

## Evolution of the Human Diet: Linking Our Ancestral Diet to Modern Functional Foods as a Means of Chronic Disease Prevention

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**ABSTRACT** The evolution of the human diet over the past 10,000 years from a Paleolithic diet to our current modern pattern of intake has resulted in profound changes in feeding behavior. Shifts have occurred from diets high in fruits, vegetables, lean meats, and seafood to processed foods high in sodium and hydrogenated fats and low in fiber. These dietary changes have adversely affected dietary parameters known to be related to health, resulting in an increase in obesity and chronic disease, including cardiovascular disease (CVD), diabetes, and cancer. Some intervention trials using Paleolithic dietary patterns have shown promising results with favorable changes in CVD and diabetes risk factors. However, such benefits may be offset by disadvantages of the Paleolithic diet, which is low in vitamin D and calcium and high in fish potentially containing environmental toxins. More advantageous would be promotion of foods and food ingredients from our ancestral era that have been shown to possess health benefits in the form of functional foods. Many studies have investigated the health benefits of various functional food ingredients, including  $\omega$ -3 fatty acids, polyphenols, fiber, and plant sterols. These bioactive compounds may help to prevent and reduce incidence of chronic diseases, which in turn could lead to health cost savings ranging from \$2 to \$3 billion per year as estimated by case studies using  $\omega$ -3 and plant sterols as examples. Thus, public health benefits should result from promotion of the positive components of Paleolithic diets as functional foods.

**KEY WORDS:** • chronic disease • functional foods • Paleolithic diet

### INTRODUCTION

**C**HRONIC DISEASES, including cardiovascular disease (CVD), cancer, and diabetes, cause substantial disability and death.<sup>1</sup> For example, CVD accounted for 36% of all deaths in the United States during 2004, with direct and indirect costs of CVD in the United States for 2008 estimated at \$448.5 billion.<sup>2</sup> Major modifiable risk factors for CVD include high blood pressure, high blood cholesterol, tobacco use, diabetes, physical inactivity, and poor nutrition. The role of diet and nutrition as determinants of chronic diseases is well recognized; a 2003 World Health Organization report previously summarized the links between diet and obesity, diabetes, CVD, cancer, and osteoporosis<sup>3</sup> (Table 1).

The evolution of the human diet over the past 10,000 years has adversely affected a number of dietary parameters known to be related to health, including glycemic load, fatty acid composition, macronutrient composition, micronutrient composition, acid/base load, sodium/potassium ratio, and fiber content.<sup>4</sup> From an evolutionary point of view, the

changes that have taken place in our environment, including dietary and lifestyle shifts, occurred at a faster rate than the human genome could adapt to, and thus humans are still biologically adapted to environments of their ancestors.<sup>5</sup> This maladaptation to modern diets has resulted in a multitude of chronic diseases in our current society,<sup>5</sup> which our ancestors did not manifest. There is indeed some evidence from historical and archaeological data showing that hunter-gatherer humans were lean and mostly free of signs and symptoms of our modern suite of chronic diseases.<sup>6</sup>

As rates of chronic diseases have continued to increase, growing interest has developed in functional foods, which may prevent and reduce their incidence. Functional foods are foods that are intended to be consumed as part of the normal diet and that contain biologically active components offering the potential of enhanced health or reduced risk of disease<sup>7</sup> and may be either in their natural form, *i.e.*, tomatoes naturally possess the antioxidant lycopene and olive oil naturally contains antioxidative polyphenols, or can also be found in the form of manufactured products, such as cheese with added  $\omega$ -3 (*n*-3) fatty acids and orange juice with added calcium. Functional foods entered the market in the early 1990s and have shown promise in reducing the risk of some chronic diseases. Some ingredients of functional foods that have been widely studied for their potential health

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TABLE 1. SUMMARY OF THE LINKS BETWEEN DIET AND OBESITY, DIABETES, CVD, CANCER, AND OSTEOPOROSIS

