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THEORETICAL EFFECTS OF DECREASING SATURATED FAT AND CHOLESTEROL INTAKE ON TOTAL SERUM AND LDL CHOLESTEROL LEVELS

DISSERTATION

Presented in Partial Fulfillment of the Requirement for the Degree Doctor of Philosophy in the Graduate School of the Ohio State University

By

Carlos Blanco, M.S., M.A.S.

*****

The Ohio State University
1996

Dissertation Committee:
Professor Jean T. Snook, Adviser
Professor Alma M. Saddam
Professor Elizabeth A. Stasny

Approved by

Jean T. Snook
Adviser
College of Human Ecology
ABSTRACT

The National Cholesterol Education Program (NCEP) recommends a low density lipoprotein (LDL) cholesterol goal above which dietary or drug therapy should be initiated. The NCEP recommends that individuals exceeding their LDL cholesterol goal consume a “Step I” diet with a maximum intake of 10% of calories as saturated fat and 300 mg of cholesterol. The NCEP also recommends a “Step II” diet, with a maximum of 7% of calories as saturated fat and 200 mg of cholesterol, to those individuals unable to meet their LDL cholesterol goal by the consumption of the Step I diet.

In order to evaluate the effectiveness of the NCEP Step diets, data from the first phase of the National Health and Nutrition Examination Survey (NHANES) III (conducted between 1988 and 1991) were analyzed. Using the 1993 Hegsted equation for the prediction of changes in LDL cholesterol levels resulting from changes in saturated fat and cholesterol, it was estimated that most individuals would be unable to meet their LDL cholesterol goal by changes to the Step diets. Further, using the 1993 Hegsted equation for the prediction of changes in total serum cholesterol resulting from changes in saturated fat and dietary cholesterol, it was estimated that most individuals would be unable to lower their total serum cholesterol to less than 180 mg/dl if they consumed the NCEP Step diets. A level of
more than 180 mg/dl of total cholesterol has been shown in the Multiple Risk Factor Intervention Trial to be associated with an increased risk of death from CHD. Therefore, most individuals need some additional dietary therapy other than the NCEP Step II diet to lower their total serum cholesterol to less than 180 mg/dl.

Using data from the Nationwide Food Consumption Survey (NFCS) 1987-88, it was found that the consumption of a low percentage of energy as saturated fat is associated with low percent intakes of the RDAs for zinc, calcium, magnesium and riboflavin. Therefore, individuals wishing to lower their saturated fat intake must make special efforts must be made to ensure an adequate intake of these micronutrients.
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VITA

November 2 ......................................................... Born - Madrid, Spain

1983 ................................................................. B. S. Biology
                      University of Windsor
                      Canada

1986 ................................................................. M. S. Microbiology
                      The Ohio State University

1991 ................................................................. M.A.S. Statistics
                      The Ohio State University

1993-1995 ........................................................... Assistant Director
                      STATcomp, Inc.
                      Waukegan, IL

FIELDS OF STUDY

Major field: Human Nutrition.
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CHAPTER I

INTRODUCTION

Within the past few decades numerous epidemiological studies have found a positive association between blood cholesterol levels and risk of coronary heart disease. Up to several years ago, this association was thought to occur only above a level of blood cholesterol of 200 to 230 mg/dl (Office of Medical Applications of Research, 1985). Now, however, in view of the results from the Multiple Risk Factor Intervention Trial (MRFIT), this association is thought to occur at levels of only 180 mg/dl or above (Neaton et al., 1992). Even though the average blood cholesterol values have declined (Johnson et al., 1993) from previous values of more than 210 mg/dl for both American men and women (National Center for Health Statistics, 1986), a high percentage of the American population is at increased risk of coronary heart disease. For this reason, a large segment of the population needs to modify the factors contributing to elevated blood cholesterol levels.

Of the various modifiable factors affecting blood cholesterol levels, diet is considered to be one of the most important. Specifically, the amount and type of fat consumed affect blood cholesterol levels more than any other nutrient. Most studies have found that an increased intake of saturated fat results in higher blood total cholesterol levels through increases in the levels of low density lipoproteins (LDL). Studies focusing on the effect of specific saturated fatty acids have found that the
cholesterol-raising effect of saturated fat is caused by the 12 to 16 carbon chain fatty acids. On the other hand, saturated fatty acids with chain lengths of 4 to 10 carbons (Keys, 1967) or more than 16 carbons (Bonanome and Grundy, 1988) do not raise blood cholesterol levels. The substitution of polyunsaturated fat for saturated fat has been found to lower overall cholesterol levels by decreasing the levels of LDL and, according to some studies, HDL. Although the substitution of monounsaturated fat for saturated fat also decreases total cholesterol levels, the observed decrease reflects a decrease in the levels of LDL. By contrast, HDL levels either remain constant or are slightly increased (Mattson, 1989).

Since 1965, a number of researchers have developed predictive equations for the change in total blood cholesterol resulting from changes in the intakes of the various types of fat and cholesterol. Initially, researchers developed these equations from a small number of observations collected in a single metabolic study that did not partition total cholesterol into its various fractions (such as LDL and HDL). Since the 1980s, researchers have developed other formulas for the prediction of changes in total cholesterol from meta-analyses using combined published data from metabolic studies and field trials. More recently, as a result of the accumulation of data from various studies which partitioned cholesterol, Hegsted et al. (1993) developed a formula for the effects of various types of fat and cholesterol on the levels of LDL cholesterol.

In response to the finding of a link between elevated levels of blood cholesterol and an increased risk of coronary heart disease (CHD), many government and private organizations have recommended a decrease in the intakes of fat and cholesterol.
The most comprehensive recommendations for the treatment of elevated levels of LDL cholesterol are those by the National Cholesterol Education Program (NCEP). For individuals at least 20 years old, the NCEP recommends an LDL cholesterol goal above which dietary or drug therapy should be initiated. The LDL cholesterol goal for each individual depends on the presence of coronary heart disease and the number of risk factors. The NCEP recommends that individuals not meeting their LDL cholesterol goal consume a "Step I" diet with a maximum intake of 10% of calories as saturated fat and 300 mg of cholesterol. The NCEP also recommends a "Step II" diet, with a maximum of 7% of calories as saturated fat and 200 mg of cholesterol, to those individuals unable to meet their LDL cholesterol goal by the consumption of the Step I diet. As the final step, the NCEP also recommends that individuals not meeting their LDL cholesterol goal by the consumption of a Step II diet should be candidates for treatment with lipid-lowering drugs.

**Rationale of Study**

Some metabolic ward studies have demonstrated the usefulness of the NCEP diets in reducing blood cholesterol levels in certain individuals. However, no researcher has estimated the proportion of individuals in the American population who would meet their LDL cholesterol goal by switching to the NCEP diets. A study of this nature would help determine the usefulness of the NCEP dietary recommendations to reduce elevated cholesterol to the desirable levels in the American population.

In order to evaluate the usefulness of the NCEP recommendations, it would be necessary to analyze recent data on the intake of fat and cholesterol as well as data
on the levels of blood cholesterol in the American population. The two most recent dietary surveys for the entire American population are the Nationwide Food Consumption Survey 1987-88 (NFCS 1987-88) and the National Health and Nutrition Examination Survey (NHANES) III, conducted between 1988 and 1994. In late 1995, the US Department of Health and Human Services made public data from the first phase of NHANES III (1988-91). Unlike other nationwide surveys conducted in the late 80s and early 90s, such as the NFCS 1987-88, the data for the first phase of NHANES III included both dietary intake data as well as data on blood cholesterol levels. Using these data and Hegsted’s 1993 formula for the prediction of changes in the levels of LDL cholesterol resulting from changes in the intake of various types of fat and cholesterol, it is possible to estimate the proportion of individuals who would meet their LDL cholesterol goal after switching to the NCEP diets.

**Statement Of Purpose**

The main purpose of this study is to determine the extent to which the NCEP recommendations can help reduce the proportion of adult individuals with elevated LDL cholesterol levels in the American population. An additional purpose of this study is to point out the possible consequences that switching to diets very low in saturated fat and cholesterol can have on the intake of certain nutrients. This type of analysis can be of interest for individuals not meeting their LDL cholesterol goal after consuming the NCEP diets. Accordingly, an analysis of the intake of certain nutrients whose consumption can be affected by major changes in the consumption of saturated fat and cholesterol, such as vitamins, minerals and essential fatty acids, is presented.
Objectives

The specific objectives of the study are the following:

1. To estimate the mean intake of various types of dietary fat and cholesterol for the American population using the NHANES III.
2. To evaluate the prevalence of risk factors for CHD in the American population using the NHANES III.
3. To estimate the proportion of individuals who are at increased risk for CHD because of elevated serum cholesterol levels in the NHANES III.
4. To estimate the usefulness of the NCEP diets to reduce the proportion of individuals who are at increased risk for CHD in the NHANES III.
5. To estimate the proportion of individuals not meeting their LDL cholesterol goal who would meet their goal by consuming the Step I and the Step II NCEP diets in the NHANES III.
6. To study the relationship between the intake of various levels of saturated fat and vitamins and minerals in the NFCS 1987-88.
7. To estimate the intake of essential fatty acids in the American population in the NFCS 1987-88.
8. To estimate the prevalence of the use of iron supplements in the American population in the NFCS 1987-88.

Content

This study is divided into a total of seven chapters. With the exception of the last chapter, which lists the major conclusions of the study and suggests some areas for future research, all other chapters are divided into a number of sections. Chapter II is
the Review of Literature and is divided into two sections. The first section discusses the role of dietary fat and cholesterol in the development of atherosclerosis. It also discusses the effect of dietary fat and cholesterol on blood cholesterol and presents evidence of the increased risk of coronary heart disease (CHD) resulting from elevated blood cholesterol. The second section presents the dietary guidelines for fat and cholesterol as well as recommendations for the treatment of hypercholesterolemia.

Chapter III presents the Materials and Methods used in this study. It is divided into five sections. The first section describes some of the analyses in this study and the reason why a certain dietary intake survey was selected to complete a particular analysis. The second and third sections describe the use of the NHANES III and the NFCS 1987-88 in this study respectively. The fourth section forewarns about the limitations associated with the NFCS 1987-88. Finally, the fifth section refers to the limitations associated with the interpretation of the results of the study.

Chapters IV, V and VI present the results of the study. Chapter IV is divided into three sections. The first section presents findings for the intakes of energy, fat and cholesterol by the target population. The second section presents findings for the levels of total serum cholesterol in the target population. It also includes an analysis of the estimated effect of reducing the intake of saturated fat and cholesterol on the levels of total cholesterol. The third section presents the percentage of individuals not meeting their LDL cholesterol goal. It also includes an analysis of the incidence of risk factors for CHD in the population and an analysis of the estimated effect of reductions in the levels of saturated fat and cholesterol.
Chapter V presents an analysis for the intake of essential fatty acids in the population and consists of only one section. Chapter VI is divided into two sections. The first section presents an analysis for the association between the intakes of each of saturated and polyunsaturated fat on the one hand and minerals and vitamins on the other. The main emphasis of the analysis is on those micronutrients which are thought to play a major role in the development of CHD: vitamins C and E, iron and zinc. The second section presents an analysis of the intake of vitamin and mineral supplements by the American population. Chapter VII is divided into two sections. The first section presents a summary of the main conclusions of the study. The second section discusses possible areas of future research related to the subject of this study.
CHAPTER II

REVIEW OF LITERATURE

This chapter consists of two major sections. The first section discusses the role of dietary fat and cholesterol in the development of atherosclerosis. It also discusses the effect of dietary fat and cholesterol on blood cholesterol levels and presents evidence of the increased risk of coronary heart disease (CHD) resulting from elevated blood cholesterol. The second section presents the dietary guidelines for fat and cholesterol as well as recommendations for the treatment of hypercholesterolemia in the United States. Given that no American organization has made any recommendations for the intake of essential fatty acids, this section also presents some of the most recent dietary recommendations for the essential fatty acids made outside the United States.

Dietary Fat And Atherosclerosis

Although the effects of diet on the development of atherosclerosis were studied early in the twentieth century, the experiments involving different fats started in the late 1950s. These studies have focused on the two topics presented in this section. The first topic is the effect of dietary fat and cholesterol on blood cholesterol levels. The second topic is the evidence that elevated blood cholesterol is associated with mortality from CHD. Additional topics, such as the roles of the
essential fatty acids, trans fatty acids and cholesterol oxidation products, are also included.

**Classical Metabolic Ward Studies**

The first evidence that various types of fat affect blood cholesterol levels was obtained in the late 1950s through studies in which men ate diets to which oils and cholesterol, as egg yolk, were added. Using these techniques, Keys et al. (1965) calculated that for every 1% increase in calories as saturated fat, plasma cholesterol increases by 2.7 mg/dl whereas for every 1% increase in calories as polyunsaturated fat plasma cholesterol decreases by 1.35 mg/dl. Based on these findings, the Keys equation was developed:

\[ \Delta \text{cholesterol} = 1.5 \Delta Z + 2.7 \Delta S - 1.35 \Delta P \]  \hspace{1cm} (1)

The Hegsted equation was similarly developed in 1965:

\[ \Delta \text{cholesterol} = 2.32 \Delta S + 0.32 \Delta M - 1.46 \Delta P + 6.51 \Delta CH + 0.83 \]  \hspace{1cm} (2)

where

\[ \Delta \text{cholesterol} = \text{estimated change in serum cholesterol in mg/dl}; \]
\[ \Delta S = \text{change in percent daily calories from saturated fat}; \]
\[ \Delta P = \text{change in percent daily calories from polyunsaturated fat}; \]
\[ \Delta M = \text{change in percent daily calories from monounsatuated fat}; \]
\[ \Delta CH = \text{change in intake of dietary cholesterol in dg/2,600 kcal}; \]
\[ \Delta Z = \text{change in the square root of daily dietary cholesterol in mg/1,000 calories}. \]
As noted by Hegsted (1986), the cholesterol coefficient ($\Delta CH$) in this last equation becomes 0.176 when expressed as the change in milligrams per 1,000 kcal.

Estimates of the effect of changes in dietary fat on the levels of dietary cholesterol obtained using the Keys equation have been similar to those observed in a number of European studies (Grande, 1983). However, for dietary cholesterol, McNamara (1990) examined the data from 68 metabolic ward (i.e., a research facility for controlled metabolic studies) studies and calculated a 2.3 mg/dl increase in blood cholesterol for every 100 mg increase in dietary cholesterol as compared to 9.6 and 6.8 mg/dl predicted by the Hegsted and Keys equations. Prior to McNamara’s study, Hegsted had revised his original formula to more accurately predict the effect of dietary cholesterol:

$$
\Delta \text{cholesterol} = 2.15 \Delta S - 1.65 \Delta P + 0.097 \Delta DC 
$$

where $\Delta DC$ refers to the change in dietary cholesterol in mg/1,000 Kcal.

In addition, in 1993 Hegsted et al. used studies published through 1991 in which the diets fed to human subjects had been modified and the resulting change in blood cholesterol measured to develop a number of equations. In their publication, the authors indicated that the equation which more likely quantifies the changes of dietary cholesterol is:

$$
\Delta C = 2.10 \Delta S - 1.16 \Delta P + 0.0670 \Delta DC 
$$
For this equation, $R^2 = 0.838$ and $SE_d = 0.347$. The $SE_d$ is the standard error of the change and is equal to $\sqrt{2}$ times the root mean square error from the covariance matrix. In the equation, the coefficient of $\Delta S$ would increase to 2.44 if $\Delta DC$ were excluded because the dietary content of saturated fat is correlated with that of dietary cholesterol.

In their 1993 publication, Hegsted et al. also developed a number of predictive formulas for changes in LDL and HDL cholesterol resulting from changes in the intake of various types of fat and cholesterol. Their formula for HDL cholesterol had an $R^2$ value of less than 40% and thus, was limited in its use to predict changes in HDL cholesterol. However, a predictive equation for LDL cholesterol with an $R^2$ of 0.821 was also developed:

$$\Delta \text{LDL-C} = 1.74 \Delta S - 0.766 \Delta P + 0.0439 \Delta DC$$  \hspace{1cm} (5)

In addition to the predictive formulas presented above, Mensink and Katan published a number of formulas in 1992 to predict the effect of changes in carbohydrate and fat intake on HDL, LDL, total cholesterol, triglycerides and the HDL/LDL cholesterol ratio. These workers developed these formulas using data from 27 controlled trials published between 1970 and 1991. A very surprising aspect of the publication by Mensink and Katan is that these researchers did not publish the $R^2$ for any of nine predictive formulas which they developed. However, in their discussion, Mensink and Katan stated that the formula for total
cholesterol which they developed was in very good agreement with the 1965 Keys and Hegsted formulas.

**Effect of Fats on Blood Cholesterol**

**Monounsaturated Fats and HDL Levels**

In the 1960s, total cholesterol was not partitioned into its components. As a result, the different effects of the three types of fat on lipoproteins was not apparent. For this reason, monounsaturated fat was considered "neutral" because its substitution for carbohydrate did not change total cholesterol levels. The concept of monounsaturated fat as neutral was first questioned with the publication by Keys (1970) of the Seven Countries Study. Despite their very high fat intake, the rate of CHD of Greek subjects was four times lower than in some of the other populations. This finding was attributed to the intake of olive oil by the Greek. In a 15-year follow-up, 44% of the variability in the coronary death rate in fifteen cohorts was accounted for by the ratio of dietary monounsaturated to saturated fat (Keys et al., 1986).

Additional support for the idea that the consumption of monounsaturated fat may protect against CHD has come from the finding that the decrease in monounsaturated fat and increase in saturated fat intakes in many Southern European countries have been accompanied by increasing CHD. These dietary changes have occurred partly as a result of increases in the consumption of meat and dairy products (Buzina et al., 1991; Kafatos et al., 1991).
As early as 1951, Barr et al. had found that HDL levels were negatively associated with the incidence of atherosclerosis. A negative association was found between HDL levels and the risk for CHD in the 1950s and early 1960s (Nikkila, 1953, Oliver and Boyd, 1955, Brunner et al., 1962). However, it was not until the publication by Gordon et al. in 1977 of a four-year follow-up of a large number of participants in the Framingham Heart Study that the idea of an inverse association between HDL levels and risk for CHD became accepted.

As a result of the finding that various cholesterol fractions were associated in different ways with the risk of CHD, subsequent studies partitioned cholesterol into its fractions. In this way, it was generally observed that polyunsaturated fat decreased the levels of total cholesterol more than monounsaturated fat when either of them replaced saturated fat. It was also noted that polyunsaturated and monounsaturated fat equally reduced LDL levels. However, while polyunsaturated fat frequently reduced HDL levels monounsaturated fat did not decrease HDL levels (Mattson, 1989).

In a study by Grundy (1986), a diet high in monounsaturated fat and a diet high in carbohydrate were compared to a diet high in saturated fat. Both the diet high in monounsaturated fat and that high in saturated fat included 40% of calories as fat and 43% as carbohydrate. By contrast, the high carbohydrate diet had 20% of calories as fat and 63% as carbohydrate. Both the high monounsaturated fat diet and the high carbohydrate diet reduced plasma total cholesterol and LDL to the...
same extent. However, the high carbohydrate diet lowered HDL levels, an effect not observed with the high monounsaturated fat diet.

Additional support for the benefits of replacing some of the saturated fat by monounsaturated fat has come from a study by Ginsberg et al. (1990). A diet with 10% of calories as saturated, 18% monounsaturated and 10% polyunsaturated when compared to the average American diet significantly decreased blood cholesterol. In addition, some studies have reported a strong negative correlation between red blood cell oleate concentrations and CHD. An example is the finding by Wenxun et al. (1990) of strong negative correlations for both men and women between the levels of plasma oleate and the natural logarithm of county cumulative mortality rates for 49 counties in China. This finding, and the finding of a negative correlation between oleate and arachidonate levels in red blood cells, led the authors to suggest that oleate may decrease platelet aggregation by reducing the synthesis of aggregation-stimulating thromboxanes. The conclusion from these findings is that monounsaturated fat may decrease the risk of CHD by means other than its effect on blood cholesterol levels.

In addition to its effect on various cholesterol fractions, monounsaturated fat exerts other effects which may decrease the risk for CHD. In a study by Berry et al. (1991) a diet high in monounsaturated fat made the LDL less susceptible to oxidative stress than a diet high in polyunsaturated fat. Furthermore, Mensink et al. (1988) found that a high-fat diet rich in monounsaturated fat did not increase blood
pressure when compared to a low-fat, carbohydrate-rich diet with the same percentage of calories as saturated and polyunsaturated fat.

Specific Saturated Fatty Acids and Hypercholesterolemia

Despite the fact that Keys' and Hegsted's equations lumped all saturated fatty acids into one category, not all saturated fatty acids are hypercholesterolemic. Early studies (Beveridge et al., 1959; Hashim et al., 1960 and Grande, 1962) showed that saturated fatty acids of 4 to 10 carbons do not raise blood cholesterol. In addition, Ahrens et al. (1957) found that cocoa butter does not increase blood cholesterol as much as butter fat. Because cocoa butter is high in stearic acid, it was suggested that stearic acid is not hypercholesterolemic. This finding was later supported by Hegsted et al. (1965) and Keys (1967). Additional support for the idea that stearic acid is a unique long-chain fatty acid that does not increase LDL or total cholesterol has recently come from the development of predictive equations using data from 18 publications (Yu et al., 1995). However, a subsequent study has indicated that stearic acid may have an effect on blood cholesterol which occurs at a slower rate than the effect which shorter fatty acids have (Dougherty et al., 1995). It is possible, therefore, that studies on the effect of stearic acid lasting several weeks may yield additional findings regarding the effect of this fatty acid on blood cholesterol levels.

Bonanome and Grundy (1988) found that using stearic acid in lieu of palmitic acid reduced both total and LDL cholesterol and did not significantly change the HDL levels. A high-oleic acid diet had the same effect on the cholesterol fractions,
as the high stearic acid diet. The high stearic acid diet did not increase stearic acid in the plasma triglycerides whereas the levels of oleic acid increased in this diet. For this reason, the authors suggested that stearic acid is converted to oleic acid. However, Emken (1992), using deuterated stearic acid, later showed that this conversion cannot entirely account for the different effects of stearic and palmitic acids.

Studies on the effects of dietary 12 to 16 carbon saturated fatty acids on plasma cholesterol have found differences among them. In a study by Hayes et al. (1991) with monkeys, palmitic acid was minimally hypercholesterolemic when compared to lauric and myristic acids. A regression of the observed cholesterol on the cholesterol predicted by the Hegsted equation yielded a higher correlation \( r = 0.995 \) when palmitic acid was considered neutral than when palmitic acid was not considered neutral \( r = 0.925 \). A study by Denke and Grundy (1992) has shown that palmitic acid is more hypercholesterolemic than lauric acid but does not have a different effect on triglycerides or HDL levels. However, both lauric and palmitic acids are hypercholesterolemic and the benefits for replacing palmitic acid with lauric acid in foods would not be sufficiently justified.

Essential fatty acids and the risk for CHD

Although the classic metabolic studies demonstrated the effect of the various types of fat on serum cholesterol levels, those studies did not investigate the effect of the essential fatty acids on the risk of CHD. However, as early as 1956 Sinclair
had proposed that the ratio of non-essential fatty acids to essential fatty acids was the main factor in atherosclerosis and coronary thrombosis. Support for Sinclair’s position has come from studies by Dyerberg et al. (1975) and Bang et al. (1976) which have found a negative association between the consumption of fish rich in essential fatty acids and the risk of CHD. In these studies, it was estimated that the Danish consumed twice as much saturated fat and more ω6 polyunsaturated fat than did the Eskimos. The Eskimos had a daily intake of 5 to 10 grams of eicosapentaenoic acid (C20:5 n-3; EPA) and docosahexaenoic acid (C22:6 n-3; DHA) and had a lower incidence of cardiovascular disease than the Danish. As a result of these findings, Sinclair (1980) and other researchers have proposed that the large concentration of ω3 fatty acids in the fish and fish-eating mammals consumed by Eskimos protect them against CHD.

A number of studies have supported the theory that a high intake of fish may protect against CHD. For example, a reduction of 50% in 20-year mortality for men who ate a minimum of one ounce of fish daily was found in a prospective Dutch study. However, no difference was observed between men who consumed low-fat fish and those who consumed high-fat fish (Kromhout et al., 1985). Using data from the Western Electric Study, Shekelle et al., found a negative association between fish consumption at entry into this study and 25-year risk of CHD (1985). A study by Curb and Reed (1985) found that the CHD death rate was higher in the
group that ate no fish compared with the group that ate fish. A study by Vollset et al. (1985) did not find any relationship between fish consumption and risk for CHD.

As a result of the similarity of the metabolic pathways of the ω3 and ω6 fatty acids, ω3 fatty acids exhibit a number of unique properties to lower thrombosis. EPA and DHA inhibit the synthesis of arachidonic acid from linoleic acid (Holman, 1964), compete with arachidonic acid for the 2-position in membrane phospholipids (Goodnight et al., 1982) and favor the synthesis of prostaglandins that are potent vasodilators and inhibit platelet aggregation (Fischer and Weber, 1984). These properties decrease the risk of thrombosis.

**Essential fatty acids: recent findings**

Although many studies on fish consumption and CHD suggested that most individuals could benefit from an increased intake of essential fatty acids, essential fatty acid deficiency has always been considered extremely rare. The reason why essential fatty acid deficiency was considered an extremely rare nutritional disorder was that it was normally occurring in patients suffering from short bowel syndrome or severe malabsorption or patients fed total parenteral solutions not receiving intravenous fat emulsions (Hirono et al., 1977). As a result of this finding and the observation that the classic signs of essential fatty acid deficiency (such as hair loss and seborrheic dermatitis) rarely occur in the population, most researchers and
organizations have expressed very little concern about the intake of essential fatty acids.

The view that the American population consumes a sufficient level of essential fatty acids has been challenged recently by Siguel and Lerman (1994). In their study, Siguel and Lerman used high-resolution capillary column gas-liquid chromatography to analyze the fatty acid patterns of the plasma from forty-seven patients with coronary artery disease and fifty-six control subjects. It was found that patients with coronary artery disease had fatty acid profiles which fell between those of patients with severe essential fatty acid deficiency and those of healthy individuals. Compared to the healthy subjects, patients with coronary heart disease had an increased level of ω7 and ω9 fatty acids, a higher 16:1 ω7 to 18:2 ω6 ratio, a higher 20:3 ω9 to 20:4 ω6 ratio, a higher 16:1 ω7, lower percentages of ω3 and ω6 fatty acids and lower polyunsaturated fat to non-polyunsaturated fat ratios.

In their study, Siguel and Lerman did not report the concentration of any fatty acids either in mmol/l or in any other units (such as mg/dl). Instead, the authors reported each fatty acid as a percentage of the total fatty acids measured or the ratio of one fatty acid to another fatty acid. The reason given by the authors for reporting relative proportions rather than total concentrations was that they considered the total concentration of any of the essential fatty acids misleading when evaluating indicators of essential fatty acid status. Thus, according to Siguel and Lerman, the
relative proportion of each fatty acid in lipoproteins determines the supply of essential fatty acids to cells because cells obtain essential fatty acids from lipoproteins. For this reason, according to these authors, an individual can have a high concentration of polyunsaturated fatty acids in the plasma but experience essential fatty acid deficiency at the cellular level, a condition which they call "relative essential fatty acid insufficiency".

