Review

Raw versus Cooked Vegetables and Cancer Risk

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Abstract

This review of the medical literature from 1994 to 2003 summarizes the relationship between raw and cooked vegetables and cancer risk and examines whether they may affect cancer risk differently. Twenty-eight studies examined the relationship between raw and cooked vegetables and risk for various cancers. Twenty-one studies assessed raw, but not cooked, vegetables and cancer risk. The majority of these assessed risk of oral, pharyngeal, laryngeal, esophageal, lung, gastric, and colorectal cancers. Most showed that vegetables, raw or cooked, were inversely related to these cancers. However, more consistent results were found for oral, pharyngeal, laryngeal, esophageal, and gastric cancers. Nine of the 11 studies of raw and cooked vegetables showed statistically significant inverse relationships of these cancers with raw vegetables, but only 4 with cooked vegetables. The few studies of breast, lung, and colorectal cancers also suggested an inverse relationship with both raw and cooked vegetables, but these results were less consistent. In the two studies of prostate cancer, there was no association with either raw or cooked vegetables. One of two bladder cancer studies found an inverse relationship with cooked, but not raw, vegetables. Possible mechanisms by which cooking affects the relationship between vegetables and cancer risk include changes in availability of some nutrients, destruction of digestive enzymes, and alteration of the structure and digestibility of food. Both raw and cooked vegetable consumption are inversely related to epithelial cancers, particularly those of the upper gastrointestinal tract, and possibly breast cancer; however, these relationships may be stronger for raw vegetables than cooked vegetables. (Cancer Epidemiol Biomarkers Prev 2004;13(9):1422–35)

Introduction

Cancer is the second leading cause of death in the United States (1). Despite advances in the treatment of this disease, there is no substitute for prevention. There is substantial evidence for the role of diet in cancer prevention, including an important role for vegetable and fruit consumption (2).

In a review of this literature, Steinmetz and Potter (3) found strong support for an inverse relationship between vegetable and fruit consumption and respiratory and gastrointestinal cancers. This relationship was even greater for *raw* vegetable consumption in particular. In their review of the literature through 1994, 33 of 39 (85%) studies evaluating raw vegetables and cancer showed an inverse association (4).

Because cooking has known and unknown effects on food and because raw vegetables may be more beneficial than cooked vegetables in decreasing the risk of certain cancers and chronic diseases, further investigation of this relationship is warranted. This article presents a review of the epidemiologic studies on raw vegetables and cancer over the past 10 years along with a discussion of possible mechanisms that explain how raw and cooked vegetables differ.

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Methods

This review includes case-control and cohort studies from 1994 to August 2003 that evaluated raw or raw and cooked vegetables and risk of cancer. We found 334 studies by performing a MEDLINE search with the keywords vegetable(s), case-control, cohort, cancer, and neoplasm. We also reviewed bibliographies and studies by authors who had published similar studies. Only studies that indicated the vegetables were raw or uncooked, with or without a cooked vegetable category, were included. We excluded 12 studies that described the vegetables as ''fresh.'' Studies that combined raw vegetables and fruits together were included; however, those that evaluated specific raw vegetables only were excluded.

For the purposes of this review, vegetables were defined by culinary usage. For example, although tomatoes and cucumbers are botanically fruits, they are included as vegetables. A review of ''raw fruit'' was not included here because we found only three articles that analyzed fruit this way.

Some Caveats. When assessing this literature, it is important to recognize that none of these studies set out to directly compare the effects of the same vegetables eaten in their raw versus cooked state. In fact, among the studies that listed the specific vegetables, there was little or no overlap in the types of vegetables in the raw versus cooked categories. In addition, individual researchers often evaluated the same vegetables in each of their studies, but the components of the raw and cooked categories differed greatly among researchers. Finally, the portion sizes usually were determined by dividing the subjects into quantiles of intake. Thus, the amount of raw vegetable intake within each quantile was often very different from that of cooked vegetables in the same quantile. Similarly, the quantity of raw and cooked vegetables consumed often differed greatly between studies.

Epidemiology

Over the past 10 years, at least 23 case-control and 5 cohort studies have been published that examined the association of both raw and cooked vegetables with cancer risk. All five cohort studies are based on the same data set from the Netherlands. These studies, as listed in Table 1, are grouped first by cancer site and then by year of publication. Information about the quantity of intake and types of vegetables evaluated is included when available. As is evident from Fig. 1, the majority of studies showed raw and cooked vegetables to be inversely associated with risk of cancer, with the most striking benefit in oral, pharyngeal, laryngeal, and esophageal cancers.

Twenty-one studies examining vegetables and cancer focused on raw vegetables without a cooked vegetable category (Table 2). Therefore, total vegetable consumption is included, when available, to allow comparison of findings across different preparation categories. The majority of these studies are of smoking-related cancers, specifically oral, pharyngeal, laryngeal, esophageal, gastric, and lung. As is evident from Fig. 2, all but three of these have odds ratios (OR) or relative risks (RR) that are <1.0, and the remaining three are essentially null. All but two (5, 6) are case-control studies.

For each cancer site described below, the studies evaluating raw and cooked vegetables are discussed first and followed by the studies of raw vegetables only.

Oral, Pharyngeal, and Laryngeal Cancers. The two case-control studies that assessed risk for oral and pharyngeal cancers reported that both raw and cooked vegetables were inversely related to risk (7, 8). A case-control study by Bosetti et al. (9) showed an inverse relationship between raw and cooked vegetables and laryngeal cancer. The other case-control study that evaluated laryngeal cancer found raw vegetables to be strongly inversely associated with risk [OR, 0.29; 95% confidence interval (95% CI), 0.15–0.56], which was not the case for cooked vegetables (OR, 0.96; 95% CI, 0.5–1.84; ref. 10).

Seven case-control studies examined raw vegetable intake and oral, pharyngeal, hypopharyngeal, and laryngeal cancers (11-17). Each showed a decreased risk of cancer with increased intake of raw vegetables, and in all but one, the 95% CI excluded 1.0. In the study by Takezaki et al. (11), in which ORs were adjusted for type of breakfast eaten, fruit intake, miso soup intake, and salty food preference, raw vegetable intake remained significant (OR, 0.6; 95% CI, 0.4–0.8). The study by Rajkumar et al. (12) showed that raw vegetables and total vegetables were associated with a 50% decreased risk of oral cancer. The study by Brown et al. (13) showed a 50% decreased risk of oropharyngeal cancer with increased intake of raw fruits and vegetables in those without a family history of cancer, with a perhaps stronger inverse association for people with a family history of oropharyngeal cancer. Sanchez et al. (14) also observed that both raw and total vegetable intake were associated with an approximate halving of risk of oropharyngeal cancer. In the studies of Uzcudun et al. (16) and Takezaki et al. (17), raw vegetables showed a strong inverse association. Only the study from Uruguay, by De Stefani et al. (15), found neither raw nor total vegetable intake to be significantly related to oral/pharyngeal or laryngeal cancers. This was a remarkably underpowered study, with only 33 cases of oral or pharyngeal cancer and 34 cases of laryngeal cancer.

As is common for head and neck cancers, the majority of subjects in these studies were male, and alcohol and tobacco use were much more common among cases than controls; appropriately, sex, alcohol, and cigarette smoking, among other factors, were adjusted in calculating the ORs.

