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Dietary Tomato Paste Protects against Ultraviolet Light–Induced Erythema in Humans[1]

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ABSTRACT Carotenoids are efficient antioxidants capable of scavenging reactive oxygen species generated under conditions of photooxidative stress. It has been shown that supplementation with high doses of β-carotene protects skin against UV-induced erythema. This study was designed to investigate whether intervention with a natural dietary source rich in lycopene protects against UV-induced erythema in humans. Tomato paste (40 g), providing ~16 mg/d of lycopene, was ingested with 10 g of olive oil over a period of 10 wk by 9 volunteers. Controls (n = 10) received olive oil only. Erythema was induced by illumination of dorsal skin (scapular region) with a solar simulator at the beginning of the study, after 4 wk and after 10 wk. Intensity of erythema was measured by chromatometry; the a-value was determined directly before and 24 h after irradiation. Serum carotenoid levels were measured by HPLC. At the beginning of the study, carotenoid levels did not differ between the two groups. Serum levels of lycopene increased in supplemented subjects; the other carotenoids did not change significantly, and no change in serum carotenoids was observed in the control group. At wk 10, dorsal erythema formation was 40% lower in the group that consumed tomato paste compared with controls (P = 0.02; Wilcoxon-Mann-Whitney test). No significant difference between groups was found at wk 4 of treatment. The data demonstrate that it is feasible to achieve protection against UV light–induced erythema by ingestion of a commonly consumed dietary source of lycopene. J. Nutr. 131: 1449–1451, 2001.

KEY WORDS: • lycopene • sunburn • skin carotenoids • erythema • humans

Photooxidative stress is induced by UV-irradiation via light-dependent formation of reactive oxygen species such as singlet molecular oxygen, superoxide radical anion or peroxyl radicals (1). Chemical reactions of these reactive intermediates with cellular lipids, proteins and DNA are thought to play a role in the pathobiochemistry of diseases affecting light-exposed tissues such as the skin or the eye. These disorders include erythema formation, premature aging of the skin, development of photodermatosis, skin cancer, cataract and age-related macular degeneration (2–5).

Carotenoids are lipophilic micronutrients with antioxidant activities, occurring in human blood and tissues, including the skin and the eye (6,7). Carotenoids in humans originate from intake of fruits, vegetables and dairy products. There are correlations between a high intake of a diet rich in carotenoids and the occurrence of several degenerative diseases (8). Such potential protective effects of carotenoids are thought to be related to their antioxidant properties (9). In vitro studies showed that carotenoids are among the most effective naturally occurring quenchers of $^1O_2$, with bimolecular rate constants in the range of 10^9-10^{10} $(mol/L)^{-1} \cdot s^{-1}$ (10–12). In addition, carotenoids interact with peroxyl radicals, thus inhibiting the process of lipid peroxidation (13,14). Several in vitro studies indicate that among the natural carotenoids, lycopene is the most efficient antioxidant (10,15).

β-Carotene has been used as a so-called oral sun protectant due to its antioxidant properties, and its efficacy has been shown in human studies (16–19). After administration of a β-carotene supplement for 8 wk, there was a 35% lowering of erythema compared with pretreatment response toward a 1.5 individual minimal erythema dose (MED) (19). The MED is the minimal amount of energy required to induce a uniform, clearly demarcated erythema response, with a maximum ~24 h after irradiation.

Tomatoes and tomato products are the major source of lycopene in the human diet in Western countries (20). Bioavailabilty of lycopene from tomato paste is higher than from other natural sources such as tomato juice or fresh tomatoes (21).

On the basis of the pronounced antioxidant activities of lycopene and its enhanced availability from tomato paste, we investigated whether protection against UV-induced erythema can be provided by dietary intervention with tomato paste.

SUBJECTS AND METHODS

Study design. Healthy adults (n = 22), 26–67 y old (8 men and 14 women), skin type II, took part in the study. Subjects were recruited by retrieval of names from a list of volunteers available to the Institute of Experimental Dermatology (Universität Witten-Herdecke); they were assigned randomly to the control group or the group that received tomato paste. Skin-type grading was according to skin coloration, hair and eye color, and history of sensitivity toward sun exposure (22). Skin type II criteria were white skin, blonde or light-brown hair, blue eyes, sensitivity to sun exposure and minimal tanning.

