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CARDIOVASCULAR DISEASE (JHY WU, SECTION EDITOR)

A Posteriori Data-Derived Dietary Patterns and Incident Coronary Heart Disease: Making Sense of Inconsistent Findings

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Abstract Inconsistent findings have been reported from numerous prospective studies for the relations of the "Western" (unhealthy) and "Prudent" (healthy) diet patterns, derived using factor, principle components, or cluster analysis methods, with incident coronary heart disease (CHD). Among contemporary prospective studies, the Prudent diet pattern was inversely related to CHD risk in 7 of 12 studies, while the Western diet pattern positively related to risk in only 3 of 11 studies. To explain these inconsistent findings, we compared the methods and results from these prospective studies conducted in the USA, Europe, and Asia. A Prudent diet pattern was consistently related to 18–65 % lower risk of incident CHD in 7 studies conducted in the USA, Europe, and Asia. In 3 of 4 US studies, but not cohorts in Europe or Asia, the Western diet pattern was related to 37–64 % greater CHD risk. In Asian cohorts, the Western diet pattern was not related to increased CHD risk, which may be partially explained by the overall higher fish intake among Asians. The "a posteriori," or data driven, approach to diet patterns is based on reported dietary intake and we found the components of each dietary pattern differed by geographic location and diet assessment instrument. We discuss how the non-standardized methods used to discern diet patterns from the dietary data may contribute to discrepant results. Further, the disparate findings may also be explained by differing sample characteristics, follow-up period, and CHD ascertainment. In summary, a posteriori derived Prudent diet pattern was related to cardiovascular health.

Keywords Diet patterns · Western diet pattern · Prudent diet pattern · Mediterranean diet pattern · Coronary heart disease · CHD mortality

Introduction

Dietary intake plays an important role in cardiovascular health [1•, 2, 3]. Observational studies have shown better cardiovascular health among adults consuming nutrients, such as n-3 fatty acids [4], and foods such as fruit and vegetables [5, 6], fish [7], and whole grains [5, 8]. Other foods, including red and processed meat, have been related to greater risk of cardiovascular disease (CVD) [9]. More recent studies have focused on the whole diet or dietary patterns, since we eat combinations of foods and beverages and not just one food or nutrient [10]. Numerous dietary patterns and scores have been created to generally characterize a population's overall dietary intake and are reviewed in detail elsewhere [11, 12••]. Briefly, there are three general approaches to characterizing dietary patterns (Table 1). The "a priori" approach to characterize a pattern of dietary intake or diet quality is based on pre-defined criteria. For example, the Healthy Eating Index (HEI) created in 1995 [13] and recently updated in 2010 [14] reflects the 2010 U.S. Dietary Guidelines for Americans (DGA) [12••]. Another a priori diet quality score or diet pattern is the Dietary Approach to Stop Hypertension or DASH diet pattern, which was developed to reduce blood pressure [15]. A posteriori diet pattern is a data-driven approach where diet patterns are created using factor analysis, principal components analysis (PCA), or cluster analysis [11, 16]. Commonly labeled diet patterns are the "Western" and "Prudent" patterns. The

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Table 1 Types of diet patterns and methods of creating them

Approach	Method	Pattern	Composition of the diet pattern
A priori	Scores or indices based on defined criteria	Healthy Eating Index (HEI) [13, 14]	The original HEI was developed in 1995 to assess diet quality; the HEI was updated in 2010 to capture key recommendations of the 2010 Dietary Guidelines
		DASH diet [15]	The DASH eating plan is based on the 2010 US Dietary Guidelines, a diet pattern rich in fruits and vegetables, low-fat and nonfat dairy, along with nuts, beans, and seeds, some fish and low in red and processed meat.
		Mediterranean diet [18]	The Mediterranean diet pattern is known for high intakes of olive oil, plant-based foods including fruit, vegetables, legumes, nuts and seeds, and whole grains, along with fish and seafood, moderate amount of dairy products (yogurt and cheese), poultry and eggs, and low amount of red and processed meat. Moderate intake of (red) wine is typically consumed with meals.
A posteriori	Scores based on available data using factor analysis or principal components analysis	Western or Unhealthy diet pattern [16]	Factor analysis or principal component analysis (PCA) is used to create diet patterns from a diet data set. PCA reduces a large number of variables (or foods) to a smaller number of factors that characterize dietary intake in the study population. An individual is assigned a score along the continuum of the distribution of each factor. A Western diet pattern is characterized by higher intakes of red and processed meat, refined grain products, fried foods, sugar-sweetened beverages, and eggs and lower intakes of fruit, vegetables, fish, low-fat dairy products, and whole grain products.
		Prudent or healthy diet pattern [16]	A prudent or healthy diet pattern is characterized by higher intakes of plant-based items including whole grains, fruit, vegetables, legumes, nuts, as well as fish and low-fat dairy, and lower intakes of fried foods and red and processed meat. See factor analysis or PCA described above.
	Scores based on available data using cluster analysis	Western, prudent diet pattern [16]	In cluster analysis, individuals with similar dietary intake (diet pattern) are aggregated into mutually exclusive groups or clusters. The derived diet patterns may include Western (unhealthy) and Prudent (healthy) diet patterns.
Diet pattern based on beliefs, food preferences, health, etc.	Diet pattern includes or excludes certain foods based on beliefs, food preferences, health, popular diets, etc.	Religious belief: Kosher; Food preference: Vegan; Celiac disease: Gluten-free; Popular diets: Atkins, Zone, South Beach [19]	Diet patterns based on individual beliefs that include or exclude certain foods or beverages based on beliefs or preferences, such as vegetarianism, lacto-ovo or vegan diets. Religious beliefs may dictate consuming Kosher foods or excluding certain (but not all) meats from the diet. Health conditions such as celiac disease dictate excluding foods with gluten from the diet. Diet patterns, such as Atkins, Zone, South Beach, etc., are promoted in the popular press.