Esophageal Cancer. Squamous cell carcinoma is the most common type of esophageal cancer and is caused, in part, by tobacco and alcohol. Studies by Bosetti et al. (18) and De Stefani et al. (19) examined only those who had squamous cell carcinoma, whereas Levi et al. (20) included a few cases of esophageal adenocarcinoma, which is usually associated with Barrett's esophagus. Each of these studies showed raw vegetables to be significantly inversely associated with risk, but of the three, only the studies by Levi et al. (OR, 0.19; 95% CI, 0.1-0.3) and De Stefani et al. (OR, 0.55; 95% CI, 0.29–1.03) showed that cooked vegetables were similarly related to risk. Of note, cooked vegetable intake in the Bosetti et al. study, which showed no association with risk, was quite low, with >4.3 servings per week in the highest quantile.

In an effort to avoid differences in food intake between cases and controls based on the development of symptomatic cancer, Levi et al. and Bosetti et al. specified that the relevant period of food intake was the 2 years prior to diagnosis. Bosetti et al. also compared the association between raw vegetables and risk, stratified on smoking status, and found a stronger inverse association with raw vegetables in smokers (OR, 0.52; 95% CI, 0.38–0.71) than in nonsmokers (OR, 0.86; 95% CI, 0.56–1.32). The association with raw vegetables in one study (18), and raw and cooked vegetables in another study (20), was independent of the level of alcohol intake.

Six case-control studies evaluated the association between raw vegetables and esophageal cancer, and all showed them to be significantly inverse (15, 17, 21-24). In the studies by Brown et al. (21, 22), raw vegetables were inversely related to adenocarcinoma of the esophagus in White men (OR, 0.4) and squamous cell carcinoma of the esophagus in White and Black men (OR, 0.4). De Stefani et al. (15) also found a 50% reduction in risk for

Table 1. Studies that compared raw and cooked vegetable intake and cancer risk

Author country	Cancer site	OR (95% CI)	Vegetable	Comparison of quantity of intake	Raw/cooked vegetables	No. subjects
Levi et al. (7) Switzerland	Oral and pharyngeal	0.3 (0.16–0.58)	Raw	>8.5 vs ≤5.0 servings/wk		156 cases, 284 controls
		0.14 (0.07–0.19)	Cooked	>8.6 vs ≤5.2 servings/wk		
Franceschi et al. (8) Italy	Oral and pharyngeal	0.4 (0.3–0.6)	Raw	>14.1 vs ≤5 servings/wk		598 cases, 1,491 controls
		0.5 (0.3–0.7)	Cooked	>4.5 vs ≤1.5 servings/wk		
De Stephani et al. (10) Uruguay	Laryngeal-male	0.29 (0.15–0.56)	Raw	>31 vs ≤8.6 g/d	Carrot, lettuce, tomato	148 cases, 444 controls
		0.96 (0.5–1.84)	Cooked	>87.7 vs ≤35.5 g/d	Onion, Swiss chard, spinach, winter squash, cabbage, cauliflower, zucchini, red pepper	
Bosetti et al. (9) Italy and Switzerland	Laryngeal	0.22 (0.14–0.34)	Raw	>13.9 vs ≤5.4 servings/wk		527 cases, 1,297 controls
		0.32 (0.21–0.49)	Cooked	>5.1 vs ≤1.6 servings/wk		
Bosetti et al. (18) northern Italy	Esophageal	0.32 (0.19–0.55)	Raw	>12.6 vs ≤3.9 servings/wk		304 cases, 743 controls
		0.79 (0.47–1.31)	Cooked	>4.3 vs ≤1.4 servings/wk		
De Stefani et al. (19) Uruguay	Esophageal	0.52 (0.27–0.99)	Raw	≥34.4 vs ≤8 g/d		111 cases, 444 controls
		0.55 (0.29–1.03)	Cooked	≥95.5 vs ≤36.1 g/d		
Levi et al. (20) Switzerland	Esophageal	0.14 (0.1–0.4)	Raw	>9.5 vs ≤5.5 servings/wk		101 cases, 327 controls
		0.19 (0.1–0.3)	Cooked	>8.0 vs ≤5.3 servings/wk		
Cornee et al. (25) France	Gastric	0.41 (0.19–0.88)	Raw		Tomato, lettuce, radish, cucumber, celery	92 cases, 128 controls
		1.06 (0.53–2.13)	Cooked		Swiss chard, spinach, cabbage, cauliflower, courgette, beetroot, green beans, peas, eggplant, leek, mushrooms	
Botterweck et al. (26) the Netherlands*	Gastric	0.81 (0.55–1.19)	Raw	Median intake 74 vs 8 g/d		310 cases, 3,346 controls
		0.79 (0.55–1.14)	Cooked	Median intake 213 vs 79 g/d		
De Stefani et al. (27) Uruguay	Gastric	0.52 (0.31–0.86)	Raw	≥29.5 vs ≤9.0 g/d	Carrot, lettuce, tomato	160 cases, 320 controls
		0.93 (0.57–1.51)	Cooked	≥90.0 vs ≤53.0 g/d	Onion, garlic, Swiss chard, spinach, winter squash, beetroot, cabbage, cauliflower, zucchini, red pepper	
Kim et al. (28) Korea	Gastric	0.55 (0.28–1.09)	Raw			136 cases, 136 controls
		0.98 (0.50–1.90)	Cooked			
Centonze et al. (36) southern Italy	Colorectal	0.67 (0.35–1.29)	Raw	≥76 vs ≤46 g/d	Salad, celery, tomato, carrot	119 cases, 119 controls
		0.59 (0.31–1.12)	Cooked	≥267 vs ≤183 g/d	Vegetable soup, spinach, beet, endive, eggplant, artichoke, green pepper, zucchini, cauliflower, peas, kidney beans, runner beans	
Franceschi et al. (38) Italy	Colon	0.7 (0.7–0.8)	Raw	>12 vs ≤4.0 servings/wk		1,225 cases, 4,154 controls
		0.7 (0.6–0.8)	Cooked	>7.3 vs ≤2.9 servings/wk		
	Rectal and rectosigmoid	0.8 (0.7–1.0)	Raw	>12 vs ≤4.0 servings/wk		728 cases, 4,154 controls
		0.7 (0.7–0.8)	Cooked	>7.3 vs ≤2.9 servings/wk		

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Table 1. Studies that compared raw and cooked vegetable intake and cancer risk (Cont'd)