According to Siguel and Lerman, essential fatty acid insufficiency, resulting from either a deficiency or an abnormal metabolism of essential fatty acids, causes changes in cholesterol metabolism. These changes are responsible for the development of CHD. For this reason, both authors supported the hypothesis advanced by Sinclair in 1956 that the ratio of essential fatty acids to non-essential fatty acids is the main factor in the development of atherosclerosis and coronary thrombosis.

**Effects Of Trans Fatty Acids On Blood Cholesterol**

Certain studies have focused on the cis and trans isomers. Trans isomers occur both in natural foods and in those with hydrogenated oils. Parodi (1976) reported that there are from 4 to 8 grams of trans fatty acids in 100 grams of milk fat. Slover et al. (1985) and Enig et al. (1983) have reported much larger amounts in certain margarines, shortenings and fats used for frying. In the United States, there is a daily intake of about 8 grams of trans fatty acids per person (Hunter and
Applewhite, 1991). Elaidic acid and its isomers are the most common trans fatty acids in the diet (Senti, 1985).

Although some reports (Jackson et al., 1977; Kritchevsky, 1982) have indicated that trans fatty acids are not atherosclerotic, studies by Mensink and Katan (1990), Zock and Katan (1992) and Judd et al. (1994) have shown that they raise blood cholesterol. In Mensink and Katan's study, trans oleic acid was hypercholesterolemic when compared to oleic acid and about half as hypercholesterolemic as a mixture of lauric, myristic and palmitic acids. However, the trans fatty acid not only increased the LDL level but also reduced the HDL level so that the LDL to HDL ratio was higher in the trans fatty acid diet than in the high saturated fat diet. In Zock and Katan's study, trans linoleic acid increased the LDL levels and decreased the HDL levels when compared to cis linoleic acid. In Judd et al's study, dietary trans fatty acids raised LDL cholesterol more than oleic acid but slightly less than saturated fat. In addition, a cross-sectional study of men by Troisi et al. (1992) found a positive association between trans-fatty acid intake and LDL and an inverse association between the intake of these fatty acids and HDL.

Effects Of Dietary Cholesterol On Plasma Cholesterol

Interaction Between Cholesterol and Fat Intake

Certain studies have reported that not all individuals respond to increases in dietary cholesterol with increases in their blood cholesterol levels. In addition, the
effect of dietary cholesterol depends on the relative proportion of saturated and polyunsaturated fat in the diet. Schonfeld et al. (1982) studied the effect of adding three or six eggs to diets with 40% fat and 300 mg cholesterol at various polyunsaturated to saturated (P/S) ratios. At P/S ratios of 0.25 and 0.4, six eggs increased cholesterol levels more than three eggs. At a P/S ratio of 0.8, six eggs raised cholesterol levels significantly whereas three eggs had no effect. Finally, at a P/S ratio of 2.5 there was no effect when either three or six eggs were added.

In a series of 75 studies, McNamara et al. (1987) compared a low cholesterol with a high cholesterol intake with two 35% fat diets, one with a high and the other with a low P/S ratio. In most cases, a feedback mechanism compensated for the increased cholesterol intake with the result that blood cholesterol did not increase. On the other hand, changes in the type of fat had an effect on blood cholesterol in 20% of the subjects who exhibited a decrease in blood cholesterol when they were on the high P/S diet independently of cholesterol intake. Cholesterol absorption decreased from 61% on the low cholesterol diet to 55% on the high cholesterol diet. Nevertheless, on both the high and the low P/S ratio diets the total amount of cholesterol absorbed increased. The high cholesterol intake did not increase the mean levels of total, LDL or HDL cholesterol on either the low or the high P/S ratio diets. Thus, when dietary cholesterol absorption is increased, the body increases the amount of cholesterol excreted or decreases the level of endogenously synthesized cholesterol.
Regulation of Serum Cholesterol

South African blacks with a mean daily intake of five eggs and a 20% fat diet consume very high levels of dietary cholesterol without substantial increases in plasma cholesterol (Vorster et al., 1987). Previous studies had shown that when dietary cholesterol is increased, there is less endogenous cholesterol synthesis and an increase in the excretion of dietary cholesterol as fecal steroids (Quintao et al., 1971; Nestel and Poyser, 1976; Quintao et al., 1977). In another study by Miettinen and Kesaniemi (1989), when dietary cholesterol absorption increased, the rates of cholesterol synthesis, biliary secretion and fecal elimination decreased. The decreased cholesterol synthesis in the liver resulting from increased dietary cholesterol is thought to inhibit the activity of the rate-limiting enzyme of cholesterol synthesis, 3-hydroxy-3-methylglutaryl-coenzyme A reductase (McNamara, 1990). Thus, there are mechanisms that protect against an excess intake of dietary cholesterol. In a review by Hopkins (1992), the author concluded that individuals may have to decrease their dietary cholesterol to 100-150 mg/day or less to experience modest reductions in blood cholesterol. Using 27 studies, Hopkins developed an equation which showed a hyperbolic shape between blood cholesterol and added dietary cholesterol:

\[
\Delta \text{cholesterol} = 1.22 e^{-0.00384x_0} (1 - e^{-0.00136x})
\]

(6)

where

\(\Delta \text{cholesterol} = \) estimated change in serum cholesterol in mmol/l;

\(x = \) added dietary cholesterol in mg/day;

\(x_0 = \) baseline dietary cholesterol in mg/day.
Other Effects of Dietary Cholesterol

Although high dietary cholesterol does not greatly increase the levels of blood cholesterol, some researchers have expressed concerns about its effects. Mahley et al. (1978) found that volunteers fed three to six eggs a day exhibited enhanced binding activity of an HDL subfraction which might increase the risk for atherosclerosis. Shekelle et al. (1981) reported a positive correlation between dietary cholesterol and risk of death from CHD in the Western Electric Study, after adjusting for blood cholesterol. Further, Grundy (1988) has indicated that dietary cholesterol might raise the cholesterol in chylomicron and VLDL remnants rendering them more atherogenic. Hence, a high cholesterol intake may contribute to atherosclerosis in ways other than by increasing blood cholesterol levels.

Cholesterol Oxidation Products

An early study that demonstrated the differences between endogenous and exogenous cholesterol is that by Chaikoff et al. (1948). In the study, two groups of chickens had similar levels of blood cholesterol but only the chickens on the cholesterol-containing diet developed many large atherosclerotic lesions. In contrast, the chickens with endogenous hypercholesterolemia exhibited little atherosclerosis. Subsequently, Beckarth (1958) showed that cholesterol oxidizes spontaneously when exposed to air. By contrast, Smith et al. (1967) showed that endogenously synthesized cholesterol is protected from autooxidation. The role of cholesterol oxidation products in the atherosclerotic process has been shown in both in vivo and in vitro experiments (Cook and McDougal, 1968; Imai et al.,
Subsequent studies by Peng et al. in squirrel monkeys (1982) and rabbits (1987) have shown that most cholesterol oxidation products are carried by VLDL and LDL whereas only minor amounts occur in HDL. In humans, the consumption of high levels of dietary cholesterol oxidation products in a butter known as "ghee" has been suggested to account for an increased risk for CHD in a population in Trinidad with a high mortality rate from CHD (Beckles et al., 1986).

As a result of findings showing the angiototoxic nature of cholesterol oxidation products, Taylor et al. (1979) have recommended that certain processed foods high in these products, such as powered eggs and powered whole milk, be restricted. In a study, Bascoul et al. (1986) concluded that a fourth of the original cholesterol in tallow was oxidized during frying. van de Bovenkamp et al. (1988) reported that there was only 1.2 micrograms per gram of cholesterol oxides in fresh egg yolk. By contrast, the cholesterol oxides in commercial egg yolk and whole egg powder stored for one year ranged from 21 to 137 micrograms per gram.

**Toxicity of Lipid Peroxidation Products**

Prior to Morin and Peng's (1989) suggestion that the atherogenicity of VLDL and LDL may be caused by cholesterol oxidation products, Hessler et al. (1983) had shown that lipid peroxidation in LDL and VLDL resulted in toxicity. In one study, Esterbauer et al. (1991) reported that the resistance of LDL to oxidation increased through the supplementation of plasma with α-tocopherol. In twelve European populations with similar plasma lipid levels and blood pressures, Gey et al. (1991) found a strong negative correlation between mortality rates from ischemic heart
disease (IHD) and plasma vitamin E levels. The association between each of cholesterol and blood pressure and ischemic heart disease IHD was smaller than that between IHD and plasma vitamin E. In a study by Riemersma et al. (1991), the plasma vitamin E level was inversely related to the risk of angina pectoris after adjusting for age, smoking, blood pressure, lipids and relative weight. The authors recommended that populations with a high incidence of CHD increase their intake of vitamin E-rich oils.

Further evidence that a high intake of vitamin E may reduce the risk of CHD came in 1993 from the publication of two studies. The first study was the Nurses’ Health Study and it initially involved a total of 87,245 nurses who were followed for eight years. It was found that participants who consumed vitamin E supplements for more than two years had a relative risk of major coronary disease of 0.59 after adjusting for age, smoking status, risk factors for coronary disease and the intake of carotene and vitamin C when compared to women who did not use supplements (Stampfer et al., 1993).

The second study published in 1993 was the Health Professionals Follow-up Study and it initially involved a total of 39,910 male health professionals. In this study, it was found that men who took at least 100 IU of vitamin E per day for two or more years had a relative risk of coronary disease of 0.63 as compared with men who did not take vitamin E supplements after controlling for age and a number of coronary risk factors (Rimm et al., 1993).
Effects of Elevating Plasma Cholesterol

One characteristic of the vast majority of the studies on the effect of cholesterol on mortality from CHD is that they have been conducted on men. One reason for selecting men rather than women in these studies is that women typically develop CHD after menopause. A second reason for selecting men is that women have a much lower risk for CHD at any age and therefore, intervention trials with women would cost much more than the same trials with men.

In the Multiple Risk Factor Intervention Trial (MRFIT), 361,662 men from 35 to 57 year-old were followed after an initial screening of two years. When the vital status of the participants was determined after an average follow-up of twelve years, a strong graded association between total serum cholesterol and death from CHD was observed. When the relative risk for various cholesterol levels was calculated by comparing each quantile with the first quantile, which included all total serum cholesterol of less than 182 mg/dl, a progressive rise in relative risk was found. For example, the adjusted relative risk estimates for white men screened in the MRFIT were 1.0, 1.4, 1.7, 2.1 and 2.9 for each of the quantiles of total serum cholesterol (Neaton and Wentworth, 1992).

For every 1% decrease in blood cholesterol there is a 1 to 1.5% decrease in the relative risk of CHD (Hulley et al., 1981 and Mann and Marr, 1981). In various drug studies, the reduction in the relative risk of CHD has been about 2% for each
1% decrease in blood cholesterol (Lipid Research Clinics Program, 1984). These figures, however, refer to the average decrease in the relative risk of CHD in these studies. The decrease in relative risk of CHD resulting from lowering blood cholesterol by a certain amount is higher at higher levels of cholesterol. As an illustration, an individual decreasing his blood cholesterol level from 300 mg/dl to 250 mg/dl would benefit more in terms of reducing his risk of CHD than an individual lowering his blood cholesterol level from 250 mg/dl to 200 mg/dl (Grundy, 1986).

**A New Factor in CHD: Iron**

**Evidence of the role of iron in CHD**

An early observation in studies on the rates of CHD is that the rate of this disease is much lower in premenopausal women than in men of a similar age. For many years, it was thought that estrogen provided protection against heart disease to women until the onset of menopause when the ovaries secrete a lower amount of estrogen. However, in the Framingham Study it was found that women whose uterus and ovaries had been removed had about the same rate of heart disease as women whose uterus but not ovaries had been removed (Gordon et al., 1976). It was concluded from these findings that estrogen did not provide any protection against heart disease and that another factor had to explain the lower CHD rates of premenopausal women.
In 1981, Sullivan proposed that differences in the amounts of iron stored in the body could explain the difference in the rates of CHD in young men and women. In support of his hypothesis, Sullivan pointed out that in the Framingham Study the risk of heart disease in men under 45 years was about four times that of women of the same age group. This ratio was very similar to the male/female ratio of 3.8 for serum ferritin, an iron-containing protein. Also in the Framingham Study, postmenopausal women ages 50-54 had a rate of heart disease that was almost double that of premenopausal women. According to Sullivan’s hypothesis, this increase in the risk for heart disease is a result of the accumulation of iron after menopause.

Support for the hypothesis that stored iron may play a role in heart disease came from a study in 1984 by Heinecke et al. In their study, the authors showed that micromolar concentrations of iron or copper, but not zinc, stimulated the oxidation of LDL cholesterol by human arterial smooth cells in vitro. In the experiments, the oxidation of LDL cholesterol was both metal ion concentration and time-dependent. As previously stated, oxidized LDL cholesterol is known to promote atherogenesis and thus, the finding that iron facilitates the oxidation of LDL cholesterol in vitro resulted in a number of epidemiological studies on the association between the levels of stored iron and the incidence of CHD.
Although a number of animal and in vitro studies supported the finding of Heinecke et al. that iron plays a role in the oxidation of LDL cholesterol, the first major study on the association between iron status and risk for CHD was that by Salonen et al. in 1991. In their study, the authors selected almost two thousand men who were free of any symptoms of CHD in Eastern Finland and followed them for three years. After adjusting for factors such as age, smoking, blood pressure, blood glucose and HDL among others, it was found that both dietary iron and an elevated serum ferritin were risk factors for acute myocardial infarction. However, as later pointed out by Sempos et al. (1994), two limitations of Salonen et al.'s study are the very low number of participants and the short follow-up period.

Recent Epidemiological Studies

The ample evidence gathered in in vitro studies for the role of iron in the peroxidation of LDL and the subsequent publication of the Finnish study by Salonen et al. stimulated the publication of more recent epidemiological studies. In contrast to the findings by Salonen et al.'s, most of these studies did not find an association between stored iron and risk for CHD. Using data from 4,237 individuals from the HANES I Follow-up Study, Liao et al. (19) found that after adjusting for a number of risk factors there was a weak inverse association between serum iron and the risk of myocardial infarction in women but not in men. In addition, iron and trasferrin saturation were inversely but weakly associated with CHD in both sexes while total iron-binding capacity and transferrin saturation were
not associated with myocardial infarction in either sex. A limitation of this study, however, is that serum ferritin, the best indicator of iron stores, was not measured. In addition, the authors warned that serum iron, total iron-binding capacity and transferrin saturation can serve as good indicators of iron deficiency but are less sensitive to iron overload. Nevertheless, the authors concluded that the results of their study did not support the iron-CHD hypothesis.

Another study based on the association between iron and CHD involving the use of data from the NHANES I Follow-up Study was that by Sempos et al. (1994). Using data from 4,518 men and women, the authors examined the association between transferrin saturation and the risk of CHD, myocardial infarction, overall mortality and mortality from cardiovascular disease. In white men or women, the risk of CHD and myocardial infarction were not associated with the transferrin saturation levels. However, in white men and women there was an inverse significant association between transferrin saturation and each of overall mortality and mortality from cardiovascular disease. In blacks, the authors did not find any association between transferrin-saturation levels and any of the clinical outcomes.

A recent study on the association between iron and the risk of CHD was conducted by Baer et al. (1994). This study involved almost 47,000 men who were at least 30 years old and whose blood had been checked for serum iron and total
iron-binding capacity between 1969 and 1971. These individuals were then followed an average of 14.1 years. In their study, Baer et al. found that iron deficiency was not protective against acute myocardial infarction after adjusting for a variety of risk factors. In their discussion, however, the authors emphasized that the method for the detection of iron deficiency was based only on transferrin saturation because neither erythrocyte protoporphyrin nor serum ferritin had been measured in their subjects. Previously, Cook et al. (1976) had shown that the use of only one of these methods was insufficient to identify iron-deficient individuals. In addition, the authors only used the results obtained in one medical health examination at the beginning of the study. No additional measurement of iron stores were used even though hospital stays for acute myocardial infarction were collected till the end of 1991. Therefore, although no association between stored iron and risk for CHD was found, the results of the study were obtained with very limited data.

In agreement with the last three studies presented, Reunanen et al. (1995) published the results of a study that included 6,068 men and 6,102 women who were free from heart disease at entry and were followed for a mean of 14 years. In their study, the authors found no association between total iron binding capacity and coronary mortality in men and an inverse but not significant association in women. In addition, there was an inverse but not significant association between
transferrin saturation and coronary mortality in men. In women, the association between transferrin saturation and coronary mortality was U-shaped. These results were not altered after adjustment for other risk factors such as age, serum cholesterol, hypertension, smoking, diabetes and obesity. Also contrary to Salonen et al’s study, Reunanen et al. did not find an association between dietary iron and coronary risk. The authors attributed this discrepancy to differences in the method used to collect dietary intake data.

Although the results obtained in the studies headed by Liao, Sempos, Baer and Reunanen differ from those obtained in the study headed by Salonen, there are a number of differences between this last study and the previous studies. First, the number of participants in the study by Salonen et al. was much smaller than the number of participants in the other studies. Second, the mean follow-up period in Salonen’s study was only three years whereas the mean follow-up in the other studies was more than 10 years. The reason for the short follow-up in Salonen’s study was that, in contrast to the data collected in the other studies, the data used in Salonen’s study was collected in the late 1980s. This last difference explains why Salonen used serum ferritin as a measure of stored iron in his study while the other researchers used other less-specific measures. At the time when the subjects in the other studies underwent a physical examination, measures other than serum ferritin were used to estimate the amount of stored iron. In addition, the amount of iron
estimated at baseline may not have been representative of the amount of iron stored by each individual during the follow-up period.

**Iron reducing diets**

As a result of the finding that iron stimulates LDL peroxidation, Lauffer (1991) has made a number of recommendations for individuals wishing to reduce the levels of stored iron. Among other recommendations, Lauffer recommends cutting down in foods that are highly fortified in iron and eating less meat and more fruits, vegetables and grains. Lauffer also recommends a high intake of foods rich in phytic acid such as wheat bran, rye and whole wheat products. Phytic acid binds metal ions such as iron and prevents its absorption. A general rule recommended by Lauffer when selecting bread that is high in phytic acid is to choose heavier breads because heavier breads have not through gone a long fermentation process. The more time that the dough rises as a result of the fermentation process the more time that yeast has had to break down the phytic acid in the bread.

Other recommendations by Lauffer are directed to decreasing the amount of non-heme iron absorbed. Thus, Lauffer recommends a decrease in the intake of alcohol because alcohol increases the acidity of the digestive tract and this increased acidity increases the amount of non-heme iron absorbed. For the same reason, Lauffer also recommends that foods rich in vitamin C or vitamin C supplements be consumed two hours after meals. In contrast, Lauffer also
recommends that individuals who drink tea or coffee and wish to decrease the amount of iron absorbed consume these drinks with their meals or soon after. Both tea and coffee contain substances collectively known as polyphenols which bind to iron and prevent its absorption.

In addition to not cooking in iron pots, especially when preparing acidic foods, such as tomato sauce, which increases the amount of iron in the food, Lauffer also recommends avoiding iron-containing supplements. Table I shows a sample of the iron supplements currently in the market in solid or liquid form. As shown in the Table, an individual consuming any of these supplements consumes several times the RDA recommended for iron (American Pharmaceutical Association, 1993).

**Effect of Low-Fat Diets on the Intake of Vitamins and Minerals**

In addition to the concern that a low-fat diet may result in an insufficient intake of essential fatty acids, a number of studies have demonstrated that decreases in fat intake may have a negative effect on the intake of certain vitamins and minerals. Thus, although the feasibility of reducing fat intake from 40-44% to 25% and increasing the P/S ratio while increasing the intake of micronutrients has been shown (Dougherty et al., 1988), reductions in dietary fat and cholesterol have often decreased the intake of certain micronutrients such as iron and zinc. Although in the past, iron deficiency was thought to be a very common nutritional problem, iron deficiency in the American population is currently thought to be very rare. In fact, iron deficiency is currently thought to be far less common than iron overload.
Table 1. Sample of iron-containing solid and liquid supplements.

<table>
<thead>
<tr>
<th>Product name</th>
<th>Manufacturer</th>
<th>Iron (mg)</th>
<th>Percent of RDA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid supplements</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hytinic capsules</td>
<td>Hyrex</td>
<td>150</td>
<td>833</td>
</tr>
<tr>
<td>Niferex capsules</td>
<td>Central</td>
<td>150</td>
<td>833</td>
</tr>
<tr>
<td>Vitron-C Plus</td>
<td>Fisons</td>
<td>132</td>
<td>733</td>
</tr>
<tr>
<td>Ferancee-HP</td>
<td>Stuart</td>
<td>110</td>
<td>611</td>
</tr>
<tr>
<td>Fumaral spncaps</td>
<td>Vortech</td>
<td>108</td>
<td>600</td>
</tr>
<tr>
<td>Fero-Grad 500 tablets</td>
<td>Abbott</td>
<td>105</td>
<td>583</td>
</tr>
<tr>
<td>Liquid supplements</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incremin with iron syrup</td>
<td>Lederle</td>
<td>90</td>
<td>500</td>
</tr>
<tr>
<td>Secran/Fe elixir</td>
<td>Scherer</td>
<td>90</td>
<td>500</td>
</tr>
<tr>
<td>Iberet-Liquid</td>
<td>Abbott</td>
<td>78.75</td>
<td>438</td>
</tr>
<tr>
<td>Zentron liquid</td>
<td>Lilly</td>
<td>60</td>
<td>333</td>
</tr>
<tr>
<td>Geritol liquid</td>
<td>SmithKline Beecham</td>
<td>50</td>
<td>278</td>
</tr>
</tbody>
</table>

and accordingly, most individuals would possibly benefit from a decreased intake of dietary iron. In contrast, the consumption of a low-fat low-cholesterol diet has been associated in some cases with a marginal or insufficient intake of zinc.

An analysis between 1982 and 1986 of the 234 Total Diet Study foods, showed that the zinc intake of large segments of the population is insufficient and, in a number of sex-age groups, well below the RDA (Pennington et al., 1989). An insufficient intake of zinc has been reported in men (Retzlaff et al., 1991) and women (Buzzard et al., 1990) on low-fat diets. In children, a diet of less than 30% of calories as fat has been associated with unsatisfactory intake of fat-soluble vitamins (Vobecky et al., 1995). Growth failure has occurred among children receiving unsupervised treatment of hypercholesterolemia (Pugliese et al., 1987; Lifshitz and Moses, 1989). However, one recent study has found that children receiving nutrition counseling were able to consume the Step I NCEP diet with no adverse effect in their intake of minerals and vitamins (Copperman et al., 1995).

Vitamin E

Another micronutrient affected by the fat intake is vitamin E. In a study involving data from the Second National Health and Nutrition Examination Survey (NHANES II), Murphy et al. (1990) calculated that ratios of vitamin E to polyunsaturated fat decreased with higher intakes of polyunsaturated fat. It was calculated that 23% of men and 15% of women had ratios of less than 0.4 mg of vitamin E per gram of polyunsaturated fat, a ratio which has been shown to
maintain normal plasma tocopherol levels in children (Lewis and Alfin-Slater, 1969).

Foods which are rich in polyunsaturated fat tend to be high in vitamin E also. However, individuals consuming large amounts of polyunsaturated fat may be deficient in vitamin E even if their total consumption of the vitamin is high. The cause of this vitamin E deficiency is that the requirement for vitamin E increases with the amount and degree of unsaturation of polyunsaturated fat in the diet, a fact not taken into account in the 1989 RDA for vitamin E. For this reason, a number of researchers have recommended a minimum ratio of 0.6 mg of α-tocopherol for every gram of polyunsaturated fat in diets in which linoleic acid is the main fatty acid in the diet. For mixtures of polyunsaturated fatty acids, Muggli (1994) has suggested this formula for the calculation of the vitamin E demand:

\[
M_{vitE} = 0.2 \times 10^{-3} (0.3 m_1 + 2 m_2 + 3 m_3 + 4m_4+5m_5+6m_6) \quad (7)
\]

where \( M_{vitE} = \text{mol of d-α-tocopherol} \) and

\[ m_n = \text{mol of unsaturated fatty acid with n double bonds}. \]

Muggli’s formula is based on the results of experiments by Witting and Horwitt (1964) in which the ratios of α-tocopherol needed to protect 1 mol of mono-, di-, tri, tetra-, penta- and hexaenoic acid from oxidation were calculated.

One conclusion associated with the recommendation for vitamin E is that individuals attempting to replace some of the saturated fat in their diet with polyunsaturated fat must be very careful in selecting foods which are rich in
vitamin E. Figure 1 shows the ratio of \( \alpha \)-tocopherol to polyunsaturated fat in a number of cooking oils. As shown in the Figure, most of these oils, including some of the most commonly used cooking oils such as soybean and corn oils, have a vitamin E to polyunsaturated fat ratio of less than 0.6.

Conclusions

The major conclusions from studies on the effects of fat and cholesterol on CHD are:

1. Polyunsaturated fat, when substituted for saturated fat, decreases LDL cholesterol while decreasing or maintaining the levels of HDL cholesterol.

2. Monounsaturated fat, when substituted for saturated fat, decreases LDL cholesterol levels while increasing or not decreasing the levels of HDL cholesterol.

3. The effect of dietary cholesterol on blood cholesterol depends on the intake of various fats. Dietary cholesterol raises blood cholesterol levels at low P/S ratios but not at high P/S ratios.

4. Cholesterol oxidation products are atherogenic whereas pure unoxidized cholesterol is not atherogenic. Some researchers have recommended restriction of foods, such as powered eggs and powered whole milk, which contain relatively large amounts of cholesterol oxidation products.
Figure 1. Ratio of $\alpha$-tocopherol equivalents to polyunsaturated fat in various oils.

Based on data by McLaughlin and Weihrauch (1979).

$\alpha$-tocopherol equivalents = $\alpha$-tocopherol + 0.5 $\beta$-tocopherol + 0.1 $\gamma$-tocopherol + 0.3 $\alpha$-tocotrienol.
5. Both in vitro and in vivo studies have demonstrated that iron promotes LDL peroxidation. Although most epidemiological studies have failed to find an association between the amount of stored iron and the risk for CHD, these studies are limited by the method used to measure the amount of stored iron.

6. A recent study suggests that an insufficient intake or an abnormal metabolism of essential fatty acids may contribute to CHD. Although classic essential fatty acid deficiency is one of the most rare disorders, an insufficient intake of essential fatty acids is now considered one of the most common nutritional deficiencies.

7. Attempts by certain individuals to reduce the intake of fat and cholesterol have sometimes resulted in an insufficient intake of vitamins and minerals, such as zinc, and inadequate growth for children.