Western pattern is characterized by higher intake of red and processed meat, fried foods, sweets, solid fats, and refined grains, while the Prudent pattern, in contrast, is usually characterized by higher intake of a variety of vegetables and fruit and whole grains. There are many dietary patterns, theoretically limitless combinations of foods and beverages habitually consumed, but common diet patterns are often based on food preferences such as a vegetarian or Mediterranean diet patterns [17, 18], religious or philosophical beliefs, and commercial diet plans including the popular diet plans such as Atkins, Pritikin, and South Beach [19].

Identifying healthy diets to prevent the development of CHD or unhealthy diets that increase CHD risk is key for developing and tailoring public health promotion strategies for specific populations. Recently, the Diet Pattern Methods Project (DPMP), a consortium to strengthen research evidence on dietary indices, reported consistency among five a priori diet quality scores/patterns as well as consistency among the associations for each of these diet scores/patterns with mortality from all-causes, CVD, and cancer [20•]. However, evidence from prospective studies is inconsistent for a posteriori derived diet patterns relative to CHD [21–32]. Although these study results were recently meta-analyzed [33], questions remain unanswered. The major limitation of a meta-analysis is the aggregation of studies with diverse study populations and methods; combining studies with stark methodologic differences is akin to comparing apples and oranges [34].

The purpose of this review was to explain the inconsistent findings among the studies. We compared and contrasted the methods from 12 published prospective studies that examined the relations of a posteriori derived dietary patterns with incident CHD.

Comparison of Study Methods

Studies included in this comprehensive review were restricted to studies included in a recent meta-analysis [33] plus 2 others published since 2000 [22, 24]. All studies had a prospective cohort design, dietary assessment at baseline, derivation of dietary patterns using factor analysis, principal components analysis, or cluster analysis, and follow-up for incident CHD [21–32]. Studies are described in Table 2.

Study Population: Differences in Underlying Populations

Of the 12 studies, 7 enrolled only white participants [21, 22, 25–29]; 1 study included 4 race/ethnic groups—White, Black, Hispanic, and Chinese [23]; 1 study with Black and White adults [24], and 3 studies enrolled Japanese and Chinese adults [30–32]. Participants in most studies were aged 40–75 years at baseline, although younger participants were enrolled in 3 studies [25, 28, 29]. Exclusion criteria varied somewhat across studies: (1) study participants with prevalent CHD were excluded from most studies except 2 [25, 31], and (2) participants with diabetes were also excluded in 3 studies [22, 23, 27].

Diet Assessment: Differences in the Capture of Dietary Intake

Dietary intake was assessed using a food frequency questionnaire (FFQ) in 11 studies, while a diet history questionnaire was used in 1 study [28]. The number of foods listed in each FFQ ranged from 26 to 127 food items. Among study participants responding to the diet history questionnaire, 662 foods were reported. Further, there was considerable variation in the food lists on the FFQs between studies, since each study's FFQ was developed for its respective population. For example, the list of vegetables on the Asian FFQs is similar within this culture, but quite different than those listed on the US and European FFQs, including seaweeds, yard-long beans, wild rice stems, Chinese cabbage and greens, wax gourd, Hyacinth beans and snow peas, white turnips, lotus roots, bamboo shoots, edible wild plants, green tea, oolong tea, and others [30–32].