Author country	Cancer site	OR (95% CI)	Vegetable	Comparison of quantity of intake	Raw/cooked vegetables	No. subjects
Boutron-Ruault et al. (39) France	Colorectal	1.0 (0.5–1.8)	Raw			171 cases, 202 controls
		0.8 (0.4–1.5)	Cooked			
Levi et al. (40) Switzerland	Colorectal	0.49 (0.3–0.78)	Raw	>9 vs ≤5.5 servings/wk		223 cases, 291 controls
		0.41 (0.26–0.66)	Cooked	>8.75 vs ≤5.25 servings/wk		
Voorips et al. (41) the Netherlands*	Colon-male	0.79 (0.54–1.16)	Raw	Median intake‖ 73 vs 7 g/d	Endive, carrot, tomato, lettuce	313 cases, 1,456 subcohort
		0.94 (0.64–1.39)	Cooked	Median intake 234 vs 79 g/d	Brussels sprouts, cauliflower, cabbage, spinach, endive, beetroot, string beans, broad beans, kale, carrot, sweet pepper, sauerkraut, rhubarb, mushroom, gherkin	
	Colon-female	1.02 (0.67–1.54)	Raw	Median intake 76 vs 10 g/d		274 cases, 1,497 subcohort
		0.75 (0.49–1.14)	Cooked	Median intake 229 vs 80 g/d		
	Rectal-male	0.93 (0.58–1.47)	Raw	Median intake 73 vs 7 g/d		201 cases, 1,456 subcohort
		0.96 (0.61–1.51)	Cooked	Median intake 234 vs 79 g/d		
	Rectal-female	1.24 (0.67–2.26)	Raw	Median intake 76 vs 10 g/d		122 cases, 1,497 subcohort
		1.34 (0.74–2.42)	Cooked	Median intake 229 vs 80 g/d		
Deneo-Pellegrini et al. (42) Uruguay	Colorectal	0.8 (0.6–1.0)	Raw		Carrot, tomato, lettuce	484 cases, 1,452 controls
		0.9 (0.7–1.2)	Cooked		Onion, Swiss chard, spinach, potato, sweet potato, winter squash, cabbage, cauliflower, zucchini, red pepper, kidney bean, lentil	
Mayne et al. (44) New York†	Lung-male (nonsmokers)	0.41‡	Raw			212 cases, 212 controls
		1.02§	Cooked			
	Lung-female (nonsmokers)	0.40‡	Raw			201 cases, 201 controls
		0.69§	Cooked			
Voorips et al. (46) the Netherlands*	Lung	0.7 (0.6–1.0)	Raw	Median intake 74 vs 8 g/d	Endive, carrot, lettuce, tomato	1,010 cases, 2,953 subcohort
		0.8 (0.6–1.1)	Cooked	Median intake 231 vs 79 g/d	Brussels sprouts, cauliflower, cabbage, spinach, endive, beetroot, string beans, broad beans, kale, carrot, sweet pepper, sauerkraut, rhubarb, mushroom, gherkin	
De Stefani et al. (45) Uruguay	Lung-male	0.97 (0.64–1.45)	Raw		Carrot, lettuce, tomato	200 cases, 600 controls
		0.50 (0.32–0.76)	Cooked		Onion, Swiss chard, spinach, winter squash, potato, sweet potato, cabbage, cauliflower, zucchini, red pepper, kidney bean, lentil	
Franceschi et al. (49) Italy	Breast	0.73 (0.6–0.88)	Raw	>12.5 vs ≤4.9 servings/wk	Lettuce-like salad, carrot, tomato, mixed salad	2,569 cases, 2,588 controls
		0.96 (0.79–1.16)	Cooked	>7.5 vs ≤3.1 servings/wk	Pulses, carrot, onion, artichoke, Cruciferae, spinach, zucchini, pepper, eggplant, savory pie, vegetable soup	

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Table 1. Studies that compared raw and cooked vegetable intake and cancer risk (Cont'd)

Author country	Cancer site	OR (95% CI)	Vegetable	Comparison of quantity of intake	Raw/cooked vegetables	No. subjects
Ronco et al. (50) Uruguay	Breast	0.51 (0.33–0.79)	Raw	>6.5 vs <2.7 servings/wk		400 cases, 405 controls
		0.58 (0.36–0.94)	Cooked	>9.8 vs <6.3 servings/wk		
Adzersen et al. (51) Germany	Breast	0.51 (0.31–0.84)	Raw	>65.0 vs <23.7 g/d	Mixed salads, fresh herbs, green leafy salads, tomatoes, cucumbers, red/green peppers, carrots, radishes, cabbage, sprouts	
		1.26 (0.77–2.06)	Cooked	>45.5 vs <18.3 g/d	Pulses, other cooked vegetables not specified	
Bosetti et al. (54) Italy	Ovarian	0.47 (0.34–0.64)	Raw	>11.5 vs ≤6.5 servings/wk		1,031 cases, 2,411 controls
		0.65 (0.48–0.87)	Cooked	>5.0 vs ≤1.8 servings/wk		
McCann et al. (53) New York	Endometrial	0.6 (0.3–0.9)	Raw	>120 vs ≤54 times/mo		232 cases, 639 controls
		0.5 (0.3–0.8)	Cooked	>111 vs ≤61 times/mo		
Schuurman et al. (55) the Netherlands*	Prostate	0.96 (0.68–1.32)	Raw	Median intake 73 vs 7 g/d		704 cases, 1,688 controls
		0.85 (0.61–1.19)	Cooked	Median intake 234 vs 79 g/d		
Balbi et al. (56) Uruguay	Bladder	1.15 (0.74–1.80)	Raw	Mean intake, cases 27.9 g/d, controls 26.6 g/d	Carrot, tomato, lettuce	144 cases, 576 controls
		0.53 (0.32–0.87)	Cooked	Cases 68.7 g/d, controls 58.9 g/d	Onion, Swiss chard, spinach, winter squash, cabbage, cauliflower, zucchini, red pepper	
Zeegers et al. (57) the Netherlands*	Urothelial	0.94 (0.69–1.27)	Raw	≥193 vs <99 g/d		619 cases, 3,346 subcohort
		1.01 (0.75–1.37)	Cooked	≥58 vs <16 g/d		

*RRs and 95% CIs calculated in these studies.
†Represents raw versus cooked fruits and vegetables.
‡95% CI does not include 1.0.
§95% CI crosses 1.0.
‖Within the highest and lowest quantiles.

esophageal cancer with increased raw vegetable consumption. Two studies in high-risk and low-risk provinces in China found raw vegetables to be strongly inversely associated with risk of esophageal cancer (23, 24). The study of the low-risk area, however, did not show total vegetable intake to be associated with risk (OR, 0.81; 95% CI, 0.46–1.44). Consistent with the evidence that raw vegetable intake may help prevent esophageal cancer, consumption of raw vegetables and raw garlic in the low-risk area is much greater than in the high-risk area, although their total vegetable consumption is slightly lower. The study of Takezaki et al. (17) examined the effect of raw vegetable intake on upper, middle, and lower esophageal cancer, the majority of which was squamous cell, and found it similarly inversely associated with risk at each subsite.

As with oral, pharyngeal, and laryngeal cancers, all ORs were adjusted for sex, alcohol intake, and smoking.

Gastric Cancer. Three case-control studies and one cohort study examined the association between raw and cooked vegetables and gastric cancer (25-28). Two of the case-control studies showed raw vegetables to be significantly inversely related to risk (25, 27), and the third study was suggestive (OR, 0.55; 95% CI, 0.28–1.09; ref. 28). However, cooked vegetables were unrelated to gastric cancer risk in all of these studies. In some contrast, the cohort study showed weak relationships with both cooked vegetables (OR, 0.79; 95% CI, 0.55–1.14) and raw vegetables (OR, 0.81; 95% CI, 0.55–1.19; ref. 26). When total fruit intake was also included in the analysis, the OR for cooked vegetables barely changed (0.81), but the relationship with raw vegetables disappeared (0.97). In the case-control study by De Stefani et al. (27), adjusting further for total fruit intake diminished somewhat the inverse association with both raw and cooked vegetables. The amount of cooked vegetables eaten was about three times greater than raw vegetables in the cohort study (26) and in one of the case-control studies (27). The other two studies did not report the quantity of intake. None of these studies assessed *Helicobacter pylori* status, a strong, perhaps necessary, risk factor for noncardia gastric cancer (29).