	<i>Obesity</i>	<i>Type 2 diabetes</i>	<i>CVD</i>	<i>Cancer</i>	<i>Osteoporosis</i>
<b>Energy and fats</b>					
High intake of energy-dense foods	C↑				
Saturated fatty acids		P↑	C↑ <sup>a</sup>		
<i>trans</i> fatty acids			C↑		
Dietary cholesterol			P↑		
Myristic and palmitic acid			C↑		
Linoleic acid			C↓		
Fish and fish oils (EPA and DHA)			C↓		
Plant sterols and stanols			P↓		
$\alpha$ -Linolenic acid			P↓		
Oleic acid			P↓		
Stearic acid			P-NR		
<b>Carbohydrate</b>					
High intake of NSP (dietary fiber)	C↓	P↓	P↓		
Whole grain cereals			P↓		
<b>Vitamins and minerals</b>					
Vitamin D					C↓ <sup>b</sup>
Folate			P↓		
High sodium intake			C↑		
Salt-preserved foods and salt				P↑ <sup>c</sup>	
Potassium			C↓		
Calcium					C↓ <sup>b</sup>
Fluoride, systemic					P-NR <sup>b</sup>
<b>Meat and fish</b>					
Preserved meat				P↑ <sup>d</sup>	
Chinese-style salted fish				C↑ <sup>e</sup>	
Fruits (including berries) and vegetables	C↓ <sup>f</sup>	P↓ <sup>f</sup>	C↓	P↓ <sup>g</sup>	
<b>Beverages</b>					
Sugars-sweetened soft drinks and fruit juices	P↑				
Very hot (thermally) drinks (and food)				P↑ <sup>h</sup>	
Unfiltered boiled coffee			P↑		
High alcohol intake			C↑ <sup>i</sup>	C↑ <sup>j</sup>	C↑ <sup>b</sup>
Low to moderate alcohol intake			C↓ <sup>k</sup>		

Data are adapted from the World Health Organization 2003 report.<sup>3</sup> C↑, convincing increasing risk; C↓, convincing decreasing risk; C-NR, convincing, no relationship; P↑, probable increasing risk; P↓, probable decreasing risk; P-NR, probable, no relationship; NSP, non-starch polysaccharides. Only convincing (C) and probable (P) evidence notations are included in this summary table.

<sup>a</sup>Evidence also summarized for selected specific fatty acids (see myristic and palmitic acid).

<sup>b</sup>In populations with high fracture incidence only; applies to men and women more than 50–60 years old.

<sup>c</sup>For stomach cancer.

<sup>d</sup>For colorectal cancer.

<sup>e</sup>For nasopharyngeal cancer.

<sup>f</sup>Based on the contributions of fruits and vegetables to NSP.

<sup>g</sup>For cancer of the oral cavity, esophagus, stomach, and colorectum.

<sup>h</sup>For cancer of the oral cavity, pharynx, and esophagus.

<sup>i</sup>For stroke.

<sup>j</sup>For cancer of the oral cavity, pharynx, larynx, esophagus, liver, and breast.

<sup>k</sup>For coronary heart disease.

benefits include *n*-3 fatty acids, polyphenols, fiber, and plant sterols, and they have been associated with the potential to reduce risk of CVD and some cancers.

What is of interest is that perhaps these compounds are perhaps not as new as we believe them to be. Foods that we now term to have “functional” components have existed for tens of thousands of years. For example, salmon, which is a good source of *n*-3 fatty acids, has been documented to have occurred as a food since 15,000 BC.<sup>8</sup> Also, various foods rich in polyphenols such as olives and tea have been purportedly consumed since 5,000 BC<sup>9</sup> and 2,737 BC,<sup>10</sup> respectively.

The objective of this review is, therefore, to examine the evolution of the human diet in the context of using food components from our ancestral consumption patterns as functional food ingredients to aid in reducing the risk of chronic diseases.

#### PALEOLITHIC DIET EVOLUTION TO MODERN DIET HABITS

The four stages of evolution of the human diet include the Miocene to early Pleistocene era, the Paleolithic era, the Neolithic era, and the Industrial Revolution. During the

Miocene to early Pleistocene period, diets consisted of foliage, leafy vegetables, fruits, seeds, and nuts, thus supplying high amounts of fiber, plant sterols, and vegetable proteins. Similarly, during the Paleolithic period, human diets were high in plant food, but also incorporated high amounts of animal protein, mainly from lean meat and seafood. The Paleolithic period ended about 10,000 years ago as agriculture emerged during the Neolithic period. The agricultural revolution saw the advent of starchy foods in the form of grains and legumes as main dietary staples. In addition, during the Neolithic period, dairy products as well as vegetable oils, such as olive oil, became available for consumption. Neolithic diets supplied considerable amounts of fiber, vegetable protein, and plant sterols. However, human diets exhibited the most profound changes with the onset of the Industrial Revolution. Over the past 200 years, the industrial revolution introduced convenience and prepackaged foods including canned meats, condensed canned soups, hydrogenated vegetable oils, and refined grains, including white bread. Hence, the human diet has become enriched in high glycemic index carbohydrate sources, animal products, meat, saturated fat, and dietary cholesterol, while becoming deficient in legumes, vegetables, fruits, and nuts.

