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Dietary Fiber Intake and Body Fat Gain: A Prospective Cohort Study of Middle-Aged Women

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DIETARY FIBER INTAKE AND BODY FAT GAIN: A PROSPECTIVE COHORT STUDY OF MIDDLE-AGED WOMEN

by

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GRADUATE COMMITTEE APPROVAL

of a thesis submitted by

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This thesis has been read by each member of the following graduate committee and by majority vote has been found to be satisfactory.

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As chair of the candidate's graduate committee, I have read the thesis of Kathryn S. Thomas in its final form and have found that (1) its format, citations, and bibliographical style are consistent and acceptable and fulfill university and department style requirements; (2) its illustrative materials including figures, tables, and charts are in place; and (3) the final manuscript is satisfactory to the graduate committee and is ready for submission to the university library.

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ABSTRACT

DIETARY FIBER INTAKE AND BODY FAT GAIN: A PROSPECTIVE COHORT STUDY OF MIDDLE-AGED WOMEN

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Master of Science

This study was conducted to determine the extent to which changes in dietary fiber consumption affect body weight and body fat percentage (BF%) over time. An auxiliary objective was to examine the influence of age, total caloric intake, and physical activity (PA) on the relationship between changes in fiber intake and changes in body composition over time. A prospective cohort design with baseline and follow-up assessments 20 months apart and 252 middle-aged women (40.1±3.0 y) was used. Diet, particularly caloric and fiber intake, was measured using 7-day weighed food records. Body fat was assessed via the Bod Pod, and PA was measured objectively using MTI accelerometers over seven consecutive days. Changes in weight, BF%, and fiber intake were calculated by subtracting baseline measurements from those taken at 20 months. Regression analysis was used to determine the extent to which baseline fiber intake/1000 kcal and changes in fiber intake/1000 kcal were predictive of changes in body weight and BF%. Partial correlation was employed to ascertain the effect of controlling for each of

the potential confounding variables on the fiber and body composition associations. Across the study, there were significant changes in all variables. For every increase of one gram of fiber/1000 kcal consumed, weight decreased by 0.55 lb (*P*=0.0061) and BF% decreased by 0.25 percentage point (*P*=0.0052). Baseline fiber intake/1000 kcal was not predictive of changes in body weight or BF% over the 20 month period. Based on these results, increasing dietary fiber intake may be an effective means of weight management in middle-aged women.

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Dietary Fiber and Body Fat Gain: A Prospective Cohort Study of Middle-Aged Women

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ABSTRACT

Objectives Determine the extent to which changes in dietary fiber consumption affect weight and body fat percentage (BF%) over time. An auxiliary objective was to examine the influence of age, total caloric intake, and physical activity (PA) on the relationship between changes in fiber intake and changes in body composition over time.

Design/ Subjects Prospective cohort design with baseline and follow-up assessments 20 months apart and 252 middle-aged women (40.1±3.0 y). Diet, particularly caloric and fiber intake, was measured using 7-day weighed food records. Body fat was assessed via the Bod Pod, and PA was measured objectively using MTI accelerometers over seven consecutive days.

Statistical Analysis Changes in weight, BF%, and fiber intake were calculated by subtracting baseline measurements from those taken at 20 months. Regression analysis was used to determine the extent to which baseline fiber intake/1000 kcal and changes in fiber intake/1000 kcal were predictive of changes in body weight and BF%. Partial correlation was employed to ascertain the effect of controlling for each of the potential confounding variables on the fiber and body composition associations.

Results Across the study, there were significant changes in all variables. For every increase of one gram of fiber/1000 kcal consumed, weight decreased by 0.55 lb (P=0.0061) and BF% decreased by 0.25 percentage point (P=0.0052). Baseline fiber intake/1000 kcal was not predictive of changes in body weight or BF% over the 20 month period.

Conclusions Increasing dietary fiber intake may be an effective means of weight management in middle-aged women.

INTRODUCTION

Over the past 40 years there has been a dramatic increase in the prevalence of overweight and obesity, and these numbers are expected to continue to rise (1). According to the newest NHANES data (2), currently in the United States 66.3% of all men and women are overweight or obese (BMI$\geq$25). The prevalence is even higher among those aged 40 and above with over 70% overweight or obese (2). When compared to the NHES I data collected in 1960-62, the prevalence of overweight and obesity has increased 48% (3).

According to Li et al.(4), this upsurge in weight gain is accompanied by serious overweight-related health problems, including cardiovascular disease, type 2 diabetes, certain types of cancer, musculoskeletal disorders, and other serious diseases. Additionally, a sizeable percentage of total health care costs can be attributed to obesity and overweight, both of which contribute substantially to world-wide morbidity and mortality.

Given the magnitude and severity of the obesity epidemic, it is understandable that billions of dollars are dispensed each year in the quest for a solution to this big problem. It is a complex issue however, resulting from the interplay of multiple variables, and there are several factors that have yet to be quantified.

A long-term energy imbalance between intake and expenditure is the primary cause of obesity (5). Hence, limiting calorie consumption is a key objective when weight loss is the goal. Over the years, much attention has been devoted to prescribing the optimal number of calories to achieve a healthy body weight. Some researchers have looked even further and investigated the possibility that consuming certain dietary factors may aid in weight regulation.

Fiber intake is one dietary factor that has been given significant attention. Reviews by several scientists (5-11) indicate that dietary fiber is inversely related to weight gain. Although a considerable amount of research has been conducted in this area, the literature still contains many inconsistencies regarding the association between dietary fiber and body weight (7). More conclusive results could be obtained however, if research methodologies were improved.

According to the literature, the vast majority of research investigating the fiber and weight gain relationship has relied on food frequency questionnaires, 24-hr recall, or 3-day food diaries to measure dietary composition. Each of these measures provides reasonable estimates, but a weighed food log of longer duration would be more representative of the typical diet (12).

Additionally, physical activity has been controlled rarely in previous studies, yet, it accounts for a significant portion of the energy balance equation. To understand weight change over time, physical activity must be measured. Objective measures of physical activity are best since self-reported levels tend to include significant error (13).

Furthermore, the role of fiber on body composition has not been thoroughly explored. Maintaining a healthy body weight over time is important. However, maintaining lean body mass while limiting gains in fat mass should be emphasized. Few studies evaluating the effects of fiber consumption have measured body fat in addition to body weight, and fewer still have used accurate methods to assess body fat. Thus, the present study, using objective and valid tools of measurement, was conducted to determine the role of fiber consumption in the prevention of weight gain and fat gain over time.

The current study focused primarily on determining intake of dietary fiber and risk of gains in body weight and body fat over a 20-month period in 252 women. Since fiber intake generally increases as total caloric intake increases, individuals who eat larger quantities of food tend to consume more fiber. In the present study, fiber consumption/1000 kcal was used to control for this. An auxiliary objective was to examine the degree to which age, caloric intake, and physical activity affect the association between consumption of fiber and changes in body weight and body fat over time.

