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Multivitamins in the Prevention of Cancer in Men

The Physicians' Health Study II Randomized Controlled Trial

J. Michael Gaziano, MD, MPH

Howard D. Sesso, ScD, MPH

William G. Christen, ScD

Vadim Bubes, PhD

Joanne P. Smith, BA

Jean MacFadyen, BA

Miriam Schwartz, MD

JoAnn E. Manson, MD, DrPH

Robert J. Glynn, ScD

Julie E. Buring, ScD

MULTIVITAMINS ARE THE most common dietary supplement, regularly taken by at least one-third of US adults.^{1,2} The traditional role of a daily multivitamin is to prevent nutritional deficiency. The combination of essential vitamins and minerals contained in multivitamins may mirror healthier dietary patterns such as fruit and vegetable intake, which have been modestly and inversely associated with cancer risk in some,³ but not all,^{4,5} epidemiologic studies. Observational studies of long-term multivitamin use and cancer end points have been inconsistent.⁶⁻¹² To date, large-scale randomized trials testing single or small numbers of higher-dose individual vitamins and minerals for cancer have generally found a lack of effect.¹³⁻¹⁸

According to the 2010 Dietary Guidelines for Americans, "For the general, healthy population, there is no evi-

Context Multivitamin preparations are the most common dietary supplement, taken by at least one-third of all US adults. Observational studies have not provided evidence regarding associations of multivitamin use with total and site-specific cancer incidence or mortality.

Objective To determine whether long-term multivitamin supplementation decreases the risk of total and site-specific cancer events among men.

Design, Setting, and Participants A large-scale, randomized, double-blind, placebo-controlled trial (Physicians' Health Study II) of 14 641 male US physicians initially aged 50 years or older (mean [SD] age, 64.3 [9.2] years), including 1312 men with a history of cancer at randomization, enrolled in a common multivitamin study that began in 1997 with treatment and follow-up through June 1, 2011.

Intervention Daily multivitamin or placebo.

Main Outcome Measures Total cancer (excluding nonmelanoma skin cancer), with prostate, colorectal, and other site-specific cancers among the secondary end points.

Results During a median (interquartile range) follow-up of 11.2 (10.7-13.3) years, there were 2669 men with confirmed cancer, including 1373 cases of prostate cancer and 210 cases of colorectal cancer. Compared with placebo, men taking a daily multivitamin had a statistically significant reduction in the incidence of total cancer (multivitamin and placebo groups, 17.0 and 18.3 events, respectively, per 1000 person-years; hazard ratio [HR], 0.92; 95% CI, 0.86-0.998; $P=.04$). There was no significant effect of a daily multivitamin on prostate cancer (multivitamin and placebo groups, 9.1 and 9.2 events, respectively, per 1000 person-years; HR, 0.98; 95% CI, 0.88-1.09; $P=.76$), colorectal cancer (multivitamin and placebo groups, 1.2 and 1.4 events, respectively, per 1000 person-years; HR, 0.89; 95% CI, 0.68-1.17; $P=.39$), or other site-specific cancers. There was no significant difference in the risk of cancer mortality (multivitamin and placebo groups, 4.9 and 5.6 events, respectively, per 1000 person-years; HR, 0.88; 95% CI, 0.77-1.01; $P=.07$). Daily multivitamin use was associated with a reduction in total cancer among 1312 men with a baseline history of cancer (HR, 0.73; 95% CI, 0.56-0.96; $P=.02$), but this did not differ significantly from that among 13 329 men initially without cancer (HR, 0.94; 95% CI, 0.87-1.02; $P=.15$; P for interaction = .07).

Conclusion In this large prevention trial of male physicians, daily multivitamin supplementation modestly but significantly reduced the risk of total cancer.

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Author Affiliations: Department of Medicine, Brigham and Women's Hospital and Harvard Medical School, Boston, Massachusetts (Drs Gaziano, Sesso, Christen, Bubes, Schwartz, Manson, Glynn, and Buring and Mss Smith and MacFadyen); VA Boston Healthcare System, Boston, Massachusetts (Dr Gaziano); and Departments of Epidemiology (Drs Sesso, Manson, and

Buring) and Biostatistics (Dr Glynn), Harvard School of Public Health, Boston, Massachusetts. Dr Gaziano is also Contributing Editor, *JAMA*.

Corresponding Author: J. Michael Gaziano, MD, MPH, Department of Medicine, Brigham and Women's Hospital, 1620 Tremont St, Boston, MA 02120 (jmgaziano@partners.org).

dence to support a recommendation for the use of multivitamin/mineral supplements in the primary prevention of chronic disease.¹⁹ A National Institutes of Health–sponsored State-of-the-Science Conference also concluded that the present evidence is insufficient to recommend either for or against the use of [multivitamins] to prevent chronic disease.²⁰ Despite the lack of definitive trial data regarding the benefits of multivitamins in the prevention of chronic disease, including cancer, many men and women take them for precisely this reason.²¹

Thus, definitive information on the potential benefits, risks, or lack thereof, related to taking a daily multivitamin may have substantial effects on personal and clinical decision making and policy making. The Physicians' Health Study II (PHS II) represents the only large-scale, randomized, double-blind, placebo-controlled trial testing the long-term effects of a common multivitamin in the prevention of chronic disease. We present the findings for multivitamin use on total and other common site-specific cancers; the effects of a multivitamin on cardiovascular events, eye disease, and cognitive decline are being published separately.