#### COMPARISON OF PALEOLITHIC AND CURRENT WESTERN DIETS

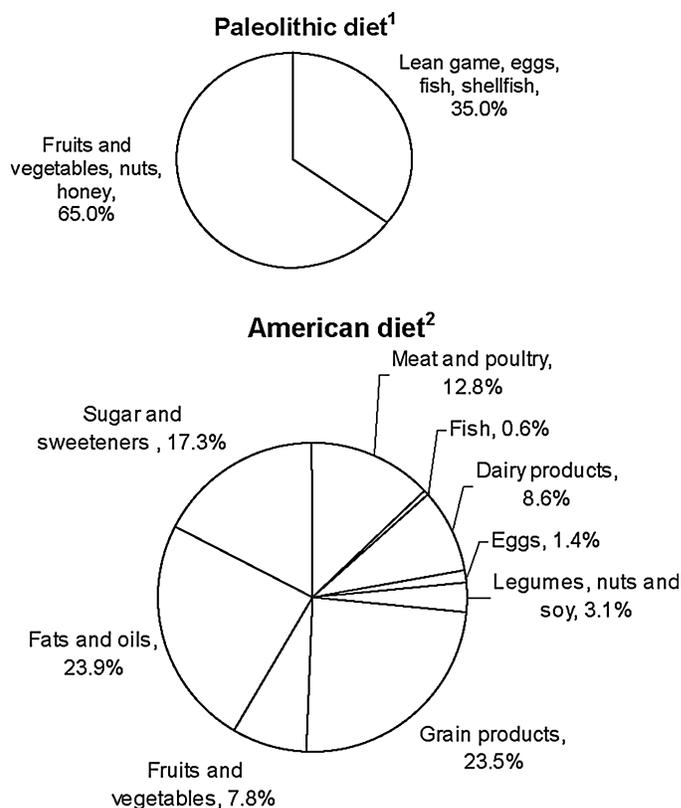
As a result of the changes described, modern Western dietary characteristics differ vastly from those of the pre-industrial age. These characteristics include the contribution of various food groups to daily energy and intake of macro- and micro-nutrients, as well as energy density of foods consumed.

##### *Contribution of food groups and macro- and micronutrients of modern foods in comparison to hunter-gatherer diets*

Ethnographic studies of hunter-gatherer societies and quantitative studies of hunter-gatherers have demonstrated that animal foods contributed more than one-third of daily energy, with plant foods making up the remainder of daily caloric intake<sup>11</sup> (Fig. 1).

In contrast, today's Western diets contain food groups that were consumed in small amounts or were not known during the Paleolithic period, including dairy products, cereals, refined sugars, refined vegetable oils, and alcohol.<sup>4</sup> Currently, grains, fats and oils, and sugar and sweeteners make up to 65% of daily energy in the American diet.<sup>12</sup> Meanwhile, meat and poultry combined and dairy products supply 12.8% and 8.6%, respectively, of daily energy in the American diet.<sup>12</sup> On the other hand, the contribution of daily energy from fish, from legumes, nuts and soy, and from fruits and vegetables in the American diet is limited, at about 0.6%, 3.1%, and 7.8%, respectively.<sup>12</sup>

Differences in the contribution of various food groups to daily energy intake between the Paleolithic diet and today's Western diet have resulted in notable disparities in macro- and micronutrient dietary intake levels (Table 2).



**FIG. 1.** Contribution of food groups to daily energy intake in (top) the Paleolithic diet and (bottom) the current American diet. Data for the Paleolithic diet are from Eaton and Cordain.<sup>11</sup> Data for the American diet are from Hiza and Bente.<sup>12</sup>

In particular, the Paleolithic diet generally provided more vitamins and minerals than current American diets. Folate contents of the current American diet are similar to that of the Paleolithic diet, which could be due to the folate fortification policy. Also, due to the increase in processed food consumption and decrease in fruits and vegetables intake, the modern American diet supplies more sodium and less potassium than the Paleolithic diet. About 77% of dietary sodium in the American diet comes from processed food.<sup>20</sup> Furthermore, the high intake of plant foods by hunter-gatherer humans provided a greater amount of fiber compared with today's Western diet.

Energy contributions from protein, carbohydrates, and fat have been estimated to be 37%, 41%, and 22%, respectively, in the Paleolithic diet. In contrast, current American diets contain about half of total daily calories as carbohydrates, whereas one-third of calories are derived from fat. The contribution of protein to daily energy in today's American diet is about 15%. In addition, a marked shift in the ratio of *n*-6 to *n*-3 fatty acids has occurred in modern human diets. The current American diet has been estimated to have 10 times more *n*-6 fatty acids than *n*-3 fatty acids,<sup>18</sup> whereas hunter-gatherers are thought to have consumed an *n*-6:*n*-3 ratio of 1:1.<sup>18</sup> Eicosanoids from *n*-6 fatty acids generally promote inflammation and aggregation of platelets, whereas

