings between studies likely result from multiple factors. While in the present study, all subjects received isocaloric meals regardless of body weight, other studies fed different weight subjects different energy intakes. Diet-induced thermogenesis is known to vary with the amount of energy ingested as well as the macronutrient composition of the food consumed. Thus, if overweight subjects are fed less energy than normal weight subjects, a diminished thermogenic response may result from the fewer calories ingested or may result from a blunted thermogenic response to meal ingestion.

Comparisons of Change in Responses to the Ingestion of the High Protein, High Fat Meal versus the High Protein, Low Fat Meal within Groups

No significant difference in change in metabolic rate was observed when overweight subjects consumed the high protein, high fat meal versus the high protein, low fat meal. Similarly, no significant difference in change in metabolic rate was observed when underweight subjects consumed the high protein, high fat meal versus the high protein, low fat meal. In contrast, changes in metabolic rate were significantly higher in normal weight subjects at 2, 3, and 3.5 hours following consumption of the high protein, high fat meal versus the high protein, low fat meal. While several studies have examined postprandial metabolic rate in subjects of different sizes after consumption of two different meals, these studies did not examine thermogenic responses within a weight group between the two meals (Nair and others 1983; Schutz and others 1984; De Palo and others 1989; Nagai and others 2005). In one study in which comparisons in postprandial responses were examined, Schwartz and others (1985) combined the overweight and normal weight subjects into one group and found a significantly greater thermogenic response to a high carbohydrate meal (85% carbohydrate, 15% protein) versus a high fat meal (85% fat, 15% protein). Because no significant difference was observed in the thermogenic response to the high fat meal between the two groups, but a significant decreased response was seen in the obese group versus the normal weight group after consumption of the high carbohydrate meal, the researchers noted that over one-half of the greater thermogenic response to the carbohydrates was due to the normal weight subjects (Schwartz and others 1985).

Reasons for the differential response between normal weight and overweight/ obese individuals to meals containing varying amounts of carbohydrate and fat are unclear. Some studies have suggested that the thermogenic response to carbohydrate intake is blunted in overweight/obese individuals (Pittet and others 1975; Golay and others 1982; Sharief and others 1982; Nagai and others 2005). In addition, one study suggested that the thermogenic response to fat is blunted in overweight/obese individuals (Swaminathan and others 1985). However, the results of other studies have shown no significant differences in thermogenic response to carbohydrates or fat between overweight/obese and normal weight individuals (Schwartz and others 1985; Marques-Lopes and others 2001; Nagai and others 2005).

The greater thermogenic response in the normal weight individuals after consumption of the high protein, high fat meal versus the high protein, low fat meal likely resulted from the higher protein content of the high protein, high fat meal (37 grams versus 30.8 grams protein) since the thermogenic response to fat and carbohydrate is thought to be about equal (Nair and others 1983; Raben and others 2003). The lack of this differential response to the two different meals in the overweight subjects may have resulted from a blunted response to the high fat (43%) content of the high protein, high fat meal (Swaminathan and others 1985). This diminished metabolic rate associated with the high protein, high fat meal would decrease the differences observed in the overweight group when comparing metabolic rates between the two meals resulting in no statistically significant differences at the various times measured.

Underweight individuals, like the overweight individuals, showed no significant difference in thermogenic response to the ingestion of the two meals. Only one study has previously reported a reduced thermogenic response to meals in underweight females but did not compare differences in response between two meals (Scalfi and others 1992). The reduced response observed in this study is thought to result from decreases in both obligatory and facultative thermogenesis in the underweight females. Further studies should investigate both the hormonal and sympathetic nervous system responses to meals in healthy, underweight individuals.

In conclusion, changes in metabolic rate in response to high protein, high fat versus high protein, low fat meals do not differ in overweight and in underweight subjects and thus, there is no metabolic advantage in diet-induced thermogenesis between the two meals. In contrast, in normal weight subjects, ingestion of a high protein, high fat meal significantly increases metabolic rate (69.3 kcal/3.5 hr) versus consumption of a high protein, low fat meal and provides a short tem metabolic advantage. Whether the higher diet-induced thermogenesis would persist with ongoing ingestion of a high protein, high fat diet in normal weight individuals and would lead to greater changes in body weight is not known.

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Table 1: Mean (± SE) age, height, weight, body mass index (BMI), fat free mass, and body fat among overweight, normal weight, and underweight subjects

	Overweight (n=6)	**Normal weight (n=12)**	**Underweight (n=3)**
Age (years)	22.83 ± 1.09^a	20.75 ± 0.77^a	20.67 ± 1.54^a
Height (m)	1.62 ± 0.02^a	1.65 ± 0.02^a	1.69 ± 0.04^a
Weight (kg)	70.77 ± 2.60^a	58.08 ± 1.84^b	51.72 ± 3.68^b
BMI (kg/m^2)	26.85 ± 0.74^a	21.14 ± 0.52^b	18.07 ± 1.04^c
Dry Fat Free Mass (kg)	14.83 ± 0.92^a	13.60 ± 0.65^a	12.77 ± 1.30^a
Body Fat (%)	31.40 ± 1.22^a	23.03 ± 0.86^b	19.50 ± 1.72^b