METHODS

Design

The PHS II was a randomized, double-blind, placebo-controlled, 2×2×2×2 factorial trial evaluating the balance of risks and benefits of a multivitamin (Centrum Silver or its placebo daily; Pfizer [formerly Wyeth, American Home Products, and Lederle]), vitamin E (400-IU synthetic α -tocopherol or its placebo on alternate days; BASF Corporation), vitamin C (500-mg synthetic ascorbic acid or its placebo daily; BASF Corporation), and beta carotene (50-mg Lurotin or placebo on alternate days; BASF Corporation) in the prevention of cancer, cardiovascular disease, eye disease, and cognitive function among 14 641 male physicians aged 50 years or older.²² The beta carotene component was terminated on

schedule in March 2003. Treatment and follow-up of the vitamin E and vitamin C components continued through August 31, 2007, their scheduled end, with findings of no overall association reported for cancer¹⁸ and cardiovascular disease.²³

The study design of PHS II has been previously described in detail.^{18,22,23} The recruitment, enrollment, and randomization of men into PHS II occurred in 2 phases (FIGURE 1). Beginning in July 1997, during phase I, we invited 18 763 living participants from PHS I, a randomized trial of low-dose aspirin and beta carotene among 22 071 male physicians,^{14,24} to participate in PHS II. Men were ineligible if they reported a history of cirrhosis, active liver disease, were taking anticoagulants, or reported a serious illness that might preclude participation. Men also must have been willing to forego the use of multivitamins or individual supplements containing more than 100% of the recommended dietary allowance of vitamin E, vitamin C, beta carotene, or vitamin A. Those men with a history of cancer, as well as myocardial infarction or stroke, remained eligible to enroll into PHS II. We randomized 7641 willing participants (41%) from PHS I into PHS II and retained their original PHS I beta carotene treatment assignment.

Beginning in July 1999, during phase 2, invitational letters and baseline questionnaires were mailed to 254 597 US male physicians aged 50 years or older identified from a list provided by the American Medical Association. Through July 2001, 42 165 men responded, of whom 11 128 were willing and eligible. A 12-week placebo, run-in period excluded men who were nonadherent.²⁵ Of 11 128 physicians who entered the run-in phase, 7000 (63%) willing and eligible men took at least two-thirds of their pills and were randomized into PHS II, resulting in a total of 14 641 participants.

Men were randomized in blocks of 16, stratified by age (in 5-year age groups), prior cancer, prior cardiovascular disease, and, for the 7641 partici-

pants in PHS I, their original beta carotene treatment assignment. There were 1312 men (9.0%) with a history of cancer (excluding nonmelanoma skin cancer) before randomization into PHS II through either confirmed events among PHS I participants or self-reports among new PHS II participants. All participants provided written informed consent and the institutional review board at Brigham and Women's Hospital, Boston, Massachusetts, approved the PHS II research protocol.

Treatment, Follow-up, and Adherence

Participants were sent monthly calendar packs containing a multivitamin or placebo (taken daily) every 6 months for the first year, then annually thereafter. We also sent participants annual questionnaires asking about adherence, adverse events, new end points, and risk factors. A National Death Index search was performed for any participants with unknown vital status. Blinded treatment and follow-up continued through June 1, 2011, the scheduled end of the multivitamin component of PHS II, for a median (interquartile range) follow-up of 11.2 (10.7-13.3) years. Data analyses included validated end points that occurred during randomized treatment and were reported by August 2012. Morbidity and mortality follow-up in PHS II were extremely high, at 98.2% and 99.9%, respectively. Furthermore, morbidity and mortality follow-up as a percentage of person-time each exceeded 99.9%, with only 2991 and 79 person-years of morbidity and mortality follow-up lost out of 164 320 person-years of follow-up through June 1, 2011.

Confirmation of Cancer End Points

For the multivitamin component, the primary end points were total cancer (excluding nonmelanoma skin cancer) and major cardiovascular events. Prespecified secondary cancer end points included prostate, colorectal, and other site-specific cancers. Epithelial cell cancer, total and cancer mortality,

and cancer-specific death were other end points examined in the analysis. Epithelial cell cancer was limited to carcinomas, which included all cancers except for lymphoma and leukemia. Because prostate cancer comprised more than half of all confirmed cancers in PHS II most likely due to increases in screening for prostate-specific antigen levels and detection of less aggressive cancer, we also evaluated the end point of total minus prostate cancer.

All cancer and mortality end points were assessed and validated by medical record review by the PHS II Endpoints Committee composed of physicians blinded to treatment assignment;

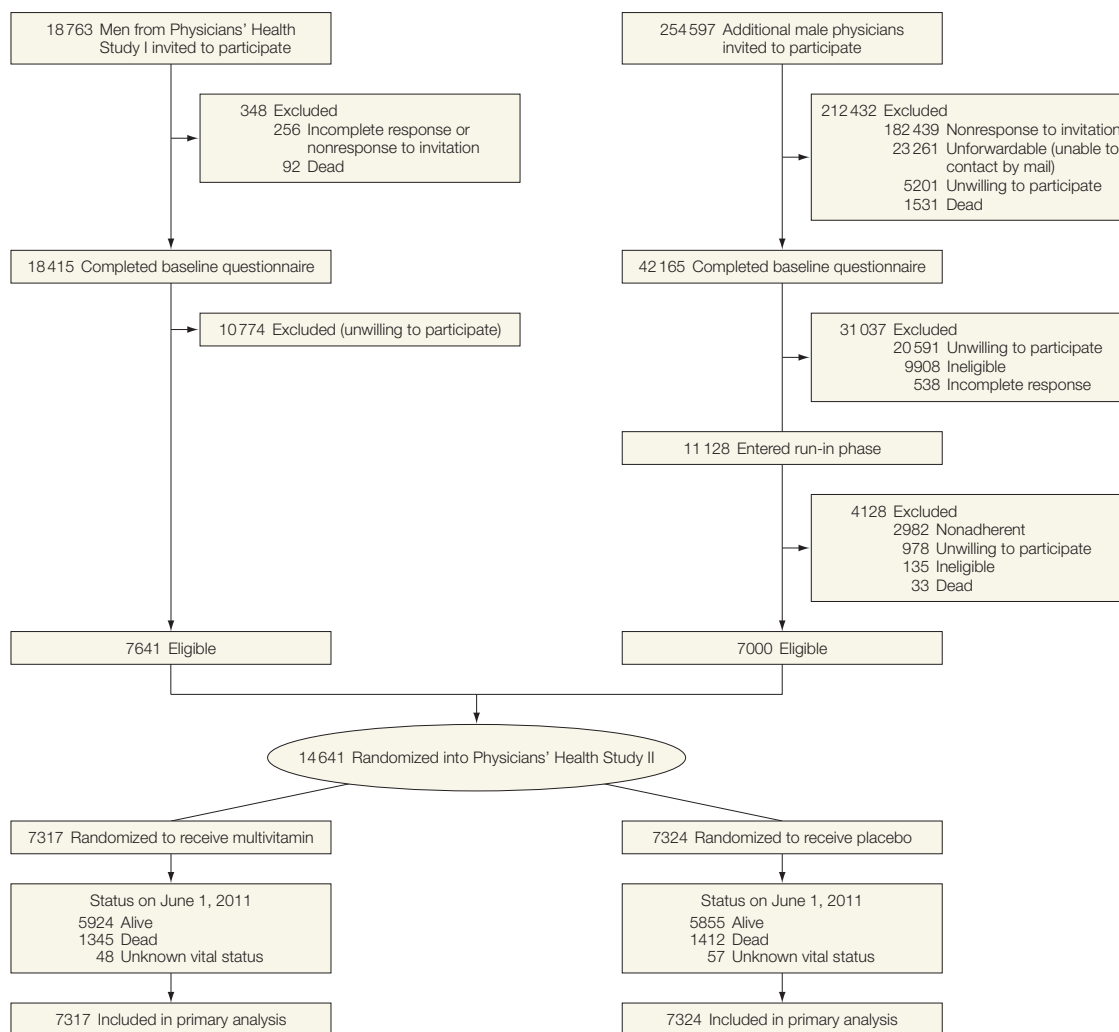
96.9% of confirmed total cancers were based on pathology or cytology reports. Cases of cancer were otherwise confirmed based on strong clinical and radiological or laboratory marker evidence. Total mortality was confirmed by the PHS II Endpoints Committee or by obtaining a death certificate. Only confirmed cancer and mortality end points are included herein.

