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Blood Pressure and Vitamin C and Fruit and Vegetable Intake

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Key Words
Blood pressure · Vitamin C · Fruits · Vegetables · Nutrition survey · Germany

Abstract
Background: A high vitamin C intake was recently associated with lower blood pressure levels. We examined this association and compared it with that between blood pressure and fruit and vegetable intake among German adults. ***Methods:*** Complete data were available for 1,628 women and 1,340 men, aged 18–79 years, who participated in the German Nutrition Survey, a subsample of the National Health Survey 1998. The participants completed a health and lifestyle questionnaire and underwent a medical examination and a comprehensive dietary interview. Multiple regression models were used to analyze the association between blood pressure and vitamin C and fruit and vegetable intakes. The associations were adjusted for age and body mass index and in addition for smoking among women and alcohol intake and sport activity among men. ***Results:*** Systolic blood pressure showed a significant inverse association with fruit and vegetable but not with vitamin C intake among women. If information about vitamin C and fruit and vegetable intakes was considered simultaneously, a high fruit and vegetable intake was stronger associated with lower systolic blood pressure levels as compared with a high vitamin C intake among women. Among men, we did not observe significant associations between blood pressure and vitamin C and fruit and vegetable intakes. ***Conclusion:*** The total vitamin C intake seems to be less associated with blood pressure levels as compared with the intake of fruit and vegetables among women.

Introduction

A high blood pressure is an important risk factor for cardiovascular disease. A genetic predisposition and hormonal as well as behavioural factors like excess body weight and physical inactivity may influence the development of hypertension. Especially eating habits may be important [1, 2]. An inverse association of blood pressure with vitamin C plasma concentration or intake was observed in several observational and experimental studies [3–7]. Some biological explanations for this association were proposed. They include involvement of nitric oxide [8], endothelial prostacyclin [9], circulating sodium levels and protein fractions [10], and cytosolic calcium and thus smooth muscle contractility [11].

However, a high intake of vitamin C may indicate a high fruit and vegetable consumption. Other nutrients in these foods may be responsible for the inverse association with blood pressure. Possibly, vitamin C might contribute to a lower blood pressure more effectively in combination with other dietary compounds as consumed in its natural

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form. This study examines and compares the magnitude of the association between blood pressure and vitamin C as well as fruit and vegetable intakes. The analyses were based on cross-sectional data of German adults.

Subjects and Methods

A total of 7,124 persons, aged 18–79 years, participated in the representative German National Health Interview and Examination Survey, conducted from October 1997 until March 1999. The participants were sampled from population registries and stratified by age, gender, community size, and federal state. The overall response rate was 61.4%. A total of 4,030 persons participated in the affiliated German Nutrition Survey. All participants completed a self-administered questionnaire which included the German version of the life quality questionnaire SF-36, questions about medical history and health-relevant habits like smoking, alcohol intake, and physical activity. In the presence of the participants the questionnaires were checked for completeness and plausibility [12].

The participants underwent a medical examination which included measurements of height and weight. A physician measured the blood pressure in the upper arm with the participant sitting, three times after at least 3 min rest, using a mercury sphygmomanometer (Erkameter 3000) with a maximum deviation of + 1.8 mm Hg [13]. Mean systolic and diastolic blood pressures (SBP and DBP) of the second and the third measurement were used in the analyses. At the medical examination, the participants were also interviewed about their drug consumption. Field work quality and standardization were inspected regularly.

The Nutrition Survey participants were interviewed comprehensively about their diet of the past 4 weeks by trained nutritionists using a validated computerized dietary history (DISHES 98 – Dietary Interview Software for Health Examination Studies) [14]. This is supposed to reflect the usual diet. In addition, the participants were asked about their dietary supplement use. The frequency of intake and the brand names of vitamin B, vitamin C, vitamin E, folate, multivitamin and mineral supplements were assessed [15].

The average daily consumption of fruit and vegetables including potatoes was calculated from the interview data for each person. From the obtained quantitative information on both foods and supplements, the average total nutrient intake per day was calculated individually using the German Food Composition Table 'Bundeslebensmittelschlüssel', version II.3, and using a new supplement composition database, respectively [16].