SUBJECTS AND METHODS

Subjects

Recruitment via newspaper advertisements, flyers, and company emails was conducted in two metropolitan areas in the Mountain West. A phone interview was performed in order to ensure that each woman fit the baseline requirements. Women were eligible to participate in the study if they were healthy, pre-menopausal, and between 35 and 45 years old. They needed to be nonsmokers and could not become pregnant during the study period. Due to the demographics of the area, over 95% of the participants were Caucasian, approximately 80% were married, and the vast majority had received some college education. A written informed consent form was signed by each woman before participation at baseline and follow-up.

Participants in this study consisted of an original cohort of 275 middle-aged women (40.1±3.0). Follow-up data was collected 20 months later. Data analysis in the present study included 252 women.

Measurements

In this study, energy intake, fiber intake/1000 kilocalories, body weight, body fat percentage, physical activity, and age were measured, as well as changes in these variables over the 20 month period. Testing protocols at baseline and follow-up were kept constant.

Fiber and Energy Intake

Seven-day weighed diet records were used at baseline and follow-up in order to measure energy and fiber intake. Each subject was provided an Ohaus 2000 electronic scale (Ohaus Corp., Florham Park, NJ) which digitally weighs food to the gram. While maintaining habitual eating habits, each subject weighed and recorded all food she consumed during a period of seven consecutive days. Food weight and descriptions were recorded on diet logs that were provided by the researchers.

In order to obtain accurate records, each subject was contacted every second day by research personnel who emphasized consistent reporting of dietary intake and answered any questions the subjects had. A registered dietitian analyzed the completed food logs using the ESHA Research software program, version 7.6 (ESHA Research Inc., Salem, OR), to ensure that they were plausible and to provide objective diet data. Subjects were asked to redo their logs if total caloric intake did not surpass 130% of estimated 24-hour resting metabolic rate. To control for the fact that fiber intake tends to increase as total food intake increases, fiber intake/1000 kcal was calculated. In addition, immediately before and after the testing week, subjects were weighed on an electronic scale (Tanita Corporation, Tokyo, Japan) to make sure that there was no significant weight change.

Body Weight

Body weight was measured to within 0.01 pound (0.005 kg) using the electronic scale previously mentioned. Daily calibration ensured reliable measurement. All women wore lightweight, one-piece bathing suits issued by the university, and were asked to refrain from eating for four hours before their visit. Baseline body weight was recorded as the mean of two measurements taken one week apart. After 20 months of follow-up, the same procedure was followed again.

Body Fat Percentage

In this study, body fat percentage was measured objectively using air displacement plethysmography, or the Bod Pod ®(Life Measurements Instruments, Concord, CA). Each subject was issued a one-piece swimsuit and a swim cap, and the Bod Pod was used to measure thoracic lung volume. Each day the Bod Pod was calibrated with a cylinder of known volume. Body fat percentage was measured at least twice for all participants, until two results were within one percentage point. These two results were then averaged.

Several studies have shown the Bod Pod to be a reliable and valid method of measuring body composition. In order to ascertain the reliability of the Bod Pod, a test-retest protocol was used on 100 subjects in the present study. Between the two Bod Pod tests, the intraclass correlation was 0.999 (*P*< .001) (14). To determine the validity of the Bod Pod, dual energy x-ray absorptiometry (DEXA, Hologic 4500W, Bedford, Massachusetts) was used to measure body fat percentage of these same 100 subjects. Between the two measures of body fat percentage, the Pearson correlation was 0.94 (*P*< .001) and the intraclass correlation was 0.97 (*P*<.001) (15). Additionally, Ballard et al. (16) compared the Bod Pod to the DEXA machine, and found no significant difference when measuring body fat. He concluded that when measuring body fat in female athletes and nonathletes, the Bod Pod is a valid method. Maddalozzo et al. (17) also compared the Bod Pod to DEXA and derived similar conclusions.

Physical Activity

Objective measurement of physical activity was accomplished through the use of MTI accelerometers (Manufacturing Technologies Inc., Fort Walton Beach FL; formerly CSA accelerometers). Each subject, at baseline, was instructed on how to properly wear the monitor. A nylon belt was worn around the waist, to which the accelerometer was attached on the left side of the body. The monitor was worn at all times for seven consecutive days, and was removed only when bathing or participating in water activities. Subjects were asked to redo the testing week if the monitor was not worn properly. If non-compliance was a problem, the subject was dropped from the study.

CSA accelerometers (now known as MTI accelerometers) have been shown to provide a reliable and objective measurement of physical activity. In a study by Liu et al.(18), when compared to doubly-labeled water, activity counts from the CSA activity monitor appeared to closely represent the total amount of physical activity in free-living adults. In addition, research by Bassett et al.(19) revealed that this monitor was correlated more highly with energy expenditure (r>0.90), measured by a portable metabolic system, than were three other accelerometers. Additionally, test-retest reliability of the accelerometer was evaluated in a pilot study conducted by the researchers. A total of 15 women participated in 17 different physical activities, including walking and jogging at precise speeds and on different grades, climbing fixed stairs, and descending fixed stairs. Within 2-4 days the 17 physical activities were repeated. The intraclass correlation showing test-retest reliability across the 17 different activities was 0.989 ($P<0.0001$). Thus, the MTI (CSA) accelerometer is a validated and reliable method of determining physical activity.

Statistical Analysis

Means and standard deviations (SD) were generated for descriptive purposes. Changes in body weight, body fat percentage, and fiber intake were calculated by subtracting baseline measurements from those taken at 20 months. Using general linear models (GLM), regression analysis was used to determine the extent to which baseline fiber intake/1000 kcal and changes in fiber intake/1000 kcal were predictive of changes in body weight and body fat percentage in the participants. Partial correlation was employed to ascertain the effect of controlling for each of the potential confounding variables, considered individually and in combination, on the fiber and body composition associations. With and without adjusting for the potential confounders, regression coefficients, *b*, were generated for each relationship to add meaning and to aid in the interpretation of each statistical model. Statistical significance was set at the 0.05 level, and SAS (version 9.1) was the software program used to analyze the data.

RESULTS

Included in the 20-month follow-up analysis were 252 (91.6%) of the original 275 baseline participants. Various reasons, including lack of interest, moving from the area, pregnancy, non-compliance, and an automobile accident, caused subjects to be dropped from the study. The average time between baseline and follow-up assessments was 597±92 days.

Table 1 shows the means and standard deviations of the key variables at baseline and at the 20 month follow-up. Over the 20 month period, there were significant changes in all of the variables. On average, body weight increased by 1.6 ± 8.2 pounds, and body fat increased by 1.0 ± 3.7 percentage point. Both changes were significant with considerable variation within the groups.

Closer examination of the data across the 20 months showed that 38.5% of the participants lost weight. Specifically, 17.5% lost more than 4 pounds, 8.7% lost between 2 and 4 pounds, and 12.3% lost up to 2 pounds. Conversely, 25.4% of the subjects gained between 0 and 4 pounds, 19.4% gained between 4 and 8 pounds, and 16.7% gained more than 8 pounds. Similarly, with body fat, great variation was seen within the sample. In total, 35.3% of the participants saw a reduction in their body fat. In particular, 8.7% lost more than 4 percentage points, 6.4% lost between 2 and 4 percentage points, and 20.2% lost up to 2 percentage points. On the other hand, 27.4% gained between 0 and 2 percentage points, 21.4% gained between 2 and 4 percentage points, and 15.9% increased their body fat by more than 4 percentage points.