Seven case-control studies examined the relationship between raw vegetable intake and gastric cancer, and all of them showed a significant inverse association (23, 24, 30-34). Harrison et al. (30) examined intestinal and diffuse types of gastric adenocarcinoma separately and found both to be equally associated. However, when additional adjustment was made for race, education, cigarette smoking, alcohol consumption, and body mass index, the relationships no longer reached statistical significance; the study was small. Similar to the results reported for esophageal cancer, Gao et al. (23) showed raw vegetables to be strongly inversely associated with gastric cancer in the high-risk province of China (OR, 0.07). The people from the low-risk area also showed an inverse association (OR, 0.63) and about a halving of risk for total vegetable intake. Huang et al. (32) found that those who had a family history of gastric cancer and ate more raw vegetables had a significantly decreased risk of antral gastric cancer than those who ate fewer raw vegetables (OR, 0.43; 95% CI, 0.19–0.98). However, this inverse association was not seen for cardia and middle gastric cancers or in people with no family history. In a study of Japanese women, Ito et al. (33) analyzed differentiated and nondifferentiated gastric cancers separately and found raw vegetables somewhat more strongly associated with differentiated cancer (OR, 0.32; 95% CI, 0.19–0.54 vs OR, 0.69; 95% CI, 0.43–1.11).

The single cohort study found a statistically nonsignificant inverse association between raw vegetables and gastric cancer, with similar results for women (RR, 0.7; 95% CI, 0.4–1.4) versus men (RR, 0.9; 95% CI, 0.5–1.5; ref. 31). Of note, the dietary questionnaire covered only 13 items.

Only one study among these measured and adjusted for *H. pylori* infection; it showed raw vegetables to have a very strong inverse relationship with early gastric cancer (34).

Pancreatic Cancer. One case-control study from Canada of pancreatic cancer and raw vegetables and fruits combined showed a significant inverse relationship (35). However, 75% of case interviews were done by proxy as opposed to 17% of control interviews.

Colorectal Cancer. There were five case-control studies and one cohort study of raw and cooked vegetables and colorectal cancer (36-42). Two of these studies separated the results for colon and rectal cancers (38, 41). The study by Franceschi et al. (38) showed raw and cooked vegetables to have a similar inverse association with colon and rectal cancers. In this study, subjects consumed more raw vegetables than cooked vegetables. The cohort study of Voorrips et al. (41) further stratified on sex, showing a possible, modest inverse association with raw vegetables for men with colon cancer and a similar relationship for cooked

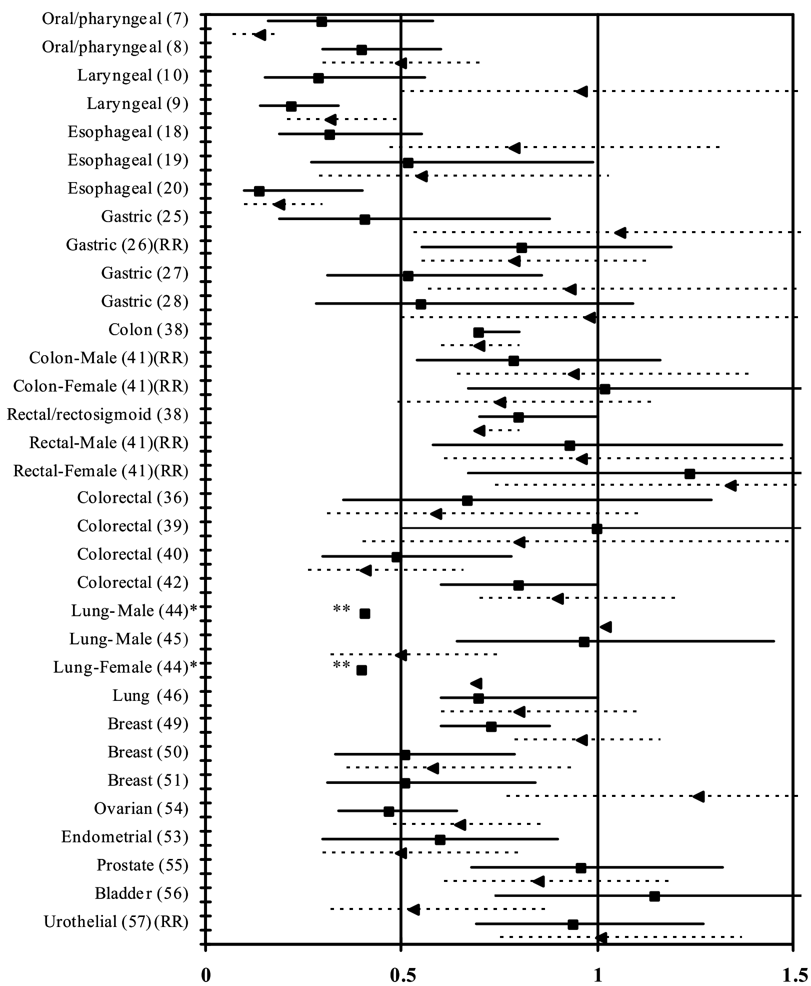

Figure 1. The risk of cancer based on highest versus lowest quantile of intake of raw vegetables (■) or cooked vegetables (◀). All values are ORs or RRs and 95% CIs. *, Fruits and vegetables combined; **, 95% CI excludes 1.0.

