

Vitamin E status of 20- to 59-year-old adults living in the Seoul metropolitan area of South Korea

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BACKGROUND/OBJECTIVES: Vitamin E is a fat-soluble vitamin and functions primarily as a lipid antioxidant. Inadequate vitamin E status may increase risk of several chronic diseases. Thus, the objectives of this study were to estimate intake and plasma concentration of each tocopherol and to evaluate vitamin E status of Korean adults.

SUBJECTS/METHODS: Three consecutive 24-h food recalls and fasting blood samples were collected from healthy 20- to 59-year-old adults (33 males and 73 females) living in the Seoul metropolitan area, South Korea. α -, β -, δ -, and γ -tocopherol intakes and plasma concentrations of tocopherols (α -, δ -, and γ - tocopherol) were analyzed by gender.

RESULTS: Dietary vitamin E and total vitamin E intake (dietary plus supplemental vitamin E) was 17.68 ± 14.34 and 19.55 ± 15.78 mg α -tocopherol equivalents, respectively. The mean daily α -tocopherol, and γ -tocopherol intakes were 3.07 ± 2.27 mg and 5.98 ± 3.74 mg, respectively. Intakes of total vitamin E and each tocopherol of males were significantly higher than those of females ($P < 0.05$). Plasma α -tocopherol concentration was 15.45 ± 10.16 of males and 15.00 ± 4.54 $\mu\text{mol/L}$ of females, respectively. There were no significant differences in plasma tocopherol concentrations by gender ($P \geq 0.05$). Plasma α -tocopherol was negatively correlated with γ -tocopherol intake ($P < 0.05$). Twenty-three percent of the subjects had plasma α -tocopherol concentrations < 12 $\mu\text{mol/L}$ indicating a biochemical deficiency of vitamin E. Approximately 8% and 9% of these participants had plasma α -tocopherol:total lipid ratio less than 1.59 $\mu\text{mol/mmol}$ and plasma α -tocopherol:total cholesterol ratio less than 2.22 $\mu\text{mol/mmol}$, respectively, which are also indicative of vitamin E deficiency.

CONCLUSIONS: Vitamin E intakes of Korean adults were generally adequate with the Korean Dietary Reference Intakes for vitamin E. However, α -tocopherol intake was lower than that reported in other countries, and 23% of the subjects in the current study were vitamin E deficient based on plasma α -tocopherol concentrations.

Nutrition Research and Practice 2015;9(2):192-198; doi:10.4162/nrp.2015.9.2.192; pISSN 1976-1457 eISSN 2005-6168

Keywords: Vitamin E status, α -tocopherol, tocopherols, Korean adults

INTRODUCTION

Vitamin E is a general term describing the α -, β -, δ -, and γ -forms of tocopherol and tocotrienol chemical classes. Good sources of vitamin E are vegetable oils, nuts, egg yolk, margarine, wheat germ, and green leafy vegetables. As a chain-reaction breaking antioxidant, vitamin E prevents the propagation of lipid peroxidation, especially polyunsaturated fatty acids and other components of cell membranes and low-density lipoproteins (LDL) from oxidation by free radicals [1]. It is known that vitamin E deficiency is rare in humans in the developed countries, although it may occur in premature infants and in persons with a chronic malabsorption of fats. However, inadequate vitamin E status may increase risk of several chronic diseases [1]. Observational epidemiological studies have shown that inadequate vitamin E intake might be associated with risk of heart disease [2,3], type II diabetes, and certain types of cancer [4]. Therefore, vitamin E status in adults may be important for

preventing these diseases.

α -Tocopherol is a major form that represents over 90% of the total tocopherols present in plasma [5]. Additionally, tissue α -tocopherol concentrations reflect changes in plasma α -tocopherol levels [6]. The concentration of α -tocopherol in serum/plasma is therefore the most commonly used biochemical marker of vitamin E status. Vitamin E circulates in the blood mainly with LDL [7] and is highly correlated with total lipid level [8]. Thus, α -tocopherol:lipids ratio has also been used to assess vitamin E status.