Dietary Pattern Construction: Differences in Pattern Constituents and Analytic Technique

Many of the procedures and decisions made to create the diet patterns were not standardized among the 12 studies. For example, the number of foods/food groups that made up each of the diet patterns varied considerably; in 5 studies, individual food items were categorized into a smaller number of food groups (range 31–47 food groups) [21–23, 28, 29]; while in the other 7 studies, individual food items were included in the factor or cluster analysis model (range 40–127 individual food items) [24–27, 30–32]. Gender-specific diet patterns were created in 4 studies [21, 22, 26, 31], while the diet patterns in the other 7 studies were based on both genders [23–25, 27–30]. The a posteriori Prudent diet pattern (or similar 'healthy' pattern) was created in all 12 studies, while the Western diet pattern (or similar 'unhealthy' pattern) was created in 11 studies, but not in the study by Akesson et al. [26]. Further, in 4 of the studies, up to 3 additional diet patterns were created [23, 24, 27, 31]. Nettleton et al. [23], Shikany et al. [24], and Cai et al. [31] retained 4, 5, and 3 factors, respectively, in their PCA models based on subjective evaluation of eigenvalues, congruence of the solution among sex, race, and geographic region, or interpretation of the factor solutions. Brunner et al. reported 4 patterns identified in cluster analysis [27].

Table 2 Characteristics of the 13 prospective studies of dietary patterns relative to coronary heart disease (CHD) according to geographic location

Author, year (reference)	Population	Diet assessment	Diet pattern method	Outcome (n = events)	Results: HR (95 % CI)
USA					
Hu, 2000[a] [21]	Male Health Professional Study, n = 44,875 men age 40–75 years, Free of CVD at baseline	131-item FFQ; 40 food groups in PCA model	PCA; -Western -Prudent	8 years follow-up of incident MI/CHD mortality (n = 1,089)	Western: 1.64 (1.24, 2.17) Prudent: 0.70 (0.56,0.86)
Fung, 2001 [22]	Nurses Health Study, n = 69,017 women age 38–63 years, Free of CVD, diabetes, and high cholesterol at baseline	116-item FFQ; 38 food groups in PCA model	PCA; -Western -Prudent	12 years follow-up of incident MI/CHD mortality (n = 821)	Western: 1.46 (1.07,1.99) Prudent: 0.76 (0.60, 0.98)
Nettleton 2009[a] [23]	MESA, n = 5,316, Black, Chinese, Hispanic, White men and women age 45–84 years, Free of CVD and diabetes at baseline	120-item FFQ; 47 food groups in PCA model	PCA; -Whole grain, fruit -Fat, processed meat -Veggies, fish -Beans, tomato, refined grain	4.6 years follow-up of incident CHD/CHD mortality (n = 87)	Whole grain, fruit: 0.35 (0.14, 0.85); Results for the other diet patterns were not reported for CHD.
Shikany, 2015 [24]	REGARDS study, n = 17,418 black and white men and women age ≥ 45 years, Free of CHD at baseline	110-item FFQ; 110 foods in FA model	Factor analysis; -Southern -Convenience (Conv) -Plant-based -Sweets -Alcohol, salads	5.8 years follow-up of incident MI/CHD mortality (n = 536)	Southern: 1.37 (1.01,1.85) Conv: 0.95 (0.71, 1.27) Plant: 1.02 (0.76, 1.36) Sweets: 1.18 (0.86, 1.62) Alco/salad: 1.0 (0.76,1.32)
Europe					
Osler, 2002[a] [25]	Copenhagen County, n = 5,834 women & men age 30–70 year, Some with CHD at baseline	26-item FFQ; 28 food groups in FA model	Factor analysis; -Western -Prudent	15 years follow-up of CHD/ CHD mortality (n = 280)	Western: 0.97 (0.85,1.10) Prudent: 1.06 (0. 93,1.21)
Akesson 2007[a] [26]	Sweden, n = 24,444 women age 43–83 years; Free of CVD at baseline	96-item FFQ; 96 individual foods in FA model	Factor analysis; -Prudent	6.2 years follow-up of incident non-fatal and fatal MI (n = 308)	Prudent: 0.58 (0.39,0.88)
Brunner 2008[a] [27]	London, England; n = 6,610 men and women average age 50 year, Free of CHD and diabetes at baseline	127-item FFQ; 125 individual foods in cluster analysis model	Cluster analysis; -Unhealthy -Healthy -Sweet -Mediterranean-like	15 years follow-up of incident CHD/CHD mortality (n = 240)	Compared to the Unhealthy pattern: 1.00 Healthy: 0.71 (0.51,0.98) Sweet: 0.90 (0.59, 1.39) Med-like: 0.77 (0.50,1.19)
Guallar-Castillon 2012[a] [28]	Spain, n = 40,757 men and women age 29–69 years, Free of CHD at baseline	Diet history, 662 foods; 33 food groups in PCA model	Factor analysis; -Western -Mediterranean (Med)	11 year follow-up of incident non-fatal MI/CHD mortality (n = 606)	Western: 0.87 (0.62,1.22) Med: 0.73 (0.57, 0.94)
Stricker 2013[a] [29]	EPIC-NL cohort, n = 35,910 men and women age 20–69 years, Free of CHD at baseline	79-item FFQ; 31 food groups in PCA model	PCA; -Western -Prudent	13 years follow-up of incident CHD/CHD mortality (n = 1,843)	Western: 0.91 (0.76,1.08) Prudent: 0.87 (0.75, 1.00)
Asia					
Shimazu 2007[a] [30]		40-item FFQ;	PCA;		Animal: 1.50 (0.95,2.37)

