

Trends in Diet and Alzheimer's Disease During the Nutrition Transition in Japan and Developing Countries

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Abstract.

Background: Alzheimer's disease (AD) rates in Japan and developing countries have risen rapidly in recent years. Researchers have associated factors such as the Western diet, obesity, alcohol consumption, and smoking with risk of AD.

Objective: This paper evaluates whether the dietary transition might explain the rising trend of AD prevalence in Japan and in developing countries, evaluating other factors when possible.

Methods: This study used two approaches to see whether dietary or other changes could explain AD trends in Japan and developing countries. One approach involved comparing trends of AD in Japan with changes in national dietary supply factors, alcohol consumption, and lung cancer mortality rates from zero to 25 years before the prevalence data. The second compared AD prevalence values for eight developing countries with dietary supply factors from zero to 25 years before the prevalence data.

Results: For Japan, alcohol consumption, animal product, meat and rice supply, and lung cancer rates correlated highly with AD prevalence data, with the strongest correlation for a lag of 15–25 years. In the eight-country study, total energy and animal fat correlated highly with AD prevalence data, with a lag of 15–20 years. Mechanisms to explain the findings include increased obesity for the eight countries, and increases in cholesterol, saturated fat, and iron from increases in animal products and meat supply for Japan.

Conclusion: Evidently AD rates will continue rising in non-Western countries for some time unless we address major risk factors involving diet, obesity, and smoking.

Keywords: Alzheimer's disease, dementia, dietary supply, iron, meat, nutrition transition, obesity, rice, zinc

INTRODUCTION

Diet is a risk factor for Alzheimer's disease (AD). In June 1997, an ecological study of 11 countries directly correlated AD prevalence and contemporaneous dietary supply of both total fat and total energy. That study also inversely correlated AD prevalence with supply of fish and cereals/grains [1]. The 1997 ecological study was conducted after reading that the

Honolulu Heart Program found a prevalence of 5.4% of AD for Japanese-American men older than 70 years, which was 2.5 times greater than for men and women in Japan about that time [2].

Soon after, a cohort study in The Netherlands directly correlated risk of dementia with increased intake of total fat, saturated fat, and cholesterol; it inversely correlated dementia risk with fish consumption [3]. Later, a prospective study in New York statistically significantly correlated risk of AD with total caloric intake [4]. A 10-year prospective study in New York associated the Mediterranean diet—which compared with the Western diet has more legumes, fruit, vegetables, unsaturated fatty acids, and cereals;

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Table 1
Comparison of dietary supply factors for Japan and the U.S., 1961 and 2008

Factor	Japan, 1961	US, 1961	Japan, 2008	US, 2008
Energy (kcal/person/d)	2542	2881	2768	3733
Animal product energy (kcal/person/d)	249	1079	573	1028
Animal fat (g/person/d)	13.8	69.5	34.9	69.7
Cereals (kg/person/y)	157.8	86.8	115.1	110.2
Rice (kg/person/y)	112.8	2.5	54.5	8.4
Sugar and sweeteners (kg/person/y)	18.0	52.1	28.6	65.5
Vegetables (kg/person/y)	97.4	93.6	103.9	117.4
Fruit (kg/person/y)	29.7	63.5	84.1	68.3
Alcohol (kg/person/y)	29.6	66.7	43.0	99.7
Meat (kg/person/y)	7.6	88.7	48.8	124.4
Milk (kg/person/y)	24.9	265.8	74.3	254.0
Fish (kg/person/y)	49.6	13.0	56.6	24.3
Lung cancer mortality rate, 60+ years, Males/females (deaths/100,000/y)*	69/22	190/24	223/57	276/169

Table 2

Dietary supply for selected factors during the nutrition transition in Japan [11] along with lung cancer mortality rates [12], men aged 60+ years