Over the study period, mean intake of fiber/1000 kcal increased by about 0.5 gram (*P*=0.0002), whereas average total energy intake decreased by approximately 100 calories (*P*<0.0001). Mean physical activity showed a significant decrease by over 150,000 counts per seven days, or almost 23,000 counts per day over the 20 months, an amount equivalent to approximately 6-7 minutes of walking per day.

Baseline fiber intake and changes in body composition

Baseline fiber intake/1000 kcal was not predictive of changes in body weight over the 20-month study period (F=0.00, *P*=0.9740). After baseline body weight, caloric intake, physical activity, and age were controlled statistically, the relationship between baseline fiber intake/1000 kcal and changes in body weight remained nonsignificant. Controlling for these potential confounders collectively also had minimal influence on the relationship between baseline fiber intake/1000 kcal and weight gain.

Similarly, baseline fiber intake/1000 kcal was not associated with changes in body fat percentage across the study period (F=0.35, *P*=0.5545). After controlling for baseline body fat, caloric intake, physical activity, and age, both individually and collectively, significance of the relationship was not influenced.

Changes in fiber intake and changes in body weight

Tables 2 and 3 indicate that changes in fiber intake/1000 kcal were predictive of changes in body weight from baseline to 20-months. With none of the potential confounders controlled, the results showed that for each one-gram drop in fiber consumption/1000 kcal, 0.55 pound was gained over the 20 months (*P*=0.0061). After adjusting for differences in baseline fiber consumption, the rate of weight gain was increased by 11% to 0.61 pound for each one-gram decrease in fiber intake/1000 kcal over the 20 months. Controlling for differences in baseline age, body weight, calorie intake, and physical activity levels individually had no effect on the fiber—weight gain association. Similarly, adjusting for changes in physical activity over the study period had no effect on the relationship (Tables 2 and 3).

Controlling for changes in caloric intake over the 20 months had the greatest influence on the relationship between changes in fiber intake and changes in body weight. Specifically, after adjusting for changes in caloric intake across the 20-month study period, the fiber—weight gain relationship was weakened by 31%. However, the relationship remained statistically significant.

After all the potentially confounding variables were controlled simultaneously, the relationship between changes in fiber intake/1000 kcal and changes in body weight over the 20-month study period was weakened by 27%, but remained meaningful and significant, as shown in Tables 2 and 3. Specifically, after adjusting for differences in all of the potential confounders simultaneously, for each one-gram drop in fiber intake/1000 kcal, 0.40 pound was gained, on average, over the 20 month study. Statistical control for the season in which data were collected at baseline and follow-up had no affect on the results.

Changes in fiber intake and changes in body fat percentage

As evidenced in Table 4, with no variables controlled, the relationship between changes in fiber intake/1000 kcal and changes in body fat percentage over the 20-month study period was significant. Specifically, with each reduction of one gram of fiber/1000 kcal in the diet, subjects tended to increase their body fat percentage by 0.25. Controlling statistically for baseline fiber intake, body fat, caloric intake, physical activity, and age, considered individually, had no effect on the association between changes in fiber intake/1000 kcal and changes in body fat percentage. Likewise, changes in physical activity over the 20 months had no influence on the fiber—body fat percent gain relationship. However, controlling for changes in caloric intake had a profound effect on the relationship between changes in fiber intake/1000 kcal and changes in body fat percentage. The relationship was weakened by 24%, but remained significant.

As shown in Table 4, when all of the potentially confounding variables were controlled statistically, the relationship between changes in fiber intake/1000 kcal and changes in body fat percentage was weakened, but remained significant. Specifically, after adjusting for all of the confounding variables together, for each reduction of one gram of fiber/1000 kcal in the diet, body fat tended to increase by 0.19 percentage point over the 20-month period. Statistical control for the season in which data were collected at baseline and follow-up did not affect the results.

DISCUSSION

The prevalence of overweight and obesity continues to increase in the United States as evidenced by national surveys (2). The cohort of 252 middle-aged women followed in the present study was no exception to this trend. On average, body weight increased by 1.6 pounds (*P*=0.0025) and body fat increased by 1.0 percentage point (*P*<0.0001) over the 20 month investigation. Closer examination of the data however, revealed great variation within the sample. In fact, almost 40% of the participants lost weight over the course of the study, whereas over 60% gained some weight from baseline to follow-up.

Thus, it is evident that although weight gain was the norm, not all women were at equal risk. Further analysis showed that women who decreased their fiber intake actually tended to gain significantly more weight than their counterparts, whereas those whose fiber intake increased over the 20 month period actually tended to lose weight. The relationship was not only significant but it was also meaningful. For each additional gram of fiber consumed/1000 kcal from baseline to follow-up, participants tended to lose more than half a pound, and for each 1-gram decrease in fiber/1000 kcal, subjects gained more than half a pound, on average.

The relationship between changes in fiber consumption and changes in body weight was independent of several factors. Baseline fiber intake did not influence the relationship, nor did the initial body weight of participants. Baseline activity level, whether participants were physically active or sedentary, and baseline caloric intake similarly had no influence on the fiber–weight gain relationship. Changes in physical activity over the 20 months also did not affect the relationship. The same effects were seen with the potential confounders and the relationship between changes in fiber consumption and changes in body fat percentage. The only factor that had a significant influence on these relationships was change in caloric intake.

Controlling for changes in caloric intake did not eliminate the relationship between changes in fiber intake and changes in body weight and body fat percentage, but it weakened it significantly. Post hoc analyses showed why controlling for changes in caloric intake had such a strong effect. Specifically, changes in caloric intake were predictive of changes in body weight ($r=0.32$, $P<0.0001$) and body fat percentage ($r=0.28$, $P<0.0001$), and changes in fiber intake/1000 kcal were predictive of changes in caloric intake ($r=-0.17$, $P=0.007$). In short, as fiber intake/1000 kcal increased, calorie intake decreased and body weight and body fat decreased as well. Why? Because fiber adds to food volume without increasing calorie consumption. Thus, more food can be eaten without a commensurate increase in energy intake, or the same total volume of food can be consumed with fewer total calories.

The results of this study agree with the results of numerous other prospective studies. Liu et al. (20), in conjunction with the Nurses' Health Study, used food frequency questionnaires to assess the dietary habits of their cohort. Results indicated that women whose consumption of fiber increased the most over the 12-year period gained less weight than their counterparts. Additionally, Ludwig et al. (21), using data from the CARDIA study, found that weight gain over a 10-year period was more strongly predicted by consumption of fiber than by fat consumption. Furthermore, Newby et al. (22) and Koh-Banerjee et al. (23) saw similar results in their prospective cohort studies.

Although there is a substantial amount of research that supports the inverse relationship between fiber intake and changes in body weight, some non-supportive results have been published. In experimental studies by Howard et al. (24), Baron et al. (25), and Thompson et al. (26), the efficacy of fiber for weight loss was not established. Moreover, the relationship between fiber intake and changes in body fat has been studied minimally.