TABLE 2. ESTIMATED DAILY INTAKE OF MACRONUTRIENTS AND MICRONUTRIENTS FROM THE PALEOLITHIC DIET AND THE WESTERN DIET

	Paleolithic intake <sup>a</sup>	Current intake <sup>b</sup>
Protein (% energy)	37	14.7
Carbohydrate (% energy)	41	51.9
Fat (% energy)	22	32.7
Polyunsaturated fat:saturated fat	1.4	0.6
<i>n</i> -6 fatty acid: <i>n</i> -3 fatty acid	1.0:1.0 <sup>c</sup>	9.8:1 <sup>c</sup>
Cholesterol (mg)	480	265
Fiber (g)	104	15.2 <sup>d</sup>
Riboflavin (mg)	6.49	2
Folate (mg)	357	361
Thiamin (mg)	3.91	1.6
Vitamin C (mg)	604	97
Vitamin A (mg of retinol equivalent)	2870	983
Vitamin E (mg)	32.8	8.8
Iron (mg)	87.4	15.2
Zinc (mg)	43.4	11.4
Calcium (mg)	1,956	863
Sodium (mg)	768	3,375
Potassium (mg)	10,500	2,628

<sup>a</sup>Data from Eaton *et al.*<sup>13</sup> unless otherwise indicated, based on 913 g of meat and 1,697 g of vegetable food/day yielding 3,000 kcal.

<sup>b</sup>Data from Wright *et al.*<sup>14</sup> and Ervin *et al.*<sup>15-17</sup>

<sup>c</sup>Data from Kris-Etherton *et al.*<sup>18</sup>

<sup>d</sup>Data from the Institute of Medicine.<sup>19</sup>

those from *n*-3 fatty acids are mostly anti-inflammatory and inhibit platelet aggregation.<sup>21</sup>

#### Caloric density of modern foods in comparison to traditional African diets

Another considerable difference between modern foods compared to our ancestors' diets is their energy density. Prentice and Jebb<sup>22</sup> compared the energy density of typical fast food restaurants in Britain to traditional African diets and found three fast food outlets to have average energy densities of 1,167, 1,087, and 1,054 kJ/100 g, *i.e.*, the average energy density of the three fast food outlets was approximately 1,100 kJ/100 g, which is 2.5 times higher than a traditional African diet, which was estimated to be 450 kJ/100 g. Similarly, snack foods commonly consumed in our modern society have high energy density values. De Graaf<sup>23</sup> conducted a review on energy density of various snacks and found that sweet snacks, *i.e.*, cookies, cakes, pies, ice cream, and chocolate bars, possessed an average energy content of 1,500–2,000 kJ/100 g, whereas savory snacks, *i.e.*, potato chips, had an energy density of about 2,200 kJ/100 g and even in a “low fat” form were found to have an energy density of about 2,000 kJ/100 g. In contrast, fruits and vegetables contain average energy densities of less than 100 kJ/100 g.

#### SHOULD WE ADOPT THE PALEOLITHIC DIET?

The characteristics of hunter-gatherer Paleolithic diets may have implications in the design of therapeutic diets to

manage chronic diseases in modern societies.<sup>24–26</sup> Of the published studies thus far, results stemming from interventions using a Paleolithic diet have been promising. A long-term animal study conducted by Jönsson *et al.*<sup>24</sup> used piglets that were randomly assigned at weaning to either a cereal-based swine feed group or a cereal-free Paleolithic diet group. At 17 months, improvements were observed for C-reactive protein, an inflammatory marker associated with CVD, insulin sensitivity, and blood pressure with the Paleolithic diet group. In addition, in comparison to the cereal group, pigs consuming the Paleolithic diet group weighed on average 22% less, were 6% shorter, and had 43% lower subcutaneous fat.

To date, small, short-term intervention trials incorporating the Paleolithic diet have been conducted in humans. Osterdahl *et al.*<sup>25</sup> investigated the effects of a Paleolithic diet on CVD risk factors in healthy human volunteers over 3 weeks. Results showed decreases in mean weight, body mass index, waist circumference, and systolic blood pressure. Furthermore, dietary intake of fat, antioxidants such as vitamins C and E, and potassium-sodium ratio all showed favorable changes. The only major adverse change observed was with calcium intake, which was due to the exclusion of milk and dairy products as per the Paleolithic dietary pattern. In another human study, Lindeberg *et al.*<sup>26</sup> examined what effect a Paleolithic diet would have in individuals with ischemic heart disease and either glucose intolerance or type 2 diabetes. Subjects were assigned to either a Paleolithic or a Mediterranean-like diet for a 12-week period. Results showed that subjects assigned to the Paleolithic diet had significant improvements in glucose tolerance with a 26% decrease in area under the curve for serum glucose, in addition to reduction of weight and waist circumference.<sup>26</sup>

With such promising preliminary data regarding Paleolithic diet interventions on CVD risk indices and glucose intolerance, combined with knowledge that our ancestors were free of today's chronic diseases, it would be easy to assume that adoption of a Paleolithic diet could be a “silver bullet” for our current dietary problems. However, certain factors argue against Paleolithic diets. First, it should be noted that the estimated life expectancy of early humans was about 25 years<sup>27</sup> and that most chronic diseases do not manifest by that age. In addition, there are limits to our knowledge on the evolution of human diet, as evidence comes from fossils, archaeological remains, and models based on information from paleo-environmental reconstructions, ethnographic and ethological analogs, and nutrient composition and energetic studies.<sup>28</sup>

Additionally, potential nutritional shortcomings associate with adoption of the Paleolithic diet by today's Western societies. Cordain<sup>29</sup> formulated a contemporary diet based on the Paleolithic food groups (Table 3) that excludes all processed foods, as well as grains, dried beans and legumes, and dairy products, three major food groups common in modern diets.