Table 2. Studies that assessed raw vegetable intake and cancer risk

Author country	Cancer site	OR (95% CI)	Vegetable	Comparison of quantity intake	Types of raw/cooked vegetables	No. subjects
Takezaki et al. (11) Japan	Oral-male	0.5 (0.4–0.7)	Raw	≥3 vs <3 times/wk		189 cases, 9,858 controls
	Oral-female	0.8 (0.5–1.3)				77 cases, 9,858 controls
Rajkumar et al. (12) India	Oral	0.47 (0.31–0.73)	Raw	≥3 vs <1 serving/wk		591 cases, 582 controls
		0.44 (0.28–0.69)	Total	≥14 vs <7 servings/wk		
Brown et al. (13) Puerto Rico*	Oral and pharyngeal	−FH†: 0.5 (0.3–1.0)	Raw	Frequent vs infrequent		59 cases, 28 controls
		+FH†: 0.15 (0.04–0.5)				155 cases, 194 controls
Sanchez et al. (14) Spain	Oral and pharyngeal	0.53 (0.35–0.80)	Raw	≥7 vs ≤2 servings/wk		375 cases, 375 controls
		0.54 (0.34–0.87)	Total	≥8 vs ≤3 servings/wk		
De Stefani et al. (15) Uruguay	Oral and pharyngeal	0.9 (0.5–1.5)	Raw		Carrot, lettuce, tomato	33 cases, 393 controls
		0.8 (0.4–1.4)	Total		Carrot, lettuce, tomato, onion, Swiss chard, spinach, cabbage, cauliflower, winter squash, red pepper	
	Laryngeal	0.7 (0.4–1.1)	Raw			34 cases, 393 controls
		0.9 (0.6–1.6)	Total			
	Esophageal	0.5 (0.4–0.8)	Raw			66 cases, 393 controls
		0.7 (0.5–0.9)	Total			
Uzcudun et al. (16) Spain	Pharyngeal	0.33 (0.11–0.63)	Raw	3–4 days/wk vs 1–3 days/mo		232 cases, 232 controls
Takezaki et al. (17) Japan	Hypopharyngeal-male	0.2 (0.1–0.4)	Raw	Everyday vs occasionally or less		62 cases, 11,936 controls
	Esophageal-male	0.6 (0.4–0.7)				284 cases, 11,936 controls
Brown et al. (21) United States	Esophageal-adenocarcinoma-male	0.4‡	Raw			162 cases, 685 controls
		0.6§	Total		Green string beans or lima beans, red beets, broccoli, cooked cabbage, coleslaw, carrot, cauliflower, southern greens (collard and mustard greens or kale), okra, green peas, black-eyed peas or cow peas, etc.	
Brown et al. (22) United States	Esophageal-male-White	0.4‡	Raw		Coleslaw, tomato, tossed salad	114 cases, 681 controls
		0.4‡	Total		Same as Brown et al. (21)	
	Esophageal-male-Black	0.4‡	Raw			219 cases, 557 controls
		1.0	Total			
Gao et al. (23) China	Esophageal	0.07 (0.03–0.19)	Raw	Frequently vs almost never		81 cases, 234 controls
	Gastric	0.07 (0.04–0.13)				153 cases, 234 controls
Takezaki et al. (24) China	Esophageal	0.30 (0.15–0.61)	Raw	Frequently vs almost never		199 cases, 333 controls
		0.81 (0.46–1.44)	Total	Everyday vs <1 time/wk		
	Gastric	0.63 (0.29–1.38)	Raw	Frequently vs almost never		187 cases, 333 controls
		0.50 (0.29–0.87)	Total	Everyday vs <1 time/wk		

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Table 2. Studies that assessed raw vegetable intake and cancer risk (Cont'd)

Author country	Cancer site	OR (95% CI)	Vegetable	Comparison of quantity intake	Types of raw/cooked vegetables	No. subjects
Harrison et al. (30) United States	Gastric-intestinal type	0.6 (0.4–1.1)	Raw			60 cases, 132 controls
		0.8 (0.5–1.3)	Total			
	Gastric-diffuse type	0.6 (0.3–1.2)	Raw			31 cases, 132 controls
		0.7 (0.4–1.2)	Total			
Galanis et al. (31) Hawaii (Japanese residents)‖	Gastric	0.8 (0.5–1.2)	Raw	≥7 vs ≤6 times/wk		108 cases, 11,907 cohort
Huang et al. (32) Japan	Gastric	0.80 (0.67–0.95)	Raw	Every day vs <3 times/wk		887 cases, 28,619 controls
Ito et al. (33) Japan	Gastric-female	0.50 (0.36–0.71)	Raw	Everyday vs almost never		508 cases, 36,490 controls
Lee et al. (34) Korea	Early gastric	0.2 (0.1–0.5)	Raw	>6 vs <4 servings/wk	Head lettuce, lettuce, cabbage, cucumber, Chinese cabbage, pepper, carrot, onion, *Perilla* leaves	69 cases, 199 controls
Ghadirian et al. (35) Canada (Francophone community)¶	Pancreatic	0.28 (0.10–0.75)	Raw	Very often vs never		179 cases, 239 controls
Takezaki et al. (47) Japan	Lung-adenocarcinoma-male	1.01 (0.62–1.65)	Raw	Everyday vs almost never		748 male cases, 2,964 male controls, 297 female cases, 1,189 female controls
	Lung-adenocarcinoma-female	0.84 (0.45–1.55)				
	Lung-squamous and small cell-male	0.8 (0.51–1.25)				
	Lung-squamous and small cell-female	1.01 (0.28–3.58)				
Wright et al. (48) Missouri	Lung-female	0.74 (0.62–0.88)	Raw		Tomato, spinach, coleslaw, green salad, carrot, carrot juice, olives, cucumber, jalapeno pepper, celery, red/green pepper, avocado, pickles	587 cases, 624 controls
		0.67 (0.55–0.82)	Total		Raw vegetables (above), string beans (green or yellow snap) peas, black-eyed peas, corn, cabbage/sauerkraut, winter squash, salsa/red chili sauce, broccoli/cauliflower/Brussels sprouts, etc.	
Le Marchand et al. (5) Hawaii‖	Prostate	1.1 (0.7–1.7)	Raw	≥302 vs ≤82 g/wk		198 cohort
Appleby et al. (6) United Kingdom‖	All malignant neoplasms	1.03 (0.83–1.23)	Raw	Daily vs less than daily	"Raw salad"	181 cases, 10,771 cohort

*Calculated ORs for raw fruit and vegetables combined.
†−FH, family history of aerodigestive cancer; +FH, no family history of cancer. Referent group was −FH.
‡95% CI does not include 1.0.
§95% CI crosses 1.0.
‖RRs and 95% CIs calculated in these studies.
¶Calculated ORs for raw fruit and vegetables combined.

vegetables in women. Neither cooked nor raw vegetables in this study were associated with rectal cancer. This was part of the same Netherlands Cohort Study; we note again that the amount of raw vegetables eaten was about one-third that of cooked vegetables in each of the respective quantiles in this study. The four remaining case-control studies did not distinguish between colon and rectal cancers. Two showed raw vegetables to be