Statistical Analyses

All primary analyses classified study participants based on the intention-to-treat principle, in which all 14 641 randomized participants were classified according to their randomized multi-

tamin treatment assignment and followed up until the occurrence of cancer, death, loss to follow-up, or the end of the multivitamin component of PHS II on June 1, 2011, whichever came first. We used SAS version 9.2 (SAS Institute Inc) and S-Plus (Insightful Corporation), with statistical significance set at $P < .05$ using 2-sided tests. The PHS II was estimated to have 80% power to detect a 10% reduction of the multivitamin on the primary end point of total cancer based on event rates among trial participants, with an average adherence of 75% during the entire treatment period and no interaction with other randomized components.

Figure 1. Flow Diagram of Participants From Screening to Completion of the Multivitamin Component of the Physicians' Health Study II



Initial analyses displayed distributions of baseline characteristics by multivitamin treatment assignment. Consistent with previous PHS II trial analyses,^{18,23} we used Cox proportional hazards regression models to es-

timate the hazard ratios (HRs) and 95% CIs comparing event rates in the multivitamin and placebo groups. For each prespecified end point, Cox proportional hazards regression models were stratified on the presence of cancer at

randomization and adjusted for PHS II study design variables for age (in years), PHS cohort (original PHS I participant, new PHS II participant), and randomized vitamin E, vitamin C, and beta carotene assignments.

Only first cancer events after randomization were considered for analyses of total cancer, epithelial cell cancer, and total minus prostate cancer. For analyses of total cancer, all new cancers were included, regardless of whether the participant had a baseline history of cancer. For analyses of each site-specific cancer, we excluded participants if they had a baseline history of cancer of that site. Thus, these analyses included 13 980 men initially without prostate cancer, 14 519 initially without colorectal cancer, and 14 610 initially without lung cancer. Analyses of each site-specific cancer did not censor men on occurrence of cancer at another site. In addition, for analyses of site-specific cancer deaths, total cancer mortality, and total mortality, we included all 14 641 participants, and for total mortality, we additionally stratified on the presence of cardiovascular disease at randomization.

We tested the Cox proportional hazards regression assumptions by including an interaction term for treatment with the logarithm of time; this assumption was not violated for total cancer, prostate cancer, colorectal cancer, or other site-specific cancers (each $P > .05$). Cumulative incidence curves compared the overall effect of the multivitamin intervention on total and major site-specific cancers over time using a crude log-rank test. We then investigated whether multivitamin adherence affected our primary results through sensitivity analyses.

Additional exploratory analyses examined the effect of the multivitamin intervention on total cancer excluding the first 2 or 5 years of follow-up to explore a possible early vs late benefit associated with long-term multivitamin use. In addition, we conducted subgroup analyses stratified by major cancer risk factors, parental history of cancer, selected dietary factors, and

Table 1. Self-reported Baseline Characteristics According to Multivitamin Treatment Assignment in 14 641 Men From the PHS II^a