In the dietary model described by Cordain,<sup>29</sup> dietary calcium intakes are lower than the currently recommended levels by 31%. Similarly, in the trial by Osterdahl *et al.*,<sup>25</sup>

TABLE 3. SAMPLE MENU FOR A MODERN DIET BASED ON PALEOLITHIC FOOD GROUPS

	Food quantity (g)	Energy (kcal)
<b>Breakfast</b>		
Cantaloupe	276	97
Atlantic salmon (broiled)	333	605
<b>Lunch</b>		
Vegetable salad with walnuts		
Shredded Romaine lettuce	68	10
Sliced carrot	61	26
Sliced cucumber	78	10
Quartered tomatoes	246	52
Lemon juice dressing	31	8
Walnuts	11	70
Broiled lean pork loin	86	205
<b>Dinner</b>		
Vegetable avocado/almond salad		
Shredded mixed greens	112	16
Tomato	123	26
Avocado	85	150
Slivered almonds	45	260
Sliced red onion	29	11
Lemon juice dressing	31	8
Steamed broccoli	468	131
Lean beef sirloin tip roast	235	400
Dessert (strawberries)	130	39
<b>Snacks</b>		
Orange	66	30
Carrot sticks	81	35
Celery sticks	90	14

The information is from Cordain.<sup>29</sup> The diet was designed for women (25 years of age, 2,200 Kcal daily energy intake).

subjects reported a 53% decrease in dietary calcium intake. Also, although the subjects in the latter trial did not show a significant decrease in vitamin D intake, the food model of Cordain<sup>29</sup> includes few sources of vitamin D. Hunter-gatherers were highly active and were able to obtain most of their vitamin D requirements from sun exposure.<sup>29</sup> Considering it is difficult to be highly active in our contemporary sedentary lifestyle and because prolonged sun exposure is not recommended as a high level of exposure to solar ultraviolet radiation is known to be carcinogenic,<sup>30</sup> following a Paleolithic diet may put one at risk of inadequate calcium and vitamin D intake. Calcium and vitamin D have both been reported to be important in prevention of osteoporosis.<sup>31</sup>

Additionally, the Paleolithic diet is high in animal protein from wild game and fish sources. Wild game meat has been shown to be lower in fat in comparison to domestic meats. However, wild game meat is not commonly available today.<sup>32</sup> Moreover, although the hunter-gatherers consumed high amounts of animal protein, they also consumed higher intakes of monounsaturated and polyunsaturated fatty acids, *n*-3 fatty acids, and fruits and vegetables. All these factors are thought to minimize adverse effects of high protein intake.<sup>13,33</sup>

Another potential concern with ingestion of a Paleolithic diet in our modern society is the possibility of higher intakes of environmental toxins when increasing fish consumption to the level contained in Paleolithic diets (Table 3).<sup>29</sup> A major risk of fish consumption at high levels is its methylmercury content.<sup>34</sup> The Environmental Protection Agency reference dose for mercury is 0.1 µg/kg of body weight/day.<sup>35</sup> Furthermore, a recent advisory on fish consumption advised pregnant women, women who may become pregnant, and nursing mothers to eat less than 340 g/week (two average meals) of a variety of fish and shellfish that are lower in mercury.<sup>36</sup> Because the sample menu from Cordain<sup>29</sup> supplies fish at about 333 g/day to be consumed by women in order to achieve a dietary intake of 7.3 g of marine *n*-3 fatty acids/day, it would be impossible to follow the Paleolithic diet while avoiding the risks associated with consuming mercury in amounts in excess of the suggested threshold. In addition, it is unnecessary to increase the dietary intake of marine *n*-3 fatty acids to the level estimated in the Paleolithic diet, as recent recommendations for intake level of marine *n*-3 fatty acids based on large epidemiological and controlled clinical studies are in the range of 100–1,000 mg/day.<sup>37</sup>

Given the aforementioned challenges, using the previously described sample menu<sup>29</sup> as a means to deliver dietary characteristics associated with the Paleolithic diet could be difficult to establish and maintain on a long-term basis. On the other hand, many foods with origins dating back to our ancestors' diets have recently been touted as having health benefits beyond basic nutrition, *i.e.*, functional foods. Thus, although it would not be the most practical solution to convert solely to a Paleolithic diet, it may be of greater value to promote the healthier aspects of the Paleolithic diet.