Separately for women and men, multiple linear regression models were used to analyze the relationship between blood pressure and dietary vitamin C intake, total vitamin C intake (dietary plus supplemental intake), and fruit and vegetable intake as the respective independent variables. For additional regression analyses, we grouped information of total vitamin C and fruit and vegetable intakes. Persons in group 1 (455 women, 373 men) had high intakes of both vitamin C (≥ 0.15 g/day) and fruit and vegetables (≥ 600 g/day). Persons in group 2 (140 women, 118 men) were characterized by a low intake of vitamin C (< 0.15 g/day) but a high intake of fruit and vegetables (≥ 600 g/day). Vice versa, women and men in group 3 consumed high amounts of vitamin C (≥ 0.15 g/day) but low amounts of fruit and vegetables (< 600 g/day; 292 women, 227 men). The remaining persons in group 4 (741 women, 622 men) had low intakes of both vitamin C (< 0.15 g/day) and fruit and vegetables (< 600 g/day).

The influence of potential confounders like age, body mass index (BMI), socioeconomic status, smoking, physical activity, alcohol and coffee intake, vegetarian diet, health-related quality of life issues, pregnancy, use of oral contraceptives, hormone replacement therapy, region, season, and energy intake was evaluated and, if appropriate, adjusted for in the regression models. For the presented analyses, information on smoking was categorized as: never smoking, ex-smoking, and current smoking. Information on physical activity was defined as sport activity with three different categories: sedentary (no sport activity), up to 2 h sport activity per week, and 2 or more hours sport activity per week. In the regression models, information on smoking, sport activity, and intakes of vitamin C and fruit and vegetables (four groups) was included as dichotomous variables.

Participants with known hypertension, at present or formerly, and those using either blood pressure lowering or raising drugs (606 women, 422 men) were excluded from the analyses. Nursing mothers (n = 33) were also excluded from the analyses. All statistical calculations were performed with the SAS package version 8.2 (SAS Institute Inc., Cary, N.C., USA).

Results

A total of 1,628 women and 1,340 men provided complete information about their nutrient intake and blood pressure. A selection of their health-relevant characteristics is presented in table 1.

The mean SBP was 127 mm Hg among women and 133 mm Hg among men. The mean DBP was 79 mm Hg for women and 83 mm Hg for men. The intake of dietary vitamin C was about 150 mg/day for both genders, on average. With the inclusion of supplemental vitamin C, the intake increased to up to 174 mg/day for women and to up to 172 mg/day for men. On average, women and men consumed slightly more than 550 g fruit and vegetables daily.

The results of the regression analyses of SBP among women with dietary vitamin C intake, total vitamin C intake, and fruit and vegetable intake as the respective independent variables are presented in table 2. The models also included age, BMI, and smoking. For all three models, we observed an inverse association with SBP. However, only the association with fruit and vegetables was significant. This association was also more pronounced (standard regression coefficient –0.07) as compared with dietary as well as total vitamin C intakes (standard regression coefficient –0.03).

Among men, we observed positive associations with SBP for all three models after the inclusion of age, BMI, alcohol intake, and sport activity. However, only the association with dietary vitamin C intake was significant (not

Table 1. Health-relevant characteristics of the study participants

	Women (n = 1,628)		Men (n = 1,340)	
	mean	SD	mean	SD
SBP, mm Hg	127.3	17.6	132.8	15.9
DBP, mm Hg	79.1	10.3	83.3	10.5
Dietary vitamin C intake, mg/day	151.7	77.8	151.2	87.1
Total vitamin C intake, mg/day	174.1	140.6	171.8	143.0
Fruit and vegetable consumption, g/day	552.9	238.7	558.0	267.0
Alcohol intake, g/day	5.7	8.4	17.2	18.4
BMI, kg/m^2	25.2	4.7	26.4	3.7
Age, years	40.8	14.5	41.6	15.0
Current smokers, %	33.8		36.3	
Ex-smokers, %	14.7		25.3	
Sport activity, %				
≥2 h	18.5		26.9	
<2 h	41.6		33.9	

Table 2. Regression coefficients for SBP (mm Hg) of intakes of vitamin C as well as fruit and vegetables among women

	Dietary vitamin C (g/day)[a]			Total vitamin C (g/day)[a]			Fruit and vegetables (kg/day)[a]		
	regression coefficient (B)	standard error of B	standard B	regression coefficient (B)	standard error of B	standard B	regression coefficient (B)	standard error of B	standard B
Intake[b]	–7.74 (NS)	4.71	–0.03	–4.28 (NS)	2.61	–0.03	–5.38***	1.55	–0.07
Age	0.54***	0.03	0.44	0.54***	0.03	0.44	0.55***	0.03	0.45
BMI	0.67***	0.08	0.18	0.67***	0.08	0.18	0.68***	0.08	0.18
Current smoking	–2.51**	0.83	–0.07	–2.50**	0.83	–0.07	–2.63**	0.83	–0.07
Ex-smoking	–3.94***	1.08	–0.08	–3.87***	1.08	–0.08	–3.79***	1.08	–0.08
Constant	90.95	2.30		90.39	2.20		92.06	2.26	
Adjusted R^2	29.9			29.9			30.3		