Factor	1961	1965	1975	1985	1995	2005	2008	Change, 1961–2008 (%)
Alcohol (kg/person/d)	29.6	35.4	52.3	57.4	73.7	44.3	43.0	39
Animal energy (kcal/person/d)	249	331	468	580	625	592	573	130
Animal fat (kg/person/y)	5.0	19.5	28.8	35.0	37.2	35.7	34.9	598
Energy (kcal/person/d)	2524	2621	2718	2858	2917	2842	2768	10
Fish (kg/person/y)	49.6	52.9	69.8	69.7	71.2	61.0	56.6	14
Fish fat (kg/person/y)	4.8	5.8	7.9	9.3	8.7	7.2	6.8	42
Fruit (kg/person/y)	29.7	39.0	61.9	51.9	53.2	60.6	55.1	86
Meat (kg/person/y)	7.6	11.5	23.4	33.7	44.1	46.9	48.8	542
Meat fat (kg/person/y)	1.6	2.8	6.5	9.2	11.5	12.7	12.7	695
Rice (kg/person/y)	112.8	107.2	85.1	69.2	63.0	61.0	54.5	-52
Sugar (kg/person/y)	18.0	22.6	27.2	33.5	30.8	28.8	28.6	59
Vegetables (kg/person/y)	97.4	120.3	122.0	120.2	117.1	108.7	103.8	7
Lung cancer mortality rate, males, females, 60+ y, (deaths/100,000/y)*	69, 22	90, 28	143, 38	213, 54	250, 58	230, 57	223, 57	223, 159

*Age-standardized rates to world age distribution.

a moderately high intake of fish; low to moderate intake of dairy products; and low intake of meat—with reduced risk of AD [5]. Several recent reviews analyzed the diet's role in the risk of AD [6–8].

The 1997 ecological study noted that AD prevalence rates were low in countries such as China, Japan, and Nigeria [1]. AD rates in Japan are still lower than in Europe and North America [9]. However, rates in Japan have risen for those aged 65+ years, from near 1% in 1985 to near 7% in 2008 [10]. Since 1960, the diet in Japan has changed from the traditional diet—with 40% of energy supplied by rice, a moderate amount of fish, but very little meat, dairy, or sugar—to one with a preponderance of meat but less rice [11], which came nearer to the U.S. diet (Tables 1 and 2). Alcohol supply and lung cancer rates have also increased.

Nutrition transitions have occurred in many other countries as well. The largest changes in nutrition supply have occurred in developing countries moving from traditional diets to the Western diet. Traditional diets

generally have low-to-moderate energy content and are weighted toward vegetable products such as grains and away from animal products such as meat and milk; they also have less added sugar than the Western diet. Such changes have increased chronic disease rates [13].

A recent study identified “eleven risk factors and four protective factors for AD... for which odds ratios were published or could be calculated (age, sex, education, body mass index, diabetes, depression, serum cholesterol, traumatic brain injury, smoking, alcohol intake, social engagement, physical activity, cognitive activity, fish intake, and pesticide exposure)” [14]. Body mass index, diabetes, serum cholesterol, and fish intake are directly related to diet. Smoking is a significant risk factor for Japanese-American men living in Hawaii [15].

This paper evaluates whether the dietary transition might explain the rising trend of AD prevalence in Japan and in developing countries, evaluating other factors when possible.

MATERIALS AND METHODS

AD prevalence data for Japan came from the review by Dodge [10, 16–22]. AD prevalence data for those ≥ 65 years were obtained from Table 1 of [10]. Prevalence of dementia was multiplied by AD percentage out of all dementia for each study. The year of the study was taken as the midpoint of the years of the study.

AD prevalence data for eight developing countries came from the tabulation in Kalaria and colleagues [23]. Data were used for China [24], India [25–29], Sri Lanka [30], Egypt [31], Nigeria [32], Cuba [33], and Brazil [34–37]. This study does not use data for Israel, which was for Arabs since Arabs are a minor population in Israel and the dietary data are more representative of the majority Jewish population. Data for Venezuela were excluded since they were for those over the age of 55 years. This study uses two sets of data, that for AD prevalence and that for AD plus other dementias but excluding vascular dementia. Most other dementias were labeled “mixed,” which would include AD. However, those for Brazil, China, India, and Nigeria also included other dementias, such as dementia with Lewy bodies and/or Parkinson’s disease.