8. Recent studies have found that trans fatty acids in the diet increase blood cholesterol levels. Additional support for this finding could result in recommendations to decrease the consumption of foods where such trans fatty acids occur naturally (such as milk fat) or where they are present as a result of hydrogenation (certain margarines, shortenings and fats).
Dietary Recommendations

This section is divided into three parts. The first part presents some of the recommendations by government and health organizations in the United States for the intakes of fat and cholesterol. Further, because no American organization has made any recommendations for the essential fatty acids, the second part of this section presents certain recommendations for these nutrients made outside the United States. Some of the latest findings on the essential fatty acids are also included. The third part of this section presents some of the guidelines made by the National Cholesterol Education Program (NCEP) for the treatment of hypercholesterolemia. Finally, the fourth part of this section discusses the expected decrease in mortality from CHD if the recommendations for fat and cholesterol intake were followed.

Recommendations for Fat and Cholesterol Intake

Recommendations for adults

Although as late as 1980 the National Research Council recommended a maximum total fat intake of 35% of calories, more recent dietary recommendations have decreased the maximum recommended intake. Table 2 summarizes the most recent dietary recommendations for fat and cholesterol intake. In addition, the 1988 Surgeon's General Report on Nutrition and Health recommended a reduction in the
Table 2. Dietary guidelines for fat and cholesterol intake in the United States.

<table>
<thead>
<tr>
<th>Organization</th>
<th>Year</th>
<th>Total</th>
<th>Saturated</th>
<th>Poly-unsaturated</th>
<th>Mono-unsaturated</th>
<th>Cholesterol (mg/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>American Heart Association</td>
<td>1989</td>
<td>[30]</td>
<td>&lt;10</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>HHS/USDA</td>
<td>1995</td>
<td>&lt;30</td>
<td>&lt;10</td>
<td>-</td>
<td>-</td>
<td>&lt;300</td>
</tr>
<tr>
<td>American Cancer Society</td>
<td>1991</td>
<td>[30]</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>National Cholesterol Education Program</td>
<td>Step I</td>
<td>1993</td>
<td>&lt;30</td>
<td>&lt;10</td>
<td>[10]</td>
<td>10 to 15</td>
</tr>
<tr>
<td></td>
<td>Step II</td>
<td>1993</td>
<td>&lt;30</td>
<td>&lt;7</td>
<td>[10]</td>
<td>10 to 15</td>
</tr>
</tbody>
</table>

Sources:


consumption of fat, especially saturated fat, and cholesterol. Although the report did not include a recommendation for a specific level of energy intake, it stated that the energy consumed should be consistent with the energy spent and that a desirable body weight should be maintained.

In contrast to the recommendations for a low intake of fat, a number of researchers have indicated that individuals would not experience an increased risk for CHD if they consumed high levels of certain types of fat. In this respect, Grundy (1989) has suggested that individuals can increase monounsaturated fat to 20% of energy. In addition, in contrast to the recommendation for a lower fat intake, Ahrens (1979) and Sinclair (1980) have proposed that the consumption of a low-fat low-cholesterol diet does not reduce the risk of CHD.

In support of Sinclair’s hypothesis that the ratio of essential fatty acids to non-essential fatty acids plays a major role in the development of CHD, the study by Sinclair and Siguel and Lerman was presented in the first section of this chapter. As discussed in that section, these two researchers concluded that a low-fat diet which provides low levels of essential fatty acids may actually increase the risk of CHD because excess carbohydrate and protein are converted into saturated fat. As a result, Siguel and Lerman have expressed great concern with the current U.S. Department of Agriculture (USDA) nutritional recommendations portrayed by the
USDA "pyramid". This "pyramid" places those foods to be eaten in larger quantities at the bottom and those foods to be consumed in small quantities at the top. According to Siguel and Lerman, many individuals attempting to follow the recommendations represented by the "pyramid" could consume large amounts of processed foods which are deficient in essential fatty acids.

**Recommendations for children**

The American Academy of Pediatrics (AAP) has also issued specific recommendations for fat and cholesterol. Although in 1986 the AAP recommended 30 to 40% of total fat for children over 2, in 1992 it recommended about 30%. The AAP also recommended less than 10% saturated fat and less than 300 mg of cholesterol. If this diet failed to lower lipid levels to the desirable levels, the AAP recommended a Step II Diet of less than 7% saturated fat, less than 200 mg of cholesterol and no more than 30% of total fat (AAP, 1992). However, the 1992 AAP recommendations have been considered less appropriate than the 1986 AAP recommendations by at least one author who believes that the 30 to 40% fat intake is more desirable (Olson, 1995). Additional support for the view that the recommendation to consume 30% of calories as fat may be too low for children has come from the latest recommendations of the Canadian Pediatric Society (CPS). Thus, while in 1990 the CPS recommended a maximum intake of 30% of calories as fat and 10% as saturated fat for children over two years old, in 1993 it recommended a gradual change from the high fat diet of infancy to the 30% total fat, 10% saturated fat diet. This change in the recommendations for total and saturated fat intake were motivated by findings from studies, such as the Bogalusa
Heart Study which showed that children consuming less than 30% of calories as total fat had a lower intake of certain vitamins and minerals than children consuming more than 40% of calories as total fat.

**The National Cholesterol Education Program (NCEP)**

**Recommendations for Adults**

In 1993 an expert panel of the NCEP updated its guidelines to treat elevated blood cholesterol in adults of 20 years of age or more. The NCEP recommended dietary treatment for LDL levels of 160 mg/dl or more if there was no CHD or two other risk factors. Dietary therapy was also recommended if LDL was 130 mg/dl or more with no CHD but two or more risk factors or if HDL was higher than 100 mg/dl with CHD. The NCEP recommended drug treatment if LDL levels were 190 mg/dl or higher if there was no CHD or two other risk factors, if LDL was 160 mg/dl or higher without CHD or two other risk factors or if LDL was 130 mg/dl or higher with CHD. The NCEP recommended that treatment for hypercholesterolemia should begin with dietary therapy in two steps: the Step I and Step II diets.

The risk factors specified by the NCEP are: age (45 years or more in men, 55 years or more in women), a family history of premature CHD, cigarette smoking, hypertension, HDL levels of less than 35 mg/dl and diabetes mellitus. An HDL level of 60 mg/dl or more is considered a negative risk factor. Therefore, an
individual with an HDL level of 60 mg/dl or more is considered to have one less risk factor.

The NCEP also indicated that consumption lard, beef fat, coconut oil, palm oil and palm kernel oil should be reduced. The decrease in palm oil consumption to reduce blood cholesterol is in disagreement with the finding that palm oil does not raise cholesterol levels. This property is thought to possibly result from the dominant α-position of its saturated fatty acid while the antithrombotic properties of palm oil are possibly a result of the high content of tocotrienols (Elson, 1992). Although the NCEP indicated that margarine is preferable to butter, it also warned that margarine and vegetable shortenings contain trans fatty acids and should be eaten in moderation. The vegetable oils most highly recommended by the NCEP were corn oil, cottonseed oil, olive oil, canola oil, safflower oil, soybean oil and sunflower oil. The use of peanut oil was considered less desirable but no reason was indicated. It is now believed that the triglyceride structure of peanut oil accounts for its high atherogenicity because randomization of this structure greatly reduces its atherogenicity (Kritchevsky, 1991).

**Recommendations for Infants and Adolescents**

In 1991, the NCEP issued dietary recommendations for adolescents and children more than 2 years of age. The panel recommended to limit screening for high serum cholesterol to children and adolescents of a parent with high blood cholesterol (240 mg/dl) or premature cardiovascular disease. According to the
NCEP, the classification of the cholesterol levels in these children and adolescents should be:

<table>
<thead>
<tr>
<th></th>
<th>Cholesterol (mg/dl)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
</tr>
<tr>
<td>Desirable</td>
<td>&lt;170</td>
</tr>
<tr>
<td>Borderline</td>
<td>170 to 199</td>
</tr>
<tr>
<td>High</td>
<td>≥200</td>
</tr>
</tbody>
</table>

The NCEP recommended the Step I Diet when the total cholesterol or LDL levels were borderline. The NCEP also recommended the Step-One Diet, followed if necessary by the Step-Two Diet, when the total cholesterol or the LDL levels were high. Both the Step-One Diet and the Step-Two Diet are the same for children, adolescents and adults. Finally, the NCEP recommended that drug therapy be considered in children of at least 10 years of age after 6 months to 1 year of dietary therapy if LDL-cholesterol levels remain at 190 mg/dl or more or at 160 mg/dl or more and there are other risk factors present (NCEP, 1991).

**Effectiveness of the NCEP Recommendations**

Three studies which have demonstrated the effectiveness of the NCEP dietary guidelines to lower blood cholesterol are those by Ginsberg et al. (1990), Barr et al. (1992) and Schaefer et al. (1996). In contrast to the proven effectiveness of the NCEP dietary guidelines, Bush and Riedel (1991) have shown that a high proportion of persons at high risk of CHD would not be evaluated for their
lipoprotein levels under the NCEP guidelines. Miller et al. (1992) found that men and women with coronary artery disease and total cholesterol levels considered desirable by the NCEP standards had an increased risk of subsequent cardiovascular events if HDL was low or the ratio of total cholesterol to HDL was high. The authors concluded that the NCEP classification of cholesterol levels was inadequate to predict the risk for CHD.

As a result of the "Report of the Conference on Low Blood Cholesterol", concern has also been expressed about extrapolating to women findings in men. Although an association between high blood cholesterol and mortality from CHD has been found for both men and women, no association has been found between high blood cholesterol and mortality from coronary cardiovascular deaths in women (Jacobs et al., 1992). As indicated by Hulley et al. (1992), the increased incidence of deaths caused by strokes at low cholesterol levels partially counterbalances the higher mortality from CHD at higher cholesterol levels.

**Validity of the NCEP guidelines**

Although changes by participants in clinical trials to the Step I and Step II diets have resulted in decreases in blood cholesterol levels, the NCEP guidelines are both inadequate and insufficient to achieve a major reduction in the incidence of CHD among the American population. First, the recommended LDL cholesterol goal of 160 mg/dl for individuals free from CHD and with less than two risk
factors is not sufficiently low. According to the NCEP, a level of 160 mg/dl of LDL cholesterol corresponds to about 240 mg/dl of total cholesterol. As previously stated, in the MRFIT an increased risk for CHD was observed in participants with more than 180 mg/dl when compared to participants with less than 180 mg/dl. Accordingly, an individual meeting his LDL cholesterol goal can still be at an increased risk for CHD.

Support for the idea that the NCEP should have selected lower levels of blood cholesterol as acceptable comes from a study by Miller et al. (1992). In that study, men and women with coronary artery disease and total cholesterol levels considered desirable by the NCEP had an increased risk of subsequent cardiovascular events if HDL or the ratio of total cholesterol to HDL was low. The authors concluded that the NCEP classification of cholesterol levels was inadequate to predict the risk for CHD. In addition, Bush and Riedel (1991) have shown that a high proportion of persons at high risk of CHD would not be evaluated for their lipoprotein levels under the NCEP guidelines.

A second area in which the NCEP guidelines are inadequate is in recommending lipid-lowering drugs for individuals unable to meet their LDL cholesterol goal after consuming the Step II diet for three months. This recommendation misleads individuals into erroneously believing that it is
impossible to lower their cholesterol levels without exposing themselves to the side effects of lipid-lowering drugs. As shown by the Lifestyle Heart Trial (Ornish et al., 1990), not only can a very low saturated fat and cholesterol diet reduce blood cholesterol levels but it can actually regress the blockage in the arteries without the use of drugs. Therefore, to those individuals for whom the Step II is insufficient for the purpose of lowering blood cholesterol levels the NCEP could have recommended more diets that are lower in saturated fat and cholesterol. Samples of these diets could include a Step III diet (with less than 5% saturated fat and less than 100 mg of cholesterol) and a Step IV diet (with less than 3% of saturated fat and less than 20 mg of cholesterol).

A third area in which the NCEP guidelines are inadequate is in establishing a maximum recommended intake for fat and cholesterol without considering the role of other nutrients in reducing or increasing the risk for CHD. The NCEP guidelines could have included some recommendations for the intake of micronutrients with antioxidant activity such as vitamins C and E and could have also included a list of foods rich in these vitamins.

In addition, the NCEP guidelines should have included a discussion on the increased risk for CHD in individuals suffering from iron overload as well as a general description of the laboratory methods used to determine its presence. The NCEP guidelines could also have included a list of recommendations for those
individuals wishing to decrease the amount of iron stored in their body. Some of the possible recommendations for an iron-reducing diet will be presented in the last section of this chapter.

A fourth area in which the NCEP guidelines are inadequate is in the risk factors for CHD which it included in its recommendations. First, the NCEP did not include hemochromatosis as one of the risk factors for CHD even though a much larger percentage of the population is affected by this disease than previously thought. Second, the risk factors are not gender-specific even though it is known that there are gender-specific risk factors for CHD. As an illustration, it was shown in the Framingham Study that elevated triglycerides are a risk factor for women only. In addition, the inverse correlation between HDL and CHD is stronger in women than in men as shown in the Framingham Study and the Lipid Research Clinics follow-up. Despite these findings, the NCEP did not make any attempt to include any gender-specific risk factors such as triglycerides or to establish different cut-off points for the low and high levels of HDL considered as risk factors.

**Estimated Decrease in Mortality from CHD**

A number of analyses have attempted to quantify the theoretical effect of reducing the percentage of total fat consumed by the American population. As an illustration of this types of analysis, the analyses by Browner et al. (1991) and by Grover et al. (1994) are presented here. Like Grover et al.'s analysis, the analyses
by both Kinlay et al. (1992) and Taylor et al. (1987) used a Framingham logistic equation and will not be discussed here.

**Analysis by Browner et al.**

To estimate some of the benefits from following the recommendation for total fat intake, Browner et al. (1991) calculated the reduction in mortality from CHD that would occur if Americans consuming more than 30% of total fat decreased their intake to 30% by reducing their saturated fat intake. The authors assumed a decrease of 20 mg/day of dietary cholesterol intake for every percent decrease in saturated fat intake. Using Keys' and Hegsted's 1965 equations and data from NHANES II, the authors calculated that for every percent decrease in saturated fat there would be a 3 mg/dl decrease in blood cholesterol.

Using each person's decrease in blood cholesterol, Browner et al. estimated the resulting decrease in risk of mortality from CHD using the relative risk of mortality from CHD for every 20 mg/dl increase in cholesterol from data from the MRFIT and the Framingham Study. The authors estimated a 20 mg/dl fall in cholesterol if fat were consumed at a maximum of 30% of energy. The reduction in mortality from CHD was calculated for both sexes at certain selected ages and varied from a maximum of 20% for men age 35 to a minimum of 5% for men age 65 or older. Only taking into account the effect that a decrease would have on mortality from CHD, Browner et al. calculated that restricting fat intake to a maximum of 30%
would increase the average life expectancy by about a month and prevent the
deaths of 16,500 women and 19,800 men every year.

**Analysis by Grover et al.**

In a more recent study, Grover et al (1994) used a computer model to estimate the expected increase in life expectancy that would result from reductions in the intake of dietary saturated fat and cholesterol. Although there are no long-term clinical trials in which the model could be tested, the model estimated annual CHD event rates that in the vast majority of cases fell within the 95% confidence interval of the observed results of the Helsinki Heart Study and the MRFIT.

As part of a larger CHD model, the model developed by Grover et al. includes a primary model which uses this formula:

$$\text{Annual probability (all CHD events) } = \frac{1}{8} \times e^{(\text{RISK})/e^{(1+\text{RISK})}} \times (\text{HDL}_{\text{mod}})$$

where: $\text{HDL}_{\text{mod}} = e^{(1.80-0.40 \times \text{HDL})}$ for men.

$\text{HDL}_{\text{mod}}$ is the gender-specific modifier that Grover et al. estimated by fitting an exponential curve to the HDL multipliers published by Gordon et al. (1982) for the Framingham Heart Study. In addition, $\text{RISK}$ is a function of sex-specific coefficients from the Framingham Heart Study. Thus, for men:

$$\text{RISK} = (0.29 \text{ AGE}) - (0.0015 \text{ AGE}^2) + (0.02 \text{ CHL}) + (0.02 \text{ DBP}) + (0.44 \text{ CIG}) + (0.62 \text{ LVH}) + (0.28 \text{ GLU}) - (0.00027 \text{ (CHL) AGE}) - 17.01$$

where: $\text{AGE}$: age in years,

$\text{CHL}$: total cholesterol level,

$\text{DBP}$: diastolic blood pressure,
CIG: presence of cigarette smoking.
LVH: left ventricular hypertrophy and
GLU: presence of glucose intolerance.

Using their CHD model, Grover et al. estimated that reductions in dietary cholesterol intake to 300 mg/day and of saturated fat to 10% of calories would decrease blood cholesterol levels in the range of 17.4 mg/dl up to 21.3 mg/dl for men and 4.6 mg/dl up to 7.0 mg/dl for women. This study was performed using the NHANES II estimates of daily saturated fat and cholesterol intake and Keys' 1965 equation. The reason for selecting the Keys' 1965 equation instead of any of the equations developed by Hegsted throughout the years was not explained in this analysis or in a previously published study by the authors (Grover et al., 1992). Combining data from NHANES II and the Canada Health Survey and using a computer model, the authors estimated that these dietary changes would increase the life span of men on the diet by 0.37 to 3.55 months and that of women by 0.16 to 0.66 months.

**The Essential Fatty Acids**

**Recommendations for Intake**

In the last few decades it has been known that linoleic acid (18:3 n-6) and linolenic acid (18:3 n-3) are essential in the human diet. Although as early as 1977 a FAO/WHO report on dietary fat recommended minimum intakes of essential fatty acids, the 1989 edition of the RDAs did not establish RDAs for these nutrients. The justification was that essential fatty acid deficiency had only been
reported in patients with problems related to fat intake or absorption. Nevertheless, the possibility of establishing requirements in the future was indicated.

Recommendations for the essential fatty acids are included in the 1988 Nordic Nutrition Recommendations and the 1990 Canadian Nutrition Recommendations. In addition, the amounts of α-linolenic acid and of longer chain fatty acids (EPA and DHA) sufficient to prevent deficiency in adults were estimated in the 1988 NATO Advanced Research Workshop on Dietary ω3 and ω6 Fatty Acids (Simopoulos, 1989). A summary of these recommendations is shown in Table 3. Not shown are the Canadian Nutrition Recommendations that 3% and 0.5% of energy should be from ω6 and ω3 fatty acids respectively and that a ratio of 4:1 to 10:1 of ω6 to ω3 fatty acids should be maintained. The Canadian Nutrition Recommendations advised that infants consuming no ω3 fatty acids with 20 or 22 carbons should consume at least 1% of linolenic acid. Not shown in Table 3 is the 1985 recommendation by the AAP that infants consume a minimum of 2.7% of linoleic acid.

**Essential Nature of DHA**

Most research on the essential fatty acids has taken place within the past few years. For this reason, certain fatty acids previously not considered essential, because of the existence of biochemical pathways for their synthesis from essential
Table 3. FAO/WHO, NATO, Nordic and Canadian Recommendations for the essential fatty acids.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Linoleic (%)</td>
<td>Linoleic/Linolenic Ratio</td>
<td>Linolenic Acid (mg/d)</td>
<td>Longer-chain ω3 fatty acids - DHA and EPA (mg/d)</td>
</tr>
<tr>
<td>Infants</td>
<td>4 to 10</td>
<td>5 to 10</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Adults</td>
<td>4 to 10</td>
<td>5 to 10</td>
<td>800 to 1,000</td>
<td>300 to 400</td>
</tr>
<tr>
<td>Pregnancy</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Lactation</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

* Depends on age and sex.
† Additional amount which depends on trimester of pregnancy.
‡ Additional amount.
fatty acids, are now thought to be necessary in the diet. Accordingly, the few existing official recommendations for the essential fatty acids have been challenged.

A fatty acid now thought to be essential in certain individuals, such as neonates, is docosahexaenoic acid (C22:6 n-3; DHA) (Farquharson et al., 1992; Innis, 1992; Uauy et al., 1992). Most infant formulas only contain vegetable oils as sources of fat and, therefore, lack any fatty acids with more than 18 carbons because these long fatty acids are usually only found in animal tissues. The use of infant formulas results in lower concentrations of DHA in the membranes of red blood cells when compared to the use of human milk (Carlson et al., 1986; Innis, 1992). It is practically impossible to use available foods to supplement the diet of infants fed formula to provide a level of long-chain polyunsaturated fats similar to that consumed by breast-fed infants (Jackson and Gibson, 1989). Finally, long-chain fatty acids may affect the development of CHD because of the effect of the ratio of linoleic acid to EPA and DHA on platelet function (Leaf and Weber, 1988).

Validity of the Recommendations

An illustration of findings which have been used to challenge the validity of both the 1977 FAO/WHO recommendations and the 1988 Nordic Nutrition Recommendations is a study by Bjerve in 1989. The author showed that to normalize the concentrations of ω3 fatty acids in plasma and red blood cell lipids
an intake of 0.54 to 1.2% of α-linolenic acid was required. In view of this finding and the recommendation of a 5 to 7 ratio of linoleic to linolenic acid, Pedersen (1991) has suggested that in future editions of the Nordic Nutrition Recommendations an intake of 5% linoleic acid and of 1% of linolenic acid and other ω3 fatty acids be recommended. In contrast, Okuyama (1992) has recommended that the intakes ω6 fatty acids be lowered to 2-4% and those of ω3 fatty acids be increased more than those of ω6 fatty acids. Okuyama has indicated that a ratio of 3 to 4 ω3 to ω6 has been the best in animal experiments and has brought to attention the finding by Dyerberg (1986) of a 2.8 ω3 to ω6 ratio in the diet of Eskimos in contrast to the 0.1 to 0.2 ratio of American diets. Of the commonly used vegetable oils, soybean oil has the highest content of linolenic acid with about 7% of calories as this acid.

In addition to the finding that a higher intake of essential fatty acids than recommended by the Nordic or Canadian recommendations would be highly beneficial, another study by Pettei et al. (1991) has shown that the previously stated 1985 recommendation by the AAP of 2.7% of calories as linoleic acid in the diets of infants is insufficient. In their work, Pettei et al. showed that the use of a formula containing 3% of linoleic acid results in linoleic acid deficiency in infants exhibiting fat malabsorption (Pettei et al., 1991).
Amounts of Linoleic and Linolenic Acids in the Food Supply

Intakes of Essential Fatty Acids

Unlike Great Britain, for which Bull (1983) has calculated the intake of specific fatty acids, none of the nationwide food consumption surveys in the U.S. have estimated the intake of specific fatty acids. Hence, estimates of the intake of essential fatty acids by the American population can only be obtained from two other sources. The first source is the very few population studies which have calculated the intakes of specific fatty acids to study the relationship between the intake of these specific fatty acids and the incidence of certain illnesses such as CHD. The second source is the estimation of the per capita availability of the essential fatty acids based on food production data.

Population Studies

One study which has estimated the consumption of specific fatty acids in the United States is the MRFIT. In this study, the usual care (UC) group of more than 6,400 middle age men provided 24-hour dietary recalls five times over a seven year period. Linoleic acid provided 87% of the mean total polyunsaturated fat while 10% was provided by linolenic acid and 0.5% by DHA (Dolecek, 1992). The proportions of polyunsaturated fatty acids that were $w_6$ fatty acids and $\omega 3$ fatty acids were 88.1% and 11.1% respectively. There was a great variability in the consumption of DHA, EPA and docosapentaenoic acid with 20% of the group reporting zero intake for the sum of these three acids.
In another study, Kim et al. (1984) calculated that the per capita intake of linoleic acid ranged from 16 to 20 grams/day for men and was about 12 grams/day for women. Marston and Welsh (1984) estimated that the total availability of this acid in the food supply was about 26 grams/day. A minimum daily intake of 3 to 6 grams of linoleic acid is required by the average adult (NRC, 1989). Finally, using food supply data, Raper et al. (1992) calculated that the per capita intake of linolenic acid steadily increased from 1.5 g/day to 2.8 g/day, largely as a result of the increased consumption of soybean oil.

**Per Capita Availability**

The per capita availability of linolenic acid in the U.S. diet was calculated by Hunter (1990) to be between 1.7 and 2.2 grams/day in 1986. Of this amount, it was estimated that about 1.2 grams was supplied by vegetable oil products and from 0.5 to 1 gram from other foods such as dairy products, beans, broccoli and lettuce. For a 2,700 kcal/day diet, Hunter claimed that the food supply provided enough linolenic acid to meet Holman et al.'s recommendation of 0.54% of this acid. However, Bjerve et al. (1989) has indicated that a much higher percentage of this fatty acid may be required.

Based on his calculations of the availability of linolenic acid and those by Kim et al. for linoleic acid, Hunter (1990) estimated a dietary ratio of linoleic to linolenic acid of about 10. This estimate is in agreement with that of Adam (1989) on the basis of world production data on edible fats and oils. This ratio is larger than the recommended ratios for the intakes of ω6 and ω3 fatty acids. One difficulty
associated with meeting this recommendation is that industrialization and the use of certain agricultural practices decrease the \( \omega_3 \) fatty acids in foods (van Vliet and Katan, 1990; Crawford, 1968; Simopoulos and Salem, 1986; Simopoulos, 1991).

Concerns about the low supply of essential fatty acids in the American diet were expressed in Simopoulos' (1991) outstanding review on the role of omega-3 fatty acids. In his review, Simopoulos claims that Western diets are extremely deficient in \( \omega_3 \) fatty acids, partly because of the use of new technologies such as the continuous screw press and the steam-vacuum deodorization which allowed the industrial production of vegetable oils for cooking. According to Simopoulos, the availability of large quantities of vegetable oils led to an increase in the consumption of fat in the American diet in the past and to a great intake of \( \omega_6 \) fatty acids. In this way, the hydrogenation in oils such as soybean oil decreases the amount of linolenic acid while maintaining high levels of linoleic acid. In addition, the use of modern agricultural practices, such as the feeding of livestock with grains that are rich in \( \omega_6 \) fatty acids led to an increased consumption of \( \omega_6 \) fatty acids and to a decreased intake of \( \omega_3 \) fatty acids.

In his review, Simopoulos gives a number of examples of naturally edible plants and animals which have a high content of \( \omega_3 \) fatty acids in contrast to the plants and animals grown by the use of modern agricultural practices. As an illustration, purslane has a content of \( \omega_3 \) fatty acids which is several times larger by wet weight than spinach or buttercrunch or red leaf lettuce. Not surprisingly, deer that forage
on ferns and mosses have a much higher content of ω3 fatty acids in their meat than cattle fed grains which are comparatively high in ω6 fatty acids and low in ω3 fatty acids. In addition, as shown by van Vliet and Katan (1990), wild fish has a higher ratio of ω3 to ω6 fatty acids than cultured fish.

Estimations have recently been made on the amounts of essential fatty acids in the food supply other than linolenic acid. Raper et al. (1992) estimated that the amounts of EPA and DHA available in the American diet were about 46 and 78 mg respectively in 1985. Fish accounted for 90% of the EPA and 75% of the DHA. In addition, because of the increasing use of fish meal in the chicken industry, poultry has become an important source of EPA and an even more important source of DHA. A shortcoming of Raper et al.'s estimation of the amounts of EPA and DHA available at various times is their use of current food composition data for the entire time series. In view of the findings by Simopoulos (1991) regarding changes in the fat content of foods as a result of modern agricultural practices, the use of current composition tables to estimate the content of EPA and DHA in previous decades is questionable.

