Vitamin E Inhibits Collagen-Induced Platelet Activation by Blunting Hydrogen Peroxide

Pasquale Pignatelli, Fabio M. Pulcinelli, Luisa Lenti, Pier Paolo Gazzaniga, Francesco Violi

Abstract—In this study, we investigated whether vitamin E at concentrations achievable in blood after supplementation inhibits platelet function in humans. Gel-filtered platelets were incubated 30 minutes with scalar concentrations (50 to 250 mmol/L) of vitamin E and then stimulated with collagen. Compared with controls, vitamin E inhibited collagen-induced platelet aggregation and thromboxane A2 formation in a dose-dependent manner. Furthermore, vitamin E inhibited, in a dose-dependent manner, Ca\textsuperscript{2+} mobilization and formation of inositol 1,4,5-triphosphate. Because it was previously shown that hydrogen peroxide formation mediates arachidonic acid metabolism and phospholipase C activation in collagen-induced platelet activation, we investigated whether vitamin E was able to blunt hydrogen peroxide. In experiments performed in unstimulated platelets supplemented with hydrogen peroxide and in collagen-stimulated platelets, vitamin E was able to blunt hydrogen peroxide. In 6 healthy subjects given vitamin E for 2 weeks (600 mg/d), we found a significant decrease of collagen-induced H\textsubscript{2}O\textsubscript{2} formation, platelet aggregation, and calcium mobilization. This study demonstrated in vitro and ex vivo that vitamin E inhibits collagen-induced platelet activation by blunting hydrogen peroxide formation. (Arterioscler Thromb Vasc Biol. 1999;19:2542-2547.)

Key Words: antioxidants • platelet aggregation • arachidonic acid metabolism • phospholipase C enzyme • thromboxane A2

Use of antioxidants to prevent coronary heart disease is based on the assumption that atherosclerosis progression is determined by oxidative modification of LDL, which is then taken up by macrophages of atherosclerotic plaque. Among antioxidants, vitamin E has been widely investigated to assess its clinical effectiveness. In healthy subjects, dietary vitamin E consumption has been associated with fewer cardiovascular events. In patients with angiographically proven coronary heart disease, 400 to 800 mg/d vitamin E significantly reduced the rate of nonfatal myocardial infarction over 2 years of follow-up. These data have not been confirmed by other studies, such as that of Rapola et al; however, in that study, daily administration of vitamin E was only 50 mg. Despite these contradictory results, additional studies have been conducted to assess whether vitamin E has biological properties that could prevent progression of atherosclerosis.

Several in vitro and in vivo studies have analyzed whether vitamin E inhibits platelet function. Recent studies demonstrated that vitamin E supplementation in healthy subjects or patients with hypercholesterolemia diminishes platelet function, as assessed by ex vivo platelet aggregation and urinary excretion of 11-dehydro-thromboxane B2, a marker of in vivo platelet activation. Inhibition of platelet function was dependent on the daily dose of vitamin E, indicating that plasma and platelet vitamin E concentrations are crucial for the inhibition of platelet function. These data seem to contradict those of in vitro studies, in which higher concentrations of vitamin E (0.5 to 1 mmol/L) than observed in plasma after supplementation were necessary to inhibit human platelet activity. To analyze this discrepancy, we performed an in vitro study using collagen as the platelet agonist. Collagen is an important platelet agonist thought to be involved in the early stages of platelet activation during both hemostasis and thrombosis. We recently demonstrated that collagen-induced platelet aggregation is associated with a burst of hydrogen peroxide, an oxidant species that contributes to activation of platelets. Because vitamin E is an antioxidant, we speculated that collagen-induced platelet aggregation may represent an interesting model to further analyze the relationship between vitamin E and platelet function. We found that a concentration of vitamin E very close to that found in human plasma after supplementation is able to inhibit collagen-induced platelet activation by blunting hydrogen peroxide formation.

Methods

Materials

\textsuperscript{3}Pi was from Amersham. Fura 2-AM and 2\textsuperscript{7}-dichlorofluorescein diacetate (DCFH-DA) were from Molecular Probes, and Sepharose 2B was from Pharmacia. Collagen, type 1, was from Semmelweis.