Dietary supply data came from the food balance sheets of the Food and Agriculture Organization of the United Nations [11]. Per capita dietary supply data are available for many dietary components from 1961 to 2008. For Japan, this study used data for rice and meat and alcohol. For the eight-country study, this study used data for total energy and animal fat. See Table 3 for total energy and animal fat supply as a function of years before the AD prevalence data. Most countries had much higher energy supply values for the year of AD prevalence data than 25 years before those data. However, Cuba, Republic of Korea, and Sri Lanka had energy supply values little changed between the two periods. Data were obtained for every five years from zero to 25 years prior to each AD prevalence value.

Although one can make an index of smoking from lung cancer incidence or mortality rates, lung cancer is a trailing index, generally occurring several decades after smoking begins. Ecological studies of cancer mortality have used lung cancer mortality rate successfully in that it identified cancers linked to smoking and estimated the effect of smoking generally as expected from the journal literature [39]. This study used lung cancer mortality rates for males 0–25 years before the AD prevalence data. The age range was varied to match the AD prevalence data for 70–80 years of age at the time of the prevalence data. Data came from Cancer Mondial (<http://www-dep.iarc.fr/>; in the navigation bar, click WHO \rightarrow Online Analysis \rightarrow Tables \rightarrow Year).

Apolipoprotein E $\epsilon 4$ (ApoE4) prevalence values are from Table 1 in Grant [40].

Graphs were made using KaleidaGraph version 4.2 (Synergy Software, Reading, PA). Regression analyses were made using IBM SPSS Statistics 20 (Armonk, NY).

RESULTS

Japan

AD prevalence data for those aged 65+ years from [10] were graphed to examine the trend. The regression fit between AD prevalence for those aged 65+ versus year from 1985 to 2008 was as follows: $r = 0.95$, adjusted $r^2 = 0.88$, $p < 0.001$ (Fig. 1). Dementia other than AD, assumed to be primarily vascular dementia, did not change significantly during that period.

Since the age-adjusted AD prevalence rates for those over the age of 65 years may be affected by the changing age distribution due to longer life expectancy, the prevalence rates for those aged 70–79 years and 80–89 years are plotted along with those aged 65+ years in Fig. 2.

Table 3
Data for the eight-country study based on AD prevalence data in [23]

Country	Year	ApoE4 (%) [40]	AD prevalence >65 y (%) (95% CI)	AD+ mixed >65 y (%)	Ref.	Energy supply 0/10/20/25 years earlier (kCal/person/day)	Animal fat 0/10/20/25 years earlier (kg/person/y)
Nigeria	1995	30	1.4 (0.6–2.2)	1.6	[32]	2529, 1822, 1792, 1951	5.2, 5.1, 3.7, 3.5
India	2001	8	1.3 (0.8–1.8)	1.6	[26–29]	2241, 2309, 2052, 1923	12.1, 10.6, 8.1, 7.6
Sri Lanka	2003	8	2.85	3.83	[30]	2348, 2095, 2311, 2254	8.9, 6.3, 6.2, 5.3
China	2005	9	3.5 (3.0–3.9)	3.9	[24]	2950, 2775, 2450, 2163	52.4, 38.8, 20.5, 15.4
Brazil	2002–8	14	2.7 (0.1–5.2)	4.4	[34–37]	3081, 2814, 2630, 2700	45.7, 39.6, 24.8, 28.0
Egypt	1998	7	2.86	4.68	[31]	3299, 3104, 2659, 2367	17.6, 18.2, 15.5, 12.2
Republic of Korea	2000	11	5.2 (3.5–6.8)	8.0	[38]	3090, 2956, 3023, 3105	30.1, 20.6, 13.7, 11.2
Cuba	1999	22	5.1 (3.6–6.6)	6.3	[33]	2929, 3016, 2722, 2830	23.5, 49.1, 49.5, 48.3