| Characteristics | Multivitamin | |
|--|-------------------|--------------------|
| | Active (n = 7317) | Placebo (n = 7324) |
| Age, y | | |
| Mean (SD), y | 64.2 (9.1) | 64.3 (9.2) |
| 50-59 | 2944 (40.2) | 2947 (40.2) |
| 60-69 | 2348 (32.1) | 2348 (32.1) |
| ≥70 | 2025 (27.7) | 2029 (27.7) |
| BMI, mean (SD) | 25.9 (3.4) | 26.0 (3.4) |
| Cigarette smoking | | |
| Never | 4145 (56.7) | 4107 (56.1) |
| Former | 2908 (39.8) | 2944 (40.2) |
| Current | 255 (3.5) | 269 (3.7) |
| Exercise ≥1 time/wk | | |
| No | 2699 (37.8) | 2806 (39.3) |
| Yes | 4444 (62.2) | 4328 (60.7) |
| Alcohol consumption | | |
| Rarely or never | 1391 (19.2) | 1339 (18.4) |
| ≥1 drink/mo | 5874 (80.9) | 5942 (81.6) |
| Current aspirin use | | |
| No | 1625 (22.5) | 1636 (22.7) |
| Yes | 5602 (77.5) | 5565 (77.3) |
| Parental history of cancer ^b | | |
| No | 2956 (47.1) | 2881 (45.9) |
| Yes | 3319 (52.9) | 3402 (54.1) |
| Parental history of prostate cancer ^b | | |
| No | 5759 (89.4) | 5746 (90.0) |
| Yes | 682 (10.6) | 642 (10.0) |
| Parental history of colorectal cancer ^b | | |
| No | 5559 (88.7) | 5485 (87.8) |
| Yes | 708 (11.3) | 759 (12.2) |
| Self-reported history of cancer | | |
| No | 6669 (91.1) | 6660 (90.9) |
| Yes | 648 (8.9) | 664 (9.1) |
| Self-reported history of prostate cancer | | |
| No | 6988 (95.5) | 6992 (95.5) |
| Yes | 329 (4.5) | 332 (4.5) |
| Self-reported history of colorectal cancer | | |
| No | 7255 (99.2) | 7264 (99.2) |
| Yes | 62 (0.8) | 60 (0.8) |
| Servings per d, median (IQR) ^c | | |
| Fruit and vegetable intake | 4.26 (2.95-5.75) | 4.19 (2.94-5.77) |
| Whole grain intake | 1.13 (0.49-2.00) | 1.07 (0.49-1.99) |
| Red meat intake | 0.63 (0.29-1.05) | 0.57 (0.29-1.00) |

Abbreviations: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); IQR, interquartile range; PHS, Physicians' Health Study.

^aData are No. (%) unless otherwise indicated. The numbers do not always sum to group totals due to missing information for some variables. $P > .05$ for all comparisons between active and placebo multivitamin groups.

^bExcludes 2083, 1812, and 2130 men with missing information on parental history of cancer, prostate cancer, and colorectal cancer, respectively.

^cAmong 13 310, 13 280, and 13 268 men with available dietary data on fruit and vegetable, whole grain, and red meat intake, respectively.

other PHS II interventions. We also evaluated treatment effects within the prespecified subgroups of 1312 men with and 13 329 men without a baseline history of cancer. Effect modification was assessed by using interaction terms between subgroup indicators and multivitamin assignment.

RESULTS

A total of 14 641 male physicians were randomized with a mean (SD) age of 64.3 (9.2) years. All baseline characteristics had comparable distributions between the multivitamin and placebo groups (TABLE 1). Participants had a mean (SD) body mass index (BMI, calculated as weight in kilograms divided by height in meters squared) of 26.0 (3.6), with a large proportion of former smokers (40.0%) and a very low proportion of current smokers (3.6%). Current aspirin use at baseline was high (77.4%) in this population of physicians, in part reflective of their previous participation and results of the PHS I randomized trial testing aspirin and cardiovascular disease.²⁴ There were 1312 men (9.0%) with a baseline history of cancer and 754 men (5.1%) with a baseline history of cardiovascular disease.

Participants in the PHS II were followed up for a mean of 11.2 years (median [interquartile range], 11.2 [10.7-13.3] years; maximum, 13.8 years), with follow-up totaling 164 320 person-years. For active multivitamin and its placebo, adherence at 4 years was 76.8% and 77.1%, respectively ($P = .71$); at 8 years, adherence was 72.3% and 70.7%, respectively ($P = .15$); and at the end of follow-up, adherence was 67.5% and 67.1%, respectively ($P = .70$). There were also no differences between the active (81.0%) and placebo (80.3%) groups comparing the percentage of men reporting avoidance of individual non-trial multivitamin use (<30 days per year) at the end of multivitamin follow-up ($P = .35$). During multivitamin treatment, we confirmed that 2669 men had cancer, including 1373 cases of prostate cancer and 210 cases of colorectal cancer, with some men experiencing multiple events. A total of 2757 men

(18.8%) died during follow-up, including 859 (5.9%) due to cancer.

Multivitamin Use and Cancer

Overall in PHS II, the rates of total cancer, which included only first cancer events during follow-up, were 17.0 and 18.3 per 1000 person-years in the multivitamin and placebo groups, respectively. Men taking multivitamins had a modest reduction in total cancer incidence (HR, 0.92; 95% CI, 0.86-0.998; $P = .04$) (TABLE 2). The cumulative incidence curves are shown in FIGURE 2 (crude log-rank, $P = .05$).

Men taking a multivitamin had a similar modest reduction in total epithelial cell cancer (HR, 0.92; 95% CI, 0.85-0.997; $P = .04$). Approximately half of all incident cancers were prostate cancer, many of which were early stage. We found no effect of a multivitamin on prostate cancer (multivitamin and placebo groups, 9.1 and 9.2 events, respectively, per 1000 person-years; HR, 0.98; 95% CI, 0.88-1.09; $P = .76$), whereas a multivitamin significantly reduced the risk of total cancer excluding prostate cancer (HR, 0.88; 95% CI, 0.79-0.98; $P = .02$). There were no statistically significant reductions in individual site-specific cancers, including colorectal cancer (multivitamin and placebo groups, 1.2 and 1.4 events, respectively, per 1000 person-years; HR, 0.89; 95% CI, 0.68-1.17; $P = .39$), lung cancer (HR, 0.84; 95% CI, 0.61-1.14; $P = .26$), and bladder cancer (HR, 0.72; 95% CI, 0.48-1.07; $P = .10$), although power was limited with fewer events. There was no statistically significant difference in the risk of cancer mortality (multivitamin and placebo groups, 4.9 and 5.6 events, respectively, per 1000 person-years; HR, 0.88; 95% CI, 0.77-1.01; $P = .07$). Total mortality was not significantly reduced (HR, 0.94; 95% CI, 0.88-1.02; $P = .13$).

In secondary analyses, the exclusion of the first 2 or 5 years of follow-up did not appreciably alter the results for total cancer. We also considered the effect of adherence during follow-up on our results. In analyses accounting for adherence, we did not de-

tect any material impact on the effect of the multivitamin on risk of total cancer.