High-performance liquid chromatography (HPLC) columns (Partisol
10 SAX) were from Whatman, BSA, HEPES, acetylsalicylic acid, α-tocopherol (vitamin E), fibrinogen, inorganic pyrophosphatase, acid/citrate/dextrose, digitonin, EGTA, EDTA, Tris, perchloric acid, formaldehyde, indomethacin, ammonium formate, maleic acid, creatine phosphate, and creatine phosphokinase were from Sigma Chemical Co.

Platelet Preparation

Human blood was obtained from drug-free healthy volunteers and anticoagulated with acid/citrate/dextrose. Platelet-rich plasma, obtained by centrifugation (15 minutes at 180g), was recentrifuged (20 minutes at 800g) to concentrate the platelets, and the pellet was resuspended in a 0.5 vol of autologous platelet-poor plasma. Platelet suspensions were incubated for 1 hour at 37°C with Fura 2-AM (3 mmol/L of cell suspension), DCFH-DA (40 mmol/L), or 32P (2 mCi/mL).

Platelets were separated from plasma proteins and from excess Fura 2-AM and 32P by gel filtration on Sepharose 2B using Ca2+ (3 mmol/L of cell suspension), DCFH-DA (16–18), which rapidly diffuses across cell membranes and is trapped within the cell by a deacetylation reaction. In the presence of hydrogen peroxide, this compound is oxidized to dichlorofluorescein (DCF) fluorescence (at 510 to 520 nm). Fluorescent parameters (expressed in arbitrary units [au]) were determined by using thromboxane B2 ELISA kits (Boehringer Mannheim GmbH). According to results of our previous study, the collagen concentrations that gave reproducible values varied on the basis of the test used, ie, a higher concentration of collagen was necessary to induce inositol 1,4,5-triphosphate (IP3) formation compared with platelet aggregation tests. To serve as controls, GPs were incubated with the dilution medium in all experiments.

Flow Cytometric Analysis

Platelet-rich plasma was recentrifuged (800g for 20 minutes) to concentrate the platelets, and the pellet was resuspended in PBS. DCFH-DA (8 mL/mL; 5-mmol/L concentration) was added, and after 15 minutes of incubation, the platelet suspension was washed twice and resuspended in Tyrode’s buffer at a final concentration of 2×10^7 cells/mL. The platelet preparation was activated with collagen, added with or without vitamin E, and the reaction was stopped after 10 minutes after gel filtration. Inositol peaks were detected with a dual-channel (H−3P) HPLC radioactivity detector (Flo-One A100 Radiomatic, Camerra Co) that used [H−]inositol 1,3,4-triphosphate as the pure standard.4

Ex Vivo Study

In 6 healthy volunteers (3 men and 3 women; age, 30 to 48 years), collagen-induced platelet H2O2 formation, platelet aggregation, calcium mobilization, and vitamin E plasma levels were measured before and after 2 weeks of oral vitamin E supplementation (600 mg/d). Collagen-induced platelet activation was analyzed by using the methods described above; all experiments were performed within 10 minutes after gel filtration. The plasma concentration of vitamin E was measured by HPLC according to the method of Bieri et al. A flow rate of 2.0 mL/min was used on an octadecilica C18 (ODS) 5 μm with a LC/233 diode array detector (Restek Corp) set at 0.02 to 0.1 attenuation.

Statistical Analysis

Data are reported as mean±SEM. Comparisons between variables were analyzed by Student’s t test for paired and unpaired data. Significance was set at P<0.05.

Results

In Vitro Study

Flow Cytometric Analysis

The flow cytometric method uses the properties of DCFH-DA, which rapidly diffuses across cell membranes and is then trapped within the cell by a deacetylation reaction. In the presence of hydrogen peroxide, this compound is oxidized to DCF, which is highly fluorescent. Figure 1 shows the DCF green fluorescence distribution of unactivated platelets (31±2.8 au, Figure 1A). The largest increase of DCF fluorescence occurred with 0.1 mmol/L H2O2 (74.1±4.3 au, P<0.01 versus control, Figure 1B). Collagen-induced platelet activation doubled the shift of DCF fluorescence in comparison to unstimulated platelets (65.0±7 au, P<0.02 versus control, Figure 1C). Vitamin E inhibited the shift of DCF fluorescence induced by collagen in a concentration-dependent manner (with 50 μmol/L, DCF fluorescence=43±7 au, P<0.05 versus collagen alone, Figure 1D; with 125 μmol/L, 28.8±3 au, P<0.05 versus collagen alone, Figure 1E; and with 250 μmol/L, 24±3 au, P<0.003 versus collagen alone, Figure 1F).