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Subjects smoking >3 cigarettes/d were not included in the study; moderate alcohol consumption was allowed. Further exclusion criteria were as follows: history of malabsorption diseases, liver diseases, diseases of lipid metabolism or photosensitivity disorders. No medication was allowed during the study. Written informed consent was obtained from each participant. The study design was approved by the ethics committee of the University of Witten-Herdecke.

The control group received 10 g olive oil/d, which was taken with the main meal. The tomato paste group ingested 40 g tomato paste/d with 10 g olive oil, providing ~16 mg lycopene, 0.5 mg β-carotene and 0.1 mg lutein. The diet was not standardized, but the participants were advised not to change their dietary habits during the study. No further supplementation with vitamins or carotenoids was allowed. Compliance was checked by questionnaire (two times during the study) and by analyses of serum carotenoid concentrations. The skin sensitivity of one subject changed substantially during the study, probably due to increased melanin production as a consequence of skin tanning by UV exposure. This individual did not develop an erythema and was excluded. Two subjects did not complete the study for personal reasons not related to the treatment.

Blood collection and analyses. Blood samples were collected on d 0 and after 4 and 10 wk of treatment. Serum was prepared from the blood samples and stored at −20°C until analysis. The analyses of carotenoids in serum were performed by HPLC as described (23). The content of carotenoids in the tomato paste was determined as described earlier (21). Skin carotenoid levels were determined by means of reflection spectroscopy (24). The palm of the hand was chosen for skin measurements.

Induction of erythema and measurement of skin color. Irradiation with UV light to induce erythema was applied only to dorsal skin (scapular region) using a solar simulator (SOL3 Hönle, Munich, Germany). Individual MED was determined for each subject before the study. On d 0 and after wk 4 and wk 10, the skin of the participants was irradiated with 1.25 MED. Skin color was evaluated by chromatometry (Chromatometer Minolta CR 200, Ahrensburg, Germany) using the three-dimensional color system (L-, a-, b-values). The L-value is a parameter for lightness of skin, the b-value (blue/yellow axis) is indicative of pigmentation. The a-value (red/green-axis) is a measure of erythema formation and the Δa-value (a-value 24 h after irradiation minus a-value before irradiation) was used to quantify skin responses toward UV-irradiation.

Statistics. Statistical analysis was performed with the program Biostatistik (Glantz, version 4.02; Maidenhead, UK). The Wilcoxon-Mann-Whitney test was used for comparison of control and treatment groups. The Wilcoxon test was applied to check trend compared with pretreatment in each group. Differences were analyzed at each time point and were considered significant when $P < 0.05$. Data are presented as means ± SEM.

RESULTS

Serum and skin carotenoid levels. Increases in serum lycopene levels were observed upon daily ingestion of 40 g tomato paste, providing about 16 mg lycopene/d (**Table 1**). No change in serum lycopene level was observed in the control group; individual changes in serum lycopene levels were within 20% of the initial value. The control and tomato paste groups differed at wk 4 ($P = 0.002$) and wk 10 ($P = 0.002$). All other carotenoids analyzed, including β-carotene, α-carotene, lutein, zeaxanthin and cryptoxanthin, did not differ between groups or change within a group over time. Skin levels of total carotenoids decreased in the control group (Table 1).

Erythema measurements. The Δa-values did not differ between the groups at the start or at wk 4 of the experiment (Table 1). However, at wk 10, the Δa-values of the treatment group (3.8 ± 1.1) were significantly lower ($P = 0.02$) than those of the controls (6.3 ± 0.7), indicating a 40% protection against UV-induced erythema formation upon ingestion of tomato paste. In the treatment group, the Δa-value at wk 10 was significantly lower than at wk 0.