The present study adds important validation to the protective role that fiber intake can play against gains in weight and body fat. The majority of previous studies have relied on estimation of serving sizes and recall of past meals, whereas two 7-day weighed diet records, as used in the present study, provided a much more accurate measure of dietary intake. Additionally, few studies have controlled for physical activity, and in those that have, crude techniques such as self-reported questionnaires have been employed. In the current study, objective measurement of physical activity via accelerometers allowed for precise control of physical activity. Lastly, the vast majority of studies interested in the effects of fiber consumption has focused on gains in body weight and has ignored changes in body fat. The present study included measurement of body fat percentage using the Bod Pod.

The current study was not without limitations. Due to the demographics of the area, the cohort was fairly homogeneous. More generalizeable conclusions would be warranted with increased ethnic and racial diversity. In addition, although 20 months is reasonable, a longer study duration would have allowed time for greater differences among those who increased their fiber consumption and those who decreased their intake.

Further, although two 7-day weighed food records are an excellent method of dietary evaluation, they still involve self-report. Self-report by nature introduces error, as there is a tendency to underreport habitual dietary intake, a weakness inherent in all self-report dietary approaches.

Due to the prospective cohort design of this study, cause and effect conclusions are not warranted. However, if a causal relationship were assumed, the results of this study would indicate that encouraging women to increase their fiber intake will likely help them to lose weight, or at least slow their rate of weight gain. Thus, more emphasis should be placed on helping women to increase fiber consumption in their diet.

The current recommendation for fiber intake in the United States, according to the U.S. Department of Agriculture and the Department of Health and Human Services, is that 14 grams of dietary fiber be consumed per1000 kcal (27). The average intake in the U.S. is far below the recommended level, which is true of this cohort as well. Yet, it is important to note that benefits were seen by those who increased their consumption of fiber over the 20-month period, regardless of their baseline fiber intake. Hence, a major objective of dieticians should be to highlight and promote fiber-rich foods in the diet. Emphasis should be placed on eating whole plant foods, such as fruits and vegetables, whole grains, and legumes.

CONCLUSION

Obesity is a serious epidemic in the United States, currently affecting approximately one-third of the adult population. Americans continue to get fatter each year, and as a group, the middle-aged women who participated in the current study followed this same trend. It was evidenced however, that although mean body weight increased significantly, variation was seen within the cohort. Analysis revealed that women who decreased their fiber intake over the 20-month study period were at increased risk of weight gain. The converse was also true, namely, that increasing consumption of fiber over time decreased risk of gains in body weight and fat, and was in fact linked to weight loss. Thus, encouragement should be given to increase intake of fiber in the American diet. This may be an effective method of weight management for middle-aged women.

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Table 1. Means and standard deviations of key variables at baseline and follow-up

	Baseline		Follow-up			
Variable	Mean	SD	Mean	SD	F	P
Weight (kg)	65.6	10.2	66.3	10.8	9.3	0.0025
Weight (lbs)	144.3	22.5	145.9	23.7	9.3	0.0025
% Body Fat	31.3	7.1	32.3	7.6	17.4	<0.0001
Fiber/1000 kcal (g)	9.5	3.1	10.1	3.4	14.1	0.0002
Calorie Intake	2053.6	309.2	1946.0	311.6	28.9	<0.0001
Physical Activity*	2762.9	807.8	2604.0	906.8	10.7	0.0012

*Physical Activity = accelerometer activity counts divided by 1000

Table 2. Relationship between changes in fiber consumption and changes in body weight (kg) over 20 months

Criterion Variable: Change in Body Weight (kg)

Change in Fiber Intake (per 1000 kcal)	***b*[a]**	**t**	**P**
Variable Controlled:			
None	-0.25	-2.77	0.0061
Baseline fiber intake	-0.28	-2.92	0.0038
Baseline body weight	-0.25	-2.76	0.0062
Baseline caloric intake	-0.25	-2.75	0.0065
Baseline physical activity	-0.25	-2.72	0.0069
Baseline age	-0.25	-2.75	0.0065
Changes in caloric intake	-0.17	-2.01	0.0453
Changes in physical activity	-0.24	-2.69	0.0077
All of the above	-0.18	-2.01	0.0456

[a]*b*=regression coefficient

Values in the column showing regression coefficients (*b*) reflect the weight changes (kg) associated with a change in 1 gram/1000 kcal of fiber consumption. For example, on the row labeled "None," meaning no variable controlled, the regression coefficient of -0.25 indicates that for every increase of 1 gram of fiber/1000 kcal consumed, body weight tends to decrease by 0.25 kg. The opposite is also true. On the row labeled "Baseline fiber intake," meaning baseline fiber intake was controlled, the regression coefficient of -0.28 indicates that for every one-gram drop in fiber/1000 kcal, body weight tends to increase by 0.28 kg.

Table 3. Relationship between changes in fiber consumption and changes in body weight (lb) over 20 months

Criterion Variable: Change in Body Weight (lb)			
Change in Fiber Intake (per 1000 kcal)	***b*[a]**	**t**	**P**
Variable Controlled:			
None	-0.55	-2.77	0.0061
Baseline fiber intake	-0.61	-2.92	0.0038
Baseline body weight	-0.55	-2.76	0.0062
Baseline caloric intake	-0.54	-2.75	0.0065
Baseline physical activity	-0.54	-2.72	0.0069
Baseline age	-0.55	-2.75	0.0065
Changes in caloric intake	-0.38	-2.01	0.0453
Changes in physical activity	-0.53	-2.69	0.0077
All of the above	-0.40	-2.01	0.0456

[a]*b*=regression coefficient. Values in the column showing regression coefficients (*b*) reflect the weight changes (lb) associated with a change in 1 gram/1000 kcal of fiber consumption. For example, on the row labeled "None," meaning no variable controlled, the regression coefficient of -0.55 indicates that for every increase of 1 gram of fiber/1000 kcal consumed, body weight tends to decrease 0.55 lb. The opposite is also true. On the row labeled "Baseline body weight," meaning baseline body weight was controlled, the regression coefficient of -0.55 indicates that for every one-gram drop in fiber/1000 kcal, body weight tends to increase by 0.55 lb.

Table 4. Relationship between changes in fiber consumption and changes in body fat % over 20 months

Criterion Variable: Change in Body Fat %			
Change in Fiber Intake (per 1000 kcal)	***b*[a]**	**t**	**P**
Variable Controlled:			
None	-0.25	-2.82	0.0052
Baseline fiber intake	-0.26	-2.76	0.0062
Baseline body fat	-0.25	-2.77	0.0061
Baseline caloric intake	-0.25	-2.80	0.0056
Baseline physical activity	-0.25	-2.78	0.0058
Baseline age	-0.25	-2.79	0.0057
Changes in caloric intake	-0.19	-2.16	0.0316
Changes in physical activity	-0.24	-2.70	0.0074
All of the above	-0.19	-2.06	0.0403

[a]*b*=regression coefficient. Values in the column showing regression coefficients (*b*) reflect the body fat changes (percentage points) associated with a change in 1 gram/1000 kcal of fiber consumption. For example, on the row labeled "None," meaning no variable controlled, the regression coefficient of -0.25 indicates that for every increase of 1 gram of fiber/1000 kcal consumed, body fat tends to decrease by 0.25 percentage points. The opposite is also true. On the row labeled "Baseline caloric intake," meaning baseline caloric intake was controlled, the regression coefficient of -0.25 indicates that for every one-gram drop in fiber/1000 kcal, body fat percentage tends to increase by 0.25 percentage points

Appendix A

Prospectus

Chapter 1

Introduction

Over the past 40 years there has been a dramatic increase in the prevalence of overweight and obesity, and these numbers are expected to continue to rise.[1] According to the newest NHANES data,[2] currently in the United States 66.3% of all men and women are overweight or obese (BMI$\geq$25). The prevalence is even higher among those aged 40 and above with over 70% overweight and obese. When compared to the NHES I data collected in 1960-62, the prevalence of overweight and obesity has increased 48%.[3]

According to Li et al.,[4] this upsurge in weight gain is accompanied by serious overweight-related health problems, including cardiovascular disease, type 2 diabetes, certain types of cancer, musculoskeletal disorders, and other serious diseases. Additionally, a sizeable percentage of total health care costs can be attributed to obesity and overweight, both of which contribute substantially to world-wide morbidity and mortality.