### FOODS OF THE FUTURE FROM OUR PAST—FUNCTIONAL FOODS

Due to the deterioration of Western dietary habits, academic researchers and industry have recently become interested in taking healthy dietary characteristics and promoting them within their original format and/or supplementing within commonly consumed foods as functional foods. Although discovery of functional components within foods is relatively new, it is of interest to note that many of these foods have generally been in existence for hundreds if not thousands of years. Some foods that are deemed to be functional foods include some fish and vegetables sources that possess *n*-3 fatty acids, plant-based foods that possess polyphenols, fiber, and plant sterols. All these functional food ingredients have recently garnered much attention due to their potential to lower risk of CVD and some cancers. A summary of each will be discussed below.

#### *ω*-3 fatty acids

*ω*-3 fatty acids, defined as a polyunsaturated fatty acid where the first double bond is positioned three carbons away from the methyl end of the carbon chain,<sup>38</sup> can be found from marine sources in the form of eicosapentaenoic acid

(EPA) and docosahexaenoic acid (DHA) and from plant sources in the form of  $\alpha$ -linolenic acid (ALA).<sup>21</sup> Fish, especially salmon, mackerel, and trout, is high in EPA and DHA with a range of 1.6–2.3 g of *n*-3 fatty acids/100 g of fish.<sup>39</sup> Vegetable sources include flaxseed and flaxseed oil, canola oil, and walnut and walnut oil, which range from 9 to 53 g of ALA/100 g.<sup>39</sup>

Many studies have shown that EPA and DHA consumption provides health benefits for decreasing CVD risk,<sup>40,41</sup> with some preliminary information on ALA stating that there may be some cardiovascular benefits associated with consuming ALA.<sup>42,43</sup> Among the various benefits on cardiovascular health, the primary focus is on the beneficial effects for plasma lipid profile due to decreases in blood triglycerides (TG). A recent meta-analysis by Balk *et al.*<sup>44</sup> investigated the lipid profiles of subjects in marine and plant *n*-3 fatty acid consumption trials. Combined data from the fish oil consumption studies showed a decrease in TG of 27 mg/dL.<sup>44</sup> The authors also found that higher fish oil dosages and higher lipid baseline levels were associated with greater reductions in serum TG. However, studies with ALA showed inconsistent effects on lipid profiles.<sup>44</sup> In another recent meta-analysis, Hartweg *et al.*<sup>45</sup> studied the effect of marine-derived *n*-3 fatty acids on all aspects of blood lipids, which could be used as cardiovascular risk markers, in type 2 diabetics. Pooled data from 23 trials showed that not only was there a 25% reduction in TG, very-low-density lipoprotein cholesterol and very-low-density lipoprotein TG were also beneficially affected with a decrease of 36% and 39.7%, respectively, whereas low-density lipoprotein cholesterol (LDL-C) increased slightly by 5.7%.<sup>45</sup> From this set of evidence, it seems that *n*-3 fatty acids can be effective in lowering TG and thus could be useful in the prevention of CVD.

### Phenolic compounds

Phenolic compounds are secondary metabolites of plants, possessing a hydroxyl group on an aromatic ring.<sup>46</sup> Phenolics are found in many plant-based foods and have received considerable interest recently for their possible health benefits. Some phenolic-rich foods to be studied in particular include tea and olive oil.

**Tea polyphenols.** Tea comes from the leaves of the *Camellia sinensis* tree. It has been of recent interest to study the effects of tea flavonols, a subclass of polyphenols, found in a range of 300–400 mg/g in green tea and 50–100 mg/g in black tea.<sup>46</sup> Both green and black teas have been investigated for their health-promoting effects, ranging from prevention of osteoporosis<sup>47–49</sup> to cancer prevention/inhibition,<sup>50–52</sup> protection against heart disease,<sup>53–55</sup> and use in weight loss.<sup>56–58</sup> Areas receiving the most attention at the moment include cancer prevention and cardiovascular health.

Peters *et al.*<sup>53</sup> performed a meta-analysis of tea consumption in relation to stroke, myocardial infarction, and coronary heart disease. The analysis showed that the incidence rate of myocardial infarction decreased by 11% with an increase

in tea consumption of three cups per day.<sup>53</sup> However, the authors felt that there was evidence of bias towards preferential publication of smaller studies that suggest protective effects and thus urge caution in interpreting this result.<sup>53</sup>

Although Peters *et al.*<sup>53</sup> suggested that longer-term studies have not been adequately emphasized, there have been some larger, longer-term studies that have shown promising results regarding tea consumption and reduced risk of CVD. A Japanese report by Kuriyama *et al.*<sup>54</sup> was based on the Ohsaki National Health Insurance Cohort Study, a population-based, prospective cohort study among 40,530 Japanese adults 40–79 years old without history of stroke, coronary heart disease, or cancer at baseline. Participants were followed for up to 11 years for all-cause mortality and for up to 7 years for cause-specific mortality. Green tea consumption was inversely associated with mortality due to CVD.<sup>54</sup> Another longer-term trial based on results from the Rotterdam study, a Dutch longitudinal study with 5.6 years of follow-up, showed that those who drank more than 375 mL of tea/day had a lower relative risk of incident of myocardial infarction compared to non-tea drinkers.<sup>55</sup> Thus it would seem that tea is a promising functional food with many potential health benefits, especially for prevention of CVD.