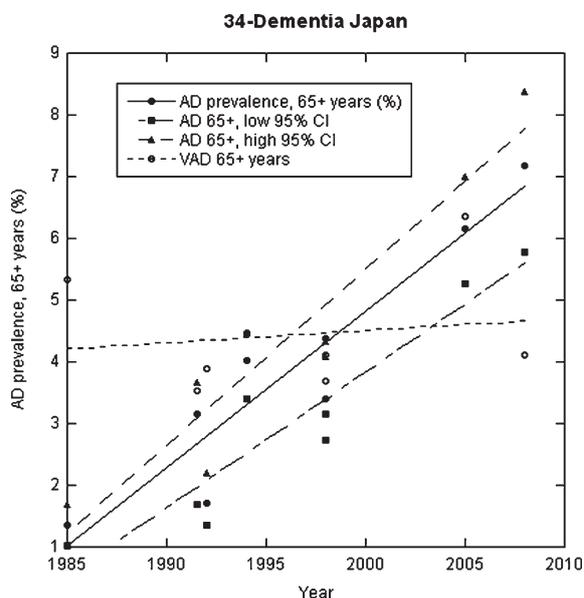


Fig. 1. Plot of AD prevalence rate (discs) with 95% confidence intervals (triangles and squares) in Japan [10] versus year of study with linear regression analysis. Also shown is prevalence of non-AD dementia (largely vascular dementia) as circles.

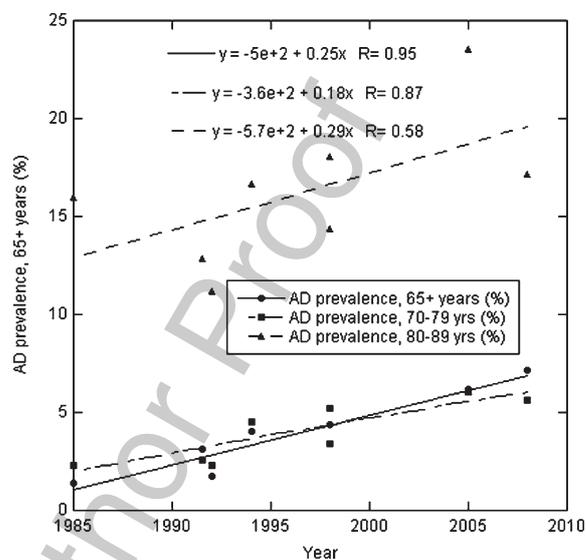


Fig. 2. Comparison of AD prevalence rates in Japan for those aged 65+ years, 70–79 years, and 80–89 years.

The next step was to review the dietary supply data from the Food and Agriculture Organization to see what macro dietary supply factors changed significantly. From 1961 to 2008, meat and animal fat increased considerably, whereas rice supply decreased considerably (Table 2).

Table 4 gives regression results for alcohol, animal product, meat and rice supply, and lung cancer (the smoking index). For meat and rice supply, there is little change difference in the correlation for any difference between the years of the factor and years of the AD prevalence (lag). However, the correlation with animal product energy and alcohol is highest for 15–25 years lag, and the correlation with lung cancer increases with lag. When all five factors are considered, the values for the 25-year lag have the highest correlation with AD prevalence, but the results for 15 and 20 years are not much lower. Note that lung cancer and alcohol are not

correlated with AD prevalence for zero or zero and five years lag, respectively. This finding is attributed to the fact that both of these factors have U-shaped variations from 1985 to 2008, peaking near 1995 (see Table. 2). With only eight values for AD prevalence, a multiple linear regression analysis with two or more factors is not possible.