NS = Not significant; ** $p \leq 0.01$; *** $p \leq 0.001$.

a Respective independent variable that is to analyze in the regression model of SBP.

b Intake of dietary vitamin C, total vitamin C, and fruit and vegetables, respectively.

shown). Similar regression models of DBP showed no significant associations neither for women nor for men (not shown).

Since it is well known that the intakes of fruit and vegetables and dietary vitamin C are highly correlated, it is not appropriate to include them both as continuous variables in a regression model. To compare the associations between blood pressure and vitamin C and fruit and vegetable intakes, when this information is considered simultaneously, we performed multiple regression models including three combinations of intake with a fourth (low vitamin C and fruit and vegetable intakes) as the reference. The gender-specific results for SBP are presented in table 3 and those for DBP are presented in table 4.

After adjustment for age, BMI, and smoking, women with a high vitamin C intake and a high fruit and vegetable intake had a 2.3 mm Hg lower SBP than the reference (95% confidence interval –4.1, –0.6 mm Hg; table 3). Women, who consumed low amounts of vitamin C but high amounts of fruit and vegetables, even had a 3.0 mm Hg lower SBP (95% confidence interval –5.7, –0.3). We found no significantly different SBP levels among the four vitamin C and fruit and vegetable intake groups of men after adjustment for age, BMI, alcohol intake, and sport activity. The associations observed in the regression models of DBP among both genders are comparable with those in the regression models of SBP, particularly for women, although the associations with DBP were not significant (table 4).

Table 3. Regression coefficients for SBP (mm Hg) of intake groups of vitamin C as well as fruit and vegetables

	Women				Men		
	regression coefficient (B)	standard error of B	standard B		regression coefficient (B)	standard error of B	standard B
Group 1	–2.33**	0.89	–0.06	Group 1	1.82 (NS)	0.94	0.05
Group 2	–2.99*	1.37	–0.05	Group 2	–1.30 (NS)	1.44	–0.02
Group 3	0.71 (NS)	1.02	0.02	Group 3	–0.74 (NS)	1.12	–0.02
Age	0.55***	0.03	0.45	Age	0.35***	0.03	0.33
BMI	0.68***	0.08	0.18	BMI	0.75***	0.11	0.17
Current smoking	–2.64**	0.83	–0.07	Alcohol intake	0.06**	0.02	0.07
Ex-smoking	–3.95***	1.08	–0.08	Sport activity ≥2 h	–1.20 (NS)	0.90	–0.03
Constant	89.98	2.19		Constant	97.23	2.96	
Adjusted R^2	30.3			Adjusted R^2	19.5		

Group 1: high intake of vitamin C, high intake of fruit and vegetables; Group 2: low intake of vitamin C, high intake of fruit and vegetables; Group 3: high intake of vitamin C, low intake of fruit and vegetables.
NS = Not significant; * $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$.

Table 4. Regression coefficients for DBP (mm Hg) of intake groups of vitamin C as well as fruit and vegetables

	Women				Men		
	regression coefficient (B)	standard error of B	standard B		regression coefficient (B)	standard error of B	standard B
Group 1	–0.34 (NS)	0.56	–0.01	Group 1	0.19 (NS)	0.64	0.01
Group 2	–1.00 (NS)	0.86	–0.03	Group 2	–1.17 (NS)	0.97	–0.03
Group 3	0.89 (NS)	0.65	0.03	Group 3	0.06 (NS)	0.75	0.002
Age	0.19***	0.02	0.26	Age	0.14***	0.02	0.20
BMI	0.53***	0.05	0.24	BMI	0.72***	0.08	0.25
Current smoking	–1.65**	0.52	–0.08	Alcohol intake	0.03 (NS)	0.01	0.05
Ex-smoking	–0.61 (NS)	0.68	–0.02	Sport activity ≥2 h	–1.85**	0.61	–0.08
Constant	58.82	1.39		Constant	58.51	2.00	
Adjusted R^2	17.8			Adjusted R^2	15.2		

Group 1: high intake of vitamin C, high intake of fruit and vegetables; Group 2: low intake of vitamin C, high intake of fruit and vegetables; Group 3: high intake of vitamin C, low intake of fruit and vegetables.
NS = Not significant; ** $p \leq 0.01$; *** $p \leq 0.001$.