TABLE 1

Serum and skin lycopene concentrations and erythema formation in controls and subjects supplemented with tomato paste for 10 wk[1,2]

Week	0	4	10
Serum lycopene, *μmol/L*			
Control	0.39 ± 0.03	0.33 ± 0.04	0.36 ± 0.05
Tomato paste	0.37 ± 0.08	0.65 ± 0.06*(**)	0.72 ± 0.07*(**)
Skin total carotenoids, *μmol/kg*			
Control	0.33 ± 0.08	0.29 ± 0.06	0.19 ± 0.07(**)
Tomato paste	0.26 ± 0.05	0.36 ± 0.08	0.30 ± 0.06
Δa-Value, *1.25 MED*			
Control	6.0 ± 0.6	5.4 ± 0.6	6.3 ± 0.7
Tomato paste	5.6 ± 1.2	5.1 ± 0.8	3.8 ± 1.1***(**)

[1] Values are means ± SEM; $n = 10$ (controls); $n = 9$ (tomato paste).
[2] Erythema formation was assessed as Δa-value (redness of the skin directly before and 24 h after UV irradiation); MED, minimal erythema dose.
* Significantly different from control; $P = 0.002$ (Wilcoxon-Mann-Whitney test).
** Significantly different to wk 0; $P = 0.02$ (Wilcoxon test).
*** Significantly different from control; $P = 0.02$ (Wilcoxon-Mann-Whitney test).

DISCUSSION

In this study, we investigated whether the intake of tomato paste for 10 wk protects against UV-induced erythema formation in comparison to controls. The major carotenoid in tomatoes and tomato products is lycopene, which protects against photooxidative stress and is one of the most efficient antioxidants among the natural carotenoids (10,15).

Baseline serum levels of lycopene were similar in the two groups and were within the range reported in the literature (25). Lycopene levels increased in the serum of subjects by 0.35 μmol/L after 10 wk of tomato paste consumption, rising from 0.37 to 0.72 μmol/L; no significant change occurred in the control group. The increase found in the present study is comparable to data from the literature (26–28), i.e., after intake of tomato puree providing 16.5 mg lycopene/d for 3 wk, an increase of plasma lycopene levels by 0.5 μmol/L (from ~0.3 to 0.8 μmol/L) was reported (26). The consumption of tomato juice, providing 40 mg lycopene/d for 2 wk, resulted in plasma levels of ~0.7 μmol/L (27). From the literature it appears that serum or plasma lycopene concentrations do not exceed 1 μmol/L after dietary lycopene intake (27,28). Little information is available on the bioavailability of lycopene from different sources. After ingestion of ~70 mg lycopene/d for 4 wk from tomato juice, oleoresin or beadlets, similar increases in plasma lycopene levels of ~0.24 μmol/L were reported (29). Significant increases in serum and skin levels were observed after the use of β-carotene supplements (24). Treatment with doses of ~25 mg β-carotene/d for 12 wk led to serum β-carotene levels of 1.8 μmol/L and skin levels of ~1.0 μmol/g on the palm of the hand.

The lack of increase in skin lycopene levels (palm of the hands) in subjects consuming tomato paste might be due to the low bioavailability of lycopene from this dietary source. Additionally, variations in the reflection photometry measurements might contribute to and possibly explain the significant decrease of total skin carotenoids in the control group. The latter might also be related to seasonal variations in dietary

carotenoid levels. It should be noted that the Δa-values in all groups and at all time points were negatively correlated with the lycopene levels in serum ($0.025 < P < 0.05$). No significant correlation was found between Δa-values and skin carotenoids ($0.05 < P < 0.1$).

Erythema formation as an indicator of the sunburn reaction was 40% lower in subjects who ingested tomato paste for 10 wk compared with the controls. Compared with the initial value within the group, the Δa-value was diminished by 32% at wk 10 of supplementation.

The protective effect observed in the present study for lycopene-rich tomato paste is consistent with data from other studies that reported protection against erythema formation upon supplementation with β-carotene (17–19). Compared with the pretreatment response upon irradiation with 1.5 MED, erythema formation on dorsal skin was diminished by ~35% after daily ingestion of a supplement containing 24 mg β-carotene for 8 wk (19). No protection was observed in another study using 90 mg/d β-carotene supplements for 3 wk (30). This might be due to the short treatment time in the latter study. Consistent with other studies, we found little if any protection after 4 wk of intervention.

This is the first study demonstrating that intervention with a normal dietary constituent rich in lycopene protects skin against UV-induced erythema formation. Although the efficacy of protection is not comparable to the use of a sunscreen with a high sun protection factor, dietary intake may provide basal protection. Much of the UV exposure over a life time occurs when the skin is not protected; thus, the use of dietary factors with sun-protecting properties might have a substantial beneficial effect.

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