Although the previous values for the availability of certain essential fatty acids in the diet indicate that it may be difficult for humans to consume a sufficient level of these fatty acids, it is interesting that certain agricultural practices can greatly increase the intake of these nutrients. An illustration of these agricultural practices is the feeding of flaxseed to chickens for the purpose of increasing the α-linolenic
acid and docosahexaenoic acid of eggs (Ferrier et al, 1995). According to these authors, in the United States the consumption of a single egg of a chicken fed a 10% flaxseed diet would increase the total average intake of α-linolenic acid and docosahexaenoic acid by 9% and 104% respectively.

Conclusions

The major conclusions from the recommendations for fat and cholesterol intake are:

1. Although dietary recommendations for the intake of fat and cholesterol have been made for children over two, the benefits of reducing the intakes of fat and cholesterol to the recommended levels may be outweighed by a reduced intake of certain vitamins and minerals.

2. Most organizations recommend a maximum intake of 30% of total fat, 10% each of saturated and polyunsaturated fats and 300 mg of cholesterol per day for adults.

3. Many of the organizations do not set a recommendation for the intake of monounsaturated fat. A few organizations or individuals typically recommend a 10-15% intake of monounsaturated fat.

4. The NCEP has recommended an increase in the intake of highly unsaturated vegetable oils such as corn, cottonseed, olive, canola, safflower, soybean and
sunflower oils and a decrease in the intake of butter, lard, beef fat, coconut oil, palm oil and palm kernel oil.

5. The validity and usefulness of the NCEP guidelines continues to be challenged as a result of new scientific evidence. The effectiveness of reducing blood cholesterol levels in women to lower the risk of CHD seems to be offset by an increased risk for mortality from other cardiovascular diseases.

6. The Nordic Nutrition Recommendations and the Canadian Nutrition Recommendations are two examples of official national recommendations which have so far established recommendations for the essential fatty acids.

7. Recent research has shown that although DHA can be synthesized from linolenic acid, it should be considered an essential fatty acid in infants.

8. Formula-fed infants do not consume essential fatty acids with 20 or 22 carbons because of the exclusive use of vegetable oils as sources of fatty acids.

9. The consumption of a certain ratio of linoleic to linolenic acid appears to be critical to lower those conditions which favor thrombosis.
10. Since it has been estimated that there is only one gram of linolenic acid available for every ten grams of linoleic acid in the food supply, special efforts have to be made to ensure the consumption of foods high in linolenic acid such as certain fish oils and soybean oil.

11. Recent studies have demonstrated that the content of certain ω3 fatty acids can be greatly increased by the use of a number of practices such as the feeding of certain oils or naturally occurring foods to animals.
CHAPTER III

MATERIALS AND METHODS

In order to achieve the objectives listed in the Introduction and to reach conclusions that could be extended to the entire American population, it is necessary to use data on dietary intake and blood cholesterol levels representative of the population. These type of data are only available from nationwide surveys such as the National Health and Nutrition Examination Survey (NHANES) and the Nationwide Food Consumption Survey (NFCS). Therefore, this chapter describes how the most recently available NHANES and NFCS were used in this study to achieve the objectives listed in Chapter I.

This chapter consists of five sections. The first section briefly describes some of the analyses in this study. The first section also gives the specific reasons why a certain database was selected to complete a particular analysis. The second section describes the use of the NHANES III in this study. The third section describes the use of the NFCS 1987-88 in this study. The fourth section forewarns about the limitations specifically associated with the use of the NFCS 1987-88. Finally, the fifth section refers to the limitations associated with the interpretation of the results of the study.

Analyses included in the study

The NHANES III was used for most of the analyses in this study because it is the most recent nationwide survey on food consumption. It was conducted between

67
1988 and 1994. However, the NFCS 1987-88 was used for those analyses for which the NHANES III did not provide the necessary data. Table 4 shows the reason why the NHANES III or the NFCS 1987-88 was selected for each analysis in this study.

As shown in Table 4, the first analysis seeks to evaluate the effect of reducing the intake of saturated fat and cholesterol on the levels of blood cholesterol. The NHANES III was used for this analysis because, unlike the NFCS 1987-88, data were collected on both dietary intake and blood cholesterol levels. In addition, as stated in the Review of Literature, very low and very high levels of HDL are considered a positive and a negative risk factor for CHD, respectively. Therefore, the NHANES III was also used for the analysis of the risk factors for CHD in the population.

Table 4 lists an analysis on the intake of essential fatty acids. Although this analysis could be completed with data from the NHANES III, the analysis was completed using data from the NFCS 1987-88 because the NFCS 1987-88 had three days of dietary intake as compared to only one day for the NHANES III. The analysis for the association between the intake of fat and the intake of vitamins and minerals was mostly completed with data from the NFCS 1987-88. In addition to three days of dietary intake, the NFCS 1987-88 database included the percentage of the 1989 RDA for each nutrient consumed by each participant. Finally, the analysis of the use of supplements by the American population could only be completed with the NFCS 1987-88 because the NHANES III did not provide these data.
Table 4. Analyses in this study and criteria for selecting the appropriate data for each analysis.

<table>
<thead>
<tr>
<th>Analysis of interest</th>
<th>Data needed</th>
<th>NHANES III (P1)</th>
<th>NFCS 1987-88</th>
<th>Chapter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Available</td>
<td>Limitation</td>
<td>Available</td>
</tr>
<tr>
<td>Effect of reducing dietary saturated fat and cholesterol on blood cholesterol</td>
<td>Dietary intake</td>
<td>Yes</td>
<td>Only one day</td>
<td>Yes</td>
</tr>
<tr>
<td>Blood cholesterol</td>
<td>Yes</td>
<td>Only one value</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Risk factors</td>
<td>Risk factors</td>
<td>All</td>
<td>Limited information about CHD</td>
<td>Some</td>
</tr>
<tr>
<td>Intake of essential fatty acids</td>
<td>Dietary intake</td>
<td>Can be estimated</td>
<td>Only one day</td>
<td>Can be estimated</td>
</tr>
<tr>
<td>Association between intake of fat and vitamins and minerals</td>
<td>Dietary intake</td>
<td>Yes (no RDA data)</td>
<td>Includes extremely small energy intake values.</td>
<td>Yes (including RDA data)</td>
</tr>
<tr>
<td>Use of supplements</td>
<td>Questionnaire</td>
<td>No</td>
<td>-</td>
<td>Yes</td>
</tr>
</tbody>
</table>
NHANES III

This section is divided into seven parts. The first part provides some general background for the NHANES III. The second part provides a brief overview of the sample design of the NHANES III and describes some of the groups that were oversampled in the survey. The third part describes some of the data collected in the NHANES III with special emphasis on the data that was either used in this study or that could be used in future analyses on the association between diet and CHD. The fourth part describes the major characteristics of the first phase of the NHANES III and the sample from the NHANES III used in this study. The fifth part describes how the LDL cholesterol goal of each individual was determined by the presence of CHD and of other risk factors for the disease. The sixth part describes the method used to estimate the decrease in LDL cholesterol that individuals switching to the Step I or Step II diets would theoretically experience. The seventh part lists the calculations and statistical analyses performed in this study which involve the use of data from the NHANES III.

General Background

The NHANES III was the seventh national examination study conducted in the United States. The first National Health Examination Survey (NHES) was conducted in 1960 and two more studies with the same name were conducted in
the 1960’s. In 1970, the name of the survey was changed to the National Health and Nutrition Examination Survey (NHANES) when a large nutrition component was added to the design. In 1982-84, a special study of the Hispanic population was completed. The NHANES III was completed between 1988 and 1994 in two phases of equal length and sample sizes. In addition to being a descriptive survey and an analytic study, the NHANES III was a longitudinal study. The NHANES III was the first NHANES to include children as young as 2 months of age and as old as 75 years and older. At this time, only some data for the first phase of NHANES III, hereafter called NHANES III (P1), conducted between October 1988 and October 1991, has been released.

**Sampling**

The NHANES III used a self-weighting, multistage, stratified area probability sample of households so as to represent the total civilian, noninstitutionalized population aged two months and older in the fifty states. The NHANES III sample consisted of two sets of 44 and 45 locations allocated, respectively, to the first phase (1988-91) and to the second phase (1991-94) of the survey. Thus, unbiased estimates could be independently obtained in each one of the two phases of the survey as well as in both phases combined. The number of sample persons included in both phases of the survey was 40,600 (Center for Disease Control and Prevention, 1994).
The NHANES III oversampled both very young children (aged 2 months to 5 years) and old individuals (aged 60 years and more). To minimize nonresponse among very young children and old participants, a home examination was developed for those participants unable or unwilling to come to the medical examination center (MEC) for a complete examination.

In previous national surveys, the sample sizes for blacks and Mexican-Americans were too small to obtain adequate estimates for those subgroups. For this reason, the NHANES III was the first national survey that oversampled these two populations. Thus, although blacks and Mexican-Americans comprise only 12% and 5% of the American population, respectively, each of these two groups separately comprised 30% of the sample in the NHANES III. Thus the large number of black and Mexican-American participants will make it possible for the data obtained for these two populations to serve as reference standards.

**Health data collection**

Among the health data collected in the NHANES III (P1) were measurements of blood pressure, blood lipid levels and electrocardiograms (ECG's). Total serum cholesterol, LDL cholesterol and fasting serum triglyceride levels were measured in both phases of the survey. Measurements of apolipoproteins A1 and B were included in phase I of the survey. In addition, participants aged 17 years and older provided information on family history of heart attack, the respondent’s history of
heart attack, stroke, transient ischemic attacks and congestive heart failure. The respondents also answered a number of questions related to their history, knowledge and treatment of high blood pressure and high blood cholesterol.

After an initial interview, participants in the NHANES III (P1) were subjected to a physical examination at a mobile examination center (MEC) where a variety of physical tests were conducted. As part of the examination at the MEC, a 24-hour dietary interview was collected. However, for homebound participants, a home examination was conducted but this examination did not include a 24-hour dietary interview. The NHANES III (P1) is the most recently available data for dietary intake for the American population.

**Dietary intake**

**The Nutrient Data Base**

The Nutrient Data Base used in NHANES III was a special modified version of release 5.5. In the Nutrient Data Base used in the NHANES III, the 1989 change by the USDA of the cholesterol value of eggs, such as that for large eggs from 274 mg to 213 mg, was included.

**Dietary data collection**

In the NHANES III (P1) a multiple pass approach was used to collect the dietary intake data. There were a total of four passes used to collect the data. In the first pass, each participant individually used a personal computer to report the food
consumed during the previous 24 hours. In the second pass, an interviewer used a personal computer to ask questions about each one of the foods consumed by the participant. As an illustration, if a participant reported in the first pass of the dietary recall that he had consumed coffee, the interviewer asked him a number of questions about any food item which the respondent may have added to the coffee. All these questions were available to the interviewer as a set of computer screens containing various questions for each of the food items reportedly consumed by the participant.

In the third pass of the dietary recall, the interviewer described to the participant the foods which the participant had reportedly consumed. In this pass, the interviewer probed the participant for additional information concerning the participant's dietary intake. Finally, in the fourth pass of the dietary recall the interviewer asked the participant if he had consumed any of a list of foods commonly forgotten during dietary recall (McDowell, 1996).

Sample Data Used in Study

Source of Data
The interim data from NHANES III (P1) was obtained for free from the National Center for Health Statistics. These interim data were released in September 1995 on five 3.5 inch computer diskettes and included dietary food intake and serum cholesterol and lipid levels. With the exception of serum
cholesterol and lipid levels, this release did not include any laboratory data. Data for laboratory analyses will be released in late 1996 (McDowell, 1996). All the procedures involving the use of the interim data were performed using version 6.0.6 of SAS on an IBM 3090 with the MVS operating system.

**Target Population**

The target population for the analyses involving the NHANES III (P1) was all individuals to whom the recommendations by the Adult Treatment Panel of the NCEP are directed, that is, individuals at least twenty years old. For the NHANES III (P1), the age of the individual during the MEC examination was selected because all the dietary intake and blood cholesterol data were collected during the MEC examination. For each analysis in this study, an attempt was made to include the maximum number of individuals with the appropriate data. Table 5 shows how the groups of individuals for the various analyses were selected.

In order to select the individuals for each analysis, a number of preliminary analyses were conducted in the present study. One of the objectives of these preliminary analyses was to select a group of individuals to estimate the effects of changes in the diet on total and LDL cholesterol levels. In addition to requiring complete and reliable dietary intake data and lipoprotein analysis for each individual in the analysis, an attempt was made to select individuals who were thought to be in energy balance. The reason for this last requirement was that the
Table 5. Number of individuals in phase I of NHANES III and criteria for selecting individuals in this study.

<table>
<thead>
<tr>
<th>Target population</th>
<th>Selection criteria</th>
<th>N(^1)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entire population</td>
<td>Sample</td>
<td>20,277</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Interviewed</td>
<td>17,464</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Examined</td>
<td>15,884</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Complete and reliable dietary recall</td>
<td>14,784</td>
<td>-</td>
</tr>
<tr>
<td>Population age ≥20 years</td>
<td>Age ≥20 years</td>
<td>7,933</td>
<td>← Estimation of 10th and 90th percentiles of energy intake.(^4) ≤ In Table 9.</td>
</tr>
<tr>
<td></td>
<td>Total cholesterol analysis</td>
<td>7,415</td>
<td>← In Table 9.</td>
</tr>
<tr>
<td></td>
<td>Complete lipoprotein analysis(^2)</td>
<td>7,346</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Triglycerides&lt;400 mg/dl(^3)</td>
<td>7,156</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>LDL&gt;20 mg/ml</td>
<td>7,153</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>HDL&lt;120 mg/ml</td>
<td>7,136</td>
<td>← In Table 9.</td>
</tr>
<tr>
<td></td>
<td>Consumed between 10th and 90th percentile of energy.</td>
<td>5,744</td>
<td>← Subgroups in Table 9.</td>
</tr>
</tbody>
</table>

1. Any number of individuals is a subset of the previous row.
2. Each of triglycerides, total and HDL cholesterol measured.
3. Triglyceride >400 mg/dl cannot be used to calculate LDL cholesterol using the Friedewald equation.
4. Estimation based on age and sex (see text) so that only individuals within 10th to 90th percentile of energy intake were included in analysis involving the use of equations to predict changes in total or LDL cholesterol from dietary changes.
predictive equations developed by Hegsted and Hopkins were based on individuals in energy balance. Since there was no way of knowing which individuals were in energy balance, individuals with unusual energy intakes were excluded from the analysis. However, although the survey included a question about whether or not the amount of food reportedly consumed was usual, the responses to this question were not reliable because individuals with extremely low (close to no caloric intake) and extremely high (as many as 17,000 kcal) caloric intake often reported that their food intake was usual. For this reason, individuals were excluded according to whether or not the actual energy intake they reported was below the 10th percentile or above the 90th percentile of energy reportedly consumed by other individuals in their same sex-age group.

First, the 10th and 90th energy percentiles consumed by the 7,933 individuals 20 years and older who had provided complete and reliable dietary intake data were calculated. For this estimation of energy intake, these 7,933 individuals were divided into a total of twenty-six sex-age groups. Thus, for men and women these age groups were created: 20-24, 25-29, 30-34, 35-39, 40-44, 45-49, 50-54, 55-59, 60-64, 65-69, 70-74, 75-79 and ‘80 and more’. For each sex-age group, the 10th and 90th percentiles of energy intake were calculated to be later used as cut-off points to eliminate individuals with extreme energy intakes. Determining extreme energy intakes using the actual data being analyzed was thought to be a better
approach than the use of arbitrarily selected percentages of the RDA for energy for each individual because it was thought that the amount of food being reported could be influenced by the method used to collect the data.

As previously stated, an attempt was made to include as many individuals as possible in any particular analysis. Therefore, all 7,415 individuals with reported values for total serum cholesterol were included in the estimation of total serum cholesterol values in the target population. Although 7,415 individuals had data for total serum cholesterol, not all of them had data for the triglycerides or the various lipoproteins. Table 5 shows how individuals with incomplete or questionable data for triglycerides or the various lipoproteins were eliminated from the sample used to estimate the proportion of individuals meeting their LDL cholesterol goal. Included in this last analysis were 7,136 individuals. This same group of individuals was also used for an analysis of the risk factors for CHD in the population because it was the largest group of individuals with data on all factors, including HDL levels.

The last type of analysis involved the use of predictive equations for changes in total and LDL cholesterol resulting from changes in dietary fat and cholesterol. Since these equations were developed from studies in which individuals were in energy balance, an effort was made to exclude those individuals with extreme
energy intakes. Thus, from the sample of 7,136 individuals, individuals with an energy intake of less than the 10th percentile or more than the 90th percentile that had been previously calculated using 7,933 individuals, were excluded from the analysis involving any predictive equation. Accordingly, a total of 5,744 individuals were included in this type of analysis. The various subgroups within the group of 5,744 individuals used in the analyses will be presented in Table 9 as part of Chapter IV.

**Sample Weights**

Each participant in the NHANES III (P1) was assigned a sample weight. A sample weight is needed because each sample person does not have the same probability of being selected. As previously stated, children of ages 2 months to 5 years, individuals 60 years and older, and blacks and Mexican-Americans were oversampled in the survey. Therefore, sample weights need to be used to estimate any descriptive statistic, such as means and medians.

As part of the data provided for the NHANES III (P1), a number of weights was provided for each individual for each phase of the study such as the interview or the MEC examination. The analyses in this study included individuals who had participated in the MEC examination because no dietary data were available for individuals who had completed a home examination. Therefore, the weight that was assigned to each individual who had participated in the MEC examination was
used in the present study. Average values for the NHANES III (P1) are shown ± one standard error of the mean when appropriate.

**Determination of LDL Cholesterol Goal**

In chapter IV, an analysis showing the proportion of the population meeting the NCEP LDL cholesterol goal will be presented. As described in the Review of Literature, the LDL cholesterol goal of each individual depends on whether or not the individual suffers from CHD. In addition, in individuals free from CHD the LDL cholesterol goal depends on the number of risk factors.

Table 6 shows the criteria used to determine whether or not an individual suffered from CHD and from a number of risk factors for the disease. At the left of the Table, each one of the risk factors included by the NCEP in its recommendations is listed. To the right of these risk factors, the information provided by the NHANES III (P1) for each factor is listed. This information was obtained by questionnaire, medical examination or both. Individuals who had indicated in the questionnaire that they had had a heart attack were considered to suffer from CHD. No information for other forms of CHD, such as atherosclerosis, was available in the data from NHANES III (P1) released in September 1995. Accordingly, the number of individuals considered to suffer from CHD by this criterion is an underestimation of the actual number.
Table 6. Determination of LDL cholesterol goal by whether or not individual has CHD and by number of risk factors.

<table>
<thead>
<tr>
<th>Risk Factors</th>
<th>NCEP</th>
<th>NHANES III</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Questionnaire</td>
<td>Medical examination</td>
</tr>
<tr>
<td>CHD(^1)</td>
<td>Has had a heart attack.</td>
<td></td>
</tr>
<tr>
<td>Positive</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>Men: ≥45 years.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Women: ≥55 years.</td>
<td></td>
</tr>
<tr>
<td>Family history of</td>
<td>A blood relative had a heart attack before 50.</td>
<td></td>
</tr>
<tr>
<td>premature CHD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hypertension</td>
<td>Informed by doctor</td>
<td>← OR → Systolic pressure≥90</td>
</tr>
<tr>
<td></td>
<td></td>
<td>OR diastolic pressure≥140 (^4)</td>
</tr>
<tr>
<td>Cigarette smoking</td>
<td>Smoke cigarettes, cigars or pipe.</td>
<td></td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>Informed by doctor</td>
<td></td>
</tr>
<tr>
<td>HDL&lt;35 mg/dl</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Negative(^3)</td>
<td>HDL≥60 mg/dl</td>
<td></td>
</tr>
</tbody>
</table>

1. If CHD present, LDL goal is 100 mg/dl.
2. If no CHD present, LDL goal is 160 mg/dl with fewer than two risk factors and 130 mg/dl with two or more risk factors.
3. If HDL≥60 mg/dl, one positive risk factor is subtracted.
4. Mean of a maximum of three measurements of blood pressure.
For hypertension, individuals who had been informed by a doctor at some time in their lives that they had high blood pressure were considered to suffer from the disease. Individuals whose mean blood pressure during the medical examination exceeded the normal high limits were also considered to suffer from the disease. These criteria for high blood pressure may result in an overestimation of the number of individuals with the disease. The reason for this overestimation is that some individuals who had been told by a physician that they suffered from the disease may have later recovered from the condition. Finally, individuals who had been informed by a physician at some point in their lives that they suffered from diabetes were considered to be diabetic.

**Changes in Serum Cholesterol Resulting from Changes in Diet**

The estimated changes in total serum or LDL cholesterol levels that may result if individuals followed the NCEP step diets will be presented in chapter IV. These results will be presented for individuals exceeding 180 mg/dl of total serum cholesterol and individuals not meeting their LDL cholesterol goal respectively. As shown in Table 7, two equations, one by Hegsted and one by Hopkins, were used to estimate the changes in total serum cholesterol levels that would be expected if NHANES III (P1) participants switched from their current diet to the NCEP step diets. The 1993 equation by Hegsted for the prediction of changes in LDL
Table 7. Predictive formulas used in the study.

<table>
<thead>
<tr>
<th>Cholesterol</th>
<th>Original publication</th>
<th>This study</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Author</td>
<td>Year</td>
</tr>
<tr>
<td>Total</td>
<td>Hopkins</td>
<td>1992</td>
</tr>
<tr>
<td>LDL</td>
<td>Hegsted</td>
<td>1993</td>
</tr>
<tr>
<td></td>
<td>Hegsted</td>
<td></td>
</tr>
</tbody>
</table>

$\Delta C =$ estimated change in serum cholesterol in mg/dl;

$x$: baseline dietary cholesterol in mg

$x_0$: added dietary cholesterol in mg

$\Delta S =$ change in percent daily calories from saturated fat;

$\Delta P =$ change in percent daily calories from polyunsaturated fat;

$\Delta DC =$ change in intake of dietary cholesterol in mg/1,000 kcal.

1. Each equation was used to obtain estimates in the Figures listed.
cholesterol was also used in the analysis. In reference to these equations, the Review of Literature briefly described how Hegsted and Hopkins developed their predictive equations.

**Sample calculation**

As an illustration of how the various predictive equations were used in this study, a sample calculation involving the 1993 Hegsted equation for the prediction in changes in the levels of LDL cholesterol is presented here. The 1993 Hegsted equation for changes in LDL cholesterol levels does not include a term for monounsaturated fat and, accordingly, changes in monounsaturated fat were not considered in any of the calculations.

Table 8 shows a sample calculation for an individual consuming a 3,000 kcal diet with 13% saturated fat, 7% polyunsaturated fat and 450 mg of cholesterol according to the NHANES III (P1) data. As shown in the Table, if the individual in the sample changes his diet to the NCEP Step I diet, his LDL cholesterol would be expected to decrease by 7.42 mg/dl. It must be noted that the method used to calculate changes in LDL cholesterol could theoretically result in an increase in LDL cholesterol in an individual consuming more than 10% of polyunsaturated fat and decreasing it to 10%. Although theoretically possible, very few individuals in the population consumed more than 10% of polyunsaturated fat. In addition, in most or all of those individuals the theoretical increase in LDL cholesterol
Table 8. Sample calculation for estimated change in LDL cholesterol if NCEP Diet I were followed.\(^1\)

<table>
<thead>
<tr>
<th>Dietary intake</th>
<th>Actual</th>
<th>Recommended</th>
<th>Change needed</th>
<th>Change in LDL cholesterol (mg/dl)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Energy (kcal)</strong></td>
<td>3,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Percent Fat</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Saturated</td>
<td>13</td>
<td>10</td>
<td>↓ by 3</td>
<td>+1.74 x (-3) → -5.22</td>
</tr>
<tr>
<td>Polyunsaturated</td>
<td>7</td>
<td>10</td>
<td>None</td>
<td>-0.766 x (0) → 0</td>
</tr>
<tr>
<td><strong>Cholesterol</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total amount (mg)</td>
<td>450</td>
<td>300</td>
<td>by 150</td>
<td>-0.0439 x (-50) → -2.20</td>
</tr>
<tr>
<td>Density (mg/1,000 kcal)</td>
<td>150(^2)</td>
<td>100(^2)</td>
<td>↓ by 50</td>
<td></td>
</tr>
<tr>
<td><strong>Total change</strong></td>
<td></td>
<td></td>
<td></td>
<td>-7.42</td>
</tr>
</tbody>
</table>

1. Based on 1993 Hegsted equation:

\[ \Delta \text{LDL (mg/dl)} = 1.74 \Delta \text{percent saturated fat} - 0.766 \Delta \text{percent polyunsaturated fat} + 0.0439 \Delta \text{cholesterol density} \]

2. Calculation based on actual energy intake of 3,000 kcal.
resulting from a decrease of polyunsaturated fat intake to 10% would typically be more than offset by a decrease in LDL cholesterol resulting from decreases in saturated fat and cholesterol intake.

**Calculations and Statistical Analyses**

The following calculations and statistical analyses involving the NHANES III (P1) were performed in this study:

1. Calculations for the intake of nutrients were performed for individuals 20 years and older in the NHANES III (P1).

2. The percentage of the population 20 years and older with more than 180 mg/dl of total serum cholesterol and the average total serum cholesterol was estimated.

3. For individuals 20 years and older exceeding 180 mg/dl of total serum cholesterol, the expected decrease in total serum cholesterol resulting from theoretical changes to the Step I and Step II NCEP diets was estimated using the 1993 Hegsted equation for changes in total serum cholesterol.

4. For individuals 20 years and older exceeding 180 mg/dl of total serum cholesterol, the expected decrease in total serum cholesterol resulting from theoretical decreases in dietary cholesterol was estimated using the 1991 Hopkins equation.
5. The percentage of individuals 20 years and older meeting the LDL cholesterol goal specified by the NCEP guidelines was estimated.

6. For individuals 20 years and older not meeting their LDL cholesterol goal, the expected decrease in LDL cholesterol resulting from theoretical changes to the Step I and Step II NCEP diets was estimated using the 1993 Hegsted equation.

**The NFCS 1987-88**

This section is divided into three parts. The first part describes the sampling method and the use of sample weights in the NFCS 1987-88. The second part generally describes the assignment of foods to the various food groups. The third part describes the Survey Nutrient Data Base used in the NFCS 1987-88.

**Sampling Method**

The NFCS 1987-88 used a self-weighting, multistage, stratified area probability sample of households in the forty-eight contiguous states. As shown in Figure 2, in the individual component of the NFCS 1987-88, a total of 13,733 households were targeted for the sample and out of these households, 12,181 had occupants. Of these households, 4,114 provided at least one day of dietary intake for at least one individual. The number of individuals who provided all three days of dietary data was 8,468 (United States General Accounting Office, 1991).