Most studies on vitamin E have focused on α -tocopherol [6] because other tocopherols (β -, γ -, and δ -) and tocotrienols are not converted into α -tocopherol in the human body and fail to bind with α -tocopherol transfer protein (TTP) [9]. However, β -, γ -, and δ -tocopherols as well as all tocotrienols may also have important, but as yet unknown, physiological functions. γ -Tocopherol may have beneficial properties such as anti-inflammatory and possibly anti-atherogenic or anti-cancer

This research was financially supported by the research fund from the National Research Foundation of Korea (2009-0066047).

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Received: May 8, 2014, Revised: December 19, 2014, Accepted: December 19, 2014

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activities [10]. Recent research has indicated that tocotrienols may be effective for the prevention of cancer [11]. Plasma γ -tocopherol concentrations and plasma γ -tocopherol: α -tocopherol ratio have been reported to be an index for nutrition-related risks [12,13]. Although several studies reported plasma α -tocopherol concentration of Korean adults to evaluate vitamin E status [14-16], none of the studies investigated the intakes and plasma concentrations of each tocopherol.

Therefore, the objectives of the present study were to estimate α -, β -, δ -, and γ -tocopherol intakes and plasma concentrations of tocopherols (α -, δ -, and γ -tocopherols) along with lipids, and to assess the vitamin E status of 20- to 59-y-old Korean adults living in the Seoul metropolitan area of South Korea.

SUBJECTS AND METHODS

Subjects

One-hundred six adults aged 20-59 years living in the Seoul metropolitan area voluntarily participated in this study between June 2009 and January 2010. The subjects were recruited by an advertisement at a convenience sampling of universities, gyms, and welfare centers. Adults who were not in good health, had known illnesses, or took medications were excluded from the study. The Institutional Review Board of Duksung Women's University approved the study (2010-01) and informed consent was obtained from each subject. All interviews were conducted in Korean by a trained interviewer.

Measurements of nutrient and tocopherol intakes

A trained interviewer recorded three consecutive 24-hour food recalls (two weekdays and one weekend day). A computer-aided nutritional analysis program (Can-Pro 4.0) developed by the Korean Nutrition Society [17] was used in calculating intakes of macronutrients, saturated fatty acids, monounsaturated fatty acids, polyunsaturated fatty acids, cholesterol, and vitamin E. Because the Korean food composition table has reported vitamin E contents in foods only as α -tocopherol equivalent (α -TE) without each tocopherol content, the dietary intake of each α -, β -, δ -, and γ -tocopherol in this study was estimated using the values of the book, "Phytonutrient Contents in Vegetable/Fruits/Legumes," reporting tocopherol contents in plant foods [18], the values of tocopherols in some Korean foods [19,20], and the tocopherol values in the United States Department of Agriculture Food database [21]. The dietary intakes of vitamin E of the subjects were compared with the Adequate Intakes (AIs) for Korean [1]. Fifteen subjects (14.2%) took supplements containing vitamin E. Thus, the amounts of vitamin E consumed by the subjects in the current study were reported as dietary vitamin E (from foods only) and total vitamin E (dietary plus supplemental vitamin E) intake expressed as mg α -TE.

Blood lipid and tocopherol analyses

Venous blood samples (8-10 mL) were collected from the subjects in a vacutainer tube containing ethylenediamine-tetraacetic acid by a qualified phlebotomist. The samples were kept in crushed ice and were protected from light throughout handling and processing. Blood samples were centrifuged at

3,000 rpm at 5°C for 10 minutes, and then plasma was frozen at -70°C until analysis. The standards for α -, δ -, and γ -tocopherols were purchased from Sigma Aldrich (St. Louis, MO, US). All reagents purchased and used in this study were high-performance liquid chromatography (HPLC) grade. Plasma concentrations of tocopherols were analyzed by HPLC method by Giraud *et al.* [22]. The HPLC system consisted of two 515 pumps, 710 auto injector, 2487 dual λ absorbance detector (Waters Associates, Inc., Milford, MA, US), and a C18 reversed-phase HPLC column (201 TP54, Vydac, Columbia, MD, US, 25 cm x 4.6 mm, 5 μ m particle size). A wavelength of 290 nm was used for the determination of tocopherols. Minimum detectable levels were 5.15 ng for α -tocopherol, 5.25 ng for δ -tocopherol, and 4.18 ng for γ -tocopherol. Percent recoveries of tocopherols ranged 92-94%. Reproducibility was measured by analyzing one plasma sample in duplicate when each time samples were analyzed and the coefficients of variance were < 8% for each tocopherol. All plasma samples were extracted in duplicate. Plasma triglyceride was analyzed with a commercial kit based on the Trinder method (Youngdong Pharmaceutical Co., Seoul, Korea). Total cholesterol and high-density lipoprotein (HDL)-cholesterol were analyzed with commercial kits based on enzymatic methods (Youngdong Pharmaceutical Co., Korea).