Modifiers of the Effect Between Multivitamin Use and Cancer

In subgroup analyses, we examined whether selected baseline characteristics—including clinical, lifestyle, familial, and dietary factors—plus the other 3 randomized interventions from PHS II modified the effect of a daily multivitamin on total cancer (eTable 1, available at <http://www.jama.com>). For age, the effect of a daily multivitamin on total cancer among men aged 70 years or older revealed an HR of 0.82 (95% CI, 0.72-0.93), but the test for heterogeneity across age groups with men aged 50 to 59 years (HR, 0.96) and 60 to 69 years (HR, 1.01) did not reach significance (P for interaction = .06).

There was significant effect modification by parental history of cancer (P for interaction = .02); men with no parental history of cancer had a beneficial effect of a daily multivitamin on total cancer (HR, 0.86, 95% CI, 0.76-0.98; $P = .02$), although men with a parental history of cancer did not (HR, 1.05; 95% CI, 0.94-1.17; $P = .37$). No significant heterogeneity by other clinical, lifestyle, and selected dietary factors, or by the previously terminated randomized vitamin C, vitamin E, and beta carotene interventions of PHS II was found (all P for interaction > .05).

Based on prespecified hypotheses, daily multivitamin use was associated with a reduction in total cancer among the 1312 men with a baseline history of cancer (HR, 0.73; 95% CI, 0.56-0.96; $P = .02$), but this result did not significantly differ from that observed among 13 329 men initially without cancer (HR, 0.94; 95% CI, 0.87-1.02; $P = .15$; P for interaction = .07) (TABLE 3). The overall rates of total cancer were 18.4 and 17.6 per 1000 person-years, respectively, in men with or without baseline cancer. Based on the cumulative incidence curve (FIGURE 3), a reduction in total cancer among men with a history of cancer at baseline emerged early during multivitamin treatment and follow-up (crude

log-rank, $P = .02$). Furthermore, the effect of a daily multivitamin on total epithelial cancer was stronger among men with a history of cancer at baseline (HR, 0.66; 95% CI, 0.50-0.88; $P = .004$) than men with no history of cancer (HR, 0.95; 95% CI, 0.87-1.03; $P = .21$; P for interaction = .02).

Among 1312 men with a baseline history of cancer, information on the number of years since their last cancer diagnosis was reported in 1279 men (97.5%), with 620 men (77 cases of total cancer) last diagnosed less than 5 years before PHS II baseline and 659 men (138 cases of total cancer) last diagnosed 5 years or more before PHS II baseline. A daily multivitamin did not have differential effects among men with more recent diagnoses less than

5 years ago (HR, 0.80; 95% CI, 0.50-1.26; $P = .33$) vs men with more distant diagnoses of 5 years or more before baseline (HR, 0.70; 95% CI, 0.50-0.98; $P = .04$; P for interaction = .70). Furthermore, no effect modification by the most recent type of cancer was found for prostate cancer (114 men; HR, 0.66; 95% CI, 0.34-1.27; $P = .21$) vs non-prostate cancer or unknown (1165 men; HR, 0.78; 95% CI, 0.58-1.05; $P = .10$) diagnosed before PHS II baseline (P for interaction = .62).

Adverse Effects

In addition to the main primary and secondary end points, we assessed a number of potential adverse effects of daily multivitamin use and found no significant effects on gastrointestinal tract

symptoms (peptic ulcer, constipation, diarrhea, gastritis, and nausea), fatigue, drowsiness, skin discoloration, and migraine (all $P > .05$). Those men taking the multivitamin were more likely to have rashes (2125 men in multivitamin group vs 2002 men in placebo group; HR, 1.07; 95% CI, 1.01-1.14; $P = .03$). In addition, there were inconsistent findings for daily multivitamin use on minor bleeding, with a reduction in hematuria (1194 men in multivitamin group and 1292 men in placebo group; HR, 0.91; 95% CI, 0.84-0.98; $P = .02$), an increase in epistaxis (1579 men in multivitamin group and 1451 men in placebo group; HR, 1.10; 95% CI, 1.02-1.18; $P = .01$), and no effect on easy bruising and/or other bleeding (2786 men in multivitamin group

Table 2. Association Between Randomized Multivitamin Assignment and the Risk of Total Cancer, Site-Specific Cancer, and Mortality in the PHS II^a

| Outcome | Total Men in Analysis ^b | Multivitamin | | | | Adjusted HR (95% CI) ^c | P Value |
|---|------------------------------------|--------------|---------------|------------|---------------|-----------------------------------|---------|
| | | Active | | Placebo | | | |
| | | No. of Men | No. of Events | No. of Men | No. of Events | | |
| Total cancer | 14 641 | 7317 | 1290 | 7324 | 1379 | 0.92 (0.86-0.998) | .04 |
| Total epithelial cell cancer ^d | 14 641 | 7317 | 1158 | 7324 | 1244 | 0.92 (0.85-0.997) | .04 |
| Total cancer minus prostate cancer ^e | 14 641 | 7317 | 641 | 7324 | 715 | 0.88 (0.79-0.98) | .02 |
| Prostate cancer | 13 980 | 6988 | 683 | 6992 | 690 | 0.98 (0.88-1.09) | .76 |
| Prostate cancer death | 14 641 | 7317 | 70 | 7324 | 78 | 0.91 (0.66-1.26) | .58 |
| Colorectal cancer | 14 519 | 7255 | 99 | 7264 | 111 | 0.89 (0.68-1.17) | .39 |
| Colorectal cancer death | 14 641 | 7317 | 37 | 7324 | 39 | 0.95 (0.60-1.48) | .81 |
| Lung cancer | 14 610 | 7300 | 74 | 7310 | 88 | 0.84 (0.61-1.14) | .26 |
| Lung cancer death | 14 641 | 7317 | 65 | 7324 | 73 | 0.89 (0.64-1.25) | .50 |
| Bladder cancer | 14 570 | 7276 | 41 | 7294 | 57 | 0.72 (0.48-1.07) | .10 |
| Bladder cancer death | 14 641 | 7317 | 15 | 7324 | 18 | 0.84 (0.42-1.67) | .62 |
| Pancreatic cancer | 14 638 | 7315 | 43 | 7323 | 36 | 1.19 (0.76-1.85) | .45 |
| Pancreatic cancer death | 14 641 | 7317 | 39 | 7324 | 39 | 0.99 (0.64-1.55) | .97 |
| Lymphoma | 14 595 | 7296 | 100 | 7299 | 88 | 1.13 (0.85-1.51) | .40 |
| Lymphoma death | 14 641 | 7317 | 38 | 7324 | 33 | 1.15 (0.72-1.84) | .55 |
| Leukemia | 14 612 | 7296 | 50 | 7316 | 60 | 0.83 (0.57-1.21) | .33 |
| Leukemia death | 14 641 | 7317 | 22 | 7324 | 37 | 0.59 (0.35-1.01) | .053 |
| Melanoma | 14 483 | 7238 | 108 | 7245 | 96 | 1.12 (0.85-1.47) | .42 |
| Melanoma death | 14 641 | 7317 | 9 | 7324 | 10 | 0.91 (0.37-2.25) | .84 |
| Total mortality ^f | 14 641 | 7317 | 1345 | 7324 | 1412 | 0.94 (0.88-1.02) | .13 |
| Cancer mortality | 14 641 | 7317 | 403 | 7324 | 456 | 0.88 (0.77-1.01) | .07 |