To investigate the mechanism underlying such effects, we analyzed whether vitamin E was able to quench H2O2 in a system containing unactivated platelets. As shown in Figure 2, we found that vitamin E
quenched up to $1 \times 10^{-4}$ mmol/L H$_2$O$_2$. The fact that collagen induced a fluorescence shift lower than that induced by $1 \times 10^{-1}$ mmol/L H$_2$O$_2$ might suggest that in vitamin E-treated platelets stimulated with collagen, the decrease of fluorescence is due to a direct interaction between vitamin E and H$_2$O$_2$ produced by platelets.

**Platelet Aggregation**

Inhibition of platelet aggregation by vitamin E was closely dependent on incubation time, with $>50\%$ inhibition observed after at least 15 minutes of incubation (Figure 3). More than 80% inhibition was observed after 30 minutes of incubation; therefore, in the following experiments, platelets were incubated with vitamin E for 30 minutes before collagen was added. We found that vitamin E inhibited collagen-induced platelet aggregation depending on the concentration used. A 50-μmol/L concentration of vitamin E significantly inhibited platelet aggregation; almost complete inhibition of platelet aggregation was observed with 250 μmol/L (Figure 4). No inhibition was observed in adenosine diphosphate, arachidonic acid, U46619, or thrombin-activated platelets (data not shown).

**Platelet Thromboxane A2 Formation**

Collagen-induced thromboxane A2 formation was inhibited in a dose-dependent manner by vitamin E (Figure 5). A 10-μg/mL concentration of collagen produced 67±7 ng/mL thromboxane A2, which was reduced to 35±3 ng/mL ($P<0.05$), 19±10 ng/mL ($P<0.01$), and 11±3 ng/mL ($P<0.01$) by 50, 125, and 250 μmol/L vitamin E, respectively.

**Changes in Intracellular Calcium Concentration**

Percentages of change in intracellular calcium concentration induced by collagen in control GFPs and GFPs treated with

![Figure 1. Results of flow cytometric evaluation of H$_2$O$_2$ production in DCFH-DA–loaded platelets. A, Fluorescence peak of unstimulated platelets. B, Shift of fluorescence after incubation with H$_2$O$_2$ (0.1 mmol/L). C, Shift induced by collagen (10 μg/mL). D, E, and F, Effects of the same dose of collagen in GFPs treated with 50, 125, and 250 μmol/L vitamin E, respectively. Results are from 1 representative experiment of 5.](http://atvb.ahajournals.org/)

![Figure 2. Mean DCF fluorescence after incubation with scalar doses of H$_2$O$_2$ (1 to $1 \times 10^{-6}$ mmol/L) in platelets pretreated with (- - - -) or without (——) 250 μmol/L vitamin E. Results are mean±SEM of 5 experiments. Differences between untreated platelets and those treated with 250 μmol/L vitamin E were calculated with Student's t test for paired data. *$P<0.01$; **$P<0.005$; ***$P<0.001$.](http://atvb.ahajournals.org/)

![Figure 3. Platelet aggregation in collagen-activated (2 μg/mL) platelets treated with 125 μmol/L vitamin E decreased in a time-dependent manner. Data are mean±SEM of 5 experiments. *$P<0.01$. ns indicates not significant.](http://atvb.ahajournals.org/)
vitamin E (50 to 250 μmol/L) are reported in Figure 6. In samples stimulated with collagen (2 μg/mL), vitamin E inhibited intracellular calcium mobilization in a dose-dependent manner.

PLC Activation
Production of 32P-labeled inositol 1,3,4-triphosphate by collagen-stimulated platelets (12 μg/mL), added with and without vitamin E, is shown in Figure 7. Collagen-induced formation of inositol 1,3,4-triphosphate was inhibited by vitamin E in a dose-dependent manner.