Given the magnitude and severity of the obesity epidemic, it is understandable that billions of dollars are dispensed each year in the quest for a solution to this significant problem. It is a complex issue however, resulting from the interplay of multiple variables, and there are several factors that have yet to be determined.

A long-term energy imbalance between intake and expenditure is the primary cause of obesity.[5] Hence, limiting calorie consumption is a key objective when weight loss is the goal. Over the years, much attention has been devoted to prescribing the optimal number of calories to achieve a healthy body weight. Some researchers have looked even further and investigated the possibility that consuming certain dietary factors may aid in weight regulation.

Fiber intake is one dietary factor that has been given significant attention. Reviews by Burton-Freeman, Howarth et al., Slavin, Schulz et al., and others, indicate that dietary fiber is inversely related to weight gain. [5-11] Although a considerable amount of research has been conducted in this area, the literature still contains many inconsistencies regarding the association between dietary fiber and body weight.[7] More conclusive results could be obtained however, if research methodologies were improved.

Of the studies examined, all but one relied on a food frequency questionnaire, a 24-hr recall, or a 3-day food diary to measure dietary composition. Each of these measures provides decent estimates, but a weighed food log of longer duration would be more representative of the typical diet.[12]

Additionally, physical activity has been controlled rarely in previous studies, yet, it accounts for roughly half of the energy balance equation. To understand weight change over time, physical activity must be measured. Objective measures of physical activity are best since self-reported levels tend to include significant error.[13]

Furthermore, the role of fiber on body composition has not been thoroughly explored. Maintaining a healthy body weight over time is important; however, maintaining lean body mass while limiting gains in fat mass should be emphasized. Few studies evaluating the effects of fiber consumption have measured body fat in addition to body weight, and fewer still have used accurate methods to assess body fat, such as the Bod Pod. Thus, the proposed study, using objective and valid tools of measurement, will attempt to determine the role of fiber consumption in the prevention of weight gain over time.

Statement of the Problem

The proposed study will focus primarily on determining intake of dietary fiber and risk of gains in body weight and body fat over a 20-month period in approximately 220 women. Since fiber intake generally increases as total caloric intake increases, individuals who eat larger quantities of food tend to consume more fiber. In the present study, fiber consumption per 1000 kcal will be used to control for this. An auxiliary objective will be to examine the degree to which age, caloric intake, fat consumption, and physical activity affect the association between consumption of fiber and changes in body weight and body fat over time.

Research Questions

1. To what extent does baseline dietary fiber consumption per 1000 kcal account for changes in body weight and fat over a 20-month period in middle-aged women?
2. To what extent do changes in fiber consumption per 1000 kcal account for changes in body weight and fat over a 20-month period in middle-aged women?
3. To what extent is the relationship between fiber consumption per 1000 kcal and changes in body weight and fat influenced by possible confounders, such as age caloric intake, fat consumption, and physical activity?

Assumptions

1. Subjects accurately weighed and recorded all food consumed, while continuing habitual eating patterns.

2. Subjects refrained from eating for at least four hours before body weight and body fat were measured.
3. Subjects correctly wore the activity monitor during a typical week of physical activity.

Limitations

The use of self-reported results presents a potential risk of human error or bias in recording dietary intake. Subjects may have unconsciously changed their eating habits, inaccurately weighed and recorded their diet, or incorrectly wore their activity monitor. Furthermore, due to the prospective nature of this study, causality cannot be established, only risk. Additionally, some subjects who participated at baseline refused to participate at follow-up. These drop-outs may have influenced the results.

Delimitations

Data for the present study were collected as the first and second phases of the Brigham Young University (BYU) Lifestyle Project. Acceptance into the study sample was contingent on the following factors: subjects had to be healthy, pre-menopausal women who were between the ages of 35 and 45, had a BMI less than 30 kg/m^2, and did not use tobacco. A large majority of the subjects were Caucasian due to the demographics of the Utah Valley area. Dietary intake, including fiber intake, was measured using seven-day weighed food diaries which were analyzed using the ESHA software. Physical activity was assessed objectively through the use of MTI accelerometers (formerly CSA accelerometers). Body weight was measured using an electronic scale, and body fat was measured through the use of the Bod Pod.

Operational Definitions

Energy Intake – Everything consumed daily in the form of liquids, foods, and supplements, stated in kilocalories, and determined from an average of the seven-day weighed food diaries.

Dietary Fiber – The edible, non-starch, polysaccharide part of plant foods which provides no calories. In the present study, dietary fiber was measured using seven-day, weighed food diaries which were analyzed using the ESHA software.

Physical Activity – Bodily movement generated by skeletal muscles, determined objectively in this study through the use of MTI accelerometers (Manufacturing Technologies Inc., Fort Walton Beach FL; formerly CSA accelerometers), which detect motion at the left hip.

Obesity – Having a Body Mass Index (BMI) of 30 kg/m^2 or greater, or a total body fat percentage greater than 32%.

Overweight – Having a BMI between 25 kg/m^2 and 29.99 kg/m^2.

Chapter 2

Review of the Literature

Overweight and obesity have dramatically increased over the past 40 years, and unfortunately, this trend is predicted to continue.[1] Due to the numerous health risks and chronic diseases associated with obesity, billions of dollars are spent annually in the United States in attempt to halt its progression.

Research on obesity has considered many different factors, one of which is the role that dietary fiber may play in prevention of long-term weight and body fat gain. A multitude of studies, summarized in reviews by Burton-Freeman, Howarth et al., Slavin, Schulz et al., and others,[5-11] indicate a trend toward weight loss, or at least reduction in weight gain, among individuals who consume large amounts of complex carbohydrates. Among these studies however, there are relatively few that address specifically the role of dietary fiber on changes in body weight and body fat, and even fewer that use high quality methods of measurement.

The current literature review will examine studies that specifically discuss dietary fiber in relation to body weight and in some instances body fat. This review will be divided, based on research design, into three categories: cross-sectional, experimental, and prospective research.

Cross-Sectional Research

Cross-sectional research examines data collected during one specific point in time. As a result, causality cannot be soundly established. This type of research is valuable however, in establishing whether or not a relationship exists between two variables. Cross-sectional studies have been conducted in the area of dietary fiber and weight gain, and an inverse relationship has been suggested.