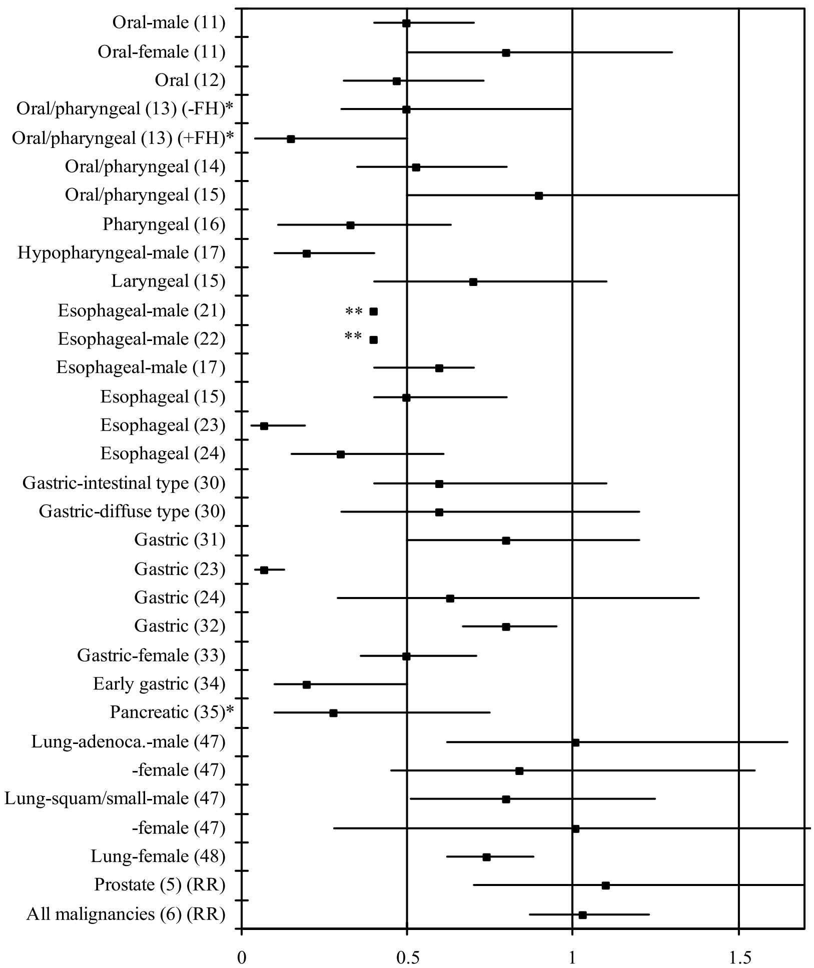

Figure 2. The risk of cancer based on highest versus lowest quantile of raw vegetables (■). All values are ORs or RRs. *, Raw fruits and vegetables; **, 95% CI excludes 1.0.

inversely associated (40, 42), and one of these showed a similar relationship with cooked vegetables (40). The two other case-control studies showed little relationship with raw or cooked vegetables (36, 39). Of note, in the two studies that showed a clear relationship with both raw and cooked vegetables, the quantity of intake of raw vegetables was greater than or equal to that of cooked vegetables (38, 40). However, given the different ways that quantity of intake was measured in each study (e.g., grams per day and servings per week), it is hard to compare across studies. These were the only studies (38, 40) to adjust for physical activity, a known risk factor for colorectal cancer (43).

Lung Cancer. Two case-control studies (44, 45) and one cohort study (46) examined the relationship between raw and cooked vegetable intake and lung cancer. The case-control study of Mayne et al. (44) analyzed the combination of vegetables and fruits in nonsmokers and former smokers. Because raw versus cooked was not specified in the food frequency questionnaire, the authors made assumptions based on which vegetables and fruits are usually eaten raw or cooked. Raw vegetables and fruits combined were significantly inversely related to risk among both men and women, with ORs of 0.41 and 0.40, respectively. However, cooked vegetables and fruits combined were not inversely related in men and were not statistically significantly so in women. They also showed that raw vegetables alone were associated with decreased lung cancer risk in both men and women (OR, 0.60; 95% CI, 0.38–0.95). The point estimate for raw vegetables and fruits was lower for former smokers (OR, 0.54; 95% CI, 0.34–0.87) than never smokers (OR, 0.69; 95% CI, 0.42–1.12) and for squamous cell carcinoma (OR, 0.39; 95% CI, 0.18–0.88) than for adenocarcinoma (OR, 0.67; 95% CI, 0.43–1.06). In contrast to this, De Stefani et al. (45) found that cooked, but not raw, vegetables were inversely related to risk in male smokers. These results were minimally changed after adjusting for total fruit intake. This study differed from that of Mayne et al. in that two-thirds of the cases were current smokers and the food frequency questionnaire was more detailed, allowing adjustment for total energy intake. In addition, the food recall in the study of Mayne et al. estimated consumption from age 25 years, whereas the De Stefani et al. study did not specify the recall period.

In the cohort study from the Netherlands, raw vegetables (RR, 0.7; 95% CI, 0.6–1.0) and cooked vegetables (RR, 0.8; 95% CI, 0.6–1.1) were both weakly inversely related to risk (46). Of the studies published from this cohort that examined both raw and cooked vegetables and risk of cancer, this was the only one that had statistically significant findings. Adjusting for total vegetable intake eliminated evidence of an inverse association with both raw and cooked vegetables; however, this may be unnecessary and probably inappropriate.

The first of two case-control studies that examined raw vegetables and lung cancer found no statistically significant associations for men or women within adenocarcinoma and squamous cell/small cell carcinoma subcategories (47). These ORs were adjusted for consumption of green vegetables, in addition to other factors, probably resulting in overadjustment. There was, however, a statistically significant, decreasing trend between squamous cell/small cell carcinomas and raw vegetable intake among men only ($P = 0.004$). The study by Wright et al. (48), which used a much longer list of raw vegetables than most of the other studies reviewed here, found a statistically significant inverse association with raw vegetables and total vegetables in women. Raw vegetables remained inversely associated with risk after adjusting for total carotenoid intake (OR, 0.77; 95% CI, 0.64–0.92), suggesting that there are other chemoprotective compounds that explain the inverse association.

Breast Cancer. Three case-control studies assessed the association between raw and cooked vegetables and breast cancer risk (49-51). The study by Franceschi et al. (49) found raw vegetables to be significantly inversely associated with risk but found cooked vegetables to have no association. This was a large study, with 2,569 cases and 2,588 controls. Consistent with all the studies from Italy that compared raw and cooked vegetables with cancer risk, the amount of raw vegetables eaten was higher than cooked vegetables in each quantile of intake. Further analysis of these data in a later study suggested slightly lower risk in premenopausal women (OR, 0.73; 95% CI, 0.6–0.9) than postmenopausal women (OR, 0.92; 95% CI, 0.8–1.0; ref. 52). A smaller study from Germany by Adzersen et al. (51) also found an inverse relationship between raw, but not cooked, vegetables and breast cancer. Only the study by Ronco et al. (50) showed both raw and cooked vegetables to be inversely associated with breast cancer despite the generally low consumption of vegetables among Uruguayans. In this study, raw vegetable consumption was about one-third to one-half *less* than cooked vegetable consumption in each quantile of intake. The food frequency questionnaire from the Italian study (49) included the 2 years prior to the cancer diagnosis or hospital admission (for controls) and the German study (51) included 1 year prior to diagnosis or admission; the Uruguayan study (50) did not specify the period. Further, the Italian study adjusted for age, study center, education, parity, energy, and alcohol intake but not for known breast cancer risk factors, such as body mass index and hormone replacement therapy, because these were not confounders. The German and Uruguayan study both adjusted for breast cancer risk factors, such as body mass index and family history of breast cancer, but did not adjust for some nonconfounders, such as education. Hormone therapy was not included in the analyses in the Uruguayan study.

Female Reproductive Cancers. One case-control study assessed raw and cooked vegetables and endometrial cancer (53). In this study, the dietary recall was for 2 years prior to the interview and the amount of raw vegetables consumed was similar to cooked vegetables in each quantile; both raw and cooked vegetable intake were independently, inversely associated with endometrial cancer risk. The analysis was adjusted for several relevant risk factors, including body mass index, age at menarche, parity, oral contraceptive use, menopausal status, and postmenopausal hormones.

One case-control study of ovarian cancer showed both raw and cooked vegetables to be significantly inversely related to ovarian cancer (54). This Italian study included 1,031 cases and 2,411 controls. After adjusting for red meat, fish, pulses, and cooked or raw vegetables as appropriate, the association with raw vegetables remained statistically significant (OR, 0.51; 95% CI, 0.37–0.70) but that with cooked vegetables did not (OR, 0.76; 95% CI, 0.56–1.04).