Abbreviations: HR, hazard ratio; PHS, Physicians' Health Study.

^aMean follow-up of 11.2 years for all 14 641 men through June 1, 2011.

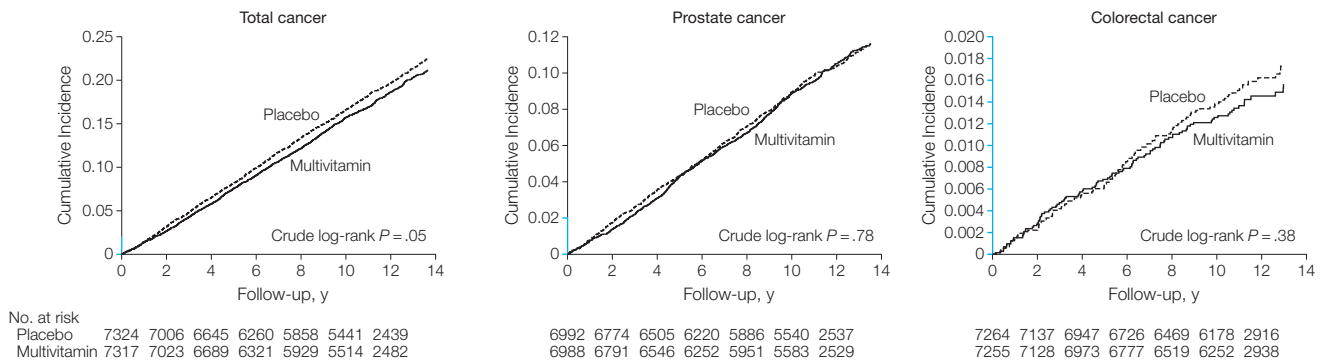
^bFor total cancer, site-specific mortality, total mortality, and cancer mortality, analyses included all 14 641 participants. For the incidence of site-specific cancers, analyses were restricted to men without that site-specific cancer at baseline.

^cAdjusted for age, PHS cohort (original PHS I participant, new PHS II participant), and randomized treatment assignment (beta carotene, vitamin E, and vitamin C), and stratified on baseline cancer.

^dEpithelial cell cancer was limited to carcinomas, which included all cancers except for lymphoma and leukemia.

^eIncludes all cancers other than prostate cancer.

^fAdditionally stratified on baseline cardiovascular disease.

Figure 2. Cumulative Incidence Rates of Total Cancer, Prostate Cancer, and Colorectal Cancer by Randomized Multivitamin Assignment in the Physicians' Health Study II

Y-axis range shown in blue indicates cumulative incidence from 0 to 0.02. The reduction in the numbers at risk from 10 to 12 years reflects the 2 phases of Physicians' Health Study II recruitment; men in the Physicians' Health Study I initially enrolled in phase 1 starting in 1997 were followed up longer on average (mean, 13 years) than the men recruited in phase 2 starting in 1999 (mean, 10 years).

and 2806 men in placebo group; HR, 0.99; 95% CI, 0.94-1.05; $P = .77$).

COMMENT

In this large-scale, randomized, placebo-controlled trial among middle-aged and older men, long-term daily multivitamin use had a modest but statistically significant reduction in the primary end point of total cancer after more than a decade of treatment and follow-up. We found no evidence that this effect was driven by any individual site-specific cancers. In prespecified analyses, we found that the effect of a daily multivitamin in reducing cancer appeared stronger among men for secondary vs primary prevention of cancer in PHS II, although this difference was not significant for total cancer but was for total epithelial cell cancer. Approximately half of those men with baseline cancer in PHS II were last diagnosed 5 years or more ago, and we found no suggestion that more remote vs proximate diagnoses affected cancer risk.

Total cancer rates in our trial were likely influenced by the increased surveillance for prostate-specific antigen and subsequent diagnoses of prostate cancer during PHS II follow-up starting in the late 1990s.²⁶ Approximately half of all confirmed cancers in PHS II were prostate cancer, of which the majority were earlier stage, lower-grade

prostate cancer with high survival rates. The significant reduction in total cancer minus prostate cancer suggests that daily multivitamin use may have a greater benefit on more clinically relevant cancer diagnoses.

In the Cancer Prevention Study II, which followed up more than 1 million US adults beginning in the early 1980s, multivitamin use was not associated with cancer mortality.²⁷ The Women's Health Initiative found that multivitamins had little or no relationship with the risk of breast, colon, or other cancers in more than 160 000 women followed up for a mean of 8 years.⁹ Among 35 000 Swedish women, however, multivitamin use was associated with a 19% increased risk of breast cancer (95% CI, 1.04-1.37) during a 10-year period compared with women not using these vitamins.⁸ How these results for breast and other cancers in women extend to our trial of men in PHS II remains unclear.