Table 2 (continued)

Author, year (reference)	Population	Diet assessment	Diet pattern method	Outcome (n = events)	Results: HR (95 % CI)
	Ohsaki National Health Insurance study (Japan), n = 40,547 men and women age 40–79 years, Free of CHD at baseline	40 food items in PCA model	-Animal (western) -Japanese (prudent)	7 years follow-up of CHD mortality (n = 181)	Japanese: 0.82 (0.51,1.25)
Cai 2007[a] [31]	Shanghai Women's Health Study, n = 74,942 women age 40–70 year, Some chronic disease at baseline	71-item FFQ; 71 food items in PCA model	PCA; -Western -Vegetable-rich -Fruit-rich	5–7 years follow-up of CHD mortality (n = 77)	Western: 1.58 (0.81,3.08) Veggie: 1.10 (0.61,1.99) Fruit: 0.71 (0.33,1.53)
Maruyama 2013[a] [32]	Japanese Collaborative Cohort (JACC) study n = 64,037 men and women age 40–79 years, Free of CHD at baseline	40-item FFQ; 40 food items in FA	Factor analysis; -Western -Prudent	12.6 years follow-up of CHD mortality (n = 479)	Men Western: 0.72 (0.48,1.08) Prudent: 0.73 (0.49, 1.08) Similar results for women
Meta-analysis of 10 Cohort Studies [33][a]					
8 cohorts	n = 323,334	FFQ, diet history (food lists are different)	-Western	Incident CHD/CHD mortality (n = 4,132)	1.03 (0.90, 1.17)
10 cohorts	n = 354,388	FFQ, diet history (food lists are different)	-Prudent	Incident CHD/CHD mortality (n = 4,680)	0.83 (0.75, 0.92)
Subgroup meta-analysis by geographic location: Western Diet Pattern [33]					
Asia	n = 190,642	FFQ (food lists are different)	-Western	Incident CHD/CHD mortality (n = 833)	1.13 (0.81, 1.59)
US, Europe	n = 132,692	FFQ, diet history (food lists are different)	-Western	Incident CHD/CHD mortality (3,299)	1.02 (0.89, 1.59)
Subgroup meta-analysis by geographic location: Prudent Diet Pattern [33]					
Asia	n = 190,642	FFQ (food lists are different)	-Prudent	Incident CHD/CHD mortality (n = 833)	0.82 (0.70, 0.96)
US, Europe	n = 163,746	FFQ, diet history (food lists are different)	-Prudent	Incident CHD/CHD mortality (n = 4,680)	0.82 (0.71, 0.95)

FFQ food frequency questionnaire, *PCA* principal components analysis, *MI* myocardial infarction, *CHD* coronary heart disease, *NS* not significant

[a] Cohort studies included in the meta-analysis by Rodriguez-Monforte [33]

Definition of CHD—Differences in the Outcome

In US and European studies, incident CHD was defined as (1) confirmed and probable incident non-fatal myocardial infarction (MI) and (2) fatal CHD. Incident non-fatal MI was generally defined the same in US [21–24] and European studies [25–29], but the Asian studies [30–32] limited the CHD outcome definition to fatal MI. CHD mortality was assessed similarly in all studies.

Ascertainment of CHD

In US studies, medical records were reviewed for incident MI [21–24]. Fatal CHD was confirmed by medical records, autopsy reports, underlying cause of death on the death certificate, or confirmation by other sources. In European studies, CHD diagnosis was obtained from national hospital registries or population-based MI registries [25, 26, 28, 29] or through study exam, doctor diagnosis, and medical records [27]. Death information was obtained from cause of death registries [25–29]. CHD mortality in Asian countries was identified by review of death certificates obtained from regional Public Health Centers or death registries [30–32].

Comparison of Study Results

Study participants in the 12 studies were aged 20 to 84 years at baseline and were followed for incident CHD or CHD death over 4.6 to 15 years (Table 2). For the Western diet pattern, there was a 37 to 64 % higher risk of incident CHD [21, 22, 24] in 3 US studies; however, results were not reported for the "Fat, processed meat" (or Western) diet pattern relative to CHD in the Nettleton et al. study [23]. In contrast, null results were observed in all 4 European and 3 Asian studies. For the Prudent diet pattern, the risk of incident CHD was lower by 13 to 65 % in 3 US and 4 European studies, while no relation was found in 1 US study [24], 1 European study [25], nor in the 3 Asian studies [30–32].