Prostate Cancer. The cohort study from the Netherlands showed that neither raw nor cooked vegetables were associated with prostate cancer risk (55). The relationships changed little after adjusting for fruit. None of the specific vegetables, raw or cooked, were statistically significantly associated with prostate cancer, including tomatoes and tomato juice. This is consistent with the literature on prostate cancer and vegetables more generally. As with the other studies from this cohort, the participants reported much greater cooked than raw vegetable intake.

A cohort study from Hawaii of raw vegetables and prostate cancer was published 10 years ago and showed no relationship with risk (5). The men in this study were part of a larger cohort described above in the section on gastric cancer; obviously, the same 13-item dietary questionnaire was used (31).

Urinary Tract Cancer. One case-control study (56) and one cohort study (57) of urinary tract cancer examined the association with raw and cooked vegetables. The study by Balbi et al. (56) showed an inverse association with cooked vegetables, but none with raw, in a Uruguayan population. As mentioned previously, this population is notable for their low intake of fruits and vegetables. In this study, the intake of cooked vegetables was at least twice that of raw vegetables. The Netherlands Cohort Study had 6.3 years of follow-up and showed no association with either cooked or raw vegetables (57). These results were unchanged after adjusting for total fruit consumption. The only group of vegetables to show an inverse association was *Brassica* vegetables, which were cooked (RR, 0.75; 95% CI, 0.55–1.03). Unlike the other studies described from this cohort, this study included only men, and their intake of raw vegetables was much greater than their intake of cooked.

All Neoplasms. One cohort study in the United Kingdom examined raw vegetable intake and subsequent mortality of cancer among ''health conscious'' individuals (58). Almost 11,000 men and women were recruited from health food stores and clinics and asked, among other things, their usual frequency of consumption of ''raw vegetable salads.'' After an average of 16.8 years of follow-up, mortality was substantially lower in this cohort than in the general population, but there was no evidence of a relationship between raw salad intake and death from cancer. A follow-up published 6 years later also failed to show a relationship (6).

Apparently, there was not enough variability among the diets of the participants, or an accurate enough method for food recall, to detect a significant difference.

Summary. The evidence from these studies consistently shows an inverse association between both raw and cooked vegetables and oral, pharyngeal, and laryngeal cancers. Raw vegetables were more often inversely associated with esophageal, gastric, and breast cancers than cooked vegetables. Most of the studies of colorectal cancer showed both to be inversely associated with risk. It is unclear whether there is any difference in the relationship between raw and cooked vegetables and lung cancer risk. There were so few studies for each of the other cancers (pancreatic, uterine, ovarian, prostate, and urinary tract) that it is difficult to draw any conclusions. Some have found that the association between diet and disease is stronger in case-control studies than in cohort studies (59). This review similarly shows an inverse relationship between raw and cooked vegetables and cancer risk that is stronger in case-control than cohort studies, possibly as a result of recall bias.

Mechanisms for Differences between Raw and Cooked Vegetables

That raw food and cooked food might affect the body differently was proposed at least as early as 1930, when Dr. Paul Kouchakoff presented his work on feeding experiments in humans at the First International Congress of Microbiology (60). He fed 10 male and female human subjects of varying ages different combinations of raw and cooked foods. These included ''green foods'' as well as many other foods. He found that eating raw foods produced no change in the peripheral WBC count; however, when the same foods were cooked, consuming them caused the WBC count to increase. Unfortunately, this presentation was lacking in specifics, such as the degree of leukocytosis. To our knowledge, this type of experiment has not been repeated.

Pottenger (61) also developed an interest in raw versus cooked food and presented his work on cats at a dental conference in 1945. He found that cats fed raw meat and raw milk were more resistant to infection and had healthier offspring than cats fed cooked meat and raw milk.

There are several possible explanations why raw and cooked food should affect physiology differently. Most of the evidence suggests that cooking food has harmful effects, as it destroys nutrients and enzymes, alters the structure and thus digestibility of the food, and creates by-products that may be harmful. However, for some foods, cooking not only kills potentially harmful organisms but also actually improves the bioavailability of certain nutrients and improves digestibility. For the purposes of this review, we will focus on mechanisms that may explain differences between raw and cooked vegetables.

Availability and Bioavailability of Nutrients. Cooking vegetables decreases water-soluble and heat-sensitive nutrients, such as vitamin C. Micozzi et al. (62) evaluated vegetables that are associated with a decreased risk of cancer for their carotenoid content before and after microwaving. He found that Brussels sprouts and kale lost 19% to 57% of their xanthophylls (oxygenated carotenoids) after being microwaved but only 14% to 15% of their β-carotene.

Cooking vegetables also seems to have a positive effect on some nutrients by increasing their bioavailability, particularly certain carotenoids. One study found that heating tomatoes resulted in significantly increased lycopene content and antioxidant activity despite a decrease in vitamin C (63). Rock et al. (64) compared the plasma β-carotene response to daily consumption of raw versus microwaved carrots and spinach. Those in the study who ate the cooked carrots and spinach had significantly increased total (94%) and all-*trans*-β-carotene (105%) levels, whereas consumption of the raw carrots and spinach raised these plasma carotenoid concentrations less dramatically (30% and 38%, respectively). Plasma *cis*-β-carotene did not increase significantly in either group, and α-carotene increased similarly in the cooked (87%) and raw (79%) groups. Despite the apparent benefit of cooking, shown in these results, a major caveat must be noted: providing an equal amount of β-carotene per meal to each study group (9.3 mg) required 54.9 g carrot and 39.0 g spinach for the raw group and 113 g each of carrot and spinach for the cooked group. Therefore, although bioavailability is improved by cooking, if one ate equal quantities of these vegetables, raw and cooked, the plasma concentration of total and *cis*-β-carotene would likely be similar, and the α-carotene level would likely be higher by eating the raw vegetables.

Enzymes. Enzymes have a prominent role in the *in situ* production of phytochemicals and are easily destroyed by heat. Cruciferous vegetables and garlic, both shown to have active anticarcinogenic phytochemicals, contain such enzymes (65, 66).

Cruciferous vegetables contain glucosinolates in the cytoplasm of their cells. These compounds are chemically stable until they come in contact with myrosinase, an enzyme found in neighboring cells (67). The two meet when the tissue is disrupted, for example, by insect predation, chewing, or microbial action (68). Together they form, among other compounds, isothiocyanate, an important inducer of phase 2 enzymes, such as glutathione *S*-transferases, which act to stabilize xenobiotics (65).

Studies of different cruciferous vegetables have shown that heating these vegetables reduces one's ability to convert glucosinolates to isothiocyanates, the active compound. One study compared the excretion of isothiocyanates in urine after eating raw or steamed broccoli (69). The broccoli was steamed for 15 minutes to completely inactivate the myrosinase. The average excretion of isothiocyanates in the 24-hour urine collection was 20.6 μmol in those who ate steamed broccoli and 68.1 μmol in those who ate it raw. Of note is the fact that eliminating bacterial conversion results in an even more marked loss of isothiocyanates (70, 71).

In a study of rats given 1,2-dimethylhydrazine, a colon-specific carcinogen, consumption of raw Brussels sprouts reduced proliferation, increased apoptosis, and produced fewer aberrant crypt foci (i.e., preneoplastic lesions) compared with blanched or no Brussels sprouts (72).