^{abc}Values in a row with different superscripts differ significantly ($p < 0.05$)

Table 2: Mean (± SE) baseline and postprandial metabolic rate (kcal/min) within and among overweight, normal weight, and underweight subjects before and following consumption of a high protein, high fat meal

Time	**Overweight (n=5)**	**Normal weight (n=12)**	**Underweight (n=3)**
	kcal/min	**kcal/min**	**kcal/min**
Baseline	$1.08 \pm 0.05^{a+}$	$0.95 \pm 0.03^{a+}$	$0.86 \pm 0.07^{a+}$
30 min	$1.29 \pm 0.04^{a\circ}$	$1.12 \pm 0.03^{b\circ}$	$0.94 \pm 0.06^{c+}$
60 min	$1.31 \pm 0.05^{a\circ}$	$1.15 \pm 0.03^{b\circ}$	$0.96 \pm 0.06^{c+}$
90 min	$1.31 \pm 0.06^{a\circ}$	$1.10 \pm 0.04^{b\circ}$	$0.92 \pm 0.08^{b+}$
120 min	$1.28 \pm 0.04^{a\circ}$	$1.13 \pm 0.03^{b\circ}$	$0.96 \pm 0.05^{c+}$
150 min	$1.26 \pm 0.04^{a\circ}$	$1.09 \pm 0.03^{b\circ}$	$0.94 \pm 0.06^{b+}$
180 min	$1.22 \pm 0.03^{a+\circ}$	$1.08 \pm 0.02^{b\circ}$	$0.92 \pm 0.05^{c+}$
210 min	$1.21 \pm 0.05^{a+\circ}$	$1.09 \pm 0.03^{ab\circ}$	$0.95 \pm 0.06^{b+}$

^{abc}Values in a row with different superscripts differ significantly ($p < 0.05$)
$^{+\circ}$Values in a column with different superscripts differ significantly ($p < 0.05$)

Table 3: Mean (± SE) baseline and postprandial metabolic rate (kcal/min) within and among overweight, normal weight, and underweight subjects before and following consumption of a high protein, low fat meal

Time	**Overweight (n=6)**	**Normal weight (n=11)**	**Underweight (n=3)**
	kcal/min	**kcal/min**	**kcal/min**
Baseline	$1.02 \pm 0.04^{a+}$	$0.95 \pm 0.03^{ab+}$	$0.83 \pm 0.05^{b+}$
30 min	$1.17 \pm 0.03^{a\circ}$	$1.12 \pm 0.03^{a\circ **}$	$0.95 \pm 0.05^{b+}$
60 min	$1.26 \pm 0.03^{a\circ *}$	$1.13 \pm 0.02^{b\circ **}$	$0.94 \pm 0.05^{c+}$
90 min	$1.25 \pm 0.03^{a\circ *}$	$1.12 \pm 0.03^{b\circ **}$	$0.94 \pm 0.05^{c+}$
120 min	$1.20 \pm 0.03^{a\circ}$	$1.08 \pm 0.02^{b\circ \#}$	$0.89 \pm 0.04^{c+}$
150 min	$1.17 \pm 0.02^{a\circ}$	$1.07 \pm 0.02^{b\circ \#}$	$0.93 \pm 0.03^{c+}$
180 min	$1.16 \pm 0.03^{a\circ}$	$1.03 \pm 0.02^{b+\circ}$	$0.93 \pm 0.04^{b+}$
210 min	$1.11 \pm 0.02^{a\circ}$	$0.99 \pm 0.02^{b+\circ}$	$0.91 \pm 0.03^{b+}$

^{abc}Values in a row with different superscripts differ significantly ($p < 0.05$)
$^{+\circ}$Values in a column with different superscripts differ significantly ($p < 0.05$)
*Values significantly greater than metabolic rate at 210 minutes in overweight group
**Values significantly greater than metabolic rate at 180 and 210 minutes in normal weight group
$^{\#}$Values significantly greater than metabolic rate at 210 minutes in normal weight group

Table 4 Mean (± SE) changes in metabolic rate (kcal/min) and mean (± SE) change in energy expended from baseline per kcal ingested (EE/I) in overweight, normal weight, and underweight subjects after consumption of a high protein, high fat (HPHF) meal versus after consumption of a high protein, low fat (HPLF) meal