Other observational studies suggest protective relationships of multivitamins with various cancers,^{28,29} no association,^{30,31} and possible harm.³² Studies with an association between multivitamins and specific cancers are typically of long duration, allowing for either a long latent period^{11,12,33,34} or increased statistical power. For example, increasing duration of multivitamin use was strongly associated with a

reduced risk of colon cancer in 88 756 participants in the Nurses' Health Study followed up for 15 years.¹² A long latency period was also noted in the Cancer Prevention Study II, with an inverse association between multivitamin use with both colon cancer incidence³⁴ and mortality¹¹ after more than a decade of multivitamin use; however, these findings were not supported in PHS II.

Only a few large-scale, long-term chemoprevention trials have considered combinations of selected vitamins or minerals, although not with the typical diversity of common multivitamin formulations with recommended dietary allowance levels of vitamins and minerals such as that tested in PHS II. The Linxian Chinese Cancer Prevention Trial,³⁵ targeting 29 584 adults with low baseline nutrient status, tested a combination of beta carotene, vitamin E, and selenium for 6 years and found significant reductions of 9% in total mortality, 13% in cancer mortality, and 21% in gastric cancer mortality. After 10 years of posttrial follow-up, the beneficial effects on total and cancer mortality remained.³⁶ The Heart Protection Study³⁷ tested higher doses of those 3 nutrients among individuals with adequate dietary intake and found no reductions in total or site-specific cancers. A meta-analysis³⁸ of 8 large randomized trials of folic acid and vitamin B supplementa-

tion found no effect on total cancer. In addition, the Supplementation en Vitamines et Mineraux Antioxydants (SU.VI.MAX) primary prevention trial³⁹ of 13 017 participants randomized to a low-dose combination of vitamin C, vitamin E, beta carotene, selenium, and zinc found no overall effect on total cancer, but there was a significant interaction with sex with a reduction in risk of total cancer in men only (relative risk, 0.69; 95% CI, 0.53-0.91).

Although numerous individual vitamins and minerals contained in the PHS II multivitamin study have postulated

chemopreventive roles, it is difficult to definitively identify any single mechanism of effect through which individual or multiple components of our tested multivitamin may have reduced cancer risk. The reduction in total cancer risk in PHS II argues that the broader combination of low-dose vitamins and minerals contained in the PHS II multivitamin (eTable 2), rather than an emphasis on previously tested high-dose vitamins and mineral trials, may be paramount for cancer prevention. For example, in the Women's Health Initiative calcium and vitamin D trial, women

not taking personal supplements randomized to vitamin D (400 IU/d) and calcium (1000 mg/d) had a reduction in total cancer similar to that observed in PHS II.⁴⁰ The role of a food-focused cancer prevention strategy such as targeted fruit and vegetable intake remains promising⁴¹ but unproven given the inconsistent epidemiologic evidence⁴² and lack of definitive trial data.

One explanation for results of some previous trials of supplements has been that the trial populations are already well-nourished.⁴³ This may also be particularly true in PHS II, composed of

Table 3. Association Between Randomized Multivitamin Assignment and the Risk of Total Cancer, Site-Specific Cancer, and Mortality Among Men Without and With Baseline Cancer in the PHS II^{a,b}

| Outcome | No Baseline History of Cancer | | | | | | | Baseline History of Cancer | | | | | | | P for Interaction |
|---|------------------------------------|------------|---------------|------------|---------------|-----------------------------------|---------|------------------------------------|------------|---------------|------------|---------------|-----------------------------------|---------|-------------------|
| | Total Men in Analysis ^c | Active | | Placebo | | Adjusted HR (95% CI) ^d | P Value | Total Men in Analysis ^c | Active | | Placebo | | Adjusted HR (95% CI) ^d | P Value | |
| | | No. of Men | No. of Events | No. of Men | No. of Events | | | | No. of Men | No. of Events | No. of Men | No. of Events | | | |
| Total cancer | 13 329 | 6669 | 1195 | 6660 | 1253 | 0.94 (0.87-1.02) | .15 | 1312 | 648 | 95 | 664 | 126 | 0.73 (0.56-0.96) | .02 | .07 |
| Total epithelial cell cancer ^e | 13 329 | 6669 | 1077 | 6660 | 1125 | 0.95 (0.87-1.03) | .21 | 1312 | 648 | 81 | 664 | 119 | 0.66 (0.50-0.88) | .004 | .02 |
| Total cancer minus prostate cancer ^f | 13 329 | 6669 | 561 | 6660 | 615 | 0.90 (0.80-1.01) | .07 | 1312 | 648 | 80 | 664 | 100 | 0.78 (0.58-1.04) | .09 | .38 |
| Prostate cancer | 13 329 | 6669 | 667 | 6660 | 662 | 1.00 (0.90-1.11) | .98 | 651 | 319 | 16 | 332 | 28 | 0.56 (0.30-1.04) | .07 | .07 |
| Colorectal cancer | 13 329 | 6669 | 88 | 6660 | 95 | 0.92 (0.69-1.23) | .58 | 1190 | 586 | 11 | 604 | 16 | 0.70 (0.32-1.52) | .37 | .52 |
| Lung cancer | 13 329 | 6669 | 67 | 6660 | 73 | 0.91 (0.65-1.27) | .57 | 1281 | 631 | 7 | 650 | 15 | 0.48 (0.20-1.19) | .11 | .19 |
| Melanoma | 13 329 | 6669 | 100 | 6660 | 89 | 1.12 (0.84-1.49) | .44 | 1154 | 569 | 8 | 585 | 7 | 1.16 (0.42-3.21) | .78 | .97 |
| Total mortality ^g | 13 329 | 6669 | 1092 | 6660 | 1134 | 0.94 (0.87-1.03) | .17 | 1312 | 648 | 253 | 664 | 278 | 0.93 (0.78-1.10) | .40 | .98 |
| Cancer mortality | 13 329 | 6669 | 289 | 6660 | 313 | 0.91 (0.78-1.07) | .26 | 1312 | 648 | 114 | 664 | 143 | 0.81 (0.63-1.04) | .10 | .51 |

Abbreviations: HR, hazard ratio; PHS, Physicians' Health Study.