A recent meta-analysis by Rodriguez-Monforte et al. reported findings for factor analysis and cluster analysis derived diet patterns relative to incident CVD, CHD, and stroke [33]. In this meta-analysis, the Prudent diet pattern was related to a 17 % lower risk of CHD, but there was no relation with the Western diet pattern [33]. Further, stratification by geographic location (USA + Europe; Asia) showed similar findings.

The published factor loadings or correlations of individual foods/food groups for each of the Western and Prudent diet patterns in 10 studies are shown in Tables 3 and 4, respectively. Factor loadings were not reported in the Akesson et al. or Brunner et al. papers [26, 27]. Loading scores for absolute values <0.30 were not reported in the Hu et al. study, and for the other studies, loading scores <0.15 were not reported. Positive factor loadings for a specific item indicate higher intake of that item characterizes the corresponding diet pattern and negative values indicate relatively lower intake of the item characterizes the pattern. For the Western diet pattern (Table 3), several studies, but not all, had positive loading scores for red and processed meat, French fries or fried food, eggs, high-fat dairy products, refined grain, and added fats (butter, margarine, oils, and olive oil) and negative loading scores for whole grains. For the Prudent diet pattern in all studies, positive loading scores were observed for fish, fruit, and fruit juice (Table 4). Further, factor loading scores for many of the US and European studies were positive for poultry, low-fat dairy, nuts/seeds, and whole grains. For US and Asian studies, loading scores were positive for a number of vegetables and legumes (miso, soybean, tofu). For studies conducted in Europe and Asia, positive loading scores were observed for sweets (candy, desserts).

The average number of servings consumed per day for major food groups for the Western and Prudent diet patterns are shown by lowest and highest quantile of intake in Tables 5 and 6, respectively, for several studies. This information was not published in 6 of the 12 studies [23, 25, 27–29, 31]. For the Western pattern, Americans [21, 22, 24] generally consumed more servings of total meat (red, processed, and poultry), dairy products, fruit and vegetables, and whole grains than Asians [30, 32]; however, Asians reported consuming more servings of fish and rice (refined grain) than Americans (Table 5). Servings of food intake were not reported for the Western diet pattern in European studies. For the Prudent pattern (Table 6), Americans and Europeans consumed more servings of total meat, dairy products, fruit, and vegetables than Asians, but Asians reported consuming more fish and rice. Alcohol consumption was not consistently reported across studies.

Discussion and Conclusions

Meta-analysis results showed a 17 % lower risk of incident CHD for the a posteriori Prudent diet pattern [33]; however, lower CHD risk ranged from 13 to 65 % as reported in 7 of 12 individual studies [21–23, 26–29]. The Prudent diet pattern was characterized by higher intake of fish, poultry, low-fat dairy, fruit, fruit juice, nuts/seeds, and/or whole grains. The Western diet pattern was generally characterized by higher intakes of red and processed meat, French fries or fried food, eggs, high-fat dairy products, refined grain, and added fats, and while the Western pattern was not associated with CHD in meta-analysis [33], the risk of CHD was significantly higher in 3 of 4 US studies [21, 22, 24].

We propose several explanations for the inconsistency of findings for the diet pattern-CHD associations. First, a posteriori or data-driven derived diet patterns are based on

Table 3 Food group factor loading scores for the Western (or similar) diet pattern of study participants from 10 cohorts