Time	**Overweight**		**Normal**		**Underweight**	
(min)	HPHF kcal/min	HPLF kcal/min	HPHF kcal/min	HPLF kcal/min	HPHF kcal/min	HPLF kcal/min
30	$0.21 \pm 0.04^{a*}$	0.20 ± 0.05^{ao}	$0.19 \pm 0.02^{a*}$	0.17 ± 0.02^{ao}	$0.08 \pm 0.01^{a*}$	0.12 ± 0.03^{ao}
60	$0.23 \pm 0.07^{a*}$	0.20 ± 0.05^{ao}	$0.21 \pm 0.02^{a*}$	0.18 ± 0.03^{ao}	$0.10 \pm 0.06^{a*}$	0.11 ± 0.03^{ao}
90	$0.24 \pm 0.08^{a*}$	0.24 ± 0.06^{ao}	$0.15 \pm 0.03^{a*}$	0.17 ± 0.03^{ao}	$0.06 \pm 0.03^{a*}$	0.11 ± 0.03^{ao}
120	$0.21 \pm 0.09^{a*}$	0.19 ± 0.06^{ao}	$0.20 \pm 0.02^{a*}$	0.13 ± 0.02^{bo}	$0.10 \pm 0.04^{a*}$	0.06 ± 0.06^{ao}
150	$0.19 \pm 0.04^{a*}$	0.18 ± 0.06^{ao}	$0.16 \pm 0.02^{a*}$	0.11 ± 0.01^{ao}	$0.08 \pm 0.05^{a*}$	0.10 ± 0.01^{ao}
180	$0.14 \pm 0.07^{a*}$	0.14 ± 0.05^{ao}	$0.15 \pm 0.02^{a*}$	0.08 ± 0.02^{bo}	$0.06 \pm 0.01^{a*}$	0.10 ± 0.03^{ao}
210	$0.13 \pm 0.09^{a*}$	0.08 ± 0.07^{ao}	$0.16 \pm 0.02^{a*}$	0.04 ± 0.02^{bo}	$0.08 \pm 0.02^{a*}$	0.09 ± 0.02^{ao}
Total	$1.35 \pm 0.46^{a*}$	1.29 ± 0.38^{ao}	$1.20 \pm 0.06^{a*}$	0.87 ± 0.11^{bo}	$0.55 \pm 0.17^{a*}$	0.68 ± 0.19^{ao}
EE/I$^{\#}$(%)	9.2 ± 1.7^{a}	8.8 ± 1.6^{a}	8.2 ± 1.1^{a}	5.9 ± 1.1^{a}	3.8 ± 2.2^{a}	4.6 ± 2.1^{a}

^{ab}Values in a row with the same superscript did not differ significantly between the HPHF meal and the HPLF meal within a BMI group

*Values in a row did not differ significantly among BMI groups following consumption of the HPHF meal

^{o}Values in a row did not differ significantly among BMI groups following consumption of the HPLF meal

$^{\#}$EE/I (%) represents the average energy expenditure over 210 minutes divided by 440 kcal intake X 100 (Schutz and others 1984)

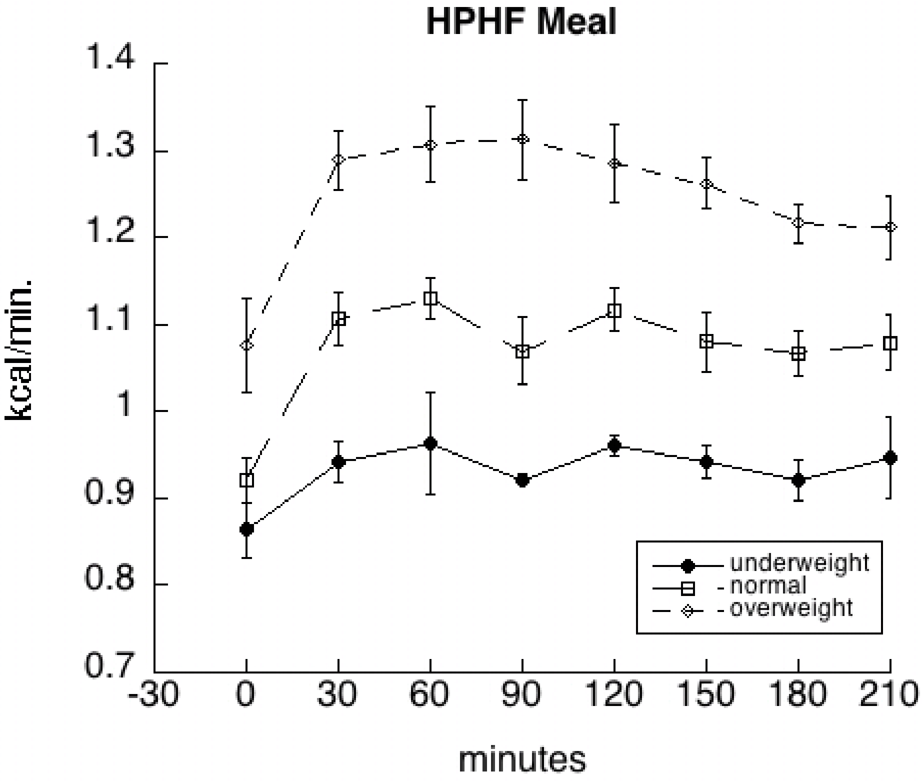

Figure 1: Mean (± SE) baseline and postprandial metabolic rate (kcal/min) among overweight, normal weight, and underweight subjects before and following consumption of a high protein, high fat meal.