Discussion

We examined and compared the magnitude of the associations between blood pressure and vitamin C as well as fruit and vegetable intakes. Analyses were based on data collected in the German National Health Survey and the affiliated German Nutrition Survey 1998.

Among women, a high fruit and vegetable intake was stronger associated with lower SBP as compared with a high vitamin C intake. Women with a high fruit and vegetable but a low vitamin C intake had the highest difference of SBP (–3.0 mm Hg) as compared with the reference (low intakes of both vitamin C and fruit and vegetables). The associations between DBP and vitamin C and fruit and vegetable intakes among women were similar, although not significant. The lack of a consistent association among men is remarkable. However, similarly as among women, the vitamin C intake seemed to be less associated with both SBP and DBP than fruit and vegetable intake.

Table 5. Dietary and total vitamin C intake among different vitamin C and fruit and vegetable intake groups

Group	Women				Men			
	dietary vitamin C, mg/day		total vitamin C, mg/day		dietary vitamin C, mg/day		total vitamin C, mg/day	
	mean	CI	mean	CI	mean	CI	mean	CI
1	229.5	222.5–236.5	264.2	251.3–277.2	231.6	222.0–241.3	260.7	245.4–275.9
2	124.4	121.6–127.2	125.5	122.7–128.3	125.9	122.7–129.2	127.0	123.8–130.2
3	182.8	175.4–190.3	237.4	219.8–255.0	189.5	179.0–200.0	246.4	223.5–269.2
4	96.9	94.8–99.0	99.6	97.5–101.7	94.0	91.7–96.2	96.9	94.6–99.1

CI = 95% confidence interval.

Group 1: high intake of vitamin C, high intake of fruit and vegetables; Group 2: low intake of vitamin C, high intake of fruit and vegetables; Group 3: high intake of vitamin C, low intake of fruit and vegetables; Group 4: low intake of vitamin C, low intake of fruit and vegetables.

Our models include age and BMI and additionally smoking among women and alcohol intake and sport activity among men. The additional inclusion of smoking, intakes of alcohol, coffee, and energy, sport activity, socioeconomic status, health-related quality of life issues, pregnancy, vegetarian diet, use of oral contraceptives, hormone replacement therapy, region, and season among women and men, respectively, did not alter the results considerably.

The results presented are in line with the Dietary Approaches to Stop Hypertension (DASH) trial which observed lower levels of 24-hour ambulatory SBP and DBP of persons consuming a diet rich in fruits and vegetables as compared with controls (–3.1 and –2.1 mm Hg, respectively). Additionally, an even lower blood pressure was observed for persons receiving the DASH diet which in addition to fruit and vegetables emphasized, e.g., low-fat dairy products [17]. Ascherio et al. [18, 19] reported inverse associations of blood pressure and a diet richer in fruit and vegetables among women and a diet higher in fruits among men. In a recent trial performed by John et al. [20], lower SBP and DBP levels were observed for persons with a higher fruit and vegetable intake in the intervention group as compared with controls (–4.0 and –1.5 mm Hg, respectively).

A review of epidemiological studies performed by Ness et al. [21] showed some inverse associations between either SBP, DBP, or both and vitamin C plasma concentration or intake. A few more recent studies reported similar results [6, 22]. Results of intervention trials examining blood pressure after vitamin C supplementation are inconsistent [5, 23–26]. Whereas the blood pressure of hypertensives was not significantly lowered after 6 weeks of vitamin C treatment as compared with placebo [23], Fotherby et al. [26] observed a significant fall in daytime ambulatory blood pressure of normotensive persons, and Duffy et al. [5] reported significantly lower SBP levels among hypertensive patients after vitamin C treatment. Studies examining the relationship between blood pressure and a combination of antioxidant supplementation also provide inconclusive results [24, 25]. The trials were often of low statistical power. They also differed in the intervention period or the supplement combinations used for intervention. A possible reason for inconsistent study results may also be due to different blood pressure measurement. The 24-hour blood pressure may be more appropriate to reflect the habitual blood pressure as compared with the ambulatory blood pressure and may be, therefore, used especially in experimental studies. In our study, a highly standardized blood pressure measurement method was used by intensively trained persons.