	U.S. studies				European studies			Asian studies		
Foods/ beverages	Hu[a] [21]	Fung [22]	Nettleton [23]	Shikany [24]	Osler [25]	Guallar-Castillon[b] [28]	Stricker [29]	Schimazu [30]	Cai [31]	Maruyama [32] men/ women
Red meat	0.63	0.56	0.42	0.26	0.36	0.57		0.48	0.33	0.34/0.34
Processed meat	0.59	0.56	0.63	0.45	0.53	0.48	0.25	0.56	0.34	0.53/0.56
Poultry			0.36					0.49	0.47	0.55/0.52
Organ meats				0.47				0.43	0.42	0.47/0.36
Fish/shellfish				0.23		0.17			−0.29	0.21/0.16
Fish paste								0.32		0.49/0.47
Eggs	0.39	0.29	0.34	0.42	0.28	0.53		0.32		0.23/0.30
Legumes		0.19				0.52	−0.36			0.20/0.17
Nuts		0.16								
Chicken/tuna salad			0.30							
Low-fat milk				−0.42		−0.35	−0.52			
High fat dairy[c]	0.45	0.36	0.42	0.24	0.43	0.15	−0.33	0.44		0.23/0.22
Pizza		0.35	0.42							
Fried food				0.56			0.65	0.39		0.54/0.57
French fries	0.46	0.47	0.60	0.16		0.66	0.70			
Sweets/desserts	0.47	0.43	0.48	0.19	0.43	0.19	−0.42			0.16/0.25
Sweet bread/ muffins			0.41							
Snacks	0.37	0.27	0.50			0.21				
Condiments	0.36	0.44	–							
Refined grain	0.49	0.58	0.28	0.37	0.51	0.66	0.43			
Whole grains				−0.25		−0.23	−0.36			
White rye bread					0.38					
Rice									−0.43	0.18/0.22
Pasta/potato salad			0.41							
Potatoes	0.33	0.41	0.37		0.28	0.64				
Vegetables							−0.21			0.18/0.13
Edible wild plants										0.32/0.25
Fruit							−0.55			
Fruit juice				0.17	0.21					0.17/0.22
Sugary drinks	0.38	0.32	0.36	0.37			0.52			
Coffee			0.29	−0.16				0.29		
Beer			0.19			0.24	0.35			
Wine						0.53		0.27		
Liquor						0.41	0.35	0.27		
Butter	0.31	0.24			0.41			0.50		0.27/0.31
Mayonnaise		0.31				0.40				
Margarine	0.34	0.32	–		0.24			0.37		0.17/0.15
Added fats/oils			0.65	0.38		0.38				
Olive oil						0.19				

[a] Loading scores for absolute values <0.30 were not reported in Hu et al. and for the other studies loading scores <0.15 were not reported

[b] Mediterranean diet

[c] High-fat dairy products or high-fat + low-fat dairy products

Table 4 Food group factor loading scores for the Prudent (or similar) diet pattern in study participants from 10 cohorts

	US studies				European studies			Asian studies		
Foods	Hu[a] [21]	Fung [22]	Nettleton [23]	Shikany [24]	Osler [25]	Guallar-Castillon[b] [28]	Stricker [29]	Schimazu [30]	Cai [31]	Maruyama [32] Men/women
Red meat							−0.25			
Processed meat							−0.22			
Poultry	0.36	0.43		0.31		0.16	0.21			
Fish	0.51	0.49		0.38	0.27	0.44	0.62	0.51		0.42/0.43
Oily fish						0.22	0.64			
Shellfish						0.20	0.74			
Organ meats		0.24								
Eggs		−0.15						0.34		0.32/0.30
Legumes	0.61	0.55		0.38					0.52	
Soybean, tofu								0.57		0.54/0.56
Miso soup										0.35/0.35
Nuts/seeds		0.19	0.46	0.26		0.19	0.23			
Chicken/tuna salad			0.30							
Pizza				−0.18						
Low-fat dairy		0.35	0.33	0.20	0.24	0.28		0.26		
Cottage cheese			0.30							
Cheese						0.23				
Dairy desserts			0.28	0.20						
Whole grains	0.35	0.41	0.59	0.30	0.61	0.27	0.36			
Whole ryebread					0.56					
White ryebread					−0.46					
Refined grain			−0.19	0.17	−0.38		−0.33			
Porridge, groats					0.30					
Pasta					0.35					
Rice					0.41					
Sweets, candy					0.36	−0.19	−0.33	0.27		0.23/0.16
Fried vegetables		−0.15						0.43		0.35/0.34
Vegetables[c]	0.75	0.67	0.27	0.48		0.64		0.64	0.54	
Green leafy veggies	0.64	0.63	0.38	0.49				0.62	0.38	0.59/0.59
Dark yellow veggies	0.63	0.60	0.21	0.41				0.59		0.64/0.64
Cruciferous veggies	0.63	0.61		0.59					0.43	
Tomatoes	0.56	0.45	0.25	0.32				0.45	0.37	0.42/0.40
Garlic	0.42	0.34								
Raw vegetables					0.53		0.66			
Boiled vegetables					0.39					
Potatoes							−0.43	0.61	0.40	0.64/0.61
Wild plant								0.27		0.25/0.25
Mushrooms								0.42	0.32	0.50/0.51
Seaweeds								0.59		0.63/0.61
Pickles, radish								0.41		0.35/0.24
Lotus root									0.32	
Bamboo shoots									0.31	
Cabbage, Chinese									0.42	0.60/0.57

Table 4 (continued)

Foods	US studies: Hu[a] [21]	Fung [22]	Nettleton [23]	Shikany [24]	European studies: Osler [25]	Guallar-Castillon[b] [28]	Stricker [29]	Asian studies: Schimazu [30]	Cai [31]	Maruyama [32] Men/women
Fruit	0.56	0.60	0.55	0.58	0.51	0.35	0.28	0.50		0.54/0.45
Fruit juice		0.25	0.24	0.25	0.36	0.16	0.28			0.22/0.16
Sugary beverages			−0.16							
Coffee			0.16		−0.26	−0.26				
Tea, green tea					0.36	0.21		0.29		
Beer				−0.16						
Wine							0.48			
Butter							−0.33			
Mayonnaise		0.17								
Veg, salad oils		0.33		0.30		−0.26				
Olive oil						0.61				