Statistical analysis

Data were analyzed by gender using SAS version 9.1.3 software (SAS Institute, Inc., Cary, NC, US). Differences in all variables between males and females were analyzed using a *t*-test. Multiple linear regression analysis was performed to determine the association of plasma tocopherols with vitamin E intake and plasma concentrations after adjusting for age, gender, body mass index (BMI), energy intake, fat intake, and plasma levels of total cholesterol and triglycerides. Logarithmic transformation of plasma tocopherol and lipid concentrations was performed before the analysis to normalize the distributions. Results were considered statistically significant at $P < 0.05$. Differences were considered significant at $P < 0.05$. Values are reported as mean \pm standard deviation.

RESULTS

General characteristics of the study subjects

Healthy Korean adults (33 males and 73 females) living in the Seoul metropolitan area participated in this study. The subjects reported that they were in good health, had no known illnesses, and had good appetites. The majority of the subjects reported that the recorded dietary intakes were typical. The mean age of all subjects was 33.4 ± 10.6 years and there was no significant difference by gender ($P \geq 0.05$).

Nutrient intake and plasma lipid analysis

The mean energy intake of all subjects was $1,833.5 \pm 427.1$ kcal. Mean dietary fat intakes of the subjects in the present study were as follows: total fat, 57.8 ± 17.0 g/day; saturated fatty acid, 9.2 ± 5.4 g/day; monounsaturated fatty acid, 10.2 ± 5.4 g/day; and polyunsaturated fatty acid, 8.4 ± 3.4 g/day. The males in this study had a higher mean energy and macronutrient intake than females ($P < 0.05$). No significant differences in plasma

Table 1. General characteristics of 106 adults aged 20-59 years living the Seoul metropolitan area, South Korea

	Males (n = 33)	Females (n = 73)	Total (n = 106)	P-value
Age (yrs)	29.6 ± 7.9	34.9 ± 11.0	33.6 ± 10.7	0.0002
Height (cm)	173.3 ± 6.5	160.3 ± 4.7	164.4 ± 8.1	< 0.0001
Weight (kg)	69.4 ± 8.8	57.9 ± 6.7	61.5 ± 9.7	< 0.0001
Body mass index (kg/m ²)	23.1 ± 2.7	22.5 ± 23.2	22.7 ± 2.9	0.3454
Nutrient intake				
Energy (kcal/day)	2,240.0 ± 432.8	1,648.0 ± 265.8	1,833.5 ± 427.1	0.0006
Carbohydrate (g/day)	286.7 ± 62.6	222.2 ± 49.6	242.3 ± 61.5	< 0.0001
Protein (g/day)	98.4 ± 32.5	71.5 ± 15.5	79.9 ± 25.3	< 0.0001
Total fat (g/day)	69.6 ± 18.1	52.4 ± 13.4	57.8 ± 17.0	< 0.0001
Saturated fatty acid (g/day)	11.5 ± 4.6	8.1 ± 5.4	9.2 ± 5.4	0.0025
Monounsaturated fatty acid (g/day)	12.5 ± 4.0	9.2 ± 5.6	10.2 ± 5.4	0.0010
Polyunsaturated fatty acid (g/day)	10.2 ± 3.7	7.7 ± 3.0	8.4 ± 3.4	0.0003
Cholesterol (mg/day)	371.6 ± 207.6	293.8 ± 182.7	318.0 ± 193.2	0.0545
Lipid analysis				
Triglyceride (mg/dl)	123.7 ± 73.9	102.7 ± 48.2	109.3 ± 57.9	0.1429
Total Cholesterol (mg/dL)	183.9 ± 36.2	191.2 ± 39.6	188.9 ± 38.5	0.3729
HDL-Cholesterol (mg/dL)	42.6 ± 13.5	45.9 ± 13.8	44.9 ± 13.7	0.2591

Means ± SD.