It was hypothesized that vitamin C has a blood pressure lowering effect due to its antioxidative capacity, preventing the free radical induced oxidative damage of endothelial nitric oxide which is likely to impair the endothelial vasomotor function, leading to a high blood pressure [8, 27]. However, in recent experimental studies, high physiological concentrations of vitamin C (>1 mmol/l) were required for the promotion of vasodilation [28, 29].

Nevertheless, the vitamin C plasma concentrations are often highly correlated with consumed fruit and vegetables. Therefore, other factors associated with fruit and vegetable intake, e.g., other vitamins like vitamin E or β-carotene with antioxidant capacity or other phytochemicals (e.g. flavonoids) or a synergistic effect of vitamin C with these substances, may contribute to the reduction of blood pressure levels [30]. The contents of potassium, magnesium, calcium, and dietary fiber in fruit and vegetables may also contribute to a lower blood pressure [31]. Since these intakes were highly correlated with fruit and vegetable intake, we could not include them simultaneously in our analyses. This was also true for, e.g., dairy products which may be consumed in high amounts by persons with a high fruit and vegetable intake and, therefore, contribute to a lower blood pressure. However, an inclusion of dairy products did not alter the results essentially. A high fruit and vegetable intake may be associated with a generally low-salt diet which may also contribute to a reduced blood pressure. Since salt intake was difficult to assess due to the amount of information in the food composition table and missing information on the use of table salt, we did not consider salt intake. Instead of salt, we considered sodium intake. The results remained the same, however. It is, therefore, not likely that salt intake would explain the observed results.

We did not analyze the association between blood pressure and vitamin C plasma concentration. High plasma vitamin C levels, similar to intake estimates, are highly correlated with a high intake of fruit and vegetables. Block et al. [32] recently reported a lipid- and energy-adjusted partial correlation for the relation of vitamin C with fruit and vegetable intake of $r = 0.64$. Therefore, total fruit and vegetable intake may still explain the inverse association between plasma vitamin C and blood pressure in several studies. The observed differences in blood pressure among the different intake groups appear relatively small and of minor clinical relevance. However, they were observed in a large sample representing the adult German population. On a population level, a reduction of this magnitude is of high public health importance, since it would achieve a substantial reduction of the prevalence of blood pressure related diseases and mortality.

The German population has a relatively high average level of vitamin C intake (table 5). Possibly, in a population with a lower vitamin C intake the association with blood pressure might be stronger. Our findings still imply an additional effect of fruit and vegetables on blood pressure independent of a high vitamin C intake.

Dietary assessment is always affected by measurement errors due to, e.g., wrong estimation of portion size and difficulties in memory. We converted nutrient intakes from the quantitative information on foods using the German Food Composition Table. This database includes corrections for nutrient losses due to food preparation. It is, however, very unlikely that the observed associations are caused by systematic bias, because sources of measurement errors in vitamin C and fruit and vegetable intakes will be largely the same. Perhaps the supplemental vitamin C intake is less subject to measurement error, since it is often consumed (and reported) as standard units. Nevertheless, without doubt, the inclusion of supplemental vitamin C intake will improve total vitamin C intake estimation. The fact that the latter was less associated with blood pressure than fruit and vegetable intake is a further indication that the vitamin C intake is not the (only) underlying cause of the blood pressure lowering effect.

The observed gender-specific associations of smoking with either SBP or DBP are not clear. Possibly, an influence of smoking was not seen among men, because of the stronger influence of alcohol intake. To clarify this, we performed regression analyses for current smokers, ex-smokers, and never smokers separately. Nevertheless, the results remained the same. The results were also similar, if the number of cigarettes was included. However, a high cigarette consumption might change the association between blood pressure and smoking. Especially heavy smoking may have adverse atherosclerotic and thrombotic effects, leading to higher blood pressure levels [2, 33]. Secondly, smoking may lead to an increased sympathetic nerve activity which is linked with an elevated blood pressure [34]. In addition, a low intake of health-beneficial fruit and vegetables often seen among heavy smokers may place them at higher risk of vascular disease as compared with never smokers [35–37].

We observed that a high intake of fruit and vegetables is stronger associated with lower SBP and DBP values than a high intake of vitamin C among women, although the association with DBP was not significant. Among men, the relationship is less clear, but is similar to that of women. This might have important practical relevance to the dietary behavior of hypertensive patients. Future efforts in examining the underlying mechanisms for the observed associations are strongly recommended. Until there is sufficient evidence that vitamin C independently of other factors lowers blood pressure levels, a high fruit and vegetable intake rather than vitamin C supplementation would be appropriate to be considered a blood pressure lowering effort.

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