In the individual component, the interviewer conducted a dietary recall for the previous day using a written questionnaire. Each household member was
Figure 2. Response rates in the individual component of the NFCS 1987-88.

* Assuming that the average sizes of both nonresponding and responding households are the same.
interviewed with the exception of children under 12 and those household members absent at the time of the interview. The main meal preparer provided the information for children under 12 and absent household members. The interviewer left questionnaires and a guide book, known as the Food Instruction Booklet, to aid each participant in completing a two-day dietary record.

Sample Weights

In order to reflect the differing probabilities of selecting the elements in the sample, sample weights were used. In the NFCS 1987-88, sample weights were constructed separately for men 20 years and older, women 20 years and older and individuals less than 20 years old for both one-day and three-day participants. For three-day participants, each individual in the sample was assigned a weight from 1,000 to 259,000.

In general, the calculation of the sample weights make it necessary to keep track of the selection probabilities separately in each stratum and at each stage of sampling. In addition, the calculation of sample weights often involves correcting for differential response rates within classes of the sample and adjusting the sample distribution by demographic variables to known population distributions. After the survey had been completed, individual weights were calculated to adjust for nonresponse. Concern about this reweighting scheme has been expressed by a panel assembled by the Assistant Secretary for Food Services and Consumer Services. The reasons stated by the panel for its concern about the reweighting scheme were the extremely large range and the unusual distribution of the weights (General Accounting Office, 1991).
The addition of all weights equals the population total for thirteen characteristics thought to be correlated with food intake:

1. Region.
2. Household income as a percent of poverty.
3. Presence of a child less than 7 years old.
4. Presence of a child between 7 and 17 years old.
5. Exactly one adult in household.
6. Exactly two adults in household.
7. Household member receiving food stamps.
8. Owning of the dwelling.
9. Male head working last week.
10. Female head working last week.
11. Female head younger than 41 years and no child younger than 18 years.
12. Race.
13. Age.

**Food Groups**

Each food or drink was assigned to one of about 6,500 food codes in the Nutrient Survey Data Base. Each of these 6,500 food codes comprised seven digits used to classify foods into various groups. Nine major food groups (such as “Milk and milk products” are identified by the first digit of the food codes. The first two digits can be used to classify foods into 47 groups. The third and fourth digits can also be used to classify foods into various smaller groups. The final three digits of the food codes can serve to identify a particular food. The following is an example of the use of this system:
First digit is 1: "Milk and milk products" group.
First two digits are 14: "Cheeses".
First three digits are 144: "Processed cheeses and cheese spreads".
First four digits are 1441: "Cheese, processed".
Specific foods within these subgroups include:

144-1041: Cheese, processed, Swiss, low sodium.
144-1042: Cheese, processed, Swiss, low-fat.

The "Fats and oils" Group

The subgroups within the "Fats and oils" group by their first digits are:

81 Fats.
811 Table fats.
812 Cooking fats.
813 Other fats.

82 Oils.
821 Vegetable oils.

83 Salad dressings.
831 Regular salad dressings.
832 Low-calorie salad dressings.

Assignments of Fats and Oils Consumed

Fats and Oils Used as Essential Components

For those items prepared at home and consumed at home or outside the home, the main meal preparer was asked if any fat or oil was used in their preparation (seasoning or cooking) and if so, which one from a list of fats and oils was used.
When the fats and oils were essential components of a food, the nutrients they provided were assigned to the food group of the main component of the food. Examples are fats or oils used in the preparation of hot cereals, vegetables, coleslaw or tuna salad. As an illustration, when an egg was fried in the home the nutrient value of the fat or oil used to fry the egg was assigned to the "Eggs" group. When an oil was used to prepare pizza made from raw ingredients in the home, the nutrients provided by this oil were assigned to the "Grain products" group (Hamma, 1992).

**Nutrient Contribution**

The fat or oil selected by the main meal preparer was not always the one used to calculate nutrient values. For example, when the respondent cooked with either olive oil, butter, animal shortenings (meat or bacon drippings), diet margarine, regular stick margarine or margarine blend, the nutrient content of this fat or oil was used. However, when the respondent cooked with either corn oil, cottonseed oil, safflower oil or sunflower oil, the nutrient value of corn oil was used. Further, when the respondent cooked with soybean oil or a vegetable or nut oil, the nutrient value for soybean oil was used. Finally, when the respondent cooked with regular tub or liquid margarine, the nutrient value for regular tub margarine was used.

No questions concerning the consumption of fats or oils for foods never brought to the home were asked. For foods in which a fat or an oil was used but the main preparer did not indicate to which of the possible nine categories indicated above the fat or oil belonged, a default fat was used to calculate the nutrient values. The most commonly used default fat was non-hydrogenated soybean oil for most foods but other default fats or oils were typically used in certain types of food. For
example, if an individual did not know what fat or oil was used to prepare scrambled eggs the nutrient values of margarine were used to calculate the nutritional composition. A default fat was also used when the main meal preparer used an unusual fat or oil such as peanut oil (Perloff, 1992).

**Fats and Oils Used as Non-Essential Components**

Unlike those oils used in the preparation of foods, those oils added to a food but not an essential component of such food were counted in the "Fats and oils" group. Thus, when salad dressing was added to a tossed or green salad the nutrient value of the salad dressing was assigned to the subgroup "Salad dressings" within the "Fats and oils" group (Perloff, 1992). In salads, fats and oils added to tossed and green salads were counted in the "Fats and Oils" group. The reason is that it is conceivable to consume a tossed or green salad without the addition of any fat or oil. By contrast, at least one fat or oil is essential in the preparation of salads such as cole slaw or tuna salad. A default fat was used for fats and oils added to foods and counted in the "Fats and oils" group. As an illustration, the default oil used in green salads was a combination of French, Italian, Thousand Island, blue cheese and butter milk dressings (Hamma, 1992).

**The Survey Nutrient Data Base**

**Development**

Figure 3 shows how the survey Nutrient Data Base used in the NFCS 1987-88 was developed starting with the Standard Reference Data Base, the computerized data set that corresponds to Agriculture Handbook No. 8 ("The composition of foods"). The Standard Reference Data Base was first used to generate the Primary Nutrient Data Set (PDS). The PDS contains all the nutrient values used to generate
Figure 3. Development and use of the Survey Nutrient Data Base used in the NFCS 1987-88 from the Standard Reference Data Base.
the Survey Nutrient Data Base. Items, such as baking powder, not typically consumed as such but as ingredients of mixed foods are found in the PDS but not in the Survey Nutrient Data Base. Nutrients, such as carotene, not included in foods from the Standard Reference Data Base were added to the PDS and full nutrient compositions were added for food items not obtained from the Standard Reference Data Base.

The PDS is linked to the Survey Nutrient Data Base through a Recipe File. Depending on whether it is a single component or a mixed food, each food code in the Survey Nutrient Data Base is linked through a recipe to one or more items in the PDS. Thus, the food code for an apple in the Survey Nutrient Data Base is directly linked to the PDS item for an apple while the survey food code for a salad is linked to the PDS items for each of the components of the salad. The recipe file includes information about the changes that foods undergo during cooking, information about each ingredient in a food mixture and codes for the table of Nutrient Retention Factors. The table of Nutrient Retention Factors contains the factors used to calculate the retention of 18 vitamins and minerals during cooking. For instance, the percentages (or retentions) of thiamin which remains in pasta after it is baked, boiled or reheated are some of the values found in the table of Nutrient Retention Factors (Perloff, 1989). In the Survey Nutrient Data Base, those recipes in which fat was added or absorbed during cooking were calculated using the chemical composition of the type of fat given in the recipe as well as the compositions of other ordinarily used fats.
For every food item consumed by an individual a record of the characteristics and the nutrient composition was made. Other information such as the time of the day and the location where it was consumed, was also collected for each food item. Examples of food include a glass of milk, an apple, a hamburger and a piece of a sandwich. As shown in Figure 2, a total of about 365,000 food items were reported to have been consumed by the three-day participants.

Status of the Nutrient Data Base

The Nutrient Survey Data Base used in the NFCS 1987-88 incorporated changes in the amount of fat in certain foods. The main change was a decrease in the amount of total fat in beef so as to take into account findings from the study on trimming practices by Savell et al. (1988). The fat from certain grain products such as pizza and macaroni and cheese was increased mostly as a result of changes in formulas to calculate their nutrient composition. The 1989 change by the USDA of the cholesterol value of eggs, such as that for large eggs from 274 mg to 213 mg, was not included.

The Nutrient Survey Data Base used in the NFCS 1987-88 was release number 7. This release contained updated data from revised sections for beverages, legume products and fish and shellfish products from Agriculture Handbook 8 (Perloff, 1989). The PDS used in the NFCS 1987-88 was release number 3 and it was based on release 7 of the Standard Reference Data Base. The table of Retention Factors used in the NFCS 1987-88 was release number 2.
Sample Data Used in Study

Source of Data

Data for the individual component of the NFCS 1987-88 was purchased from the National Technical Information Service, U.S. Department of Commerce. All the procedures involving the use of these tapes were performed using version 6.0.6 of SAS on an IBM 3090 with the MVS operating system.

Target Population

The target population in the study was all individuals in the contiguous states other than breast-fed infants. Accordingly, a subsample of 8,427 from a total of 8,468 three-day participants in the NFCS 1987-88 was selected. Thus, since no data on the amount of milk consumed was given for any breast feeding, forty-one children who received one or more breast-feedings (representing 0.38% of the weighted population of three day participants) were excluded. Six other children who had been breast fed at some time other than during the three days of data collection were included in the subsample. This subsample comprised 3,845 males (47.8% of the weighted population) and 4,582 females and included all three-day participants for whom complete dietary intake records were available.

Sex-Age Groups

In some analyses, babies below one year of age were not included because their diet was so dissimilar to that of the rest of the population. The choice of one year of age as the cut-off point was arbitrary and the effect of the exclusion of these individuals was practically negligible. The exclusion of these babies in some analyses is noted in all the graphs and tables reporting the results of these analyses.
Nutrient Intake

The percent contribution of each type of fat to caloric intake was calculated by multiplying the average daily amount in grams of the particular type of fat by 9 kcal per gram and by dividing such value by the average daily energy intake. The percent contribution of each of protein, carbohydrate and alcohol was calculated in the same manner but using the Alwater factors of 4, 4 and 7 kcal per gram respectively. Similarly, the densities of various micronutrients (the amount in milligrams or micrograms of such micronutrient per 1,000 kcal) was calculated using the average individual daily intakes of such micronutrient and of energy.

Calculations and Statistical Analyses

The following calculations and statistical analyses were completed in the study:

1. Weighted means, standard deviations and standard errors were calculated for nutrient intakes for various groups.

2. The proportion of individuals who met the recommendations for essential fatty acids given by the 1988 Nordic Dietary Recommendations and the 1990 Canadian Nutrition Recommendations were calculated.

Use of sample weights

Unless otherwise indicated, all means and percentages of individuals in a population were calculated using the sample weights. For the logistic regression analysis, each individual was assigned a weight equal to the individual's original
weight divided by the total sum of weights of the individuals included in the logistic regression analysis.

**Limitations of the NFCS 1987-88**

This section is divided into two parts. The first part describes the limitations associated with the low response rate in the survey. The second part explains the limitations associated with the variances calculated in the study.

**Limitations Associated with the Low Response Rates**

In reference to problems associated with the NFCS 1987-88, a report issued in July 1991 by the General Accounting Office raised the issue of whether the data are representative of the American population. According to this report, the main problem associated with the data is the low response rate for the basic sample. This low response rate may cause the data to be biased. The response rates for the NFCS 1987-88 were previously shown in Figure 2.

In the basic survey, assuming that the average sizes of both nonresponding and responding households were the same, the response rate for individuals providing three days of dietary intake was 25.9%. The main reason given for the low response rate was the length and complexity of the survey. Some respondents refused to complete the interviews because of their length (1-1/3 hours to 5-1/2 hours per household, not counting the time to complete the subsequent 2 days of dietary records). Moreover, in the NFCS 1987-88 sample households were not given advanced notice of the survey and the payment for participating in the survey was insufficient.
The GAO report indicated that the low response rate may have resulted in biased results because of the possibility of significant differences between respondents and nonrespondents. Whether these differences exist cannot be ascertained because no profile of nonrespondents was performed to determine possible differences between respondents and nonrespondents. Initially, it was intended that National Analysts, which conducted the survey, would develop a profile of nonrespondents through a mail-out questionnaire and interviews involving subsamples of (a) households that did not participate in the complete interview, (b) their neighbors, (c) other proxy sources. Unfortunately, this analysis for nonrespondents was not completed. In addition, nontraditional families such as those headed by working women, were underrepresented. Since nontraditional families were heavily weighted because of their low numbers, there could be significant biases if the nontraditional families in the survey were not representative of nontraditional families in the population.

Another problem was that the interviews were not distributed across the four seasons. Because of the unexpected low response rate, the planned quarterly design for the interviews was disrupted and even extended by five months. Thus, instead of completing the interviews by winter 1988 they were completed by summer 1988.

**Limitations with the Interpretation of the Variances**

The sampling method of obtaining three consecutive days of dietary intake is thought to underestimate true within-subject variation when compared to sampling between nonadjacent days because of the failure of a limited adjacent-day sample
to sample all the days of the year. As a result, when sampling adjacent days the actual intake means of an individual are underestimated or overestimated. This bias decreases the within-subject variation and increases the between-subject variance (Tarasuk and Beaton, 1992). Other limitations related to the variances but associated with both the NFCS 1987-88 and the NHANES III (P1) are discussed in the last section of this chapter.

Interpretation of Results

This section lists a number of factors which must be taken into account when interpreting the results of this study. The section is divided into two sections. The first section lists those factors which are associated with issues related to the intake of nutrients. The second section lists the factors related to the calculation in the study.

Nutritional Factors

The following factors need to be considered when interpreting the results of the study:

1. As noted in the Review of Literature, the recommendations for the intake of the energy-providing nutrients assume no alcohol consumption. The percent intakes of each type of fat would be slightly higher in the older groups if alcohol had been considered to contribute no calories. Accordingly, the proportion of individuals in these older groups consuming more than a given percent of any type of fat would be slightly higher if alcohol had contributed no calories.
2. The general factors of 4, 9, 4 and 7 kcal/gram for each of carbohydrate, fat, protein and alcohol were used in the calculations. However, even though these general factors are considered appropriate in mixed diets, the actual factors vary according to the food. For this reason, the percent energy contributed by various nutrients do not add up to 100.

3. The amount and the percent of total fat for any given food is higher than the addition of the amounts or percents of saturated, polyunsaturated and monounsaturated fats. This difference is a result of including the weight of the glycercyl backbone of the triglyceride molecule as part of total fat. Even though this glycercyl backbone enters the calculations as total fat, in reality its energy value is less than the average of 9 kcal/gram contributed by the various fatty acids.

**Statistical Calculations**

The following factors related to the calculations in the study must be taken into account when interpreting the results:

1. For the sample from the NFCS 1987-88, the percent intakes of various energy-providing nutrients were calculated on the basis of three consecutive days of intake. The results would vary slightly if these calculations had been
performed for each day and an average for the three days had been calculated for each individual to be used in the calculation for the entire population.

2. In the NFCS 1987-88 or the NHANES III (P1) the observations are not independent and identically distributed because of the use of clusters. The usual standard deviations and standard errors underestimate the actual values because the design effect was not taken into account when they were calculated. In order to calculate the estimated variance of the sample statistic, the design effect must be taken into account. The design effect of a statistic is the ratio of the sampling variance that reflects all the complexities of the design to the sampling variance expected from a simple random sample with the same number of elements.

The NFCS 1987-88 has relatively large design effects as a result of the clustering of the sample design and the variability of the sampling weights. The average design effect for nutrients in particular domains is in the 3 to 5 range (Kott, 1992). In the NFCS 1987-88, an average design effect of 3.3 has been calculated (Goldman, 1996). In the NHANES III, a design effect of only 1.2 or 1.3 (lower than the average design effect of 1.5 for NHANES I and NHANES II) has been calculated by preliminary analyses for each of
the ethnic groups. However, for the entire population an average design
effect of 1.8 has been calculated using the design effects for each energy,
total fat and cholesterol (Carroll, 1996).

Unlike programs such as SUDAAN or PCCARP, which use an
appropriate method to estimate variances from a complex sample, the
formula for standard errors and test procedures used in SAS assume that the
observations are independent and identically distributed, that is, that they
are selected by simple random sampling with replacement. In order to
calculate the actual standard errors and standard deviations for the intake of
a certain nutrient by the population, the unweighted estimates obtained
using SAS must be multiplied by the square root of the design effect for the
nutrient.
CHAPTER IV

RESULTS AND DISCUSSION

Theoretical Effect of Decreasing Fat and Cholesterol on Serum Cholesterol

This chapter is divided into three sections. The first section presents findings for the intakes of energy, fat and cholesterol by the target population in the NFCS 1987-88 and NHANES III (P1). The second section presents two types of analyses of the estimated effect of reducing the intake of saturated fat and cholesterol on the levels of total serum cholesterol. In the first type of analysis, the decrease in total serum cholesterol resulting from changes to the levels of saturated fat and cholesterol recommended by the NCEP Step diets was estimated. In the second type of analysis, the effect of decreasing the level of dietary cholesterol on total serum cholesterol was estimated. The third section presents an analysis of the estimated effect of reductions in the intake of saturated fat and cholesterol to the levels recommended by the NCEP Step diets on LDL cholesterol.

Table 9 shows the number of individuals included in the analyses in this chapter. In the Table, the number of individuals used in any analysis appears in bold print. As stated in the Materials and Methods, each analysis was performed using the maximum number of individuals for whom the necessary data were available for that particular
Table 9. Selection criteria and number of individuals in the analyses involving the NHANES III (P1).

<table>
<thead>
<tr>
<th>Selection criteria</th>
<th>CHD</th>
<th>Equation used</th>
<th>Analysis (table, figure)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Within complete and reliable dietary data</td>
<td>7,933</td>
<td>-</td>
<td>1. Dietary intake (10, 17).</td>
</tr>
<tr>
<td>With total cholesterol analysis</td>
<td>7,415</td>
<td>-</td>
<td>1. Total serum cholesterol levels (4).</td>
</tr>
<tr>
<td>With complete and reliable lipoprotein analysis</td>
<td>7,136</td>
<td>-</td>
<td>1. LDL cholesterol goals and levels (9). 2. Percentage not meeting LDL goal (10). 3. Risk factors (11, 12, 13).</td>
</tr>
<tr>
<td>Between 10th and 90th percentile of energy</td>
<td>Yes</td>
<td>1,640</td>
<td>Hegsted’s 1993 (for total cholesterol) 1. Effect of NCEP Step diets (5, 6).</td>
</tr>
<tr>
<td>No</td>
<td>4,104</td>
<td></td>
<td>Hopkins’ 1992 (for total cholesterol) 1. Effect of low cholesterol diets (7, 8).</td>
</tr>
<tr>
<td>Met LDL goal</td>
<td>Yes</td>
<td>39</td>
<td>Hegsted’s 1993 (for LDL cholesterol) 1. Effect of NCEP Step diets (11, 14, 15).</td>
</tr>
<tr>
<td>No</td>
<td>222</td>
<td>1,614</td>
<td></td>
</tr>
</tbody>
</table>

1. Selection of this group of individuals is shown in Table 4.
2. Includes a total of 5,744 individuals (corresponds to the last figure shown in Table 4).
3. The LDL cholesterol goal of each individuals is either 100 mg/dl (if individual has CHD), 130 mg/dl (no CHD but two or more risk factors) 160 mg/dl (no CHD and less than two risk factors).
4. Only group of individuals whose number appears in bold were included in an analysis.
5. Fifty men and thirty-six women with less than 100 Kcal of energy intake were excluded from the analysis in Figure 17.
analysis. Accordingly, the number of individuals used to estimate the proportion of the target population exceeding a certain level of total serum or LDL cholesterol was larger than the number of individuals included in an analysis to estimate the theoretical effect of dietary changes on the levels of total serum and LDL cholesterol. There are two reasons why smaller groups of individuals were used in the analyses involving the use of the Hegsted and Hopkins equations. The first reason is that, as stated in the Materials and Methods, individuals with extreme energy intakes were excluded from the analysis. The second reason is that only individuals exceeding 180 mg/dl of total serum cholesterol or not meeting their LDL cholesterol goal were included in these analyses.

The primary objective of the analyses in this chapter was to determine the adequacy of the NCEP Step diets for the treatment of hypercholesterolemia. As part of this analysis, the two Hegsted formulas for the expected change in total serum and LDL cholesterol resulting from changes in the intakes of fat and cholesterol were used. It must be noted, however, that most of the observations used to develop the Hegsted formulas were within the typical range of intake of fat and cholesterol. For this reason, no attempt was made in any of the analyses to estimate the effect of reducing the intake of saturated fat and cholesterol to levels below those recommended by the NCEP Step II diet. In contrast, the Hopkins equation was developed from observations which included cholesterol-free diets. Therefore, the Hopkins equation was used in the analyses in this chapter to predict the effect of even extreme reductions in cholesterol intake.
Intakes of Energy, Fat and Cholesterol

Although the main objective of this study was to evaluate the usefulness of the dietary recommendations, all analyses of the effects of changes in dietary fat and cholesterol on serum cholesterol involved calculations using the intakes estimated by the NHANES III (P1). Accordingly, the results and conclusions of these analyses largely depend on the validity of the data collected by the NHANES III (P1). For this reason, a short description of the findings for the target population of the NHANES III (P1) will be presented in this section. This section is divided into four parts. The first part presents findings for the intake of energy. The second part presents findings for the intake of cholesterol. The third part presents findings for the intake of fat. The fourth part presents possible reasons for the difference in the energy percent of fat and cholesterol density between the NFCS 1987-88 and the NHANES III (P1).

Energy Intake

Table 10 presents the intakes of energy and various types of fat and cholesterol by the target population in the NFCS 1987-88 and NHANES III (P1). As shown in Tables 5 and 9, a total of 7,933 participants in the NHANES III (P1) were included in the analysis presented in Table 10. As stated in the Materials and Methods, the results for the NFCS 1987-88 were for three days of intake and those for the NHANES III (P1) were for one day of intake.

As shown in Table 10, there were large differences in the intakes of energy of both men and women age 20 years and older in the two surveys. For example, it was
Table 10. Average intake of energy, energy percent of fat, cholesterol and cholesterol density in 1987-88 and 1988-91 by individuals at least 20 years old.

<table>
<thead>
<tr>
<th></th>
<th>NFCS 1987-88</th>
<th>NHANES (P1) 1988-91</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Men (2.619)</td>
<td>Women (3.293)</td>
</tr>
<tr>
<td>Total (kcal/day)</td>
<td>2,066.6±25.5</td>
<td>1,447.0±15.2</td>
</tr>
<tr>
<td></td>
<td>Men (3.963)</td>
<td>Women (3.970)</td>
</tr>
<tr>
<td>Fat %</td>
<td>37.3±0.2</td>
<td>36.4±0.2</td>
</tr>
<tr>
<td>Saturated</td>
<td>13.2±0.1</td>
<td>13.2±0.1</td>
</tr>
<tr>
<td>Polyunsaturated</td>
<td>7.1±0.1</td>
<td>7.1±0.1</td>
</tr>
<tr>
<td>Monounsaturated</td>
<td>14.1±0.1</td>
<td>13.5±0.1</td>
</tr>
<tr>
<td>Cholesterol</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density (mg/1,000 Kcal)</td>
<td>171.6±2.9</td>
<td>166.0±2.6</td>
</tr>
<tr>
<td>Total (mg)</td>
<td>347.2±6.8</td>
<td>237.2±4.1</td>
</tr>
</tbody>
</table>

1. Fifty men and thirty-six women from NHANES III (P1) with less than 100 kcal/day of energy intake were excluded from calculation of average cholesterol density. All individuals in NFCS 1987-88 consumed more than 100 kcal/day. A design effect of 3.3 was used to calculate the standard error shown for the NFCS 1987-88. A design effect of 1.8 was used to calculate the standard error shown for the NHANES III (P1).
estimated that men and women consumed almost 500 and 300 kcal, respectively, more in the NHANES III (PI) than in the NFCS 1987-88. It is possible that the high nonresponse rate in the NFCS 1987-88 may account for some of the difference in energy consumption between the two surveys. However, these findings can most likely be explained by differences in the way the data were collected in both surveys. As described in the Materials and Methods, the NHANES III (PI) used a multiple pass approach for the collection of dietary data. The use of four different passes and frequent probing by an interviewer for additional data in the NHANES III (PI) may account for the much higher intake of energy and various nutrients in this last survey. Nevertheless, the estimated levels of energy intake for men and women 20 years and older were well below the RDA for energy. Considering the levels of obesity in the American population, the levels of energy in the NHANES III (PI) appear to be underestimates of the actual caloric intakes.

**Cholesterol Intake**

Although the intake of cholesterol was similar for both men and women in both surveys, the amount of cholesterol per 1,000 kcal was much lower for both men and women in the NHANES III (PI) than in the NFCS 1987-88. As shown in the Table, individuals with less than 100 kcal of energy intake were excluded from the calculation of the average cholesterol density of the target population of the NHANES III (PI). The reason for excluding these individuals was that a few individuals with extremely small energy intakes exhibited an extremely high cholesterol density which distorted the calculation of the average cholesterol density of the whole group.
One reason why the cholesterol intake appears to be slightly higher in the NFCS 1987-88 than in the NHANES III (P1) is that the cholesterol values of eggs in the Nutrient Data Base of the NFCS 1987-88 were overestimations of the actual values. The values in the data base of the NFCS 1987-88 were based on the official USDA cholesterol content of eggs prior to its change to a lower value in 1989. The Food Consumption Research Branch of the USDA has estimated that the use of the corrected cholesterol value of eggs in the calculation of the cholesterol intake of women 19-50 participating in the CSFII 1985 would result in a 9% decrease in their calculated cholesterol intakes from all foods (Raper, 1991). It seems reasonable that a similar adjustment could have been made for most of the population in the NFCS 1987-88. Thus, with the possible exceptions of young children whose diets tend to be dissimilar to those of the rest of the population and of those consuming a diet that reduces or totally excludes the intake of eggs, it is possible that for most population groups the actual cholesterol consumption was about 9% less than that calculated from data in the NFCS 1987-88.

**Fat Intake**

As shown in Table 10, there was a large difference in the energy percent intake of total, saturated and monounsaturated fat between the NHANES III (P1) and the NFCS 1987-88. For example, the intake of total fat was 3.6 and 3.1 points lower for men and women, respectively, in the NHANES III (P1) than in the NFCS 1987-88. In addition,
the intake of saturated fat was 1.6 and 1.7 lower for men and women, respectively, in the NHANES III (P1) than in the NFCS 1987-88. On the other hand, the intake of polyunsaturated fat was similar for both men and women in the two surveys.