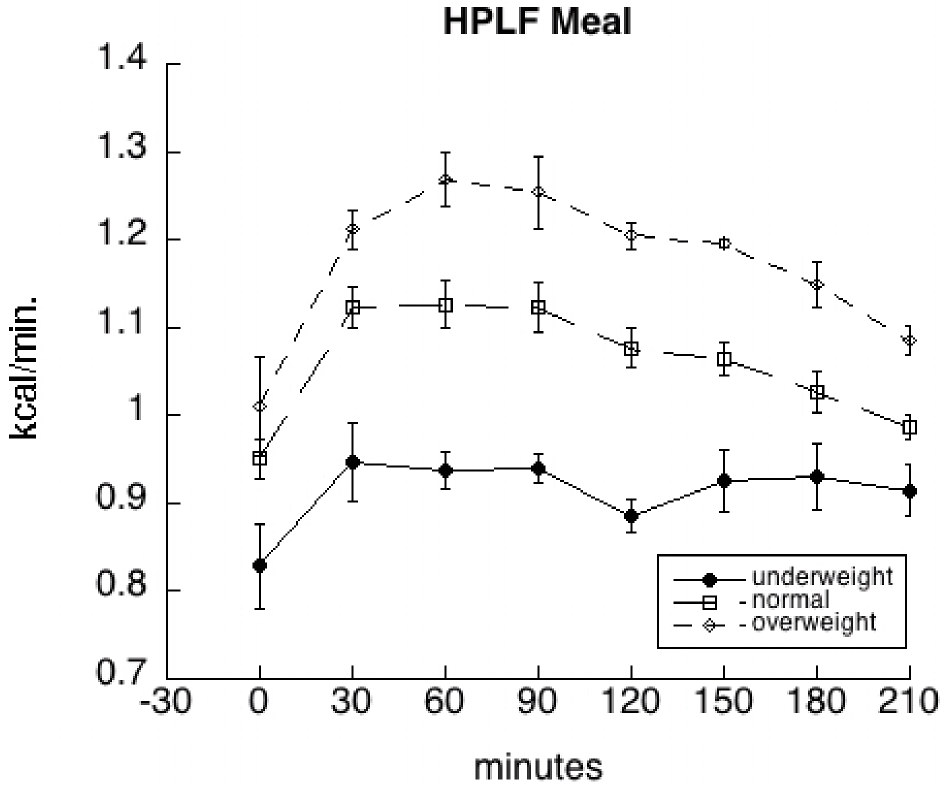

Figure 2: Mean (± SE) baseline and postprandial metabolic rate (kcal/min) among overweight, normal weight, and underweight subjects before and following consumption of a high protein, low fat meal.

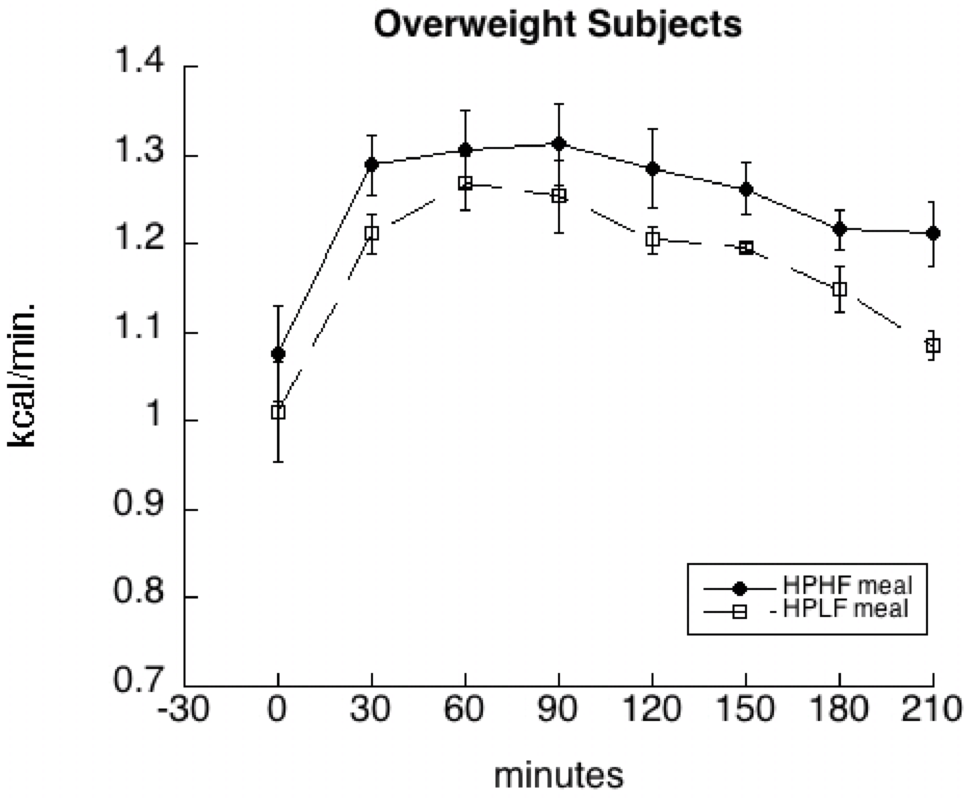

Figure 3: Mean (± SE) changes in metabolic rate (kcal/min) and mean (± SE) change in energy expended from baseline per kcal ingested (EE/I) in overweight subjects after consumption of a high protein, high fat meal versus a high protein, low fat meal.