** $P < 0.01$, *** $P < 0.001$ **Table 2.** Vitamin E intake and plasma concentrations of tocopherols of 106 adults aged 20-59 years living the Seoul metropolitan area, South Korea

	Males (n = 33)	Females (n = 73)	Total (n = 106)	P-value
Vitamin E intakes				
α -tocopherol (mg/day)	4.21 ± 2.22	2.56 ± 2.11	3.07 ± 2.27	0.0007
β -tocopherol (mg/day)	0.16 ± 0.09	0.11 ± 0.07	0.13 ± 0.08	0.0034
γ -tocopherol (mg/day)	8.01 ± 4.53	5.07 ± 2.93	5.98 ± 3.74	0.0013
δ -tocopherol (mg/day)	2.39 ± 1.35	1.46 ± 0.91	1.75 ± 1.14	< 0.0001
Dietary vitamin E ¹⁾ (mg α -TE ²⁾ /day)	23.15 ± 23.81	15.21 ± 5.32	17.68 ± 14.34	0.0668
Total vitamin E ³⁾ (mg α -TE/day)	25.39 ± 25.00	16.91 ± 7.94	19.55 ± 15.78	0.0437
Plasma measurements				
α -tocopherol (μ mol/L)	15.45 ± 10.16	15.00 ± 4.54	15.14 ± 6.84	0.8108
δ -tocopherol (μ mol/L)	0.29 ± 2.15	0.26 ± 0.13	0.27 ± 0.18	0.4121
γ -tocopherol (μ mol/L)	2.15 ± 2.72	1.30 ± 0.63	1.56 ± 1.66	0.0137
α -tocopherol/total lipid (μ mol/mmol)	2.51 ± 1.16	2.48 ± 0.62	2.51 ± 1.16	0.7045
α -tocopherol/Tcho ⁴⁾ (μ mol/mmol)	3.13 ± 1.50	3.06 ± 0.77	3.13 ± 1.50	0.6001

Means ± SD.

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

1) Vitamin E from food alone

2) Tocopherol equivalent

3) Dietary plus supplemental vitamin E intake

4) Total cholesterol

concentrations of triglyceride, total cholesterol, and HDL-cholesterol were observed by gender (Table 1).

Vitamin E intake and plasma tocopherol concentrations

Vitamin E intake and plasma concentrations of tocopherols are shown in Table 2. The mean α -tocopherol intake of the subjects was 3.07 ± 2.27 mg/day, and dietary vitamin E intake (from food alone) was 17.68 ± 14.34 mg α -TE/day. Total vitamin E intake (dietary plus supplemental vitamin E) was 19.55 ± 15.78 mg α -TE/day. Tocopherol and vitamin E intakes of male subjects were significantly higher than those of female subjects. The mean plasma concentration of α -tocopherol and γ -tocopherol was 15.13 ± 6.84 μ mol/L and 1.56 ± 1.66 μ mol/L, respectively. There were no significant differences in plasma tocopherol

concentrations by gender, except γ -tocopherol level. The mean γ -tocopherol concentration of males was significantly higher than that of females ($P < 0.05$). In all subjects, 12.3% consumed vitamin E less than the AIs for vitamin E (data not shown).