**Reasons for the Decreased Intake of Fat**

There are two possible reasons for the very large differences in the intakes of total, saturated and monounsaturated fat as well as for the very low cholesterol density between the two surveys. The first possible reason is that differences in the methods used to collect the data account, at least partially, for differences in the energy percent intake of various fats. Unlike in the NFCS 1987-88, dietary data in the NHANES III (P1) were collected during the mobile examination center (MEC) visit. The collection of data in a setting in which a battery of medical tests were conducted may have encouraged some individuals to somehow underreport the consumption of foods high in saturated fat and cholesterol.

The second possible reason is that a larger proportion of individuals may have tried to reduce their intake of saturated fat and cholesterol in 1988-91 than in 1987-88. In support of this possible explanation is the increasing percentage of the population following a low-fat low-cholesterol diet during the 1980s. Thus, while 3% of adults reported a prescribed cholesterol-lowering diet in 1983, this figure was 3.8% for the 8,427 individuals in the sample for the NFCS 1987-88 and 9% in a national survey in 1991, the last year for which data were collected for the NHANES III (P1) (Schucker et al., 1991).
Conclusions

1. There were major differences in the intake of energy between the NFCS 1987-88 and the NHANES III (P1) for individuals at least 20 years old. Probably, most of these differences can be logically explained by the method used to collect the dietary intake data.

2. In 1988-91, the intakes of total, saturated and monounsaturated fat were more than 3 points lower, more than 1.5 points lower and more than 1.5 points lower, respectively, for both men and women 20 years and older when compared to 1987-88. Although some of the difference may be explained by differences in data collection, the difference may also reflect increasing efforts by individuals to reduce their intake of saturated fat.

3. Between 1987-88 and 1988-91, no major differences in the energy percent consumption of polyunsaturated fat were observed for individuals at least 20 years old.

Total Serum Cholesterol Levels

It was stated in the Review of Literature that individuals with total serum cholesterol exceeding 180 mg/dl in the MRFIT were found to be at an increased risk for CHD. Accordingly, a calculation of the proportion of individuals in the NHANES III (P1) with more than 180 mg/dl can help estimate the percentage of the target population
at an increased risk for CHD as a result of elevated total serum cholesterol levels. This section presents an analysis of the levels of total serum cholesterol in the target population.

This section is divided into four parts. The first part presents findings for the levels of total serum cholesterol in the target population. The second part presents the theoretical effect of changes to the NCEP Step I and Step II diets on the levels of total serum cholesterol. The analysis presented in this second section involved the use of the 1993 Hegsted equation for the prediction of changes in the levels of total serum cholesterol. The third part describes the theoretical effect of decreasing the intake of dietary cholesterol to very low levels. The analysis presented in this third section involved the use of the 1991 Hopkins equation. The fourth part discusses how the Framingham equation used by Grover et al. (1994) could be used to estimate the decrease in mortality from CHD that would result from reductions in total serum cholesterol levels.

**Total Serum Cholesterol**

Figure 4 shows the levels of total serum cholesterol in the American population according to the NHANES III (P1) data (Table 15 in the Appendix shows the standard errors). As shown in the Figure, the percentage of the population with elevated total serum cholesterol increased with age up to the group of age 60-69 and then declined in the oldest group. One explanation for this finding is that individuals with lower levels of cholesterol.
Figure 4. Estimated percentage of population with various total serum cholesterol levels and estimated mean serum cholesterol level. By age and sex.

Analysis included 7,415 individuals in the NHANES III (P1) with and without CHD.
of blood cholesterol. A second explanation is that older individuals tend to suffer from diseases such as cancer at higher rates than younger individuals. Cancer and other diseases have been associated with a decreased level of blood cholesterol. For example, in an analysis of participants who had been followed for an average of 12 years in the MRFIT, Neaton et al. (1992) found an inverse association between total serum cholesterol and all deaths from cancer. Based on this finding and on similar findings by other researchers, the authors suggested that preclinical cancer has a hypocholesterolemic effect. It is possible that some of older individuals in the population have a higher incidence of cancer and other diseases which may partially account for their lower total serum cholesterol levels.

In addition, Figure 4 shows that a majority of individuals in the population were at increased risk for CHD because of their elevated total serum cholesterol levels. In some groups of individuals, such as men and women 50-59 and 60-59 more than 80% of men and more than 90% of women exhibited more than 180 mg/dl of total serum cholesterol. Another finding shown in Figure 4 is that blood cholesterol levels tend to be higher in young men than in young women but this pattern is reversed after age 50 or so. The increased levels of total serum cholesterol in older women may be a result of physiological changes occurring after menopause.
Theoretical Effect of NCEP Step Diets

The previous analysis showed that a large percentage of the target population had total serum cholesterol levels exceeding 180 mg/dl and was, therefore, at increased risk for CHD. As was shown in Table 2, the NCEP recommends that individuals with elevated serum cholesterol first consume the Step I diet and, if necessary, further reduce their intake of saturated fat and cholesterol to the levels recommended by the Step II diet. The analysis presented here was performed to determine whether or not the NCEP recommendations are sufficient to lower the total serum cholesterol levels of a large percentage of the population at increased risk for CHD below 180 mg/dl.

Effect on Individuals with Hypercholesterolemia

As was shown in Table 5, 5,744 individuals had both complete and reliable dietary data, a lipoprotein analysis and had consumed between the 10th and 90th percentiles of energy. As shown in Table 9, of these 5,744 individuals, 4,104 had total serum cholesterol levels of more than 180 mg/dl. Therefore, a total of 4,104 individuals were included in the analysis presented in Figure 5.

Figure 5 shows the results of the analysis for the estimated decrease in total serum cholesterol resulting from decreases in the intakes of saturated fat and cholesterol (Table 16 in the Appendix shows the standard errors). As shown in the Figure, younger individuals would benefit more from changes in diet than older individuals. The apparent reason is that younger individuals consumed more cholesterol than older
Figure 5. Estimated percentage of population whose total serum cholesterol would decrease to 180 mg/dl or less by changes to the NCEP diets and estimated mean decrease in total serum cholesterol. By age and sex.

Analysis included 4,104 individuals in the NHANES III (P1) with more than 180 mg/dl of total serum cholesterol.
individuals. Therefore, the theoretical effect of reducing the intake of cholesterol was larger in younger individuals than in older individuals. However, the consumption of the NCEP diets by individuals at an increased risk for CHD was clearly insufficient to reduce the total serum cholesterol levels of most individuals to a level below 180 mg/dl. For this reason, for most individuals with elevated serum cholesterol, the NCEP recommendations were insufficient to reduce their total serum cholesterol levels to a safe level. However, their risk would be reduced theoretically.

Figure 5 also shows the average theoretical decrease in total serum cholesterol experienced by individuals switching to the NCEP diets. As shown in the Figure, the largest decrease in total serum cholesterol would be the slightly more than 15 mg/dl decrease in total serum cholesterol experienced by men 20-29. It must be noted, however, that all individuals exceeding 180 mg/dl of total serum cholesterol were included in the analysis regardless of whether or not they met the dietary guidelines. Therefore, the average estimated decrease in total serum cholesterol would be larger if only individuals not meeting the recommended guidelines had been included in the analysis.

**Effect on Entire Population**

The estimated changes in serum cholesterol resulting from decreases in the intakes of saturated fat and cholesterol by individuals with total serum cholesterol of more than 180 mg/dl have just been presented. However, an additional Figure summarizing the major overall findings of the previous analyses will be presented here. Figure 6 shows
the estimated percentage of the population requiring various types of therapy to lower their cholesterol to 180 mg/dl or less. As shown in the Figure, a very low percentage of the population would benefit from changing their intake of saturated fat and cholesterol to the levels recommended by the NCEP Step I and Step II diets. Especially in some of the older groups, most individuals wishing to decrease their total serum cholesterol to less than 180 mg/dl would need to lower their intake of saturated fat and cholesterol much more than recommended by the Step II diet or follow some alternative therapy.

**Theoretical Effect of Reductions in Dietary Cholesterol**

The previous analysis showed that, for most individuals with elevated serum cholesterol levels, changes to the NCEP Step diets would be insufficient to reduce their serum cholesterol to a level that is theoretically safe. Although no organization recommends extreme reductions in the intake of cholesterol, the predictive equation developed by Hopkins can be used to estimate the theoretical effect that reductions in dietary cholesterol would have on serum cholesterol. An analysis of this type could provide information about the possible role that very low cholesterol diets might play in reducing elevated serum cholesterol levels in the population. Therefore, all 4,104 individuals with more than 180 mg/dl of serum cholesterol included in the analysis for the effect of the NCEP diets were also included in the present analysis. An assumption of this analysis is that only the intake of dietary cholesterol is decreased and that the intake of the various types of fat remains constant.
Figure 6. Estimated percentage of population requiring therapy to lower their total serum cholesterol to 180 mg/dl or less.

Analysis included 5,744 individuals in the NHANES III (P1).
Figure 7 shows the estimated percentage of the target population whose serum cholesterol would decrease to 180 mg/dl or less if men and women with elevated serum cholesterol reduced their intake of dietary cholesterol. As shown in the Figure, the estimates presented were for each of five hypothetical maximum levels of dietary cholesterol: 300, 200, 100, 50 and 0 mg. Each one of these five levels of dietary cholesterol intake was considered a ‘maximum’ level because individuals consuming less than the level specified in each analysis were assumed to maintain their intake of dietary cholesterol.

As an illustration, if an individual consumed 176 mg of dietary cholesterol, it was assumed that this individual still consumed 176 mg in the analysis in which either 300 or 200 mg was the theoretically maximum amount of cholesterol consumed by any individual. However, for the analysis in which the maximum dietary cholesterol consumed by any individual was 100 mg, an individual with an intake of 176 mg was considered to have decreased his dietary cholesterol to 100 mg. An assumption of this analysis is that, when the level of dietary cholesterol is decreased, the energy percent intake of the various types of fat remains constant.

As expected, younger individuals would benefit the most from reductions in the intake of dietary cholesterol because these individuals consumed higher amounts of cholesterol. Also, by comparing Figures 5 and 7, it can be seen that these younger groups of individuals would theoretically benefit more from the consumption of a
Figure 7. Estimated percentage of population whose total serum cholesterol would decrease to less than 180 mg/dl if dietary cholesterol were reduced. By age and sex.

Analysis included 4,104 individuals in the NHANES III (P1) with more than 180 mg/dl of serum cholesterol.
cholesterol-free diet than from the consumption of the NCEP Step II diet. In the older groups, reductions of dietary cholesterol to a maximum of 50 mg/dl would be insufficient for more than 90% of individuals to decrease their serum cholesterol to 180 mg/dl or less. Roughly, in the older groups the consumption of a cholesterol-free diet would theoretically have a similar effect as the consumption of the NCEP Step II diet.

Figure 8 shows the expected average decrease in total serum cholesterol resulting from reductions in dietary cholesterol (Table 18 in the Appendix shows the standard errors). As shown in the Figure, when the theoretical maximum intake of dietary cholesterol was 200 mg/day the average decrease in serum cholesterol expected was extremely small (i.e., less than 4 mg/dl). Only major reductions in the intake of dietary cholesterol would be effective in significantly decreasing serum cholesterol levels. On the average, the various groups of men would experience a 13-17 mg/dl decrease in serum cholesterol while the groups of women would experience a 10-12 mg/dl decrease by the consumption of a cholesterol-free diet.

**Theoretical Effects on Life Expectancy and Mortality**

The previous analyses presented the expected decrease in total serum cholesterol resulting from the consumption of the NCEP diets and from reductions in the intake of dietary cholesterol alone. An analysis which would be of great interest would be the estimation of the effect of the reductions in total serum cholesterol on the probability of developing CHD, mortality from CHD, as well as the estimation of the resulting increase in life expectancy. Of particular interest would be the use of Grover et al.'s
Figure 8. Estimated average decrease in total serum cholesterol resulting from reductions in dietary cholesterol.
By age and sex.

Analysis included 4,104 individuals in the NHANES III (P1) with more than 180 mg/dl of serum cholesterol.
(1994) CHD model for these estimations because this model has been shown to accurately estimate the results observed in a number of clinical trials.

Unfortunately, it is not possible to use Grover et al.’s model in the present analysis for a number of reasons. First, the NHANES III (P1) did not include information as whether or not the participants suffered from left ventricular hypertrophy. This variable is needed for the calculation of the annual change in the ‘RISK’ factor included in the formula for the probability of developing CHD that was presented in the Review of Literature. Second, the interim data released in September 1995 from the NHANES III (P1) did not include information on glucose intolerance, a second factor included in the formula used by Grover et al. Data for glucose intolerance for the NHANES III (P1) will be released in late 1996 as part of the laboratory data (McDowell, 1996). Third, certain medical tests were conducted only in individuals of certain age groups. As an illustration, the oral glucose tolerance test was conducted only in adults 40-74 years old. Thus, even if these data were available, it would not be possible to apply the formula used by Grover et al. to individuals less than 40 years old.

The fourth reason why the formula used by Grover et al. could not effectively be used in the present study is that the formula was based on results from the Framingham Heart Study. The individuals participating in the Framingham Heart Study had different characteristics from the ones included in the NHANES III (P1) such as different cholesterol levels. As stated in the Review of Literature, Grover et al.’s CHD computer
model accurately predicted the results of a number of epidemiological studies. However, the large decrease in the levels of serum cholesterol and changes in factors such as medical treatment and the proportion of smokers in the population, may greatly limit the usefulness of any model including a logistic regression developed from Framingham data.

Conclusions

1. In NHANES III (P1), most individuals had levels of total serum cholesterol of more than 180 mg/dl, the level above which there is an association between total serum cholesterol and an increased risk for mortality from CHD.

2. For most individuals with more than 180 mg/dl of cholesterol, the NCEP Step diets were insufficient to lower their total serum cholesterol to 180 mg/dl or less.

3. The average decrease in serum cholesterol experienced by individuals with more than 180 mg/dl of total serum cholesterol who switch to the NCEP Step I and Step II diets would be 4-9 mg/dl and 9-15 mg/dl respectively depending on age.
4. For most individuals with more than 180 mg/dl of cholesterol, the complete elimination of dietary cholesterol without a decrease in saturated fat would be insufficient to lower total serum cholesterol level to 180 mg/dl or less.

**LDL Cholesterol Levels**

The analysis in the previous section showed that the NCEP Step diets are insufficient for most individuals wishing to reduce their serum cholesterol levels to less than 180 mg/dl. However, as stated in the Review of Literature, the NCEP Step diets were recommended to individuals who exceeded a particular LDL cholesterol goal. As defined in the NCEP guidelines, the LDL cholesterol goal of each individual depends on the presence of CHD. In addition, for individuals without the disease, the LDL cholesterol goal depends on the number of risk factors. Accordingly, this section presents an analysis of the validity of the NCEP Step diets in helping individuals reach their LDL cholesterol goals.

This section is divided into four parts. The first part presents the estimated percentage of the population with various LDL cholesterol goals. The second part presents an analysis of the risk factors in the American population. The third part presents an analysis of the extent to which the NCEP Step diets can help individuals meet their LDL cholesterol goals. The analysis is presented separately for individuals with CHD and for individuals with no record of CHD. The fourth part discusses the need for more stringent NCEP guidelines.
**LDL Cholesterol Goal**

Before presenting any analysis of the extent to which changes to the Step NCEP diets can help individuals not meeting their LDL cholesterol goals meet their goals, an analysis of the estimated percentage of the population with various LDL cholesterol goals will be presented here. This analysis will be helpful in understanding the association between factors such as age and sex and the LDL cholesterol goal.

Figure 9 shows the percentage of the population with various LDL cholesterol goals by sex and age. As shown in the Figure, older individuals tended to have lower LDL cholesterol goals than younger individuals and men tended to have lower LDL cholesterol goals than women of the same age group. The LDL cholesterol goal of an individual is determined by the presence of CHD and, for those individuals without CHD, by the number of risk factors. Therefore, Figure 9 also shows the percentage of the population with CHD (goal is 100 mg/dl) as well as the percentage of the population with two risk factors or more (goal is 130 mg/dl). The percentage of the population with fewer than two risk factors (goal is 160 mg/dl) is also presented in the Figure. In addition, Figure 9 shows the average LDL cholesterol value for individuals in each age group (Table 19 in the Appendix shows the standard errors). The values of the mean LDL cholesterol appear at the second Y-axis of the Figure. As shown in the Figure, younger men tend to have higher LDL cholesterol than younger women but in the older groups the pattern is reversed.
Figure 9. Estimated percentage of population with various LDL cholesterol goals and mean LDL cholesterol. By age and sex.

Analysis included 7,136 individuals in the NHANES III (P1) with complete and reliable lipoprotein analysis.
Figure 10 shows the percentage of the population not meeting their LDL cholesterol goal. For each sex-age group, the percentage of the individuals with each of the three LDL cholesterol goals is plotted with a different pattern. By comparing Figures 9 and 10, it is possible to see that most individuals with an LDL cholesterol goal of 100 mg/dl (i.e., individuals with CHD) did not meet their goal. In addition, a large proportion of individuals with an LDL cholesterol goal of 130 mg/dl did not meet their goal either. Individuals with an LDL cholesterol goal of 130 mg/dl would increase their LDL cholesterol goal by reducing the number of risk factors to fewer than two.

Analysis of Risk Factors for CHD

The previous analysis showed that a large percentage of individuals free from CHD but with two or more risk factors did not meet their LDL cholesterol goal. In order to meet their LDL cholesterol goals, these individuals can either increase their LDL cholesterol goal by reducing their number of risk factors to two or fewer or they can reduce their intake of saturated fat and cholesterol. The theoretical effect of changes in the intakes of saturated fat and cholesterol on the levels of LDL cholesterol will be presented later in this chapter. This part presents an analysis of the risk factors for CHD. Only factors which can be modified are included in the analysis. Therefore, no information will be presented for the incidence of family history of CHD and age as risk factors for CHD.
Figure 10. Estimated percentage of population not meeting their LDL cholesterol goal. By age and sex.

Analysis included 7,136 individuals in the NHANES III (P1) with complete and reliable lipoprotein analysis.
Risk Factors and Age

Figure 11 shows the association between each of three risk factors, high blood pressure, smoking and diabetes, and age. Each one of these three risk factors is associated with age. Thus, while slightly more than 10% of men and women aged 20-29 had high blood pressure, around 60% of men and 70% of women aged 70 and over had high blood pressure. The incidence of diabetes also increases with age to a maximum of more than 10% of men and women of age 60 and older. In contrast, the percentage of both men and women smokers decreases with age to less than 20%, respectively, for men and women aged 70 and more. Within each age group, the percentage of men smokers is higher than the percentage of women smokers.

Figure 12 shows the percentage of individuals with low and high levels of HDL cholesterol as well as the average level of HDL cholesterol for each sex-age group (Table 20 in the Appendix shows the standard errors). As shown in the Figure, women had higher HDL cholesterol levels than men of the same age group. In addition, the percentage of women with high HDL levels (i.e., ≥60 mg/dl) was around 40% for most age groups while the percentage of men with high HDL levels was less than 20% in all age groups. Less than 10% of women of any age group had HDL levels that could be considered a positive risk factor (i.e., <35 mg/dl).
Figure 11 Estimated percentage of population with risk factors. By age and sex.

Analysis included 7,136 individuals in the NHANES III (P1) with complete and reliable lipoprotein analysis.
Figure 12. Estimated percentage of population with low and high HDL cholesterol and estimated mean HDL cholesterol. By age and sex.

Analysis included 7,136 individuals in the NHANES III (P1) with complete and reliable lipoprotein analysis.
Risk Factors and Body Mass Index

Figure 13 shows the association between the body mass index (BMI) and the various risk factors for CHD. As shown in the Figure, the BMI was associated with all five risk factors included in the Figure. As an illustration, the percentage of individuals with a BMI of 32 or more who suffered from high blood pressure was about three times as large as the percentage of individuals with a BMI of less than 20 who suffered from the disease. In a similar manner, although the levels of diabetes in the population were much lower than the levels of high blood pressure, the percentage of individuals with diabetes was about three times as high in individuals with a high BMI than in individuals with less than a BMI of 20. The Figure also shows that the percentage of individuals with high levels of serum HDL cholesterol tended to be inversely associated with the BMI, a finding previously reported in a number of studies (Leclerc et al., 1983; Chumlea et al., 1992; Mykkanen et al., 1992; Lamon-Fava et al., 1994). Finally, there was a higher percentage of smokers among individuals with lower BMI than in individuals with a higher BMI. Thus, smoking appeared to be the only risk factor which tended to be associated with a lower BMI.

Effect of NCEP Diets

In order to evaluate the effectiveness of the NCEP Step diets, the 1993 Hegsted equation was used to estimate the expected decrease in LDL cholesterol resulting from decreases in the intakes of saturated fat and cholesterol. However, because of the unique difficulties that individuals with CHD would be expected to encounter when attempting
Figure 13. Estimated percentage of population with risk factors. By body mass index.

Analysis included 7,136 individuals in the NHANES III (P1) with complete and reliable lipoprotein analysis.
to reduce their LDL cholesterol to 100 mg/dl, the analysis will be presented separately for individuals with CHD and for individuals without the disease.

**Individuals with CHD**

As was shown in Table 9, only 39 of the 222 individuals with CHD met their LDL cholesterol goal of 100 mg/dl. Table 11 shows the results of the analysis for individuals with CHD not meeting their LDL cholesterol goal. The Table shows the percentage of men and women with CHD that met the recommendations for saturated fat, dietary cholesterol, and both saturated fat and dietary cholesterol for the Step I and Step II diets. As an illustration, 44.7% of the men consumed a maximum of 10% of energy as saturated fat, 68.5% consumed a maximum of 300 mg of cholesterol and 35.6% consumed a maximum of both 10% of energy as saturated fat and 300 mg of cholesterol. These figures show that a large percentage of individuals with CHD who did not meet their LDL cholesterol goal already consumed the recommended intakes of saturated fat and cholesterol.

Table 11 also shows the estimated percentage of individuals who would meet their LDL cholesterol goal and the average decrease in LDL cholesterol that all individuals would theoretically experience if they all switched to the Step diets. As an illustration, if all men not meeting their LDL cholesterol goal switched to the Step I diet, 3.8% of them would meet their goal and all of them would experience an average decrease of 4.4 mg/dl in their LDL cholesterol. As shown in the Table, only 5.4% of the men and 12.3% of the women would meet their LDL cholesterol goal by switching to the Step II diet.
Table 11. Percentage of individuals who have had a heart attack not meeting their LDL cholesterol goal who met the recommendations for saturated fat and cholesterol and potential effect on cholesterol if all individuals consumed the Step I or II diets.

<table>
<thead>
<tr>
<th>NCEP diet</th>
<th>Men (158)</th>
<th>Women (64)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Met recommendation</td>
<td>If all individuals met recommendation</td>
</tr>
<tr>
<td></td>
<td>would meet goal</td>
<td>Decrease in LDL±SE (mg/dl)</td>
</tr>
<tr>
<td>Step I</td>
<td>SF</td>
<td>44.7</td>
</tr>
<tr>
<td></td>
<td>CL</td>
<td>68.5</td>
</tr>
<tr>
<td></td>
<td>SF/CL</td>
<td>35.6</td>
</tr>
<tr>
<td>Step II</td>
<td>SF</td>
<td>14.1</td>
</tr>
<tr>
<td></td>
<td>CL</td>
<td>48.6</td>
</tr>
<tr>
<td></td>
<td>SF/CL</td>
<td>9.0</td>
</tr>
</tbody>
</table>

SF: saturated fat.
CL: cholesterol.
Step I diet recommendation is a maximum of 10 energy percent of saturated fat and 300 mg of cholesterol.
Step II diet recommendation is a maximum of 7 energy percent of saturated fat and 200 mg of cholesterol.
Not included in the table are 27 men (9.5% of men) and 12 women (11.6% of women) who had had a heart attack and met their LDL cholesterol goal.
A design effect of 1.8 was used to estimate the standard errors shown in the Table.
The results clearly show that the vast majority of individuals with CHD cannot lower their LDL cholesterol to 100 mg/dl or less by the consumption of the NCEP diets.

**Individuals without CHD**

As previously stated, individuals without CHD had an LDL cholesterol goal of 130 mg/dl if they had fewer than two risk factors for the disease or 160 mg/dl if they had more than two risk factors. As was shown in Table 9, 1,614 of the 5,744 individuals without CHD did not meet their LDL cholesterol goal. The bars in Figure 14 show the estimated percentage of individuals free from CHD who would meet their LDL cholesterol goal by switching to the NCEP Step diets. Figure 14 also shows the average decrease in LDL cholesterol that these individuals would experience by switching to the NCEP diets (Table 21 in the Appendix shows the standard errors). The values for the average decrease in LDL cholesterol appear in the second Y-axis at the right of the Figure. From the Figure, it can be seen that most individuals free from CHD would still be unable to meet their LDL cholesterol goals even if they consumed the Step II diet.

**The Need for New Dietary Guidelines**

The previous analyses showed that most individuals exceeding their LDL cholesterol goal would not be able to lower their LDL cholesterol to the desired level by consuming the Step II diet. This finding was especially true for both men and women with CHD because of the very low goal recommended by the NCEP for these individuals. However, because the previous analyses included only individuals exceeding their LDL cholesterol goals and presented the analyses separately by whether or not the individuals suffered from CHD, the results presented did not give any sense of
Figure 14. Estimated percentage of population free from CHD that would meet their LDL cholesterol goal by consuming the NCEP Step I and Step II diets. By age and sex.

Analysis included 1,614 individuals in the NHANES III (P1) free from CHD who do not meet their LDL cholesterol goal (either 130 or 160 mg/dl).
the overall effect which dietary therapy could have on reducing LDL cholesterol to the desired levels in the target population. The analysis presented here attempts to show the role which the NCEP guidelines could possibly play in reducing the incidence of hypercholesterolemia in the American population.

Figure 15 shows the estimated percentage of individuals within each age group requiring various types of therapy to meet their LDL cholesterol goals. Each of the sex-age groups includes all individuals who meet their LDL cholesterol goals and were not included in any of the previous analyses. These individuals are shown in white in each of the bars included in the Figure. The main finding in the Figure, however, is the very low percentage of men and women who would meet their LDL cholesterol goal because of the consumption of the NCEP Step diets. In fact, according to the NCEP guidelines, most men and women with excessive LDL cholesterol levels would be considered for drug therapy to lower their levels of LDL cholesterol. In the Figure, the percentage of individuals who would be unable to meet their LDL cholesterol goals by the consumption of the NCEP Step diets are shown in black.

Conclusions

1. A higher percentage of men 20-49 and of women 20-59 had an LDL cholesterol goal of 160 mg/dl than had any other goal. However, because older individuals tended to have more risk factors than younger individuals,
Figure 15. Estimated percentage of population needing therapy to meet their LDL cholesterol goals. By age and sex.

Analysis included 5,744 individuals with and without CHD.
more men at least 50 years old and more women at least 60 years old had an LDL cholesterol goal of 130 mg/dl than any other goal.

2. Smoking was the most common risk factor for CHD among men and women of ages 20-49 but the percentage of smokers within each sex-age group tended to decrease with age and was lowest among men and women ages 70 and older.