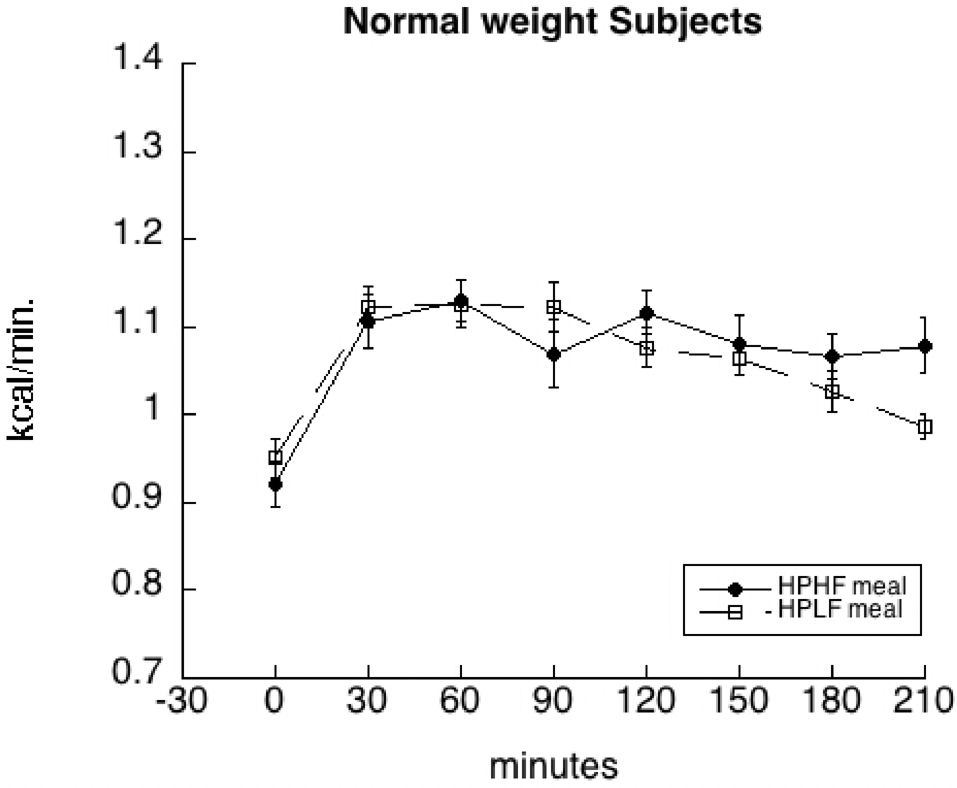

Figure 4: Mean (± SE) changes in metabolic rate (kcal/min) and mean (± SE) change in energy expended from baseline per kcal ingested (EE/I) in normal weight subjects after consumption of a high protein, high fat meal versus a high protein, low fat meal.

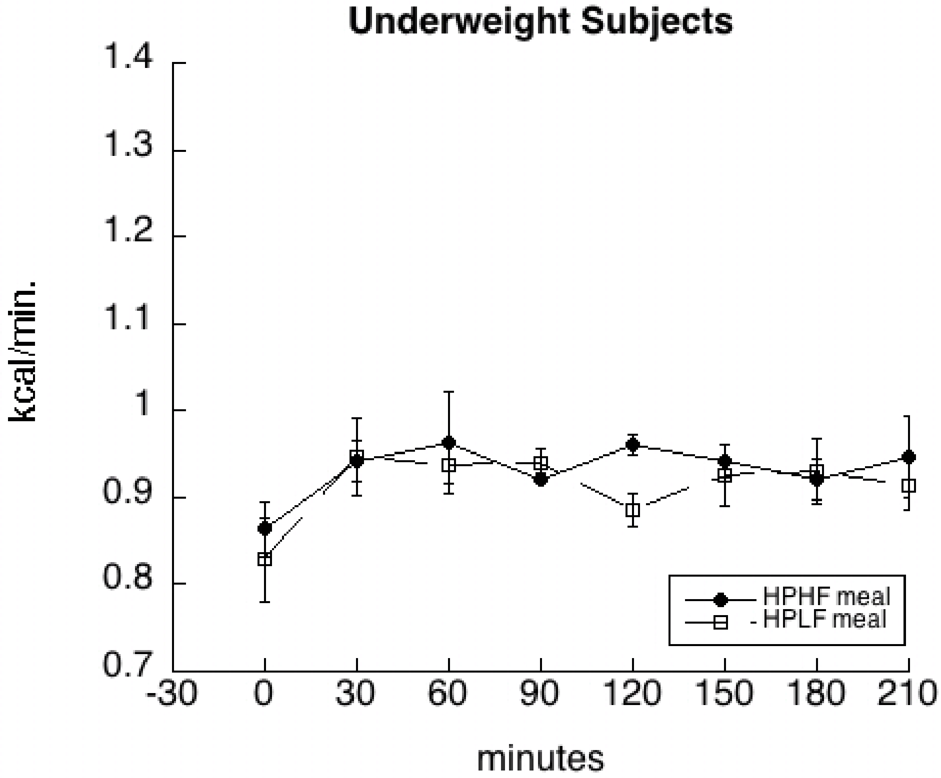

Figure 5: Mean (± SE) changes in metabolic rate (kcal/min) and mean (±SE) change in energy expended from baseline per kcal ingested (EE/I) in underweight subjects after consumption of a high protein, high fat meal versus a high protein, low fat meal.