**Olive oil.** Olives are originally native to the Mediterranean region and thus are viewed as an important component of the “Mediterranean diet.” The Mediterranean diet has been associated with chronic disease prevention,<sup>59</sup> while olive oil in particular has been studied more closely and found to exert health benefits by potentially lowering incidence of CVD<sup>60,61</sup> and some cancers.<sup>62,63</sup> Health benefits of olive oil have been suggested to be due to its high monounsaturated fatty acid content, namely, oleic acid, which can make up 56–84% of the fatty acid content.<sup>46</sup> It has also been increasingly suggested that the beneficial effects attributed to olive oil may also be due to its antioxidant content. Polyphenol components within olive oil have been reported to be found at levels of 50–800 mg/kg of olive oil.<sup>46</sup> Recently Covas *et al.*<sup>64</sup> tested whether the phenolic content of olive oil contributed to additional benefits on lipid levels and oxidative stress in comparison to monounsaturated fatty acid content. Subjects in the trial were given olive oils which were either low, medium, or high in phenols for 3 weeks, resulting in a linear increase in high-density lipoprotein cholesterol levels.<sup>64</sup> Also, oxidative stress markers decreased linearly with increasing phenolic content. The authors thus concluded that not only do the monounsaturated fats in olive oil provide health benefits, seemingly its phenolic content can also provide benefits for both plasma lipid levels and oxidative damage.<sup>64</sup>

Tea and olive oil are just two of many plant-based foods that have been studied for their polyphenolic content. Many other foods rich in polyphenols exist; a recent meta-analysis by Hooper *et al.*<sup>65</sup> investigated different phenolic flavonoid subclasses and flavonoid-rich food sources on CVD risk factors such as lipoproteins, blood pressure, and flow-

mediated dilatation in over 130 randomized controlled trials. Results from the meta-analysis showed that various flavonoid-rich foods including chocolate, soy protein isolate, and black and green tea had favorable effects on blood pressure, LDL-C levels, and parameters associated with flow-mediated dilatation.<sup>65</sup>

Therefore, it would seem that many polyphenolic-rich foods play a role in prevention of chronic diseases, including CVD, via improvements of various risk factors including blood lipid levels and blood pressure.

### Fiber

Dietary fiber consists of edible plant cell, polysaccharides, lignin, and associated substances that are resistant to digestion by human alimentary enzymes.<sup>66</sup> Although our ancestors have been said to consume over 100 g fiber/day,<sup>13</sup> current intake is estimated to be around 15 g/day.<sup>19</sup> Fiber is commonly classified as either insoluble or soluble, with about 75% of dietary fiber in foods being insoluble; both types of fiber have positive effects on human health.<sup>66</sup>

Insoluble fiber is prevalent in whole grain products, legumes, and vegetables, is made up of cell wall components, including cellulose, lignin, and some hemicellulose, and helps to promote regularity by shortening bowel transit time, increasing fecal bulk, and helping to make feces softer and therefore is being studied for its potential to reduce the risk of colon/rectal cancers.<sup>66</sup> Key and Spencer<sup>67</sup> recently reviewed epidemiological evidence on carbohydrates and risk of cancer development and found that although no firm conclusion can be made on dietary fiber and colorectal cancer, the available data do suggest that high intakes of dietary fiber could possibly reduce risk of colorectal cancer.

Soluble fiber, which can be found in various fruits and legumes and some grains such as oats and barley, is made up of noncellulosic polysaccharides such as pectin, gums, and mucilages and helps to delay gastric emptying, slow glucose absorption, enhance immune function, and lower blood cholesterol levels.<sup>66</sup> A meta-analysis by Brown<sup>68</sup> examined various soluble fibers, including pectin, oat bran, guar gum, and psyllium, and found a small but significant decrease for total cholesterol and LDL-C. Thus, evidence to date shows promise for reduction in risk of cancer and CVD from intake of dietary fiber.