[a] Loading scores for absolute values <0.30 were not listed for Hu et al., for the other studies loading scores <0.15 were not listed

[b] Mediterranean diet

[c] Vegetables (in the USA) include celery, mushrooms, green pepper, corn, mixed vegetables, eggplant, summer squash

Table 5 Number of average daily servings of major food groups consumed in the lowest and highest quantile for the Western (or similar) diet pattern in 5 prospective studies

Food group	US studies: Hu [21] Q1	Hu [21] Q5	Fung [22] Q1	Fung [22] Q5	Shikany[a] [24] Q1	Shikany[a] [24] Q4	Asian studies: Shimazu [30] Q1	Shimazu [30] Q4	Maruyama [32] Men Q1	Maruyama [32] Men Q5
Red meat	0.2	0.6	0.3	1.0			0.2[b]	0.5[b]	0.3[b]	0.7[b]
Processed meat	0.1	0.7	0.1	0.6						
Poultry	0.4	0.3	0.3	0.3						
Fish	0.5	0.3	0.4	0.3			0.9	0.9	0.6	1.0
Eggs	0.2	0.6								
Dairy[c]	1.2	2.6	1.6	2.5			0.8	0.9	0.4	0.3
Butter	0.1	0.6	0.2	0.7						
Vegetables	3.1	3.0	2.9	3.2	2.9	2.4	1.4	1.2	1.2	1.3
Seaweed							0.1	0.1		
Legumes							0.6	0.5	0.2	0.2
Fruit	2.1	1.8	1.5	1.3	1.5	1.0	1.2	1.0	0.9	0.8
Whole grains	1.0	1.2	0.8	0.8	3.7	4.3				
Refined grains	0.6	1.9	0.5	2.1			3.9[d]	4.7[d]		
Sweets/desserts	0.4	1.9	0.5	1.9						

Q1 quantile 1, *Q4* quartile 4, *Q5* quintile 5

[a] Servings of vegetables, fruit and whole grain intakes were reported, only

[b] Total meat intake = red and processed meat or poultry

[c] Dairy = lowfat + high fat dairy products

[d] White rice

Table 6 Number of average daily servings of major food groups consumed in the lowest and highest quantile for the Prudent (or similar) diet pattern in 6 prospective studies

	US studies						European study		Asian studies			
Food group	Hu [21]		Fung [22]		Shikany[a] [24]		Akesson [26]		Shimazu [30]		Maruyama [32] Men	
	Q1	Q5	Q1	Q5	Q1	Q4	Q1	Q5	Q1	Q4	Q1	Q5
Red meat	0.7	0.5	0.6	0.6			1.0[b]	1.24[b]	0.3[b]	0.3[b]	0.4[b]	0.5[b]
Processed meat	0.5	0.3	0.4	0.3								
Poultry	0.2	0.5	0.2	0.5								
Fish	0.2	0.6	0.2	0.5			0.2	0.4	0.7	1.3	0.6	1.0
Eggs	0.4	0.3										
Dairy[c]	1.7	1.9	1.4	2.5					0.5	0.9	0.3	0.4
Butter	0.3	0.3										
Vegetables	1.3	5.4	1.4	5.3	1.4	4.6	1.6	6.1	0.8	1.8	0.6	1.7
Seaweed									0.1	0.2		
Legumes							0.1	0.2	0.4	0.6	0.2	0.3
Fruit	0.9	3.1	0.6	2.4	0.6	2.1	0.9	3.1	0.7	1.4	0.5	1.0
Whole grains	0.5	1.7	0.3	1.5	2.9	4.5	3.0	4.1				
Refined grains	1.2	1.1	1.3	1.1			1.6	1.3	5.2[d]	3.6[d]		
Sweets/desserts	1.2	0.9	1.1	1.0			1.6	1.9				
Beer							0.1	0.1				
Wine							0.1	0.1				
Liquor							0.03	0.03				