CHAPTER IV

SUMMARY OF FINDINGS

1. The change in metabolic rate following the consumption of the high protein, high fat meal did not significantly differ among overweight, normal weight, and underweight females. This finding supports the first null hypothesis.
2. The change in metabolic rate following the consumption of the high protein, low fat meal did not significantly differ among overweight, normal weight, and underweight females. This finding supports the second null hypothesis.
3. No significant difference in change in metabolic rate was found in the overweight females after consumption of a high protein, high fat meal versus a high protein, low fat meal. This finding supports null hypothesis three.
4. Significant differences were found in change in metabolic rate in normal weight females after consumption of a high protein, high fat meal versus a high protein, low fat meal. This finding rejects null hypothesis four.
5. No significant difference in change in metabolic rate was found in underweight females after consumption of the high protein, high fat meal versus the high protein, low fat meal. This finding supports null hypothesis five.
6. Following consumption of a meal, metabolic rate remained significantly greater than baseline for at least two hours in overweight females. This finding supports null hypothesis six.

7. Following consumption of a meal, metabolic rate remained significantly greater than baseline for at least two hours in normal weight females. This finding supports null hypothesis seven.
8. Following consumption of a meal, metabolic rate failed to rise significantly above baseline at any of the times measured in underweight femeales. This finding does not support null hypothesis eight.

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APPENDICES

Appendix A
Advertisement Flyer

CURIOUS ABOUT HOW MANY CALORIES YOUR BODY BURNS ON A DAY-TO-DAY BASIS?

CURIOUS HOW YOUR BODY REACTS TO CERTAIN NUTRIENTS?

The Auburn University Department of Nutrition and Food Science is conducting a research project for females 19-28 years of age who want to be part of a research project.

The Department of Nutrition and Food Sciences will measure how many calories your body burns while you rest and after we fed you a meal.

For further information, please contact Dr. Gropper at the Department of Nutrition and Food Sciences at 844-3271 or email groppss@auburn.edu or AJ Riggs at the Department of Nutrition and Food Science at 844-8074 or email riggsaj@auburn.edu.

Appendix B
Demographic Information

Demographic Information

Name: ____

Email Address: ____

Phone Number: ____

Age: ____

Appendix C
Medical Questionnaire

CODE # __________

GENERAL MEDICAL QUESTIONAIRE

Have you ever been diagnosed or do you suspect you have an allergy to nuts?
 _____ Yes ___No

Have you ever been diagnosed or do you suspects you have an allergy to chocolate?
____ Yes ____ No

Have you had a recent illness including a cold, flu, sore throat, infection, etc?
____ Yes ____ No

If yes, what was the appropriate date? ____

Are you taking any medications? ____ Yes ____ No

If yes, what is/are the name(s) of the medication(s)? ______________________________

____

____

Do you smoke? ____ Yes ____ No

Are you taking any diet or herbal supplements? ____ Yes ____ No

If yes, you will need to bring all supplements in before you can be implicated into this study.

Do you exercise regularly? ____ Yes ____ No

If yes, what time of day? ____

What type of exercise? ____

How many minutes do you exercise per session? _________________________________

Are you currently following a special diet to lose, maintain, or gain weight?
____ Yes ____ No

If yes, describe diet and how long you have been following it.
____

Appendix D
Informed Consent

INFORMED CONSENT FOR
Changes in Energy Expenditure Associated with Meals Containing Different Nutrient Compositions

You are invited to participate in a research study investigating the changes in energy expenditure associated with ingesting meals (diet-induced) containing different nutrient compositions (one similar to a popular high protein, low carbohydrate, high fat diet and one similar to a high protein, low carbohydrate, low fat diet). This study is being conducted by Amy Jo Riggs, MS, RD, LD, under the supervision of Dr. Sareen Gropper, PhD, RD, LD, Associate Professor in the Nutrition and Food Science Department. We hope to learn about the differences in diet-induced energy expenditure from eating two different meals (one similar to a popular high protein, low carbohydrate, high fat diet and one similar to a high protein, low carbohydrate, low fat diet) among underweight, normal weight, and overweight/obese college females. You were selected as a possible participant because you are a 19-28 year old female that is healthy, free from nut and chocolate allergies, and have normal menstrual cycles.

If you decide to participate, we will ask you to report on three separate occasions for a total time commitment of about ten hours. On the first visit, your height and weight will be measured using a standard scale and measuring tape. Your body fat percentage will be measured through bioelectrical impendence. For measurement of body fat, you will be asked to lie down. Two self-adhesive disposable electrodes will be placed on the right hand and two on the right foot. A safe, battery generated signal will pass through your body enabling the calculation of your body fat and muscle mass. Bio-impendance analysis is safe and will not cause any discomfort. We will have you complete a consent form and fill out a medical questionnaire. You will also take a menstrual cycle log home with you to record the dates of your first day, and last day of your period. You will participate in this study on days 1 through 14 of your menstrual cycle counting from the last day of your last menstrual cycle.