Eight-country study

The eight-country study used total energy supply and animal fat supply in linear regression analyses with AD and AD plus mixed dementia. Data were used for zero to 25 years before the midpoint of the prevalence data, with 5-year intervals (Table 5). For AD plus mixed dementia, total energy has the highest correlation for a lag of 20 years before the prevalence data, although results for 15 and 25 years were not much different. The results for animal fat peaked around 15–20 years but were much weaker than for total energy. Regression analyses were also run for sup-

Table 4
Regression results for AD in Japan

Lag (y)	Meat (r , adjusted r^2 , p)	Animal energy (r , adjusted r^2 , p)	Rice (r , adjusted r^2 , p)	Lung cancer, M (r , adjusted r^2 , p)	Alcohol (r , adjusted r^2 , p)
0	0.91, 0.80, 0.002	—	−0.95, 0.89, <0.001	—	—
5	0.92, 0.83, 0.001	0.50, 0.13, 0.22	−0.94, 0.85, 0.001	0.71, 0.42, 0.05	—
10	0.89, 0.76, 0.003	0.73, 0.46, 0.04	−0.84, 0.65, 0.01	0.86, 0.69, 0.007	0.53, 0.16, 0.18
15	0.94, 0.86, 0.001	0.92, 0.83, 0.001	−0.89, 0.76, 0.003	0.92, 0.81, 0.001	0.87, 0.72, 0.005
20	0.93, 0.84, 0.001	0.87, 0.72, 0.005	−0.88, 0.74, 0.004	0.94, 0.86, 0.001	0.93, 0.84, 0.001
25	0.92, 0.82, 0.001	0.91, 0.80, 0.002	−0.95, 0.88, 0.001	0.95, 0.89, <0.001	0.90, 0.78, 0.002

Table 5
Regression results for AD plus mixed dementia or AD for the eight-country study

Lag (y)	AD + mixed dementia		AD	
	Energy (<i>r</i> , adjusted <i>r</i> ² , <i>p</i>)	Animal fat (<i>r</i> , adjusted <i>r</i> ² , <i>p</i>)	Energy (<i>r</i> , adjusted <i>r</i> ² , <i>p</i>)	Animal fat (<i>r</i> , adjusted <i>r</i> ² , <i>p</i>)
0	0.64, 0.31, 0.09	0.45, 0.07, 0.27	0.53, 0.16, 0.18	0.41, 0.03, 0.31
5	0.58, 0.23, 0.13	0.46, 0.08, 0.25	0.42, 0.04, 0.29	0.41, 0.03, 0.31
10	0.85, 0.68, 0.008	0.66, 0.34, 0.08	0.71, 0.41, 0.05	0.59, 0.24, 0.12
15	0.92, 0.82, 0.001	0.71, 0.42, 0.05	0.80, 0.58, 0.02	0.62, 0.29, 0.10
20	0.95, 0.89, <0.001	0.70, 0.40, 0.05	0.87, 0.71, 0.005	0.62, 0.29, 0.10
25	0.92, 0.83, 0.001	0.65, 0.33, 0.08	0.87, 0.72, 0.005	0.56, 0.20, 0.15

ply data 20 years before the prevalence data for alcohol, cereals (grains), total fat, fish, meat, milk, rice, and sugar and sweeteners. No regression results for these dietary factors were as strong as that for animal fat. ApoE4 prevalence did not correlate significantly with AD prevalence. For AD alone, the regression results for 20 and 25 years lag had the highest correlation.

DISCUSSION

Results of this analysis suggest that the rising prevalence of AD in Japan is related to the nutrition transition from a traditional to a Western diet. The nutrition transition effect has been recognized for several types of cancer, and changes in cancer mortality lagged ~10 years behind the inception of the nutrition transition toward a westernized diet [41]. Diet's effect on cancer risk by country was also indicated by the first multi-country study of dietary supply and cancer [42].

Obesity is linked to meat consumption in Japan [43] and China [44]. Obesity rates among working men started to increase around 1985, from 17% to 39% in 2008 for men aged 40–49 years and from 19% to 32% for men aged 50–59 years [45].