Ex Vivo Study
In 6 healthy subjects given vitamin E, the plasma concentration of vitamin E rose from 19.0 ± 3.1 to 75.0 ± 8.4 μmol/L (P, 0.05). After vitamin E supplementation, we observed a significant decrease of collagen-induced platelet H2O2 formation, platelet aggregation, and calcium mobilization (Table).

Discussion
This study showed that a concentration of vitamin E as low as 50 μmol/L is able to inhibit collagen-induced platelet activation by interfering with arachidonic acid metabolism and the PLC pathway. We recently demonstrated that during platelet aggregation by collagen, there is a burst of hydrogen peroxide that amplifies the platelet response to the agonist.10 Thus, hydrogen peroxide stimulated arachidonic acid metabolism, contributing to platelet production of thromboxane A2; in addition, hydrogen peroxide stimulated IP3 formation and Ca2+ mobilization. In this experimental model, vitamin E inhibited platelet thromboxane as well as IP3 formation and Ca2+ mobilization, suggesting that it influences both arachidonic acid metabolism and the PLC pathway. The inhibition of platelet function by vitamin E was due to its interaction with hydrogen peroxide. Thus, in experiments performed by incubating unstimulated platelets with scalar concentrations of hydrogen peroxide, vitamin E blunted hydrogen peroxide depending on the concentration of hydrogen peroxide present in the system; with a concentration of hydrogen peroxide of 1 × 10−4 mmol/L, 250 μmol/L vitamin E almost completely prevented the hydrogen peroxide–mediated increase in DCF fluorescence. In collagen-stimulated platelets, vitamin E blunted hydrogen peroxide formation in a dose-

Figure 4. Vitamin E inhibited collagen-induced (2 μg/mL) platelet aggregation in a dose-dependent manner. Data are mean±SEM of 5 experiments. *P<0.01; **P<0.005.

Figure 5. Vitamin E inhibited thromboxane B2 (TxB2) production in collagen-stimulated platelets. Platelet thromboxane B2 production in collagen-stimulated (10 μg/mL) platelets in the absence and presence of scalar doses (50 to 250 μmol/L) of vitamin E. Data are mean±SEM of 5 experiments. *P<0.05; **P<0.01.

Figure 6. Vitamin E inhibited collagen-induced calcium mobilization. Percentage of change (Δ) of calcium mobilization in collagen-stimulated platelets in the absence and presence of scalar doses (50 to 250 μmol/L) of vitamin E. Data are mean±SEM of 5 experiments. *P<0.05; **P<0.01.

Figure 7. 32P-Inositol 1,3,4-triphosphate (Ins 1,3,4 P3) production induced by collagen-stimulated (12 μg/mL) platelets in the absence and presence of scalar doses (50 to 250 μmol/L) of vitamin E. Data are mean±SEM of 5 experiments. *P<0.05; **P<0.01.
Plasma Vitamin E Concentration, Platelets H$_2$O$_2$ Formation (Baseline and After Collagen Stimulus), Platelet Aggregation, and Calcium Mobilization Before and After Vitamin E Supplementation (600 mg/d) in 6 Healthy Volunteers

<table>
<thead>
<tr>
<th>Subject</th>
<th>Vitamin E, μmol/L</th>
<th>DCFH Oxidation, au</th>
<th>Aggregation, maximum %</th>
<th>Ca$^{2+}$ Mobilization, Δ%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
<td>After</td>
<td>Before</td>
<td>After</td>
</tr>
<tr>
<td>1</td>
<td>30</td>
<td>84</td>
<td>38.1</td>
<td>34.5</td>
</tr>
<tr>
<td>2</td>
<td>16</td>
<td>43</td>
<td>23.8</td>
<td>20.6</td>
</tr>
<tr>
<td>3</td>
<td>10</td>
<td>59</td>
<td>46.3</td>
<td>25.3</td>
</tr>
<tr>
<td>4</td>
<td>22</td>
<td>90</td>
<td>28.0</td>
<td>8.4</td>
</tr>
<tr>
<td>5</td>
<td>24</td>
<td>98</td>
<td>30.4</td>
<td>8.8</td>
</tr>
<tr>
<td>6</td>
<td>12</td>
<td>74</td>
<td>28.4</td>
<td>18.7</td>
</tr>
</tbody>
</table>