Howarth et al.[14] used data from the Continuing Survey of Food Intakes by individuals (CSFII) 1994-1996. They included a total of 1,932 men and women, ages 20 to 59 years, in their analysis. In order to study the relationship between different components of the diet and BMI, self-reported energy intake was estimated using two 24-hour recalls. Results indicated that of the sample analyzed, 5% consumed the recommended intake of fiber. In women, fiber was independently associated with BMI, whereas in men, no such relationship was found. Additionally, compared with a high-fiber, low-fat diet, a low-fiber (1.5 g/MJ), high-fat ($\geq$ 35% energy) diet was associated with the greatest increase in risk of overweight or obesity in women. Howarth et al.[14] conclude that greater emphasis should be put on fiber consumption when giving weight management advice to U.S. women.

Nelson and Tucker[15] used 203 healthy men, ages 21 to 71 years, to examine the relationship between dietary components and body fat percentage. The National Cancer Institute food frequency questionnaire was used, as well as an additional questionnaire to obtain lifestyle data. Body fat percentage was estimated using 3-site skin fold measurements, and aerobic fitness was estimated using a sub-maximal treadmill test. Analysis of the data showed that after adjusting for energy intake, age, and fitness level, reported intakes of carbohydrate, complex carbohydrate, and fiber were all inversely associated with body fat. In addition, the fattest subjects reported consuming significantly less fiber than the leanest subjects. Nelson and Tucker add a recommendation that foods high in complex carbohydrates and fiber should be included when making dietary modifications.

Alfieri et al.[16] examined 150 subjects, divided into three weight groups of 50 subjects each. Nutritional information was obtained using detailed 3-day food records. The lean group was found to consume significantly higher amounts of total fiber than the other two groups. Analysis also revealed that after adjustment for age, sex, education level, and income, there was an inverse association between both total fiber in grams and fiber in g/1000 kcal, and BMI.

In a study by Kromhout et al.[17] the association between dietary fiber, dietary fat, physical activity, and body fat was studied. Sixteen cohorts in seven countries were examined, which included 12,763 middle-aged adult males. Diet and physical activity information was obtained using questionnaires, and height and weight were measured. In addition, body fat was indexed using subscapular skinfold thickness. Each of these parameters was then expressed as an average measure of the population. Results indicated that both intake in dietary fiber and physical activity were inversely related to subscapular skinfold thickness. In addition, 90% of the variance in skinfold thickness was explained by these two measurements.

Miller et al.[18] assessed the relationship between individual dietary components and body fatness in 78 obese and lean men and women. A food frequency questionnaire and a 3-day food diary were used to collect nutrition information. Hydrostatic weighing was performed to determine body fat percentage. Results showed that there was no significant difference between lean and obese subjects for energy intake. Compared with lean men and women however, obese men and women had lower fiber intakes.

Lairon et al.[19] took information from 5,961 middle-aged French adults in the SU.VI.MAX study to determine the association between fiber intake and cardiovascular disease risk factors. Fiber intake was determined from six, 24-hr dietary recalls, and standardized procedures were used in order to measure height, weight, and waist and hip circumferences of the participants. An inverse and significant association was found between BMI and waist-to-hip ratio, and total fiber intake. This relationship suggests that a diet high in fiber may play a role in maintaining a lower body fat composition.

In conclusion, the data from cross-sectional studies support an inverse relationship between intake of dietary fiber and body weight. This information is useful, yet there are several limitations which support the necessity of further research. First, each of these studies gathered nutritional information using either 24-hr recalls or food frequency questionnaires. Second, physical activity was not controlled in any of the cross-sectional investigations. Three of the cross-sectional studies measured body fat percentage, and although the methods used provided acceptable representations of body composition, the methods of measurement were not strong. The most important limitation however, innate in this type of research, is that causality cannot be established from correlational studies.

Experimental Research

Experimental research, in which observation follows treatment, is useful in determining cause and effect. Several experimental studies have been conducted wherein dietary fiber has been mentioned. However, only a few have actually focused on the effect of dietary fiber intake on body weight. Among these, conflicting results have been seen.

Raben et al.[20] designed a study in which 48 normal-weight, young, healthy students participated. Twenty-four participants in the control group made no adjustment to their diets, whereas the remaining 24 in the intervention group followed an ad libitum low-fat, high-fiber diet (25.5% energy from fat, 3.9 g fiber/MJ). During the first 11 weeks, unintentional weight changes were observed. The results illustrated that there was an overall decrease in body weight (1.3 ± 0.2 kg, $p<0.01$) and fat mass (1.6 ± 0.2 kg, $p<0.001$) in the intervention group, whereas the control group experienced no changes. The authors concluded that in young, normal-weight subjects, the ad libitum consumption of a low-fat, high-fiber diet led to an unintended, small loss of fat mass and overall body weight.

Hays et al.[21] conducted a similar study in order to test the controversial idea that ad libitum low-fat diets promote weight reduction. Thirty-four adults with impaired glucose tolerance (IGT) participated in this study, and were divided into three groups: the control group (41% fat, 45% CHO, 7 g fiber/1000 kcal); a high-carbohydrate diet (HI-CHO: 18% fat, 63% CHO, 26 g fiber/1000 kcal); or a high-carbohydrate diet plus exercise (HI-CHO + EX: same high-carbohydrate diet, plus 4 days of exercise/week for 45 minutes/day, at 80% peak oxygen consumption). All subjects were told to eat food ad libitum. It was noted that among the three groups, total food intake was not significantly different, nor was there a change in energy intake over time. More weight was lost in the

HI-CHO + EX group (-4.8 ± 0.9 kg) and HI-CHO group (-3.2 ± 1.2 kg) compared to the control group. Body composition was also measured and body fat losses were higher in the HI-CHO + EX group (-3.5% ± 0.7%) and HI-CHO group (-2.2% ± 1.2%) than in the control group (0.2% ± 0.6%). The overall conclusion was that even with no change in energy intake, an ad libitum high-carbohydrate diet leads to weight and body fat losses in older adults.

A very large randomized intervention trial, headed by Howard et al.,[22] studied the association between changes in dietary components and body weight, secondarily to cancer incidence. A total of 48,835 ethnically diverse postmenopausal women, who participated in the Women's Health Initiative Dietary Modifications Trial, were included. The intervention group included 40% of the participants, each of who received one-on-one coaching as well as group meetings to encourage increased consumption of fruit, vegetables, and grains, and decreased consumption of fat. The remaining 60% of the women were given information on diet. Follow-up was 7.5 years after 5 years of enrollment in the study. Analysis revealed that in the first year, women in the intervention group lost more weight than those in the control group (mean difference of 1.9 kg), and over the 7.5 years of follow-up, kept a lower weight than controls. Increasing fiber intake did not cause a significant decrease in weight.

Baron et al.[23] designed a three-month randomized controlled trial in which 135 overweight men and women were divided into two groups. Each group was put on a low-calorie diet, but fat, fiber, and carbohydrate content was different for each group. After three months, subjects given a higher fiber/higher carbohydrate diet experienced less weight loss than those given advice on low fiber/low carbohydrate diets (mean of 3.7 kg vs. 5.0 kg). Baron et al. state that for weight loss, the efficacy of fiber may be exaggerated.