Association of plasma tocopherols with tocopherol intake and plasma lipid levels

The relationships of plasma tocopherols with vitamin E intake and plasma lipids are shown in Table 3. Plasma α -tocopherol was negatively correlated with γ -tocopherol intake, but there was no significant association of plasma α -tocopherol with dietary vitamin E intake. Plasma δ -tocopherol was significantly associated with γ -tocopherol and total vitamin E intakes. Plasma α -tocopherol concentration had a strong positive association

Table 3. Linear regression analysis of plasma tocopherols and vitamin E intakes/plasma measurements of 106 adults aged 20-59 years living the Seoul metropolitan area, South Korea

	Plasma concentration								
	Log _e (α-tocopherol)			Log _e (γ-tocopherol)			Log _e (δ-tocopherol)		
	slope	SE ¹⁾	P-value ²⁾	slope	SE	P-value	slope	SE	P-value
Vitamin E intake									
Log _e (α-tocopherol)	-0.02424	0.02555	0.3450	-0.02381	0.04713	0.6145	0.07021	0.05214	0.1812
Log _e (β-tocopherol)	-0.06494	0.04219	0.1270	-0.8247	0.07807	0.2934	0.13981	0.08640	0.1088
Log _e (γ-tocopherol)	-0.10325	0.04655	0.0288	0.00644	0.08770	0.9416	0.20459	0.09559	0.0348
Log _e (δ-tocopherol)	-0.06380	0.03639	0.0827	0.04015	0.06783	0.5553	0.17524	0.07368	0.1812
Log _e (dietary vitamin E)	-0.02424	0.02555	0.3450	0.02381	0.04713	0.6143	-0.00081	0.04779	0.9865
Log _e (total vitamin E)	-0.05050	0.02274	0.0287	0.06294	0.04238	0.1407	0.88293	0.18693	< 0.0001
Plasma measurements									
Log _e (α-tocopherol)	-	-	-	0.93386	0.15999	< 0.0001	0.55613	0.09764	< 0.0001
Log _e (γ-tocopherol)	0.27624	0.04733	< 0.0001	-	-	-	0.55613	0.09764	< 0.0001
Log _e (δ-tocopherol)	0.21003	0.04447	< 0.0001	0.44723	0.07852	< 0.0001	-	-	-
α-tocopherol/Total lipid	0.21722	0.01122	< 0.0001	0.24275	0.03811	< 0.0001	0.21434	0.04566	< 0.0001
α-tocopherol/Tcho ³⁾	0.16999	0.00849	< 0.0001	0.18329	0.02996	< 0.0001	0.16735	0.03545	< 0.0001
Log _e (triglyceride)	0.00012	0.00053	0.8168	-0.00104	0.00098	0.2917	0.00024	0.00110	0.8274
Log _e (total cholesterol)	0.00331	0.00081	0.0001	0.00341	0.00150	0.0257	0.00424	0.00167	0.0127
Log _e (HDL-cholesterol)	0.00171	0.00226	0.4498	0.00234	0.00394	0.5541	0.00065	0.00440	0.8814

¹⁾ Standard error

²⁾ P-values for linear regression are adjusted for age, gender, BMI, energy intake, fat intake, and plasma total cholesterol and triglyceride.

³⁾ Total cholesterol

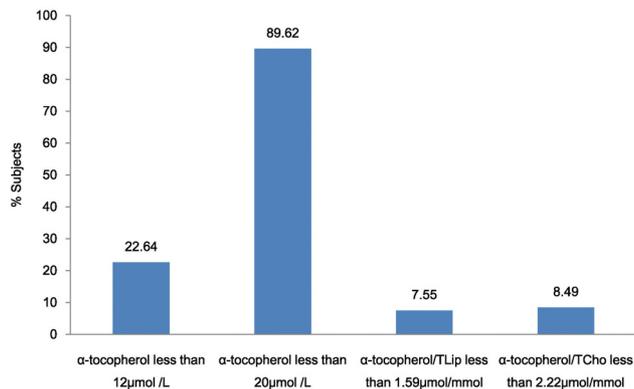


Fig. 1. Percentages of South Korean adults with a vitamin E deficiency. TLip: plasma total lipid and TChol: plasma total cholesterol concentration

with plasma γ-tocopherol and δ-tocopherol concentrations. All of plasma tocopherols increased with increasing plasma total cholesterol. However, there were no significant relationships of plasma tocopherols with other plasma lipids.