3. The percentage of men and women with high blood pressure increased several-fold with age so that at ages 70 and older about 60% of men and 70% of women suffered or had suffered from high blood pressure.

4. The incidence of diabetes increased with age so that slightly more than 10% of men and women ages 70 and older were or had been diabetic.

5. The levels of HDL in women tended to be about 10 mg/dl higher than those of men of the same age group. High levels of HDL were considered a negative risk factor for CHD for about 35 to 40% of women of each of the age groups.

6. As the body mass index increased, all the positive modifiable risk factors for CHD tended to also increase with the exception of smoking. There was a higher percentage of smokers among individuals with a lower body mass index than among individuals with a higher body mass index.

7. Only 5.4% of men and 12.3% of women with CHD who exceeded their LDL cholesterol goal would be able to lower their LDL cholesterol sufficiently to meet their goals by consuming the NCEP Step II diet.
CHAPTER V

Intake of Essential Fatty Acids

The results of the analyses presented in Chapter IV show that a very large segment of the American population needs to drastically decrease its intake of saturated fat and cholesterol to reduce its LDL cholesterol to the recommended level. One approach that individuals may use to reduce their intakes of saturated fat and cholesterol is to decrease their overall intake of dietary fat by replacing most of the fat they consume by carbohydrate and protein. An advantage of a very low fat diet is that it can help individuals lose weight because the conversion of dietary carbohydrate and protein to body fat is much more inefficient than the conversion of dietary fat to body fat. Thus, the consumption of a very low-fat diet can help reduce the incidence of medical conditions, such as hypertension and diabetes, which are often associated with obesity.

Even though the consumption of a very low fat diet reduces the levels of LDL cholesterol, major changes in fat intake can possibly have an undesirable effect on the intake and absorption of other nutrients. Among the nutrients most likely to be affected by major reductions in the intake of total fat are the essential fatty acids. Given that in the United States there are no official recommendations for the essential fatty acids, the Review of Literature presented some of the recommendations made outside the United States for these fatty acids. It also
presented recent findings which suggest that these official recommendations may be insufficient for optimal health.

In view of the evidence that an insufficient intake of essential fatty acids is associated with an increased risk for CHD, a reduction in fat intake may have an undesirable effect if it does not provide an adequate level of essential fatty acids. For this reason, an analysis of the levels of essential fatty acids consumed by the population can help establish whether or not individuals wishing to consume a very low fat diet must make a special effort to eat foods that are rich in essential fatty acids. Unfortunately, the NFCS 1987-88 and the NHANES 1988-91 only provided data on the intake of the three major types of fat. Neither of these two surveys provided data on the intake of specific fatty acids by the population. For this reason, this analysis was based on the assumption that a certain percentage of the polyunsaturated fat was essential fatty acids. This chapter presents this type of analysis.

**Intake of Essential Fatty Acids**

As stated in the Materials and Methods, the NFCS 1987-88 provided three days of dietary intake while the NHANES 1988-91 only provided one day. For this reason, the NFCS 1987-88 was selected for the analyses presented in this section. This section is divided into three parts. The first part presents the assumptions made in the analysis. The second part presents the results of the analysis. The third part presents an analysis for the consumption of linoleic acid by infants.
Assumptions of the analysis

Ideally, an estimation of the intake of essential fatty acids by each participant in the survey would involve the use of a database which includes either the individual fatty acids in a food or at least, the essential fatty acids. Thus, a database which could be used for this type of analysis is that developed by the Nutrition Coordinating Center (NCC) at the University of Minnesota. This database has the individual fatty acids of each food and uses USDA codes. However, a disadvantage of the NCC database is that it does not have all 6,500 foods which were consumed in the NFCS 1987-88 (McDowell, 1996). For this reason, a less accurate but simpler approach was used to conduct the present analysis.

As stated in the Review of Literature, for the Usual Care (UC) group of the MRFIT a mean of 11.1% of total polyunsaturated fat was calculated to be α-linolenic acid and longer ω3 fatty acids. The linoleic and other ω6 fatty acids comprised 88.1% of all polyunsaturated fat consumed. Using these figures it is possible to get an approximate estimate of the amounts and percentages of ω3 and ω6 fatty acids that were consumed by individuals in the target population in the NFCS 1987-88 and to estimate the proportion who met the Canadian Nutrition Recommendations and the Nordic Nutrition Recommendations for the essential fatty acids.

As an illustration, an individual consuming 30 grams of polyunsaturated fat was estimated to consume (30 x 0.111) grams of ω3 fatty acids and (30 x 0.881) grams of ω6 fatty acids respectively. The calculated figures were used to determine whether or not the individual met the Canadian Nutrition Recommendations for ω3
and ω6 fatty acids. In a similar manner, the factor of 0.111 was used to estimate the percentage of calories as linolenic acid and very long ω3 fatty acids in order to determine whether or not the individual met the Nordic Nutrition Recommendations for these fatty acids.

In addition to the above calculations, when calculating the amount of total essential fatty acids consumed, the total of each of the proportions of ω6 fatty acids (88.1%) and ω3 fatty acids (11.1%) consumed by the UC group of the MRFIT was used to calculate the proportion of individuals meeting the Nordic Nutrition Recommendations for total essential fatty acids. Thus, an individual consuming 10 grams of polyunsaturated fat was estimated to consume a total of 9.92 grams of these essential fatty acids. This figure was then compared to the amount of total essential fatty acids specified by the Nordic Nutrition Recommendations to determine if the individual had met the specific recommendation.

**Results of the analysis**

Table 12 shows the results of the analysis. Babies of less than four years of age were not included because the assumption that the type of polyunsaturated fat consumed by the target population is similar to that of the UC group in the MRFIT is probably invalid for them. Moreover, many young infants consumed infant formula containing very small amounts of linolenic acid, if any at all, and no long chain ω3 fatty acids (Dolecek and Grandits, 1991). Further, it is reasonable to assume that the type of polyunsaturated fat consumed by individuals of a different sex or age differs more than that of middle age males from that of the UC group of the MRFIT. Therefore, the validity of the results shown in Table 12 is probably greater for middle aged men than for other individuals.
Table 12. Percentage of individuals meeting the recommended intakes of essential fatty acids in the NFCS 1987-88.

<table>
<thead>
<tr>
<th>Age group</th>
<th>Meet Canadian Nutrition Recommendations (%)</th>
<th>Meet Nordic Nutrition Recommendations (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Males</td>
<td>Females</td>
</tr>
<tr>
<td>N</td>
<td>ω3</td>
<td>ω6</td>
</tr>
<tr>
<td>4-6</td>
<td>245</td>
<td>54.8</td>
</tr>
<tr>
<td>7-9</td>
<td>198</td>
<td>59.7</td>
</tr>
<tr>
<td>10-12</td>
<td>171</td>
<td>48.8</td>
</tr>
<tr>
<td>13-15</td>
<td>163</td>
<td>53.1</td>
</tr>
<tr>
<td>16-18</td>
<td>161</td>
<td>44.7</td>
</tr>
<tr>
<td>19-24</td>
<td>277</td>
<td>55.1</td>
</tr>
<tr>
<td>25-49</td>
<td>1.409</td>
<td>61.4</td>
</tr>
<tr>
<td>50-74</td>
<td>840</td>
<td>68.4</td>
</tr>
<tr>
<td>75 or older</td>
<td>135</td>
<td>66.6</td>
</tr>
<tr>
<td>Pregnant</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Lactating</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Note: Table 3 shows the Canadian and Nordic recommendations for the essential fatty acids.
The results in Table 12 indicate that a higher proportion of individuals met the Canadian Nutrition Recommendations for \( \omega6 \) fatty acids than for \( \omega3 \) fatty acids. The Table also shows that a higher proportion of individuals met the Nordic Nutrition Recommendations for the total of essential fatty acids than for the \( \omega3 \) fatty acids. The results do not lend support to the long-held belief that essential fatty acid deficiency is practically non-existent in the United States. The extreme rarity of readily visible signs of essential fatty acid deficiency does not necessarily imply the consumption of sufficient levels of these fatty acids for optimal health. In fact, it is possible that a larger proportion of Americans does not consume a sufficient level of essential fatty acids than what Table 12 suggests. This situation could occur if the percentages of polyunsaturated fatty acids consumed as either \( \omega3 \) or \( \omega6 \) are lower than those for the UC group in the MRFIT. However, it is also possible that the percentages of \( \omega3 \) or \( \omega6 \) are higher than those for the UC group in the MRFIT.

Even if the results shown in Table 12 accurately reflect the proportion of individuals consuming certain levels of essential fatty acids, it must be noted that the proportions of individuals meeting the Nordic or the Canadian recommendations are much higher than the proportion that would meet the more stringent recommendations made by researchers such as Pedersen (1991) and Okuyama (1992). In addition, Table 12 does not show the proportion of individuals meeting the Canadian recommendations that a ratio of 4:1 to 10:1 of \( \omega6 \) to \( \omega3 \) fatty acids should be consumed. In the analysis presented here, the assumption was made that all individuals consumed a ratio of 9:1 of \( \omega6 \) to \( \omega3 \) fatty acids.
Recent findings regarding the essential fatty acids in both pregnancy and lactation show their unique role in both physiological processes. Of great interest are the findings from a recent study showing that fish-oil supplementation appears to prolong pregnancy (Olsen et al., 1992) and those from studies showing the effect of diet on the essential fatty acid content of breast milk (Innis, 1988; Jensen et al., 1992; Sanders and Reddy, 1992). It is possible that if these findings are confirmed by future studies, the recommendations for the intake of ω3 fatty acids by lactating and pregnant women will be increased.

Although Table 12 shows that the intake of ω3 fatty acids by a relatively large segment of the population may be insufficient, this problem has been ignored in many studies on fat intake. Thus, a number of studies (Dougherty et al., 1988) have appeared in the literature on how to improve the American diet by reducing the intake of cholesterol and total and saturated fat through certain dietary changes. Although these studies have clearly demonstrated the feasibility of reducing the intakes of cholesterol and saturated fat to the recommended levels while maintaining or even increasing the intake of all or almost all micronutrients, they have not reported the effect that these dietary changes would have on the intake of ω3 fatty acids or on the ratio of ω6 to ω3 fatty acids. Therefore, future studies of this nature should address the issue of whether or not the recommended dietary changes for the purpose of decreasing the intakes of cholesterol and total and saturated fat have a negative effect on the intake of the ω3 fatty acids. If the dietary changes suggested in these studies are found to be insufficient to maintain the recommended
intakes of ω3 fatty acids then the consumption of foods rich in these acids must also be recommended.

Consumption of linoleic acid by infants

The recommendation by the American Academy of Pediatrics that infants consume a minimum of 2.7% linoleic acid was presented in the Review of Literature. To illustrate the difficulties encountered in meeting this recommendation an analysis was conducted for babies under one year of age. Of the 104 babies under 1 in the sample, it was reported for 97 whether or not they consumed a special diet. Of these 97 babies, none consumed a low-fat low-cholesterol diet, a low salt diet, a low sugar/sugar free diet or a diabetic diet but ten of them consumed a diet different from these diets. Of these ten children who consumed some unspecified diet, only one consumed less than 2.7% polyunsaturated fat.

In contrast, 22 of the remaining 87 babies under one for whom it was reported that they did not consume any special diet consumed less than 2.7% of polyunsaturated fat. Thus, it appears that the consumption of the unspecified diet was associated with a higher intake of polyunsaturated fat and a lower chance of suffering from linoleic acid deficiency. The most probable reason for this finding is that the individuals consuming an unspecified diet consumed infant formula which was rich in linoleic acid. The high content of linoleic acid in their formulas made it
possible for them to obtain more than 2.7% calories as linoleic acid even if weaning foods were consumed.

Conclusions

1. A sizable percentage of the population (almost 60% in some sex-age groups) did not meet the Canadian Nutrition Recommendations for the essential fatty acids, especially for the \( \omega 3 \) fatty acids. Given that these recommendations may be increased as a result of recent studies on the role of essential fatty acids, an insufficient intake of essential fatty acids by the population should be considered a major nutritional problem.

2. Of special interest, in view of the results of recent studies on the role of essential fatty acids in child development, is the finding that a high percentage of pregnant and lactating women did not meet the Canadian Nutrition Recommendations for the \( \omega 3 \) and \( \omega 6 \) fatty acids.

3. More than 25% of the infants in the NFCS 1987-88 not consuming any special diet consumed less than the 2.7% of calories as linoleic acid recommended by the AAP.
CHAPTER VI

Effect of Changes in Diet on Micronutrients

In Chapter IV, it was shown that most individuals with hypercholesterolemia will not achieve their LDL cholesterol goals by lowering their intake of saturated fat and cholesterol to the levels currently recommended by the Step II NCEP diet of 7% saturated fat and 200 mg of dietary cholesterol. However, the consumption of a diet with less than these levels of energy percent saturated fat and cholesterol could possibly result in an insufficient intake of certain vitamins and minerals. Accordingly, this chapter presents an analysis for some of the vitamins and minerals whose intake is likely to be affected by major changes in the intake of saturated fat. In addition, given that certain individuals may consume large amounts of vitamins and minerals as supplements, a brief analysis is also presented for the intake of these supplements.

This chapter is divided into two sections. The first section presents an analysis for the association between the intakes of each of saturated and polyunsaturated fat on the one hand and the intakes of minerals and vitamins on the other. The main emphasis of the analysis is on those micronutrients which are thought to play a major role in the development of CHD: iron, zinc and vitamins C and E. In addition, given that an individual can obtain large amounts of vitamins and
minerals by consuming supplements, the second section presents an analysis of the intake of vitamin and mineral supplements by the American population.

Most of the analyses in this chapter were performed using data from the NFCS 1987-88 for a number of reasons. First, the dietary intake of the three-day participants in the NFCS 1987-88 was thought to be more representative than the one day of intake provided in the NHANES III (P1). Second, unlike in the NFCS 1987-88, in the NHANES III (P1) there are individuals with extremely low energy intakes because only one day of dietary intake was available in this survey. As a result, the calculations for the density of a certain vitamin or mineral in the diet of individuals with extremely low energy intakes in some instances yield extremely high values which are not representative of the density of these micronutrients in their diets. Third, unlike the NHANES 1988-91, the NFCS 1987-88 includes the percent intake of the 1989 RDA of all nutrients for every individual in the survey.

**Association of Fat with Other Nutrients**

Attempts to reduce the consumption of saturated fat by substituting part of this fat with polyunsaturated fat may reduce the intake of certain micronutrients. For this reason, an analysis of the association of vitamins and minerals with each of saturated and polyunsaturated fat may be helpful in evaluating the nutrients that are more likely to be deficient in the diet of individuals making major changes in the intakes of these two types of fat.

This section is divided into three parts. The first part describes some of the factors which need to be considered when interpreting the results presented in the
last two parts. The second part presents the association between the energy percent intake of saturated fat and the intake of vitamins and minerals. The third part describes the association between the energy percent intake of polyunsaturated fat and the intake of vitamin and minerals.

**Calculation of Vitamin Intakes**

Before presenting the results for the association between each of saturated and polyunsaturated fat and various micronutrients, it must be pointed out that there are a number of reasons why the entire amount of a certain vitamin or mineral consumed by an individual may not have been included in the analysis. First, the analyses in this first section only include the amount of vitamins and minerals consumed as part of the diet and not as supplements. As previously stated, an analysis for the use of supplements is presented in the second section of this chapter.

A second factor to consider is that, in the NFCS 1987-88, some precursors were included for some vitamins but not for all. Thus, in this survey, the total amount of both provitamin A (such as carotenes) and vitamin A was expressed together as retinol equivalents (RE). By convention, 1 µg of all-trans retinol, 6 µg of all-trans carotene or 12 µg of other provitamin A carotenoids equal 1 RE (National Research Council, 1989). The results presented are for the intake of REs of vitamin A. In a similar way, the results of the analysis for vitamin E are for α–tocopherol equivalents (TE).
In contrast to vitamins A and E, in the NFCS 1987-88 the niacin content of foods only included preformed niacin. Niacin which could be derived from tryptophan was not included. By convention, each 60 mg of tryptophan is considered to be equivalent to 1 mg of niacin or 1 niacin equivalent (NE) because the body can synthesize niacin from tryptophan (NRC, 1989). Foods such as eggs and milk have a low content of preformed niacin but are excellent sources of tryptophan and thus, provide a large number of NEs. Therefore, any analysis of the association between niacin intake and the intake of any other nutrient should ideally be performed using niacin equivalents rather than preformed niacin.

A third factor to consider is that, like the NHANES III (P1), the data of the NFCS 1987-88 did not distinguish between the non-heme iron and heme-iron consumed by an individual. For this reason, and because the absorption of iron is influenced by a number of dietary and non-dietary factors (National Research Council, 1989), it is very difficult to reach any conclusions concerning the adequacy of the iron intake of any group of individuals.

Another factor to consider is that in order to determine which vitamin or mineral intakes are likely to be affected when an individual switches to a very low saturated fat diet, it is necessary to compare an individual’s intake of a particular vitamin or mineral to the range of intake recommended for that particular micronutrient. The best measure for the intake of a particular micronutrient in relation to an
individual’s needs is the RDA. However, any RDA depends on knowledge available at the time the RDA is established. As an illustration, the 1980 RDA for folate was reduced in the 1989 edition by about 50% for most groups. After 1989, a number of researchers have indicated that the 1989 RDA for folate is too low, particularly for pregnant women (Bailey, 1992). Hence, for folate and for other nutrients, different conclusions regarding intake could be reached if an RDA other than the 1989 value were used. In the following analyses, the 1989 RDA was used for each nutrient.

Saturated Fat and Mineral and Vitamin Intake

Figure 16 shows the percentages of calories from saturated fat versus the percentages of the RDAs for zinc, calcium, magnesium and riboflavin. As shown in this Figure, lower percent intakes of saturated fat were associated with lower mean percentages of the 1989 RDAs for these nutrients. With the exception of vitamin B₁₂, whose percent intake in terms of its RDA also increased with an increased percent intake of saturated fat, no associations were found between the percentages of saturated fat and the mean percentages of the RDAs of other micronutrients. Vitamin B₁₂ is not included in the Figure because most individuals consumed a percentage of the RDA that far exceeded their needs.

It is possible that no association was found for iron because of the use of this mineral to fortify many foods. When analyzing Figure 16, however, it must be taken into account that the groups of individuals consuming various percentages of saturated fat differed in their caloric intake. They also differed in characteristics such as age, sex and in women, physiological status (i.e. pregnancy or lactation).
Figure 16. Estimated energy percent saturated fat consumption versus estimated percent of 1989 RDA's for zinc, calcium, magnesium and riboflavin, NFCS 1987-88. Individuals at least one year old.

Number of individuals in parentheses.
These characteristics are the basis for setting different allowances of a given nutrient for different individuals. Hence the relationships between saturated fat intake and micronutrient densities could be more indicative of the possible consequences of decreasing saturated fat.

The positive associations between percent saturated fat intake and the mean percent of the RDAs achieved for riboflavin and calcium probably exist because of the high concentration of these nutrients in milk and milk products. On the other hand, the associations between the percent saturated fat intake and each of the percents of the RDAs for zinc and vitamin B\textsubscript{12} consumed probably exist because of the high concentration of these micronutrients in animal products. The finding that the mean percent of the 1989 RDAs consumed by those females and males eating 18\% or more of calories as saturated fat was slightly lower than that of females and males eating between 16 and 18\% is probably a result of the lower intake of zinc-rich lean animal tissues by the former group.

Figure 17 shows the association between the densities (mg/1,000 kcal) of vitamin C, iron and zinc and the percent intake of saturated fat. As shown in the Figure, individuals with a lower energy percent intake of saturated fat consumed diets that were more dense in both vitamin C and iron but were slightly less dense in zinc. Unfortunately, as previously stated, the NFCS 1987-88 did not distinguish between heme and non-heme iron. Even if that distinction had been made it would still have been very difficult to reach some firm conclusions regarding the amount of iron absorbed by individuals consuming various percentages of saturated fat. On the one hand, it is possible that individuals with a low energy percent intake of
Figure 17. Average density of vitamin C, iron and zinc in the diet. NHANES III. Individuals at least 20 years old.
By percent saturated fat.

Individuals with less than 100 Kcal/day of energy intake were excluded from the analysis.
saturated fat may have absorbed a higher proportion of their non-heme iron than individuals with higher energy percent saturated fat intakes as a result of their higher intake of vitamin C. On the other hand, individuals with a low energy percent intake of saturated fat may have had a lower intake of heme iron because foods, such as meat, which are rich in saturated fat are also rich in heme iron. Given that a much higher percentage of heme iron as compared to nonheme iron is absorbed, the total amount of iron absorbed tends to depend more on the amount of heme iron than on the amount of nonheme iron in the diet.

Another finding from Figure 17 is that the diets of individuals with a lower percent intake of saturated fat had a lower density of zinc than the diets of individuals with higher percent saturated fat intakes. Although the differences in the density of zinc between the various groups were apparently low, they may have been sufficient to merit recommending increased intakes of zinc-rich foods to individuals wishing to reduce their intake of saturated fat. The recommendation to consume zinc-rich foods for individuals consuming a very low percent intake of saturated fat appears especially important in view of the results presented in Figure 16. As shown in Figure 16, individuals consumed a lower percent of the RDA for zinc than for any of the nutrients in the figure. The findings in Figures 16 and 17 are in agreement with the finding that some individuals on a low saturated fat and cholesterol diet consume inadequate amounts of zinc (Retzlaff et al., 1991; Buzzard, 1990).

With the exception of calcium, riboflavin and vitamin B_{12} (nutrients which are high in animal foods) all other micronutrients studied were more dense in the diets
of persons consuming diets lower in saturated fat. Therefore, diets low in saturated fat are often more dense in mineral and vitamin content than diets higher in saturated fat with the exception of micronutrients that are high in animal foods. For this reason, special care must be taken when reducing saturated fat consumption to ensure an adequate intake of micronutrients that are high in animal foods.

A conclusion of the results presented in the previous analysis is that attempts by doctors and other health professionals to recommend a lower intake of saturated fat and cholesterol to their patients may also have a major impact in the intake of micronutrients. Figure 18 shows the percent difference in the density of iron, the percent intake of saturated fat and the density of cholesterol between individuals who consumed a low-fat low-cholesterol diet and those who did not after being advised to do so by their doctor. As shown in the Figure, eating fewer high fat or high cholesterol foods had a larger impact on the intake of iron than on the intake of either percent saturated fat or cholesterol. For example, women eating fewer high fat or high cholesterol foods experienced an almost 50% increase in the density of iron in their diet while experiencing about a 21% and a 12% decrease in the percent of saturated fat and in the density of cholesterol consumed, respectively.

A difficulty in interpreting Figure 18 is that the Figure does not show the percent difference in the density of heme and nonheme iron between the two groups of individuals. Although individuals eating fewer high fat or high cholesterol foods consumed diets that were more dense in iron, it is possible that these individuals actually experienced a decrease in the amount of heme iron they consumed. The
Figure 18. Estimated percent difference in density of iron, energy percent saturated fat and density of cholesterol between individuals who ate fewer high fat or high cholesterol foods and those who did not. Individuals at least 20 years old.

Analysis compared individuals of the same sex who were advised by a doctor to consume fewer high fat or high cholesterol foods. A total of 389 men and women reported consuming these foods while 53 and 55 women did not.
reason for this decreased intake of heme iron is that foods that are high in saturated fat and cholesterol, such as beef, are also high in heme iron.

Whether or not an individual benefits from an increase in the intake of iron differs in each individual. For an individual suffering from anemia or having marginal iron stores, an increase in the amount of iron consumed would be beneficial. However, for an individual wishing to decrease his levels of total serum and LDL cholesterol, an increase intake of iron could increase the levels of stored iron in his body. As discussed in the Review of Literature, high levels of stored iron are thought to actually increase his risk for CHD by increasing the levels of oxidized LDL cholesterol. Therefore, the main conclusion reached from the analysis in Figure 18 is that individuals wishing to decrease their intake of saturated fat and cholesterol must be careful so that they do not experience an undesirable increase in iron intake that may increase their risk for CHD.

**Polyunsaturated Fat and Mineral and Vitamin Intake**

Since some individuals may want to increase their intake of polyunsaturated fat for the purpose of reducing their high blood cholesterol levels, it is of interest to determine the possible effects of these dietary changes on the intake of certain micronutrients. Figure 19 shows that individuals who consumed higher percentages of energy as polyunsaturated fat generally consumed a lower percentage of their RDAs for riboflavin, calcium, magnesium and folate. Of special significance for women is the finding that a higher intake of polyunsaturated fat tends to be associated with a low percent intake of the RDA for folate because a number of researchers have suggested that the RDA for folate should be increased. Thus,
Figure 19. Estimated energy percent polyunsaturated fat consumption versus estimated percent of 1989 RDA's for folate, riboflavin, magnesium and calcium, NFCS 1987-88. Individuals at least one year old.

Number of individuals in parentheses.
although the percent of the RDA consumed for folate is higher than for any other nutrient in Figure 19, the results are probably misleading for this nutrient because the level of folate consumed by many individuals is less satisfactory than what the Figure indicates.

In contrast to the association between the nutrients in Figure 19 and the percent energy intake of polyunsaturated fat, higher energy percent intakes of polyunsaturated fat were associated with higher mean percent intakes of the RDA of vitamin E. Thus, as shown in Figure 20, individuals with higher percent intakes of polyunsaturated fat tended to consume a higher percent of their RDA for vitamin E than individuals with lower percent intakes of polyunsaturated fat. However, individuals consuming higher levels of polyunsaturated fat may not have been in a better nutritional status in terms of vitamin E intake. The reason is that the consumption of 0.6 mg of vitamin E for each gram of polyunsaturated fat, when the main fatty acid in the diet is linoleic acid, has been recommended for the prevention of the oxidation of this polyunsaturated fat (Witting and Lee, 1975). As shown in Figure 20, with the exception of individuals consuming a very low percent intake of polyunsaturated fat all the other groups of individuals consumed less than the 0.6 ratio recommended by a number of researchers.

The relationship between the intakes of polyunsaturated fat and vitamin E would be more clear if it were not for the fortification of certain foods with vitamin E. For example, in a study involving NHANES II data, Murphy et al. (1990) found that vitamin E intakes were high as a result of the use of the high value for vitamin E of the U.S. RDA, which serves as the standard for the fortification of foods. The U.S.
Figure 20. Estimated average percentage of the RDA for vitamin E and estimated mean ratio of vitamin E (mg) to polyunsaturated fat (g), NFCS 1987-88. By energy percent intake of polyunsaturated fat.
RDA is the standard for nutrition labeling developed in 1973 by the FDA based for most nutrients on the 1968 edition of the RDA. The U.S. RDA for vitamin E is 20 mg TE, and is based on the 1968 RDA for men which was double the 1989 RDA for men. The U.S. RDA has been used as the standard for the fortification of foods such as cereals and instant breakfast. One result of the high fortification of these foods with vitamin E is a decrease in the relative contribution to the intake of this vitamin by polyunsaturated fat-rich foods.

Conclusions

1. Diets low in saturated fat were more dense in mineral and vitamin content than diets higher in saturated fat with the exception of micronutrients that are high in animal foods (such as calcium and vitamin B₁₂).