Regression results for lung cancer and AD in Japan are difficult to interpret because lung cancer is a trailing index of smoking rates. Those who died from lung cancer in the age ranges considered may have developed lung cancer at younger ages than most of their cohort. However, smoking is a risk factor for adverse cardiovascular disease (CVD) in Japan [46], and CVD is a risk factor for AD [47]. Also, smokers have a reduced life expectancy compared to nonsmokers, which could reduce the apparent effect of smoking on risk of AD. Although the present study found a significant correlation between lung cancer and AD prevalence in Japan, the finding may be linked to diet more than to smoking. A study comparing Japanese and U.S. lung cancer rates for smokers from 1992 to 1998 found that Japanese smokers had less than 1/10 the risk of lung cancer of U.S. smokers for comparable smoking histories [48]. A

previous study had suggested that dietary differences, such as much higher U.S. fat intake, might account for the disparity [49].

The finding of the eight-country ecological study that total energy had the highest correlation with AD prevalence suggests that the prevalence of overweight and obese inhabitants increased in each country during the past two to three decades. That no dietary supply factor other than total energy supply highly correlated with risk of AD is likely due to the fact that the national diets had much different profiles and indicates that different types of food might be associated with increased risk of obesity and AD in different countries. Unmodeled factors, such as smoking and physical activity, might accompany the nutrition transition and contribute to the AD trends.

Several studies investigating midlife factors and risk of AD and other dementia, some of which were prospective studies with 15–31 years of follow-up, support the finding in the eight-country study that total energy supply values 20 years before the prevalence data correlated most strongly with prevalence. Table 6 lists factors found to precede AD. Many are related to diet, whereas some are related to physical activity or AD-related biomarkers. In total, they strongly support the concept that a long lead time exists between risk factors for and diagnosis of AD.

A UK study associated the Western diet with a significant risk of both CVD and non-CVD death rates in a model adjusted for age, gender, and total energy intake, whereas it significantly inversely correlated the healthy-foods diet with non-CVD death rates [65].

Transition metals and aluminum have long been associated with increased risk of AD [1, 66–69]. “Over the decades, various studies have established an association between accumulation of iron and both aging and neurodegenerative disorders such as Alzheimer’s disease and Parkinson’s disease. Excess levels of iron can lead to increased oxidative stress through Fenton chemistry” [70]. Rice is a source of zinc but not iron [71]. Because AD rates in Japan correlate directly with meat supply and inversely with rice supply, iron may

Table 6
Midlife factors linked to risk of AD and dementia

Factor	AD, dementia (D), or vascular dementia (VaD)	Reduced risk	Increased risk	Modified by ApoE status	Observation period or average follow up time (y)	Reference
Alcohol consumption	AD		X	Yes		[50]
Amyloid- β_{42} in cerebrospinal fluid, decline	AD		X		25	[51]
Brain atrophy	AD		X		15	[51]
Cholesterol, >6.5 mmol/L	AD		X		Midlife (21)	[52]
Cholesterol, >200 mg/dL	AD, VaD		X		Midlife (30)	[53]
Coffee drinking	AD, D	X			21	[54]
Depressive symptoms	AD		X		Midlife	[55]
Diabetes mellitus	AD		X		Midlife	[56]
Diet, healthy	AD	X			Midlife	[57]
Fat	AD, D	Polyunsaturated	Saturated	Yes	21	[58]
Exercise	D	X			31	[59]
Fitness, cardiorespiratory	D	X			25	[60]
Hypertension	AD		X		21	[52]
Obesity	AD, D		X	Yes	21	[61]
Obesity	AD		X		Midlife	[62]
Obesity, overweight	AD, D, VaD		X		Midlife (30)	[63]
Physical activity, leisure time	AD	X		Yes	Midlife (21)	[64]
Smoking	AD		X	Yes	Midlife	[15]