Assessment of vitamin E status

The percentages of the subjects with a vitamin E deficiency are presented in Fig. 1. Plasma α-tocopherol concentrations of 22.6% of the subjects were < 12 μmol/L, indicating a biochemical deficiency of vitamin E in adults [5,23]. However, 89.6% of the subjects had α-tocopherol levels < 20 μmol/L, which is selected more conservative cutoff because of the apparent increased risk of cardiovascular disease below this concentration [24,25]. Plasma α-tocopherol:total lipid ratios that are > 1.59 μmol/mmol [8] and plasma α-tocopherol:total cholesterol ratios > 2.22 μmol/mmol [23,26] are thought to indicate

adequate vitamin E status. Only less than 10% of the subjects had inadequate vitamin E status based on the ratios of plasma α-tocopherol:total lipid or total cholesterol.

DISCUSSION

This study determined dietary intakes and plasma concentrations of α-, β-, δ-, and γ-tocopherols, and determined the vitamin E status of 20-59 year-old adults in the Seoul metropolitan area in South Korea. Energy intakes of the male and female subjects in this study were in line with the intakes reported in the Forth Korean National Health and Nutrition Examination Survey (KNHANES IV) (n = 969) [27]. The carbohydrate intake in the current study was lower than those of KNHANES IV, but fat intake was higher than that of KNHANES IV, although the protein intakes of both were similar. In this study, the subjects consumed 54.3% energy from carbohydrate, 17.4% from protein, and 28.3% from fat, which is lower in carbohydrate intake but higher in fat intake compared the Acceptable Macronutrient Distribution Ranges of Dietary Reference Intakes (DRIs) for Koreans [1]. High fat intake is associated with an increased risk of dyslipidemia, obesity, diabetes, and cardiovascular disease. Blood lipid concentrations are affected by fat intake along with the consumption of other nutrients and lifestyle. In the present study, total plasma total cholesterol was negatively correlated with monounsaturated fatty acids ($r = -0.20671$, $P = 0.0335$) and positively correlated with saturated fatty acids ($r = 0.19173$, $P = 0.0490$). However, no association was detected between total fat intake and blood lipid levels (data not shown). Additionally, the mean concentrations of plasma triglyceride and total cholesterol were within normal ranges. However, 19.8% and 34.0% in all subjects had

high triglyceride (≥ 150 mg/dL) and high total cholesterol levels (≥ 200 mg/dL), respectively. Thus, nutrition education for the adults living in the Seoul metropolitan area, Korea, may be needed to emphasize the adequate amount of fat intake and reduced saturated fat intake.

A study conducted by Kim *et al.* [16] reported 12.4 mg α -TE/day consumed by Korean male subjects ($n = 314$), and Shim *et al.* [28] and Oh *et al.* [29] reported vitamin E intakes of Korean male and female subjects as 9.74 ($n = 208$) and 9.5 mg α -TE/day ($n = 72$), respectively. In the KNHANES IV 2007-2008, 20-64 year-old men and women consumed dietary vitamin E of 9.2-12.7 mg α -TE/day and 6.7-9.8 mg α -TE/day, respectively [30]. In the current study, the mean dietary vitamin E intake (17.68 ± 14.34 mg α -TE/day) was higher than those of these Korean adults, which may be due to high energy intake from fats as indicated previously. However, vitamin E intake of this study is in line with the intake of European adults (11.9 mg α -TE/day) reported in the European Prospective Investigation into Cancer and Nutrition study [31].

This study is the first report on the dietary intake of tocopherols of a group of Korean adults. In the Korean food composition table revised in 2006, vitamin E content is expressed as mg α -TE without accounting for each tocopherol content like previous revisions of the table. [32]. Thus, studies regarding the intake of each tocopherol in South Korean adults have been limited. The α -tocopherol intake reported in this study (3.07 mg/day) was much lower than those of the adults in other countries [33,34]. Japanese adults reported a daily α -tocopherol intake of 6.6-7.1 mg [33], and American adults indicated an α -tocopherol intake of 5.9 - 8.8 mg according to the 2003-2006 National Health and Nutrition Examination Survey (NHANES) US [34]. γ -Tocopherol intake observed in the present study was lower, but δ -tocopherol intake was similar compared to the intake of African American adults [35].