2. The consumption of higher percentages of energy as polyunsaturated fat was associated with lower percent intakes of the RDAs for riboflavin, calcium, magnesium and folate.

3. Attempts to reduce the intake of saturated fat and cholesterol resulted in major increases in the density of iron in the diet. Therefore, individuals making dietary changes to reduce their risk for CHD should closely monitor both their intake of iron and their levels of stored iron.
4. Although the consumption of higher percentages of energy as polyunsaturated fat was associated with higher percent intake of the RDA of vitamin E, individuals consuming higher percentages of polyunsaturated fat tended to consume a lower ratio of vitamin E to polyunsaturated fat.

**Use of Supplements**

The previous analysis showed some of the associations between the energy percent intakes of saturated fat and polyunsaturated fat on the one hand and the intakes of vitamins and minerals on the other hand. As previously stated, however, the results just presented only included the amounts of various micronutrients obtained from the diet. The analysis did not include the amount of various nutrients consumed from supplements. A general analysis of the intake of vitamin and mineral supplements by the target population is presented in this section.

Although the NFCS 1987-88 did not report the amount or specific name of the supplement consumed, the survey collected some data on the frequency and general type of the supplements used. An analysis of these data is presented in this section. This section is divided into three parts. The first part briefly discusses some of the limitations of the analyses presented in the last two parts. The second part presents a brief analysis of the frequency of the use of vitamin and mineral
supplements. The third part presents results of an analysis of the use of particular supplements.

**Limitations of the analysis**

As was shown in Table 1, a number of iron supplements provide a very high percentage of the RDA for iron. In a similar manner, other vitamin or mineral supplements can provide a large percentage of the RDA for other micronutrients. Accordingly, individuals consuming vitamin or mineral supplements may have obtained a large percentage of their RDA for a certain vitamin or mineral from supplements. Unfortunately, there are a few reasons why the NFCS 1987-88 only allowed a very limited analysis of the effects of supplement use on the intake of micronutrients. First, neither the name of the supplement or the amount of vitamin or mineral provided by each supplement was available in the NFCS 1987-88. Second, some of the supplements were grouped in a general category, such as "Vitamin/mineral" or "Other vitamin/mineral" supplements. For supplements grouped in these general categories, the vitamins or minerals in the supplement were unknown. Third, the NFCS 1987-88 did not provide any data that can be used to determine whether or not a particular individual could have benefited from the use of a certain vitamin or mineral supplement. An examples of these data could be a measure of iron status, such as serum ferritin, which could help determine whether or not a particular individual could have benefited from the consumption of an iron supplement.
An illustration of data indicating the level of a micronutrient in the body is the level of serum ferritin. As stated in the Review of Literature, serum ferritin is an indicator of the amount of iron stored in the body. Similarly, other indicators of vitamin or mineral status could have been helpful in determining whether or not an individual could possibly benefit from the use of a particular supplement. Given that the NFCS 1987-88 did not collect those types of data, the limited data available in the NFCS 1987-88 only allowed for a general descriptive analysis of the intake of vitamin and mineral supplements by the target population. As part of the analysis, comparisons will be presented between groups of individuals according to whether or not they suffered from heart disease or consumed a low-fat, low-cholesterol diet.

**Vitamin E**

In terms of the use of supplements by individuals wishing to reduce their risk of CHD, the interpretation of the results of the analysis would have been difficult even if the exact amount of each vitamin and mineral consumed by each individual as supplements had been known. As stated in the Review of Literature, the use of vitamin E supplements has been found to lower the risk of CHD in men (Rimm et al., 1993) and in women (Stampfer et al., 1993) but no organization has recommended the use of vitamin E supplements for the prevention of CHD. Nevertheless, the intake of very high levels of vitamin E have not been found to be
toxic. Therefore, even if individuals consuming vitamin E supplements did not lower their risk for CHD by the use of these supplements, at least it appears that these individuals are not exposed to any health hazard by the consumption of these supplements.

**Iron and Vitamin C**

Unlike vitamin E supplements, iron supplements can be toxic if consumed in excess amounts. Thus, even though the various studies of the association between stored iron and the risk for CHD have provided mixed results, the consumption of iron supplements can represent a health hazard to individuals already consuming large amounts of iron from their diets. For this reason, Lauffer has recommended that individuals with high levels of stored iron avoid the use of iron supplements (1991). This researcher has also recommended that individuals with elevated levels of stored iron should not consume vitamin C supplements during meals so that the consumption of these supplement does not increase the amount of dietary iron absorbed.

**Frequency of use of supplements**

Figure 21 presents the percentage of men and women using vitamin and mineral supplements according to whether or not they suffered from heart disease and whether or not they consumed a low-fat low-cholesterol diet. Within each sex, a higher percentage of men and women with heart disease who consumed a low-fat low-cholesterol diet consumed supplements every day than the percentage of any
Groups: A. Had heart disease and consumed a low-fat low-cholesterol diet.
B. Consumed a low-fat low-cholesterol diet but had no heart disease.
C. Had heart disease but did not consume a low-fat low-cholesterol diet.
D. Did not have heart disease and did not consume a low-fat low-cholesterol diet.

Figure 21. Estimated frequency of use of vitamins and mineral supplements. Individuals at least 20 years old.
other group. Thus, as shown in the Figure, the percentage of men consuming vitamin and mineral supplements every day was double for men with heart disease who were on a low-fat low-cholesterol diet than for men who did not suffer from the disease and were not on a low-fat low-cholesterol diet.

The results from this analysis indicate that both heart disease and the consumption of a low-fat low-cholesterol diet are factors which are associated with the frequency of the use of supplements. However, these results do not provide any information about the specific types of vitamin and mineral supplements used by these four groups in the target population. An analysis of that nature is presented in the next section.

**Types of vitamin and mineral supplements used**

Table 13 shows the percentage of individuals who consumed various iron-containing supplements. As in Figure 21, individuals are divided into four groups according to whether or not they have heart disease and consume a low-fat low-cholesterol diet. The results in Table 13 show that the percentage of individuals who consumed a “multivitamin supplement with iron or other minerals” ranged from 7.3% to 17.6% in the groups included in the Table. In contrast, an extremely low percentage of individuals consumed either an iron supplement or a vitamin C/iron supplement.
Table 13. Estimated percentage of individuals at least 20 years old who use iron-containing supplements, NFCS 1987-88.

<table>
<thead>
<tr>
<th>Supplement</th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A (69)</td>
<td>B (80)</td>
</tr>
<tr>
<td>Multivitamin with iron or other minerals</td>
<td>7.8 12.7 7.3 7.6</td>
<td>10.1 17.7 13.3 17.8</td>
</tr>
<tr>
<td>Vitamin C/iron</td>
<td>1.5 0.0 0.0 1.5</td>
<td>1.2 3.3 1.6 1.9</td>
</tr>
<tr>
<td>Iron</td>
<td>0.0 0.0 1.4 0.7</td>
<td>2.6 1.2 1.4 2.7</td>
</tr>
</tbody>
</table>

A: individuals with heart disease on a low-fat low-cholesterol diet.
B: individuals on a low-fat low-cholesterol diet who have no heart disease.
C: individuals with heart disease who are not on a low-fat low-cholesterol diet.
D: individuals who are free from heart disease and are not on a low-fat low-cholesterol diet.

Individuals in each category shown in brackets.
From the results in Table 13, it appears that a very low percentage of the population is interested in increasing the intake of iron in the form of supplements. Therefore, an area of interest would be to determine why individuals consume a multivitamin supplement with iron. It is possible that many of the individuals consuming this type of supplement would switch to a multivitamin supplement without iron if they were informed by their doctor that an excessive intake of iron can be harmful. In addition, the percentage of women consuming iron-containing supplements was larger than that of men for almost all the groups shown in the Table. Most likely, the higher consumption of this supplement by women is a result of the increased need for iron in menstruating women.

Table 14 shows the percentage of individuals who consumed supplements that did not specifically mention iron as one of the micronutrients in the supplement. However, it is possible that the “multivitamin” supplement or the “vitamin/mineral” supplement contained some iron. As shown in the Table, the “multivitamin” supplement was the one most commonly consumed. Also, a much higher proportion of men with heart disease who were on a low-fat low-cholesterol diet consumed “Other vitamin or mineral” supplement than men or women of any of the four categories of individuals included in the table. An analysis of interest would be to determine the specific vitamin and mineral supplements consumed by individuals who have suffered from heart disease.
Table 14. Estimated percentage of individuals at least 20 years old who used vitamin or mineral supplements, NFCS 1987-88.

<table>
<thead>
<tr>
<th>Supplement</th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A (69)</td>
<td>B (80)</td>
</tr>
<tr>
<td>Multivitamin</td>
<td>23.1</td>
<td>21.1</td>
</tr>
<tr>
<td>Vitamin mineral</td>
<td>6.2</td>
<td>1.0</td>
</tr>
<tr>
<td>Vitamin C</td>
<td>8.9</td>
<td>9.0</td>
</tr>
<tr>
<td>Calcium</td>
<td>6.0</td>
<td>1.5</td>
</tr>
<tr>
<td>Other vitamin or mineral</td>
<td>19.7</td>
<td>8.3</td>
</tr>
</tbody>
</table>

A: individuals with heart disease on a low-fat low-cholesterol diet.
B: individuals on a low-fat low-cholesterol diet who have no heart disease.
C: individuals with heart disease who are not on a low-fat low-cholesterol diet.
D: individuals who are free from heart disease and are not on a low-fat low-cholesterol diet.

Individuals in each category shown in brackets.
Conclusions

1. Almost 40% of men and more than 45% of women with heart disease consumed at least one vitamin or mineral supplement daily. These percentages are higher than the percentages of men and women with no heart disease that consumed a vitamin or mineral supplement daily.

2. When individuals were grouped in four categories, according to whether or not they had heart disease or consumed a low-fat low-cholesterol diet, the percentage of individuals who consumed either an iron or a vitamin C/iron supplement ranged from 0 to 1.5 in men and from 1.2 to 3.3 in women.

3. When individuals were grouped in four categories, according to whether or not they had heart disease or consumed a low-fat low-cholesterol diet, the percentage of men who consumed a “multivitamin with iron or other minerals” ranged from 7.3 to 12.7 in men and from 10.1 to 17.8 in women.

4. In contrast to the very low percentage of men and women consuming an iron or vitamin C/iron supplement, a higher percentage of men and women consumed a multivitamin supplement than any other supplement. It is possible that many individuals consuming a “multivitamin with iron or other
minerals" could benefit from changing to a multivitamin supplement that contains no iron.
CHAPTER VII

Conclusions and Future Research

The conclusions for the various analyses included in this study have already been presented at the end of the sections in Chapters IV, V and VI. For this reason, this chapter will only present a brief summary of the main conclusions of the study, their overall significance as well as areas of future research. This chapter is divided into two sections. The first section describes the major conclusions of this study. The second section lists a number of areas of future research.

Major Conclusions

The major finding of the study is that a high proportion of individuals would be unable to meet their LDL cholesterol goals by decreasing their intake of saturated fat and dietary cholesterol to the levels recommended by the NCEP Step diets. In addition, an even higher proportion of individuals would still have a total serum cholesterol level of more than 180 mg/dl after switching to the Step diets. Based on these results and the finding of an association between levels of total cholesterol of more than 180 mg/dl and an increased risk for CHD in the MRFIT, it is concluded that most individuals wishing to reduce their risk for CHD should consider an alternate diet to the Step II NCEP diet.
Another finding of this study was that individuals who consumed a higher energy percent of saturated fat tended to consume a higher percentage of the RDA's for zinc, calcium, magnesium and riboflavin. By contrast, individuals consuming a higher energy percent of polyunsaturated fat tended to consume a lower percentage of the RDA's for folate, calcium, magnesium and riboflavin. Therefore, individuals substituting polyunsaturated fat for saturated fat, for the purpose of decreasing their serum cholesterol levels, need to ensure an adequate intake of these micronutrients.

A conclusion from this study is that different dietary approaches for the reduction of elevated serum cholesterol levels should be investigated. One possibility is to reduce the intake of saturated fat to less than 7% and the intake of cholesterol to less than 200 mg. In addition to recommending lower intakes of saturated fat and cholesterol than those recommended by the Step II diet, these new dietary guidelines should also recommend the consumption of foods rich in nutrients whose intake is likely to be diminished by reductions in the intake of saturated fat and cholesterol.

Future Research

The present study used data from nationwide food consumption surveys to analyze the effect of reducing the intake of saturated fat and cholesterol on the levels of total and LDL cholesterol. All future studies in this area should be of two types. The first type of research would involve the use of existing (such as those for the NHANES III
and the NFCS 1987-88) or upcoming food consumption surveys. The second type of
research would not involve the analysis of data from any of the food consumption
surveys. This second type of research (which could involve techniques such as
sensory testing or clinical trials) would provide additional information about diets
which restrict the intake of saturated fat and dietary cholesterol to levels lower than
those in the NCEP Step II diet.

This section is divided into two parts. The first part lists a number of areas in which
future research involving the use of existing and upcoming databases from nationwide
food consumption surveys could be conducted. The second part lists a number of
areas related to the subject of this study which could be the subject of future research
but do not involve the use of any existing nationwide food consumption database.

**Future Research Using Nationwide Food Consumption Databases**

The first area of research would involve the use of data from nationwide food
consumption surveys to obtain estimates not included in this study. An example of
this type of research would be the use of the databases from the NHANES III (P1) and
the NFCS 1987-88 to estimate the intake of specific fatty acids. This analysis was not
included in this study because the Survey Nutrient Database did not include any data
for the content of specific fatty acids in foods.
Estimates of the specific fatty acids (such as lauric or palmitic fatty acids) would also make it possible to estimate the amount of each type of fatty acids (such as trans fatty acids or essential fatty acids) consumed by each individual. This type of descriptive analysis would be helpful to estimate the percentage of the population meeting the recommendations for the essential fatty acids. It would also make it possible to compare the intake of the various types of fatty acids among certain groups of individuals, such as individuals consuming a low-fat low-cholesterol diet and those not consuming a low-fat low-cholesterol diet.

As stated in Chapter V, the database developed by the Nutrition Coordinating Center (NCC) at the University of Minnesota could be used to estimate the amounts of each specific fatty acid consumed by each participant. This analysis would be possible because the NCC database has the individual fatty acids in each food and uses USDA codes. However, the analysis would be limited to the foods which are in the NCC database. The NCC database does not have all the foods consumed in a particular nationwide food consumption survey (McDowell, 1996).

Future Research Not Using Nationwide Food Consumption Surveys

The second type of research would involve studies on the acceptability, safety and effectiveness of a diet with less than 7% of saturated fat and less than 200 mg of cholesterol. First, studies would be needed to assess whether or not this diet would be acceptable to most individuals in terms of taste, satiety and other qualities. Findings from these studies could be used to suggest ways by which individuals wishing to
reduce their intake of saturated fat and cholesterol could make their diets more satisfactory and enjoyable.

A second area of research would involve studies to determine whether or not the consumption of this type of diet would be safe. These studies would determine whether or not this type of diet would provide a sufficient amount or energy percent of essential nutrients (such as vitamins, minerals and essential fatty acids). Based on the findings, these studies could suggest foods low in saturated fat and cholesterol but rich in the essential nutrients likely to be present at insufficient or marginal levels in this type of diet.

A third area of research would involve metabolic ward or field studies that would assess the effectiveness of this type of diet in lowering total and LDL cholesterol to desirable levels. These studies would be similar to those conducted since the late 1950s to assess the effect of various types of fat on the levels of total and LDL cholesterol. A major difference of the studies suggested here is that these studies would involve the use of diets much lower in saturated fat and cholesterol than those used in most clinical studies in the past. An aim of these studies could be the development of predictive equations, similar to those developed by Hegsted and others, to estimate the effect of very large reductions in both the percent intake of saturated fat (i.e., to 5% or less) and dietary cholesterol (to 0 mg). Ideally, these
equations should be developed using data from studies in which only one dietary variable is changed to reduce the problem of collinearity. These predictive equations could be useful in estimating the maximum decrease in total and LDL cholesterol that an individual would be able to experience by dietary changes.
APPENDIX

Mean±SE of lipoproteins and of changes in lipoproteins induced by diets
Table 15. Estimated mean total serum cholesterol levels, NHANES III (P1).
Individuals at least 20 years old.

<table>
<thead>
<tr>
<th>Age group</th>
<th>N</th>
<th>Mean±SE</th>
<th>N</th>
<th>Mean±SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>20-29</td>
<td>775</td>
<td>180.6±1.7</td>
<td>771</td>
<td>183.3±1.8</td>
</tr>
<tr>
<td>30-39</td>
<td>691</td>
<td>203.4±2.0</td>
<td>737</td>
<td>188.4±1.9</td>
</tr>
<tr>
<td>40-49</td>
<td>596</td>
<td>211.2±2.3</td>
<td>571</td>
<td>202.1±2.3</td>
</tr>
<tr>
<td>50-59</td>
<td>452</td>
<td>222.3±3.0</td>
<td>428</td>
<td>230.2±2.8</td>
</tr>
<tr>
<td>60-69</td>
<td>521</td>
<td>221.3±2.5</td>
<td>518</td>
<td>237.5±2.9</td>
</tr>
<tr>
<td>70 and over</td>
<td>690</td>
<td>209.2±2.1</td>
<td>665</td>
<td>233.1±2.4</td>
</tr>
</tbody>
</table>

Estimated mean values are shown in Figure 4.

Analysis included 7,415 individuals in the NHANES III (P1) with and without CHD.

A design effect of 1.8 was used to estimate the standard error shown in the Table.
Table 16. Estimated average decrease in total serum cholesterol induced by changes to the NCEP Step diets. By age and sex.

<table>
<thead>
<tr>
<th>Age group</th>
<th>N</th>
<th>Step I</th>
<th>Step II</th>
<th>N</th>
<th>Step I</th>
<th>Step II</th>
</tr>
</thead>
<tbody>
<tr>
<td>20-29</td>
<td>289</td>
<td>8.8±0.7</td>
<td>15.3±0.9</td>
<td>304</td>
<td>6.4±0.7</td>
<td>12.3±0.9</td>
</tr>
<tr>
<td>30-39</td>
<td>372</td>
<td>7.4±0.7</td>
<td>14.0±0.8</td>
<td>348</td>
<td>7.1±0.6</td>
<td>13.4±0.8</td>
</tr>
<tr>
<td>40-49</td>
<td>341</td>
<td>6.2±0.7</td>
<td>12.7±0.9</td>
<td>310</td>
<td>6.0±0.6</td>
<td>12.3±0.7</td>
</tr>
<tr>
<td>50-59</td>
<td>292</td>
<td>7.0±0.7</td>
<td>13.6±0.8</td>
<td>294</td>
<td>5.8±0.6</td>
<td>11.6±0.8</td>
</tr>
<tr>
<td>60-69</td>
<td>335</td>
<td>7.2±0.7</td>
<td>13.3±0.9</td>
<td>361</td>
<td>5.0±0.6</td>
<td>10.4±0.8</td>
</tr>
<tr>
<td>70 and over</td>
<td>402</td>
<td>6.8±0.6</td>
<td>13.2±0.8</td>
<td>456</td>
<td>3.9±0.3</td>
<td>9.3±0.6</td>
</tr>
</tbody>
</table>

Estimated mean values are shown in Figure 5.

Analysis included 4,104 individuals in the NHANES III (P1) with more than 180 mg/dl of serum cholesterol.

A design effect of 1.8 was used to estimate the standard errors shown in this Table.
Table 17. Estimated average decrease in total serum cholesterol induced by reductions in dietary cholesterol to the NCEP Step diets in men with more than 180 mg/dl of total serum cholesterol.

<table>
<thead>
<tr>
<th>Age group</th>
<th>N</th>
<th>0</th>
<th>50</th>
<th>100</th>
<th>200</th>
<th>300</th>
</tr>
</thead>
<tbody>
<tr>
<td>20-29</td>
<td>289</td>
<td>17.5±0.7</td>
<td>12.7±0.6</td>
<td>9.0±0.6</td>
<td>4.3±0.4</td>
<td>2.2±0.3</td>
</tr>
<tr>
<td>30-39</td>
<td>372</td>
<td>16.4±0.6</td>
<td>11.9±0.6</td>
<td>8.4±0.5</td>
<td>3.8±0.3</td>
<td>1.7±0.2</td>
</tr>
<tr>
<td>40-49</td>
<td>341</td>
<td>15.3±0.6</td>
<td>10.8±0.5</td>
<td>7.4±0.5</td>
<td>3.2±0.3</td>
<td>1.3±0.2</td>
</tr>
<tr>
<td>50-59</td>
<td>292</td>
<td>14.9±0.6</td>
<td>10.5±0.6</td>
<td>7.2±0.5</td>
<td>3.1±0.3</td>
<td>1.3±0.2</td>
</tr>
<tr>
<td>60-69</td>
<td>335</td>
<td>14.2±0.6</td>
<td>9.9±0.5</td>
<td>6.7±0.5</td>
<td>2.9±0.3</td>
<td>1.3±0.2</td>
</tr>
<tr>
<td>70 and over</td>
<td>402</td>
<td>13.0±0.5</td>
<td>8.8±0.4</td>
<td>5.7±0.4</td>
<td>2.3±0.2</td>
<td>0.8±0.1</td>
</tr>
</tbody>
</table>

Estimated mean values are shown in Figure 8.

Analysis included 2,031 men in the NHANES III (P1) with more than 180 mg/dl of serum cholesterol.

Analysis was performed using the 1992 Hopkins equation.

A design effect of 1.8 was used to estimate the standard errors shown in the Table.
Table 18. Estimated average decrease in total serum cholesterol induced by reductions in dietary cholesterol to the NCEP Step diets in women with more than 180 mg/dl of total serum cholesterol.

<table>
<thead>
<tr>
<th>Age group</th>
<th>N</th>
<th>Maximum dietary cholesterol intake (mg)</th>
<th>Mean decrease (mg/dl)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>20-29</td>
<td>304</td>
<td>12.2±0.6</td>
<td>8.1±0.5</td>
</tr>
<tr>
<td>30-39</td>
<td>348</td>
<td>12.3±0.5</td>
<td>8.2±0.4</td>
</tr>
<tr>
<td>40-49</td>
<td>310</td>
<td>11.6±0.5</td>
<td>7.6±0.4</td>
</tr>
<tr>
<td>50-59</td>
<td>294</td>
<td>10.8±0.5</td>
<td>6.9±0.4</td>
</tr>
<tr>
<td>60-69</td>
<td>361</td>
<td>10.1±0.5</td>
<td>6.3±0.4</td>
</tr>
<tr>
<td>70 and over</td>
<td>456</td>
<td>19.8±0.4</td>
<td>6.1±0.3</td>
</tr>
</tbody>
</table>

Estimated mean values are shown in Figure 8.

Analysis included 2,073 women in the NHANES III (P1) with more than 180 mg/dl of serum cholesterol.

Mean values were estimated using the 1992 Hopkins equation.

A design effect of 1.8 was used to estimate the standard errors shown in this Table.
Table 19. Estimated mean LDL cholesterol levels, NHANES III (P1).
Individuals at least 20 years old.

<table>
<thead>
<tr>
<th>Age group</th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean±SE</td>
</tr>
<tr>
<td>20-29</td>
<td>752</td>
<td>110.2±1.6</td>
</tr>
<tr>
<td>30-39</td>
<td>664</td>
<td>129.2±1.9</td>
</tr>
<tr>
<td>40-49</td>
<td>539</td>
<td>132.4±2.1</td>
</tr>
<tr>
<td>50-59</td>
<td>428</td>
<td>142.6±2.5</td>
</tr>
<tr>
<td>60-69</td>
<td>504</td>
<td>142.7±2.4</td>
</tr>
<tr>
<td>70 and over</td>
<td>669</td>
<td>133.1±1.9</td>
</tr>
</tbody>
</table>

Estimated mean values are shown in Figure 9.

Analysis included 7,136 individuals in the NHANES III (P1).

A design effect of 1.8 was used to estimate the standard errors shown in the Table.
Table 20. Estimated mean HDL cholesterol levels, NHANES III (P1).
Individuals at least 20 years old.

<table>
<thead>
<tr>
<th>Age group</th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean±SE</td>
</tr>
<tr>
<td>20-29</td>
<td>752</td>
<td>48.4±0.6</td>
</tr>
<tr>
<td>30-39</td>
<td>664</td>
<td>46.9±0.7</td>
</tr>
<tr>
<td>40-49</td>
<td>539</td>
<td>47.2±0.9</td>
</tr>
<tr>
<td>50-59</td>
<td>428</td>
<td>47.5±0.9</td>
</tr>
<tr>
<td>60-69</td>
<td>504</td>
<td>45.6±0.8</td>
</tr>
<tr>
<td>70 and over</td>
<td>669</td>
<td>47.0±0.7</td>
</tr>
</tbody>
</table>

Estimated mean values are shown in Figure 12.

Analysis included 7,136 individuals in the NHANES III (P1)

A design effect of 1.8 was used to estimate the standard errors shown in the Table.
Table 21. Estimated average decrease in LDL cholesterol induced by changes to the NCEP Step diets by individuals free from CHD who did not meet their LDL cholesterol goal. By age and sex.

<table>
<thead>
<tr>
<th>Age group</th>
<th>N</th>
<th>Step I</th>
<th>Step II</th>
<th>N</th>
<th>Step I</th>
<th>Step II</th>
</tr>
</thead>
<tbody>
<tr>
<td>20-29</td>
<td>61</td>
<td>10.0±1.2</td>
<td>15.7±1.4</td>
<td>54</td>
<td>5.9±1.3</td>
<td>10.5±1.6</td>
</tr>
<tr>
<td>30-39</td>
<td>118</td>
<td>5.7±0.9</td>
<td>11.3±1.1</td>
<td>73</td>
<td>5.3±1.2</td>
<td>10.1±1.5</td>
</tr>
<tr>
<td>40-49</td>
<td>137</td>
<td>4.4±0.9</td>
<td>9.4±1.1</td>
<td>92</td>
<td>4.8±0.7</td>
<td>9.7±0.9</td>
</tr>
<tr>
<td>50-59</td>
<td>159</td>
<td>6.1±0.7</td>
<td>11.4±0.8</td>
<td>132</td>
<td>4.7±0.6</td>
<td>9.3±0.8</td>
</tr>
<tr>
<td>60-69</td>
<td>188</td>
<td>6.4±0.8</td>
<td>11.6±0.9</td>
<td>195</td>
<td>4.4±0.7</td>
<td>8.8±0.8</td>
</tr>
<tr>
<td>70 and over</td>
<td>171</td>
<td>5.7±0.8</td>
<td>10.8±0.9</td>
<td>234</td>
<td>3.0±0.4</td>
<td>7.4±0.5</td>
</tr>
</tbody>
</table>

Estimated mean values are shown in Figure 14.

Analysis included 1,614 individuals in the NHANES III (P1) with more than 180 mg/dl of serum cholesterol.

A design effect of 1.8 was used to estimate the standard errors shown in this Table.
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