Q1 quantile 1, *Q4* quartile 4, *Q5* quintile 5

[a] Servings of vegetables, fruit and whole grain intakes were reported, only

[b] Total meat intake = red meat, processed meat and/or poultry

[c] Dairy = lowfat + high fat dairy products

[d] White rice

subjective methods and require decisions that have consequences for the analysis and interpretation of the study results. Importantly, the methods to construct diet patterns in the 12 studies were not standardized. These methodological differences likely contribute to the inconsistency of results in this body of evidence. In constructing the diet pattern, the choice and treatment of food and beverage variables included in the model may influence study results. For example, the decision to include individual food items or food groups varied among the 12 studies; half of the studies collapsed individual food items into a smaller number of food groups (ranging from 30 to 50 food groups) [21–23, 28, 29], while the others input all individual food items in the factor analysis model. Subjective decision-making has also been involved with food grouping. For example, should red meat and processed meat be grouped together or kept separate? Or should all vegetables be grouped into 1 group or grouped into botanically similar groups or grouped according to another scheme. These decisions influence the factor loadings and study results. Another aspect to consider in diet pattern construction is whether to use absolute (i.e., servings or grams of food groups per day) or density amounts (i.e., mean weight of food adjusted for total energy intake). However, Smith et al. determined no differences between diet patterns derived using absolute and density amounts in a children's diet study [35]. Finally, there is evidence suggesting that dietary intake differs between men and women; not only amount of food and beverage intake but choices of food and beverages vary [36]. Half of the studies created gender-specific diet pattern scores, while the others created diet patterns inputting data from both genders into the factor analysis/PCA model.

Second, dietary assessment varied between studies, including the instrument to assess dietary intake (FFQ vs. diet history), differences in the FFQ food list (food and beverage items queried), the number of food and beverages listed on the FFQ varied between studies (ranging from 26 to 131 items), interviewer- vs. self-administration of the FFQ, and food and beverage intake not listed on the FFQ (alcohol or other beverages, high-calorie snack foods, or other foods to capture total diet). Osler et al. used a short item FFQ (26 items) which did not capture total dietary intake, which may have contributed to the null relation between both food patterns and CHD [25].

Third, ascertainment of CHD cases differed by country. It is possible that the number of cases captured in US studies was underestimated since national hospital charge registries were not available as in Europe. In addition, non-fatal CHD was not captured in the studies conducted in Japan and China [30–32]. Diverse capture of CHD cases, including different CHD definition in Asian studies, may potentially attenuate the diet-CHD point estimate, thus providing another potential explanation for differing study results.

Furthermore, geographic and/or cultural differences influence eating habits, including availability of food and type of food consumed, food preparation and cooking method (such as roasting, steaming, food preservation using salt), and amount of food consumed. Amount of food intake varied by geographic location; Asians consumed more fish and less meat for both lower (Q1) and higher (Q4 or Q5) Prudent and Western pattern scores compared to American quantile values. In the individual Asian cohorts, no relation was observed between the Prudent diet pattern and CHD, which was somewhat surprising given their higher fish and legume intake, and lower meat intake; although the study samples were relatively young and only CHD mortality was ascertained over 5–12 years of follow-up. In meta-analysis, results showed a statistically significant 18 % lower risk of CHD mortality associated with the Prudent pattern among Asian cohorts, a result likely driven by the large pooled sample size. Although sodium intake was not queried, sodium intake is high among Chinese and Japanese populations and may have contributed to CHD mortality [37, 38]. The risk of CHD was higher among adults consuming a Western diet pattern in US cohorts, but not in Europe or Asia; however, the meta-analysis results did not stratify between U.S. and Europe [33]. Since the European studies did not report average number of servings from each food group for the Western diet pattern, we were unable to compare food intake between studies from the two geographic areas. For comparison between studies, it is important to be transparent and report methodology related to constructing the diet patterns as well as the results of pattern analysis, including the factor loading scores and average food intake for all quantiles of diet pattern score. Further, more research is needed to understand the differences in diet pattern-disease associations by geographic location and culture as well as to conduct collaborative studies for development of standardized methods to reduce heterogeneity to better compare diet patterns among the numerous cohort studies.

In summary, the recommendations of the 2015–20 Dietary Guidelines for Americans [12••] and the AHA/ACC guidelines on lifestyle management [1•] that a diet pattern characterized by higher intake of fish, vegetables, legumes, fruit, whole grain, nuts, and lower intake of red and processed meat is related to lower risk of CHD. Other studies of the health benefits of this type of healthy diet pattern have been demonstrated in the PREDIMED Study [2]; the Lyon Heart Study [3], the 7th Day Adventist study [17]; the DASH trial, [15], and others. The Western dietary pattern has been inconsistently and positively associated with CHD risk and the inconsistency in results across studies is likely explained by the shifting constituents of the pattern from study to study in addition to the other methodological variations discussed. Although studies of diet patterns do not identify mechanisms contributing to lower risk, we may speculate that higher intake of omega3 fatty acids [4, 7], bioactive fruit and vegetables [6], whole grains [5, 8], nuts [39], and olive oil [2, 3] may work synergistically [10] to promote cardiovascular health.

Compliance with Ethical Standards

Conflict of Interest Lyn M. Steffen and Katie C. Hootman declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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