Currently, two units of vitamin E are used for vitamin E recommendation; mg α -TE and mg α -tocopherol. Vitamin E intake recommendations for US/Canadians, Japanese, and Filipinos are based only on α -tocopherol because other tocopherols (β -, γ -, and δ -) and tocotrienols are not converted into α -tocopherol in the body and fail to bind with α -TTP [1]. However, vitamin E recommendations [1] and contents of foods [32] in South Korea are expressed as α -TE. Factors for the conversion of tocopherols and tocotrienols into α -TE units are based on the biological activity of the various forms as determined by the rat fetal resorption assay. The Korean Nutrition Society reported that there was insufficient evidence to set Estimated Average Requirements (EARs) for vitamin E; thus, AIs were established for vitamin E [1]. EARs are nutrient intake values that are estimated to meet the median requirement of healthy individuals in a particular life-stage group. AIs are recommended intake values based on observed or experimentally determined approximations or estimations of nutrient intake by groups of healthy people that are assumed to be adequate. The AIs for Korean males and females are 12 mg α -TE and 10 mg α -TE, respectively [1]. The Japanese recommendations for vitamin E have set as AIs, 7.0 mg α -tocopherol for males and 6.5 α -tocopherol for females [33]. In the current study, 12% of the subjects had inadequate vitamin E intake measured as mg α -TE

that fell below the recommended Korean AIs. However, only 9.4% of the subjects consumed vitamin E (α -tocopherol) more than the Japanese AIs. γ -Tocopherol intake of the adults in the current study was much higher than α -tocopherol intake, which contributed to the vitamin E intake expressed as mg α -TE. Thus, if only α -tocopherol is considered vitamin E, the vitamin E intake of many Korean adults in this study may be inadequate.

Shim *et al.* [28] reported that South Korean adults ($n = 208$) had a mean serum α -tocopherol concentration of 1.17 mg/dL ($27.17 \mu\text{mol/L}$) in 2001. Another study conducted in 2000-2004 reported that 304 Korean males had 1936 $\mu\text{g/dL}$ ($44.95 \mu\text{mol/L}$) [15]. Mean plasma α -tocopherol concentration of 72 South Korean adults and 356 Korean middle-aged adults recruited in 2004-2005 was 1.08 mg/dL ($25.08 \mu\text{mol/L}$) [29] and 0.81 mg/dL ($18.80 \mu\text{mol/L}$) [36], respectively. In the current study, the subjects recruited in 2009-2010 had 15.14 $\mu\text{mol/L}$ of mean plasma α -tocopherol concentration. Although the study populations of each investigation were recruited from different areas of South Korea, the α -tocopherol concentration of South Korean adults seems to be decreasing year after year. Recently, Japanese adults ($n = 206$) were found to have a median serum α -tocopherol concentration of 6.5 mg/L ($15.09 \mu\text{mol/L}$) [32], which is similar to the level observed in the present study. The mean plasma γ -tocopherol level of all subjects in the current study was 1.56 $\mu\text{mol/L}$, which is more than two times lower than γ -tocopherol value reported in Korean middle-aged adults [36] but similar to that (1.16 $\mu\text{mol/L}$) of Japanese adults [32].

The α -tocopherol concentration is the most commonly used biochemical marker of vitamin E status [23]. The recommended plasma α -tocopherol concentration for adults is above 12 $\mu\text{mol/L}$ [1]. In the present study, 22.64% of the subject had plasma α -tocopherol concentrations below 12 $\mu\text{mol/L}$. In Korean middle-aged adults, 11.6% were vitamin E deficient [36]. Plasma α -tocopherol concentrations $< 20 \mu\text{mol/L}$ were classified as "low" based on the NHANES III, US, by Ford and Sowell [37]. This conservative cutoff value was selected because of the apparent increased risk of cardiovascular disease associated with levels below this concentration [24,25]. In the present study, the majority of subjects (89.62%) had plasma α -tocopherol concentrations $< 20 \mu\text{mol/L}$.