### Plant sterols/stanols

Plant sterols are found in all foods of plant origin and have structures similar to cholesterol with an extra methyl or ethyl group and a double bond in the side chain.<sup>69</sup> Plant stanols are sterols that are saturated, *i.e.*, do not possess a double bond in the structure.<sup>69</sup> Some common food products that have been studied for their plant sterol content include commonly consumed cereal foods in Sweden and Netherlands, with rye and barley possessing high amounts of plant sterols at 95.5 mg and 76.1 mg, respectively, per 100 g of cereal.<sup>70</sup> Plant sterol content has also been analyzed in commonly consumed nuts and seeds in the United States,

with sesame seed and wheat germ possessing the highest plant sterol content at 400–413 mg/100 g of nuts or seeds.<sup>71</sup> Vegetable oils also contain considerable amounts of plant sterols, with corn and rapeseed oil containing 850 mg and 820 mg/100 g of crude oil, respectively, and 730 mg and 770 mg/100 g of refined oil, respectively.<sup>72</sup> Current intake of plant sterols has been estimated to be 160–400 mg/day, whereas our ancestors consumed up to 1 g/day.<sup>73</sup>

The majority of research on plant sterols and stanols has focused on their ability to lower LDL-C<sup>74–79</sup>; however, it is now suggested that plant sterols may prevent cancer.<sup>80–82</sup> Two recent, large meta-analyses by AbuMweis *et al.*<sup>78</sup> and Demonty *et al.*<sup>79</sup> have investigated to what extent plant sterols can lower cholesterol. AbuMweis *et al.*<sup>78</sup> pooled data from 59 trials and showed that 2 g/day plant sterols or stanols reduced LDL-C by 0.31 mmol/L. Demonty *et al.*<sup>79</sup> pooled data from 84 trials and found that a mean daily dose of 2.15 g of plant sterols reduced LDL-C by 0.34 mmol/L. Therefore, it would seem that plant sterols are capable of effectively lowering LDL-C and would be helpful in the prevention of CVD. Preliminary research also indicates that plant sterols may potentially aid in the prevention of cancer.<sup>80–82</sup>

The functional food ingredients mentioned in this section are just a few of many emerging food components possessing health benefits beyond basic nutrition. And although there are certain limitations to functional foods due to the fact that not all functional food–chronic disease relationships are confirmed and concrete, promising new data continue to emerge that many foods such as fruits, vegetables, and grain products rich in polyphenols, fiber, and plant sterols and fish rich in *n*-3 fatty acids, which our ancestors consumed, have healthful benefits. Functional foods cannot be the sole answer to the ever-increasing prevalence of chronic disease in our society, but combined with a healthy lifestyle, functional foods possess strong potential to prevent and reduce risk of certain chronic diseases.

## FUNCTIONAL FOODS FOR PREVENTION OF CHRONIC DISEASE—ECONOMICS

Could the use of functional foods for health benefits also translate to savings in the cost of health care? Using functional food ingredients such as *n*-3 fatty acids and plant sterols for prevention of CVD as examples, it would seem that there is the potential for savings in health care expenditures.

Holub<sup>83</sup> estimated that at a cost of 13 cents/day, supplementation of *n*-3 fatty acids (EPA/DHA) would result in lowering TG by 15%, which in turn could reduce CVD risk by 7.5% and 20% in men and women, respectively. The decreases in CVD risk would translate to a yearly reduction of \$2.70 billion in expenditures for heart disease, *i.e.*, reduction in dependency on cholesterol- or TG-lowering drugs later in life and reduction in risk for later disease development and its associated costs in medical treatment.<sup>83</sup> Similarly, by supplementing plant sterols at 20 cents/day in

order to lower cholesterol by 8% could result in a 20% decrease in CVD risk, resulting in reduced expenditures for heart disease of \$3.26 billion/year.<sup>83</sup> Likewise, Gerber *et al.*<sup>84</sup> calculated the cost-benefit analysis for consuming a low-fat plant sterol-containing margarine from a health insurer's perspective of a 10-year time frame. This analysis found that plant sterol supplementation could lead to a reduction of 117,000 coronary heart disease cases over 10 years, which would correspond to a reduction of 1.3 billion Euros for this time period.<sup>84</sup> From these various economics case studies, it would seem prudent to promote functional foods to attempt to help prevent chronic diseases, which in turn could help to decrease the costs associated with medical treatments.

### SUMMARY AND CONCLUSIONS

Pursuit of the optimal human diet has come full circle, with an increased interest emerging in the positive aspects of ancestral diets. While such interest in our predecessors' diets has led to suggestions that we should adopt an ancestral-based Paleolithic diet, care should be exercised in recognizing that a typical Paleolithic diet would fail to meet current daily requirements and may not be feasible on a long-term basis. A more practical approach would be to promote foods with added health benefits found prevalent in ancestral diets as functional foods, in addition to a healthy lifestyle to help prevent chronic diseases. The marked interest in using foods as a means of chronic disease prevention and treatment has led to much research in the area of functional foods, which have many varied potential health benefits including prevention of CVD and some cancers.

### AUTHOR DISCLOSURE STATEMENT

P.J.H.J. consults for companies dealing with functional foods, including Unilever, Danone, Whitewave, and Merck Frosst, and has an ownership position in Nutritional Fundamentals for Health, which markets functional food components. No competing financial interests exist for S.J. and S.S.A.

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