Thompson et al.[24] recruited 90 obese individuals to participate in their controlled trial. Subjects were randomized into one of the following three diets: high-dairy, high-dairy and fiber, and standard diet. Each diet provided a 500 kcal/day deficit over a 48-week time period. Significant weight and fat loss were experienced in all three diets, but there were no significant between-group differences. They concluded that diets high in dairy products (>800 mg of calcium) or high in fiber do not appear to aid in weight loss beyond simple caloric restriction.

In conclusion, experimental research is the best approach to establish causality between two variables. Several experimental studies have been conducted in order to determine the association between consumption of dietary fiber and body weight and composition. These studies have ranged in time from a few months to several years, and have involved different forms of intervention. Inconsistent results have been observed, possibly due to potentially confounding factors such as physical activity and adherence to the treatment. Only in the Hays et al.[21] study was physical activity considered, and even then, it was only measured in one-third of the participants. In addition, although subjects were provided dietary instruction, food was not weighed, making it difficult to precisely measure specific quantities of fiber in the diet.

Prospective Research

Prospective research, although not as conclusive as experimental, allows risk to be measured over time. Several cohort studies have examined the role of dietary fiber in relation to weight gain and cardiovascular disease, and all have suggested that fiber intake plays a protective role.

Ludwig et al.[25] used data from the Coronary Artery Risk Development in Young Adults (CARDIA) Study to assess fiber intake and other dietary constituents, and their relative importance in various cardiovascular disease risk factors. This cohort was comprised of 2,909 adults, ages 18 to 30 years at baseline, and was followed for a 10 year period. A linear association was seen between the lowest and highest quintiles of dietary fiber intake and body weight (a difference of approximately 8 lbs.). Weight gain was more strongly predicted by consumption of fiber than by fat consumption, thereby leading the authors to state that obesity may be protected by diets high in fiber.

Newby et al.[26] studied the possible relationship between various food patterns and anthropometric changes. They took their data from 449 healthy participants in the Baltimore Longitudinal Study of Aging. Each subject was instructed on how to fill out 7-day dietary records, and was provided a portable scale in 1994 to weigh food portions. Weight and height measurements were taken at each visit in order to calculate BMI, and an adapted version of the Harvard Alumni questionnaire was used in order to assess physical activity. After assessing diet and entering 40 food groups into a factor analysis, six food patterns were developed. The authors concluded that smaller increases in BMI in women may result from a food pattern high in high-fiber foods and reduced-fat dairy products.

In another prospective investigation, Liu et al.[27] used data from 74,091 U.S. female Nurses who were followed from 1984 to 1996. Food-frequency questionnaires assessed their dietary habits in 1984, 1986, 1990, and 1994. Average weight, BMI, fluctuations in weight over time, and the odds ratio of becoming obese, were all calculated in relation to change in dietary habits. Results illustrated that women were consistently lighter who ate more whole grains than those who ate less whole grains. Women whose consumption of fiber increased the most over the 12-year period gained less weight (on average 1.52 kg less) than those whose intake was minimally increased. In addition, a 49% lower risk of major weight gain was seen for women in the highest quintile of fiber consumption compared to those in the lowest quintile.

An eight year prospective study was conducted by Koh-Banerjee et al.[28] using a cohort of 27,082 men. Self-reported questionnaires provided information on lifestyle factors, and body weight was self-reported at baseline in 1986, and again eight years later. Analysis showed that there was an inverse association between increase in whole-grain intake and long-term weight gain. Specifically, weight gain was decreased by 0.49 kg for every 40-g/day increase in overall whole-grain intake. This dose-response relationship was observed to an even greater extent when wheat bran was added.

In a study by Iqbal et al.[29] the influence of dietary fiber, and specifically energy density, on five-year weight changes in adults was examined. They used 862 men and women from the Danish World Health Organization Multinational Monitoring of Trends and Determinants in Cardiovascular Disease (MONICA1) and the 1936 cohort dietary studies. A weighed 7-day food record was used in order to gather nutritional information, from which fiber intake was estimated. Body weight was measured to the nearest 0.1 kg both at baseline and follow-up, and leisure time activity was ranked according to one of three categories. Results indicated an inverse association between consumption of fiber and change in body weight for women, but not men. After adjusting for factors such as age, physical activity, BMI, educational level, and smoking status however, the relationship in women disappeared.

In summary, several prospective studies have been conducted to examine the association between fiber intake and weight gain. While most of these studies have reported inverse relationships, mediocre measurement methods have resulted in potentially flawed conclusions. Specifically, none of these studies have objectively measured changes in body composition over time, only body weight. Additionally, Newby et al.[26] was the only researcher to precisely measure dietary energy intake using portable scales. Moreover, although half of the studies have measured physical activity, it has been measured only crudely with questionnaires. Furthermore, in two of the five prospective studies, body weight was self-reported, which often results in personal bias and an inaccurate report. Thus, with more precise measurements, the strength of the relationship between fiber intake and weight gain could be investigated more thoroughly.

Conclusions

The inverse relationship between consumption of dietary fiber and weight gain is supported by the majority of the current literature. Through cross-sectional and prospective research, observation is possible and associations can be established. Prospective and experimental studies provide consequential data on changes over time, and experimental studies specifically, through the use of interventions, allow more conclusive statements on causality. Although the general consensus is that fiber intake plays a protective role against weight gain, this relationship merits further investigation.

A limitation of virtually all the studies reviewed is the technique used to measure dietary composition. A food frequency questionnaire, 24-hr recall, or 3-day food diary was employed in every study but one. Although these methods strive to obtain accurate information, energy intake is often under-reported due to unknown portion size, and food frequency questionnaires leave room for vagueness and estimation.[12]

Another significant inadequacy is that physical activity was not measured in the majority of the studies. Physical activity, however, naturally plays a large role in long-term weight maintenance. Consequently, it must be considered. In the studies where activity was measured, it was assessed roughly with self-reported questionnaires which often lead to overestimation of energy expenditure.[13]

In addition, while it is important to monitor body weight changes over time, body composition is also a measure which deserves attention. Losses in protein, muscle, and bone mineral content occur with aging,[30] thus, decreasing fat free mass and negatively changing body composition. Only four studies examined the role of dietary fiber in body composition changes, and in two of these, it was determined by a skinfold test. Although this is an accepted technique, accuracy could be improved. Therefore, the relationship between dietary fiber and changes in body fat merits further consideration.

Chapter 3

Methods

The purpose of this study will be to examine the association between intake of dietary fiber and changes in body weight and body fat over a 20-month period. A secondary aim of the study will be to assess the extent to which energy intake, fat consumption, and objectively measured physical activity influence the association between fiber intake and changes in body weight and body fat.

Subjects

Data from the first and second phases of the BYU Lifestyle Project, conducted from 1998 to 2000, will be used to answer the research questions of this study. Approximately 275 women participated at baseline, and approximately 220 subjects will be included in the analysis. Initially, advertising to the Utah Valley and Salt Lake Valley public was employed to help recruit potential subjects. Each potential participant was then interviewed by phone to ensure she fit the baseline requirements.