Since plasma α -tocopherol is highly dependent upon circulating blood lipids [38], plasma α -tocopherol concentration can be misleading for assessing vitamin E status, especially in subjects with abnormally high or low lipid concentrations [39]. Therefore, plasma α -tocopherol:total lipid ratio of 1.59 $\mu\text{mol/mmol}$ (0.8 mg/g) is also used as an indicator of vitamin E status [8]. In the current study, only 7.55% had plasma α -tocopherol:total lipid ratio indicative of vitamin E inadequacy. In the NHANES III, US, serum cholesterol was one of the strongest predictors of serum α -tocopherol concentration [39]. In the current study, there was a significant positive correlation between plasma α -tocopherol and only total cholesterol among blood lipids. As a result, plasma α -tocopherol:total cholesterol ratio is now the preferred measurement of vitamin E status [23]. Plasma α -tocopherol:total cholesterol ratio that is less than 2.2 $\mu\text{mol } \alpha$ -tocopherol/mmol cholesterol is thought to indicate an adequate vitamin E status, and lower ratios have been associated with erythrocyte hemolysis after exposure [26]. In

all subjects of the current study, 8.49% had the ratios below 2.2 $\mu\text{mol}/\text{mmol}$.

Several epidemiologic studies have indicated a positive relationship between vitamin E intake and plasma α -tocopherol concentration [40,41], but the association was mostly driven by supplement use. In the present study, only 14% of the subjects took supplements containing vitamin E; therefore, no clear correlation might be observed between intake and plasma concentrations of tocopherols. Plasma α -tocopherol was positively correlated with plasma γ - and δ -tocopherols, and plasma γ - and δ -tocopherols also had a strong positive association with plasma total cholesterol in this study. Therefore, people having high α -tocopherol level may be considered to have high γ - and δ -tocopherol concentrations. Moreover, plasma total cholesterol should be taken into account in evaluating plasma γ - and δ -tocopherol levels.

γ -Tocopherol is the predominant form of vitamin E found in food. γ -Tocopherol intake was two times higher than α -tocopherol intake, while the concentration of α -tocopherol in blood was ten times higher than that of γ -tocopherol in the present study. Hepatic α -TPP has the greatest affinity for α -tocopherol compared to γ -tocopherol and is crucial for the relative percentage of transport of various vitamin E forms in plasma lipoproteins. High intake of α -tocopherol may reduce intestinal absorption, cell membrane transport, and utilization of other forms of tocopherols, especially γ -tocopherol [42]. Furthermore, γ -tocopherol intake was negatively associated with plasma α -tocopherol [9]. Thus, some studies indicated that plasma γ -tocopherol was inversely related to plasma α -tocopherol [13,43]. However, a study by Bates *et al.* [12] reported to a positive correlation between plasma α -tocopherol and γ -tocopherol concentrations. In the current study, plasma α -tocopherol decreased with an increased γ -tocopherol intake but increased with elevated plasma γ -tocopherol concentrations. Thus, further research is needed to investigate the association between intakes and plasma concentrations of tocopherols for Koreans because vitamin E intake of Koreans is mostly based on γ -tocopherol.

Several studies indicated that plasma γ -tocopherol and plasma γ -tocopherol: α -tocopherol ratio were inversely related to healthy food choices [12,13,25] and antioxidant status in humans [43]. However, it has been recently recognized that γ - and δ -tocopherols have strong anti-nitrative and anti-inflammatory actives as well as anti-thrombotic effects [11,13], which may be effective for preventing cancer as well as cardiovascular and neurodegenerative diseases. Currently, there are no databases for recording the intakes and plasma levels of γ - and δ -tocopherols for Korean adults and no recommendations or cut-off values for γ -tocopherol and δ -tocopherol.

In this study, vitamin E intakes of Korean adults were generally adequate compared with the Korean DRIs for vitamin E. However, α -tocopherol intake was lower than those of other countries. Assuming that only α -tocopherol is considered to be vitamin E, the intake of many subjects in the present study may be inadequate. Although about 7-8% of the subjects had vitamin E deficiency by ratios of plasma α -tocopherol: blood lipids, approximately 23% of the subjects were in vitamin E deficient status. Therefore, research regarding the bioavailability

of tocopherols and tocotrienols in South Koreans is needed to determine whether the current vitamin E unit in South Korea is appropriate. Additionally, consumption of vitamin E-rich food sources by some adult South Koreans should be encouraged.

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