Based on your menstrual cycle, the researchers will arrange a time for you to come in to have your energy expenditure measured. On the second visit, you will be asked to come to the Poultry Science Building 102B conference room after a 12-hour fast. In addition, we will ask that you refrain from caffeine use and exercise 24 hours prior to your visit. If you are a smoker, we will ask that you refrain from smoking 2 hours prior to your visit and throughout the visit. You will receive either a high protein, low carbohydrate, high fat meal replacement bar on your first visit or a high protein, low carbohydrate, low fat meal replacement bar. On your third visit, you will receive the meal replacement bar that you did not receive during the second visit. You will receive 400 calories in both trials.

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Participants Initials
Page 1 of 4

Your energy expenditure will be measured using MedGem (Healthetech, Golden, Colorado), a FDA cleared medical device. Before measuring your energy expenditure, we will have you sit quietly for ten minutes. After ten minutes of sitting, you will be given a nose clip to place on your nostrils.

Then you will hold the MedGem in your hands, and through your mouth, you will breath into a mouthpiece on the MedGem instrument. The MedGem measures your oxygen use and carbon dioxide production.

You will continue to breathe in and out as normal, but through your mouth, for about ten minutes. When the measurement is completed, the MedGem will "beep" and you will hand the instrument to the researcher and can remove your nose clip.

After measuring your resting energy expenditure, you will go to 102B conference room to eat your meal. You will have 15 minutes to finish the meal. After consumption, energy expenditure will be measured at 30-minute intervals for the next 3.5 hours. During this 3.5 hour study period, when metabolism is not being measured, you will be allowed to rest quietly, read or study in a seated position. If needed, you will be allowed one bathroom break per hour and water as desired. This process will be repeated on the third visit; however, you will receive the alternate meal. You will need to wait at least four days between the second and third visit.

To minimize the risk of breech of confidentiality, all data will be coded and your name will not be revealed. Because there have been a few complaints of dry mouth in previous testing, water will be provided for you after measurement is completed. You will be free to withdraw from the study at any time.

As a participant there are benefits for you in this study. This study will provide you with your individual energy needs as well as how your metabolism responds to ingestion of two different types of meals. This study will also have benefits to the researchers and general population. Because metabolism is an individual factor that affects ones weight and body composition, it is important for researchers to learn how individuals may differ in their metabolic response to meal composition in order to help individuals reach weight goals.

Any information obtained in connection with this study and that can be identified with you will remain confidential. Data will be coded to ensure confidentiality. Email addresses and a phone number are being requested to allow for follow-up notification and results of individual energy expenditure.

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Participants Initials

You will be assigned a code using the first two letters of your last name followed by the first letter of your first name and then a number based on the date of enrollment into the study.

Information collected through your participation may be used to fulfill an educational requirement, published in a Information collected through your participation may be used to fulfill an educational requirement, published in a professional journal, and/or presented at a professional meeting. If so, none of your identifiable information will be identified.

A master list of all participants' names and codes will be kept in a locked file in the office of Dr. S. Gropper, Poultry Science room 102C. Only Dr. Gropper and the graduate student associated with the study will have access to the subject names and codes. Shredding will ultimately destroy identifying information. Codes will be used for all data collected as part of the study.

You may withdraw from participation at any time, without penalty, and you may withdraw any data that has been collected about you as long as that data is identifiable.

Your decision whether or not to participate will not jeopardize your future relations with Auburn University or the Department of Nutrition and Food Science.

If you have any questions, we invite you to ask them now. If you have questions later, Dr. S. Gropper (groppss@auburn.edu; 844-3272) or Amy Jo Riggs (riggsaj@auburn.edu; 844-8074) will be happy to answer them. You will be provided a copy of this form to keep.

For more information regarding your rights as a research participant you can contact the Office of Human Research by phone or email. The people to contact there are Executive Director E.N. "Chip" Burson (334) 844-5966 (bursoen@auburn.edu) or IRB Chair Dr. Peter Grandjean at (334) 844-1462 (grandpw@auburn.edu).

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Participants Initials

HAVING READ THE INFORAMTION PROVIDED, YOU MUST DECIDE WHETHER OR NOT YOU WISH TO PARTICIPATE IN THIS RESEARCH STUDY. YOUR SIGNATURE INDICATES YOUR WILLINGNESS TO PARTICIPATE.