Mean ± SEM 19.0 ± 3.1 75.0 ± 8.4 32.5 ± 3.3 19.4 ± 4.2 58.5 ± 9.1 15.0 ± 6.4 52.5 ± 7.4 35.2 ± 4.2 307.7 ± 66.3 136.7 ± 76.5

Collagen concentrations were the same for in vitro experiments. All differences before and after vitamin E supplementation are <0.05.

dependent manner. Inhibition was evident with concentrations of vitamin E as low as 50 μmol/L, because in collagen-stimulated platelets, the concentration of hydrogen peroxide is much lower than 1 × 10$^{-3}$ μmol/L. Together, these findings indicate that vitamin E inhibits platelet function through its antioxidant properties, in particular by blocking the capacity of hydrogen peroxide to stimulate platelet arachidonic acid metabolism and the PLC pathway.

Our results differ from those of previous studies showing that concentrations of vitamin E much higher than those found in human plasma after supplementation are necessary to reduce in vitro platelet function. Recently, Freedman et al$^{9}$ reported that 0.5 mmol/L vitamin E inhibits platelet aggregation by interfering with the protein kinase C pathway, with no evidence of platelet inhibition using lower concentrations. In this study, however, the relationship between vitamin E and collagen-induced platelet aggregation was not investigated.

In the same study,$^9$ it was also demonstrated that incorporation of vitamin E into platelet membrane was time-dependent; incorporation was crucial to obtaining evident platelet inhibition. Even if we did not measure vitamin E incorporation into platelets, our finding is in agreement with the demonstration that vitamin E inhibits platelet aggregation depending on its incubation time. In this study, we observed the maximum effect on platelet inhibition by incubating platelets with vitamin E for 30 minutes.

Our finding may be of clinical relevance because it provides experimental support for 2 recent studies showing that vitamin E supplementation in humans decreases ex vivo and in vivo platelet activation.$^{6,7}$ Both of these studies indicate a close relationship between plasma vitamin E levels and platelet activation (ie, higher plasma levels of vitamin E and lower platelet function). In particular, a plasma vitamin E concentration of about 50 μmol/L was associated with ex vivo and in vivo platelet inhibition, which is in accord with our data indicating that 50 μmol/L vitamin E inhibits in vitro platelet activation. This suggestion is supported by results of our ex vivo study, which showed that vitamin E significantly inhibits collagen-induced platelet activation; interestingly, after supplementation, the plasma concentration of vitamin E was very close to that shown in vitro to inhibit collagen-induced platelet activation. However, there is a discrepancy between the results of the in vitro and ex vivo studies that requires more investigation. The ex vivo study showed complete suppression of platelet H$_2$O$_2$ formation, but this was observed in vitro only with the addition of 250 μmol/L. However, this difference could be due to the different incubation times that were used in the in vitro and ex vivo studies.

In conclusion, these in vitro and ex vivo studies showed that vitamin E inhibits collagen-induced platelet activation. This effect is due to its interaction with hydrogen peroxide, an important mediator of collagen-induced platelet activation. This finding gives new insight into the mechanism of action of vitamin E and provides experimental support for its possible use as an antiplatelet agent.

Acknowledgment
This work was partially supported by a grant from the Ministero dell’Università e della Ricerca Scientifica e Tecnologica.

References


Vitamin E Inhibits Collagen-Induced Platelet Activation by Blunting Hydrogen Peroxide
Pasquale Pignatelli, Fabio M. Pulcinelli, Luisa Lenti, Pier Paolo Gazzaniga and Francesco Violi

doi: 10.1161/01.ATV.19.10.2542

Arteriosclerosis, Thrombosis, and Vascular Biology is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1999 American Heart Association, Inc. All rights reserved.
Print ISSN: 1079-5642. Online ISSN: 1524-4636

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://atvb.ahajournals.org/content/19/10/2542

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in Arteriosclerosis, Thrombosis, and Vascular Biology can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to Arteriosclerosis, Thrombosis, and Vascular Biology is online at:
http://atvb.ahajournals.org/subscriptions/