be a risk factor for AD in Japan, but zinc may be a risk-reduction factor. A U.S. ecological study inversely correlated dietary zinc index with 12 types of cancer, whereas the dietary iron index directly correlated with 10 types of cancer [72]. However, a laboratory study found that zinc competes with copper for amyloid- β binding, thereby inhibiting copper-mediated amyloid- β redox chemistry [73]. An earlier study found that low zinc levels were protective, whereas high zinc levels were detrimental [74]. In a study conducted in 2005, rice contributed 1.97 ± 0.90 mg/d zinc out of a total of 9.49 ± 3.11 mg/d [75]. Rice consumption declined from 1170 kcal/d in 1965 to 708 kcal/d in 1988 and 618 kcal/c in 2003 and 587 kcal/d in 2008. Thus, rice contributed about 4 mg/d zinc in 1965, down to 2.4 mg/d in 1988 [11].

However, it seems that the association between rice supply and AD in Japan is more likely due to replacement of rice by animal products. A recent paper reported data for AD in China for three periods, 1990, 2000, and 2010 [76]. AD prevalence rose from 1.7×10^{-3} in 1990, to 2.94×10^{-3} in 2000 and 4.25×10^{-3} in 2010 (age-adjusted rates were not provided). When dietary supply values for China were compared to these rates as done for China, animal products, meat, and total energy supply had very high correlations with AD prevalence for lags between five and 20 years; rice supply was directly correlated with AD prevalence for a 20-year lag as per capita rice consumption increased from 1961 to 1983, then declined little subsequently [11].

Inflammation appears to be a risk factor for AD [77, 78]. A postmortem study found evidence of upregulated arachidonic acid metabolism in the brains of people who died with AD, suggesting that arachidonic acid cascade and inflammatory markers contribute to AD pathology [79]. The prudent diet (higher intakes of fruit, vegetables, legumes, fish, poultry, and whole grains) inversely correlated with plasma C-reactive protein, an important biomarker of inflammation, whereas the Western diet showed a direct correlation [80].

Vitamin D deficiency is another emerging risk factor for AD [81]. A pooled study found that AD patients had 25-hydroxyvitamin D [25(OH)D] levels lower by 1.4 standard deviations ($p=0.02$) than control subjects [82]. However, having a lifestyle affected by AD could reduce 25(OH)D levels (reverse causality). Vitamin D appears to reduce risk of cognitive impairment, often a prelude to AD. In a 4-year prospective study in Minnesota, women with serum 25(OH)D levels below 10 ng/mL at time of enrollment had an odds ratio of 1.6 (95% CI, 1.05–2.42) of developing cognitive impairment compared with women with 25(OH)D levels above 30 ng/mL [83].

In many countries, serum 25(OH)D levels have decreased for several reasons, including spending more time indoors, wearing sunscreen when outdoors, and higher obesity rates [84].

Study limitations include that since the analyses are ecological studies, the factors found associated with AD prevalence may be correlated with other unmodeled factors that are causal. For example, the

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finding for rice in the Japanese diet is very likely due to the foods that replaced rice such as meat and other animal products. Also, dietary supply values are estimates for food actually consumed as the values represent the food that enters the consumer supply, some of which is lost to human consumption. In addition, diagnostic criteria for AD and vascular dementia may have changed with time in Japan as well as be different in different countries.

Worldwide dementia prevalence will increase from 35.6 million in 2010 to 65.7 million in 2030 and 115.4 million in 2050 [85]. That review made no apportionment between AD and non-AD dementia. However, as developing countries change, AD becomes more prevalent than vascular dementia [86]. **On the basis of findings here, the rate of AD and dementia will continue to rise as estimated in that projection unless dietary patterns change to those with less reliance on animal products or new ways are found to reduce risk of AD.** Another study suggested that reducing seven risk factors (diabetes, midlife hypertension, midlife obesity, smoking, depression, cognitive inactivity or low educational attainment, and physical inactivity) could prevent 10%–25% of projected new cases of AD [87]. The adverse health effects of the nutrition transition discussed by Popkin starting in the 1990s [88] will continue to accumulate unless steps are taken to provide healthier foods worldwide.

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The author's disclosure is available online (<http://www.j-alz.com/disclosures/view.php?id=1890>).

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