Garlic contains the enzyme alliinase that converts alliin to allicin. It is activated by crushing or cutting the garlic and can be completely inactivated by 60 seconds of microwave heating (66). Rats given raw garlic had a 64% reduction in DNA adduct formation after being given the carcinogen 7,12-dimethylbenz(*a*)anthracene, whereas microwaving the uncrushed garlic for 60 seconds or oven-heating it for 45 minutes completely blocked the suppression of adduct formation. When the garlic was crushed and allowed to stand for 10 minutes prior to being microwaved for 60 seconds, it retained some of its enzyme activity.

Perhaps because these vegetables are eaten more often in the cooked state, at least in the United States, most epidemiologic studies have not differentiated between the effects of raw and cooked cruciferous vegetables or garlic.

Heating Affects the Structure and Digestibility of Food. Heat changes the physical structure of food and therefore its digestibility and physiologic effect. For example, cooking vegetables causes an increase in the soluble dietary fiber content of vegetables and tubers and a decrease in insoluble fiber (73). Soluble fiber helps to decrease insulin levels. Insoluble fiber decreases fecal transit time and increases binding and excretion of carcinogens (74).

Heat also initiates the Maillard reaction in foods rich in reducing sugars and amino acids, peptides, or proteins. This affects the color of the food (turning it brown) and the flavor of the food, often favorably, but also destroys many of the essential amino acids (75). Proteins may become harder to digest because they form cross-links with reducing sugars. Certain Maillard products can inhibit digestive enzymes, such as trypsin. In addition, some Maillard reaction products seem to be mutagenic. Increasing cooking time and temperature increases dietary advanced glycation end products, a Maillard reaction product, and these have been shown to increase inflammatory mediators, such as C-reactive protein and tumor necrosis factor (76). Diabetic subjects, randomized to diets with higher advanced glycation end product content, had higher levels of the inflammatory mediators (76).

Heating pure proteins, peptides, and amino acids in the absence of carbohydrates leads to pyrolysis, which is different from the classic Maillard reaction. The compounds formed by this reaction are also often mutagenic (77). In addition, the modification of certain amino acid side chains and the cross-linking between molecules decreases digestibility. Conversely, heating protein can also increase digestibility by modifying its structure.

Because most vegetables are low in protein and sugar, the above reactions may not cause major problems. However, Maillard reactions occur readily in sweet vegetables, such as carrots and tomatoes, as well as in tubers, legumes, and fruits.

Beneficial Effects of Cooking. In addition to the increased bioavailability of certain carotenoids and the killing of harmful microbes, there are two other major benefits to heating vegetables. Legumes and certain tubers contain enzyme inhibitors, particularly protease inhibitors, which reduce the effectiveness of certain pancreatic enzymes. Foods containing these enzyme inhibitors are difficult to digest raw and can lead to pancreatic enlargement (78) and even cancer in animals (79). Although cooking diminishes the digestibility of foods such as legumes by forming Maillard reaction products, it also inactivates enzyme inhibitors, thus enhancing its digestibility through a different mechanism. However, cooking is not the only way to accomplish this for legumes (80, 81). Soaking, germinating, or fermenting them is also effective. Germination also reduces phytic acid, a mineral chelator, more effectively than heat treatment and improves protein quality (80). Protease inhibitors and phytic acid may also decrease risk of cancer (79).

Cooking may help decrease the level of pesticides in or on vegetables. One study examined pesticide levels in beans and corn after washing and/or peeling plus cooking (82). Cooking decreased the level of pesticides in both these vegetables.

Discussion

As is evident from Figs. 1 and 2, the majority of the studies included in this review show an inverse association between both raw and cooked vegetables and cancer. For each of the comparisons in Table 1, 88% showed a decreased risk of cancer with raw vegetables and 85% with cooked vegetables (OR or RR < 1). More of the studies showed a statistically significant inverse relationship with raw vegetables than with cooked. Of the analyses in Table 2, 91% showed an inverse relationship between raw vegetable intake and cancer, and almost two-thirds reached statistical significance. Of the analyses of total vegetable intake, 92% showed an inverse association, of which nearly half reached statistical significance. These results are consistent with those of Steinmetz and Potter (4), in which 85% of the studies they reviewed that examined raw vegetables and cancer reported an inverse association.

That the results, which represent only a subset of the studies of vegetable consumption and cancer risk, so consistently show an inverse relationship between vegetable intake and many cancers is impressive, considering the inaccuracy of dietary recall. Differentiating between raw and cooked vegetables may add to this inaccuracy if subjects defined ''cooking'' differently.

One theory for different effects of raw versus cooked food is based on human evolution (83). Coffey has argued that because humans evolved into our current form ~150,000 years ago, but started eating a diet high in animal products and cooked foods and low in fresh and wild vegetables and fruits much more recently, we have not had sufficient opportunity to adapt.

In addition to changing bioavailability of nutrients, enzyme activity, and structure, cooking vegetables may also affect their glycemic indices. Some studies have indicated that eating a diet with a high glycemic index can increase risk of breast (84), lung (85), and colorectal (86) cancers. Although most vegetables are extremely low in carbohydrates, there are some exceptions, such as carrots, corn, legumes, and tubers. Foster-Powell et al. (87) reported that the glycemic index of raw carrots is ~30% to 50% that of cooked carrots. However, these measurements were not done by the same laboratory and were not necessarily done on the same type of carrot. We found no data on glycemic indices of other vegetables in both their raw and cooked states. As cooking these vegetables can affect the rate at which the carbohydrates are digested and absorbed, it may be worth investigating the differences between cooked and raw (or germinated, for legumes) vegetables.

If raw vegetables are more protective against certain cancers than cooked vegetables, this may help explain some of the ethnic disparities in cancer incidence and mortality. Two studies of raw vegetable intake by ethnicity indicate that African Americans eat fewer raw vegetables than Whites (22, 88). In a study of squamous cell esophageal cancer, however, both Black and White men received the same level of protection from raw vegetables, a 70% reduction in risk, when comparing highest versus lowest levels of intake (22).

There are some caveats. First, the types of vegetables in the raw categories generally differed from those in the cooked categories. Second, there was great variation in portion sizes for raw and cooked vegetables, both within studies and between studies. Third, studies used different vegetables in their raw and cooked categories. They even differed in what they defined as a vegetable. Fourth, most studies adjusted for the same basic confounders, such as age, sex, and residence, but other factors that were adjusted for varied between studies. Compared with those who eat cooked vegetables, people who eat more raw vegetables may also tend to have different lifestyle habits that were not adequately accounted for in the statistical adjustments. Finally, the cohort studies, which were from the Netherlands and Hawaii, generally showed less significant relationships than the case-control studies, making recall bias and the effects of cancer-related symptoms on food choices more of a concern.

Conclusion

It is clear from this review that both raw and cooked vegetables are inversely related to several epithelial cancers, particularly those of the upper gastrointestinal tract, and possibly to breast cancer. Although more of the studies showed a statistically significant inverse relationship between raw vegetables and cancer than either cooked or total vegetables, the literature is too varied to compare definitively. Studies on diet and cancer need to differentiate between raw and cooked vegetables in their methods of food recall and in their analyses. In addition, more consistency is needed regarding the types of vegetables assessed in each category. In the meantime, the public should be encouraged to increase their vegetable intake and to consider eating some of them raw.

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