Healthy, pre-menopausal females, 35-45 years old, with a BMI less than 30 kg/m^2 qualified for the study. Average age at baseline was approximately 40 years. Subjects had to be nonsmokers and not planning on becoming pregnant during the study. In addition, due to the demographics of the area, over 90% of the study sample was Caucasian and educated. A university IRB-approved informed consent was completed by all subjects before participating in the baseline and follow-up assessments.

Instrumentation and Methods

Age, dietary fiber and fat intake, energy consumption, physical activity, body weight, and body fat percentage will be the variables examined in this study. Baseline measurements were taken in 1998 and then these same variables were reassessed in 2000. Changes in these variables for each subject over the 20-month period will be examined.

Fiber, Fat, and Energy Intake

Seven-day weighed diet records were used at baseline and follow-up in order to measure energy, fat, and fiber intake. Each subject was provided an Ohaus 2000 electronic scale (Ohaus Corp., Florham Park, NJ) which digitally weighs food to the gram. While maintaining habitual eating habits, each subject weighed and recorded all food she consumed during a period of seven consecutive days. Food weight and descriptions were recorded on diet logs that were provided by the researchers.

In order to obtain accurate records, each subject was contacted every second day by research personnel who emphasized consistent reporting of dietary intake and answered any questions the subjects may have had. A registered dietitian analyzed the completed food logs using the ESHA Research software program, version 7.6 (ESHA Research Inc., Salem, OR), to ensure that they were plausible and to provide objective diet data. Subjects were asked to redo their logs if total caloric intake did not surpass 130% of estimated 24-hour resting metabolic rate. To control for the fact that fiber intake tends to increase as total food intake increases, fiber intake per 1000 kcal will be calculated. In addition, immediately before and after the testing week, subjects were weighed on an electronic scale (Tanita Corporation, Tokyo, Japan) to make sure that there was no significant weight change.

Body Weight

Body weight was measured to within 0.01 pound (0.005 kg) using the electronic scale previously mentioned (Tanita Corporation, Tokyo, Japan). Daily calibration ensured reliable measurement. All women wore lightweight, one-piece bathing suits issued by the university, and were asked to refrain from eating for four hours before their visit. Baseline body weight was recorded as the mean of two measurements taken one week apart. After 20 months of follow-up, the same procedure was followed again.

Body Fat Percentage

In this study, body fat percentage was measured objectively using air displacement plethysmography, or the Bod Pod. Each subject was issued a one-piece swimsuit and a swim cap, and the Bod Pod was used to measure thoracic lung volume. Each day the Bod Pod was calibrated with a cylinder of known volume. Body fat percentage was measured at least twice for all participants, until two results were within one percentage point. These two results were then averaged.

Several studies have shown the Bod Pod to be a reliable and valid method of measuring body composition. In order to ascertain the reliability of the Bod Pod, a test-retest protocol was used on 100 subjects in the present study. Between the two Bod Pod tests, the intraclass correlation was 0.999 ($p < .001$).[31] To determine the validity of the Bod Pod, dual energy x-ray absorptiometry (DEXA, Hologic 4500W, Bedford, Massachusetts) was used to measure body fat percentage of these same 100 subjects.

Between the two measures of body fat percentage, the Pearson correlation was 0.94 ($p <$ .001) and the intraclass correlation was 0.97 ($p >$ .001).[32] Additionally, Ballard et al.[33] compared the Bod Pod to the DEXA machine, the new Gold Standard for measuring body composition, and found no significant difference when measuring body fat. He concluded that when measuring body fat in female athletes and nonathletes, the Bod Pod is a valid method. Maddalozzo et al.[34] also compared the Bod Pod to the DEXA and came up with similar conclusions.

Physical Activity

Objective measurement of physical activity was accomplished through the use of MTI accelerometers (Manufacturing Technologies Inc., Fort Walton Beach FL; formerly CSA accelerometers). Each subject, at baseline, was instructed on how to properly wear the monitor. A nylon belt was worn around the waist, to which the accelerometer was attached on the left side of the body. The monitor was worn at all times for seven consecutive days, and was removed only when bathing or participating in water activities. Subjects were asked to redo the testing week if the monitor was not worn properly. If non-compliance was a problem, the subject was dropped from the study.

CSA accelerometers (now known as MTI accelerometers) have been shown to provide a reliable and objective measurement of physical activity and energy expenditure. In a study by Liu et al.,[35] when compared to doubly-labeled water, activity counts from the CSA activity monitor appeared to closely represent the total amount of physical activity in free-living adults. In addition, research by Bassett et al.[36] revealed that this monitor was correlated more highly with energy expenditure ($r > 0.90$), measured by a portable metabolic system, than were three other accelerometers. Additionally, test-retest reliability of the accelerometer was evaluated in a pilot study conducted by the Lifestyle Study researchers. A total of 15 women participated in 17 different physical activities, including walking and jogging at precise speeds and on different grades, climbing fixed stairs, descending fixed stairs, etc. Within 2-4 days the 17 physical activities were repeated. The intraclass correlation showing test-retest reliability across the 17 different activities was 0.989. Thus, the MTI accelerometer is a validated and reliable method of determining physical activity.

Procedure

The Human Performance Research Center at Brigham Young University in Provo, Utah, was where all appointments took place. Baseline data were collected in 1998, and included measurement of dietary intake, body weight, body fat percentage, and physical activity. These same variables were again measured in identical fashion at a follow-up visit 20 months later.

All possible risks and benefits related to involvement in the study were explained in the written consent forms. Subjects were required to sign a consent document at both testing periods before any assessments were performed, and they were reminded that participation was voluntary and all information would remain confidential. In addition, a Physical Activity Readiness Questionnaire (PAR-Q) was filled out by each woman to screen for possible complications she might experience during the assessments.

At baseline, subjects came in for their first appointment and were given a digital scale, seven dietary logs, and an activity monitor. They were all educated on how to weigh and record their dietary intake, and how to wear the activity monitor. Height and weight (wearing a one-piece swimsuit) were measured, and body fat was assessed using the Bod Pod. During the following seven days, subjects were required to weigh and log everything they consumed, and to wear the activity monitor nonstop, with the exception of bathing or water activities. Research personnel called the subjects every other day over this week to ensure they were complying with the diet and physical activity instructions. After the seven days, subjects came in again for a second appointment where they returned the equipment and handed in their completed logs. Any problems or questions were addressed during this time, and subjects were re-weighed in the one-piece swimsuit. Twenty months later, the subjects were called in for a follow-up visit, during which the baseline procedures were repeated. After reviewing the data, subjects were sent a letter of appreciation and a $25 gift certificate, in addition to their individual test results.

Data Analysis

Determining the extent to which dietary fiber intake is associated with changes in body weight and body fat percentage is the primary aim of this proposed study. Differences in body weight and body fat will be determined by subtracting the baseline measurements from those taken at 20 months.

Subjects will be categorized into quartiles based on their intake of fiber per 1000 kcal, and the two middle groups will be condensed into one, thus leaving three fiber groups for analysis. Using the general linear model (GLM), regression analysis will be performed to determine the extent to which changes in body weight and body fat vary according to consumption of dietary fiber. Control of potential confounding variables, such as dietary fat intake, energy consumption, and physical activity level, will occur by means of partial correlation. Statistical analysis of the data will be calculated using the SAS system (SAS institute Inc., Cary, NC), and alpha will be set at the 0.05 level.

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