Participant's signature Date	**Investigator's signature Date**
Print Name	**Co-investigator's signature Date** **(If appropriate)**

Appendix E
Time Sheet for Energy Expenditure Measurements

Trial One
Resting Metabolic Rate

Code: _____________
Date: _____________
Meal Bar: __________

Initial: RMR: ____________
VO_2: __________

Time Bar was given: _________

Time Bar was finished: _________

30-minute interval after eating: RMR: ____________
VO_2 _____________

1-hour interval after eating: RMR: ____________
VO_2 ______________

1.5-hour interval after eating: RMR: ___________
VO_2: _____________

2-hour interval after eating: RMR: ___________
VO_2: ____________

2.5-hour interval after eating: RMR: ___________
VO_2: ____________

3-hour interval after eating: RMR: ___________
VO_2: ____________

3.5-hour interval after eating: RMR: ____________
VO_2: _____________

Trial Two **Code: _____________**
Resting Metabolic Rate **Date: _____________**
Meal Bar: __________

Initial: RMR: ____________
VO_2: __________

Time Bar was given: _________

Time Bar was finished: _________

30-minute interval after eating: RMR: ____________
VO_2 _____________

1-hour interval after eating: RMR: __________
VO_2 ___________

1.5-hour interval after eating: RMR: ________
VO_2 __________

2-hour interval after eating: RMR: ________
VO_2: ________

2.5-hour interval after eating: RMR: ________
VO_2: ________

3-hour interval after eating: RMR: ________
VO_2: ________

3.5-hour interval after eating: RMR: ________
VO_2: _________

Appendix F
Raw Subject Data

RAW SUBJECT DATA

Part 1

Subject	Age	Ht. (inches)	Wt. (kg)	BMI	BMI Classification
HOM71205N	20	68.25	68	22.6	Normal
KNK70705N	23	66	60	21.3	Normal
PEK82605N	19	69	64	20.9	Normal
PIN82605N	20	65	55	20.0	Normal
RAC80205N	24	65.75	63	22.7	Normal
WIC82605N	19	63.5	48	18.5	Normal
YOC82005N	20	62.5	53	21.1	Normal
POS101305N	25	64.5	63	23.4	Normal
SHB82005N	19	64.5	61	22.5	Normal
SMK82605N	19	62	53	21.3	Normal
MOA91505N	21	65	50	18.5	Normal
JAR82605N	20	66.25	59	20.9	Normal
GAQ82605O	19	64	84	31.4	Overweight
CAA91105O	23	64	66	25.1	Overweight
DAE82405O	27	67.5	74	25.0	Overweight
GIC82705O	28	59	62	27.6	Overweight
LUL101305O	21	62	67	27.0	Overweight
WOA92005O	19	67	72	25.0	Overweight
FOC71205U	20	66	51	18.1	Underweight
MOA82505U	20	65	48	17.7	Underweight
GRM92305U	22	68.5	56	18.4	Underweight

Part 2

Subject	FFM (kg)	% Body Fat	Order	Days btwn trials	B-Day Cycle	O-Day Cycle
HOM71205N	17.1	25.7	O-B	86	11	16
KNK70705N	14.5	21.2	B-O	1	10	9
PEK82605N	17.0	24.8	B-O	7	14	21
PIN82605N	13.1	20.2	O-B	2	13	11
RAC80205N	14.4	26.8	B-O	35	11	17
WIC82605N	10.5	23.5	B-O	2	15	17
YOC82005N	11.7	22.5	O-B	2	15	13
POS101305N	14.0	25.9	B-O	1	13	14
SHB82005N	14.2	26.0	B-O	1	17	18
SMK82605N	10.7	22.4	O-B	61	13	15
MOA91505N	11	21.1	B-O	28	12	9
JAR82605N	15	16.1	B-O		18	
GAQ82605O	16.7	35.7	O-B	5	20	15
CAA91105O	14.4	31.3	B-O	1	10	11
DAE82405O	16.5	28.1	B-O	1	18	19
GIC82705O	10.7	31.7	B-O	1	12	13
LUL101305O	13.6	30.1	B-O	21	18	13
WOA92005O	17.1	31.5	O-B			10
FOC71205U	12.2	20.9	B-O	7	12	19
MOA82505U	11.5	22.0	B-O	22	12	10
GRM92305U	14.6	15.6	B-O	1	20	21

Appendix G
Supplement and Equipment Information

Supplement and Equipment Information

1. Atkins Nutritional, Inc.
   2002 Orville Dr. North Suite A
   Ronkankoma, NY 11779
   631-738-7370

2. ZoneLabs, Inc.
   222 Rosewood Dr.
   Suite 500
   Danvers, MA 01923

3. Proximate Estimations
   Silliker, Inc.
   Illinois Laboratory
   1304 Halssted St.
   Chicago, IL 60411
   708-756-3210

4. BodyStat
   BioVant System, LLC
   1535 Sixth St, Suite 7
   Detroit, MI 48226
   313-963-7555

5. MedGem
   Indirect Calorimetry
   HealtheTech Inc.
   523 Park Point Dr. 3rd Floor
   Golden, CO 80401

6. Detecto Scale
   Commonwealth Enterprises, Inc.
   4415 Cox Road
   Glenn Allen, VA 23060
   804-965-0076

Appendix H
Calculations

Calculations

1. Energy expenditure/I: This represents the average energy expenditure over the 210 minute measurement period divided by the 440 calories that was ingested at the second and third visit X 100.

2. The total on Table 4 was calculated by adding the 30 min, 60, min, 90 min, 120 min, 150 min, 180 min, and 210 min measurement periods together.