^aMean follow-up of 11.4 years for 13 329 men without baseline cancer through June 1, 2011.

^bMean follow-up of 9.8 years for 1312 men with baseline cancer through June 1, 2011.

^cFor total cancer, site-specific mortality, total mortality, and cancer mortality, analyses included all 14 641 participants. For the incidence of site-specific cancers, analyses were restricted to men without that site-specific cancer at baseline.

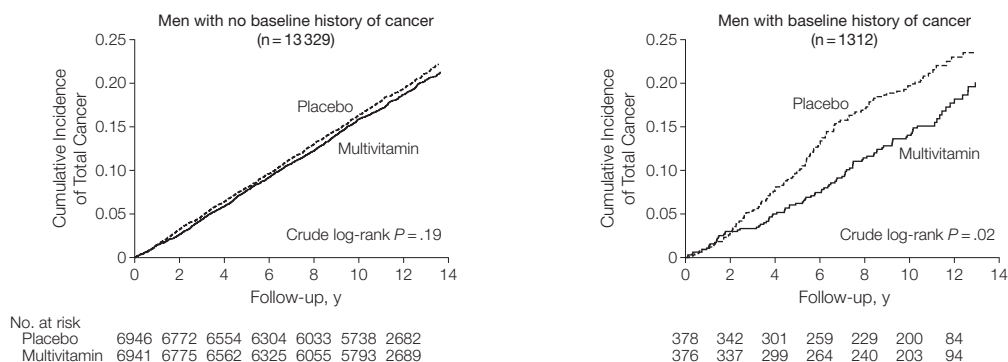
^dAdjusted for age, PHS cohort (original PHS I participant, new PHS participant), and randomized treatment assignment (beta carotene, vitamin E, and vitamin C).

^eEpithelial cell cancer was limited to carcinomas, which included all cancers except for lymphoma and leukemia.

^fIncludes all cancers other than prostate cancer.

^gAdditionally stratified on baseline cardiovascular disease.

Figure 3. Cumulative Incidence Rates of Total Cancer Among 13 329 Men With No Baseline History of Cancer and 1312 Men With a Baseline History of Cancer in the Physicians' Health Study II



male physicians, although population-based clinical trials also recruit healthier individuals.⁴⁴⁻⁴⁶ Participants in PHS II represent on average a well-nourished population for whom the effect of a daily multivitamin on cancer outcomes may be less applicable to those of poorer nutritional status. Additional studies need to evaluate how the range of baseline nutritional status modifies the effect of a daily multivitamin on cancer.

Strengths of PHS II include the long duration of treatment and follow-up and consistently good adherence to taking a daily multivitamin. The inclusion of physician participants provided high-quality reporting of health information. We are unaware of other long-term clinical trials testing a common multivitamin in the prevention of cancer and chronic disease. We selected a commonly used multivitamin formulation, Centrum Silver, at the time we initiated PHS II in 1997 to increase the potential generalizability of our findings.

Several limitations should also be considered. The formulations of the multivitamin preparation used in our trial and other multivitamin preparations have changed over time, reflecting evolving perspectives and priorities in nutrition. For example, since PHS II was initiated, in the commercial form of this multivitamin, vitamin D increased from 400 to 500 IU, vitamin A (% as beta carotene) decreased from 5000 IU (50%) to 2500 IU (40%), and 250 µg of lutein and 300 µg of lycopene were added. However, the formulation of the multivitamin used throughout PHS II (eTable 2) remained the same, resulting in a consistent intervention in our trial. An improved understanding of the effects of single vs combined nutrients—at usual levels of dietary intake—on intermediate mechanisms leading to cancer is critically needed.

It is unclear how easily our trial results for cancer outcomes may be replicated given the high prevalence of multivitamin use in adults and difficulty of conducting a long-term, blinded

clinical trial. This is especially important given the potential challenge of generalizing to younger men and women and racial and ethnic groups not included in PHS II. It remains possible that more effective chemoprevention via multivitamins may occur with longer treatment or follow-up than conducted to date in PHS II, given the apparent latent results on colon cancer and mortality in some cohorts.^{11,12,34} This is particularly salient in our analyses of site-specific cancers, for which continued PHS II follow-up would increase statistical power and detect any emergent latent effects. Adherence remains of concern as in any long-term trial, but adherence with the multivitamin component of PHS II remained consistently good during a mean follow-up of 11 years. Drop-in rates of outside multivitamin use did increase during follow-up, paralleling general population trends of increased vitamin supplement use in the United States,^{2,47} but there were no differences in rates in active vs placebo multivitamin groups and analyses accounting for adherence did not greatly affect the HRs of total and site-specific cancers.

As in any trial, the role of chance must be considered. This is particularly important when multiple hypotheses are being addressed. In PHS II, we had only 2 primary outcomes—total cancer and major cardiovascular events. However, there are additional secondary outcomes that include eye disease, cognitive function, and a number of prespecified secondary analyses. Caution must be applied in the interpretation of these analyses.

In this large-scale randomized trial of 14 641 middle-aged and older men, a daily multivitamin supplement significantly but modestly reduced the risk of total cancer during a mean of 11 years of treatment and follow-up. Although the main reason to take multivitamins is to prevent nutritional deficiency, these data provide support for the potential use of multivitamin supplements in the prevention of cancer in middle-aged and older men.

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Study concept and design: Gaziano, Sesso, Christen, Manson, Glynn, Buring.

Acquisition of data: Gaziano, Sesso, Christen, Bubes, Smith, MacFadyen, Schwartz, Manson, Glynn, Buring.

Analysis and interpretation of data: Gaziano, Sesso, Christen, Bubes, Manson, Glynn, Buring.

Drafting of the manuscript: Gaziano, Sesso.

Critical revision of the manuscript for important intellectual content: Gaziano, Sesso, Christen, Bubes, Smith, MacFadyen, Schwartz, Manson, Glynn, Buring.

Statistical analysis: Gaziano, Sesso, Bubes, Glynn.

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