

Consumption of Polyphenols in Coffee and Green Tea Alleviates Skin Photoaging in Healthy Japanese Women

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Purpose: Hyperpigmentation of the skin can occur at any age depending on etiological factors but its intensity increases during adolescence in Japanese females and gradually develops further in adults. The purpose of this study was to characterize factors that influence skin hyperpigmentation, including age, skin type and dietary polyphenol sources.

Patients and Methods: A cross-sectional survey of healthy Japanese women aged from 30 to 60 years (n=244) was conducted using food and environmental questionnaires and a VISIA™ facial photoimage analyzer.

Results: UV Pigmented Spot (PS) scores correlated negatively with the consumption of total polyphenols (TPs) ($R=-0.224$, $p<0.001$) and the rate of hyperpigmented spot development (PS score/age after 18 years of age) was suppressed by the consumption of TPs. This trend was independent of the melanin index and the skin type, which indicates the ability of the skin to tan after sun exposure. Consumption of coffee, the largest source of TPs, suppressed the PS score ($p<0.001$). Consumption of green tea, the second largest source of TPs, also suppressed the PS score, which was weaker than coffee but was statistically significant ($p=0.029$). The PS score was suppressed the most in subjects with both a high consumption of coffee and green tea.

Conclusion: Higher consumption of TPs may be beneficial to alleviate photoaging of the skin, and coffee as well as green tea contribute to suppress skin hyperpigmentation through adding large amounts of TPs in the diet.

Keywords: coffee, green tea, polyphenol, photoaging, skin hyperpigmentation

Introduction

Sunlight, especially its ultraviolet (UV) light component, is the major factor that causes skin photoaging, which results in facial hyperpigmentation and wrinkle formation¹ UV light leads to collagen degradation and dysregulation of extracellular matrix homeostasis, and induces extensive skin damage through direct DNA damage, the production of reactive oxygen species (ROS), which cause lipid and protein peroxidation, and immune dysregulation that results in cell dysfunction and death.² DNA damage caused directly by UV light and ROS generated by UV exposure may result in defective DNA repair and gene mutations.³ In vivo and in vitro studies have shown that oxidative stress and DNA damage in the skin caused by UV exposure are alleviated by the intake of antioxidants including vitamins, carotenoids and polyphenols.⁴ Therefore, photoaging of the skin could be modified by changing environmental and/or lifestyle factors including a diet with antioxidants.

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Recently, photoimaging technology has advanced significantly and non-invasive image analysis of hyperpigmented spots can now be used to analyze the photoaging status.^{5–7} In a previous study, we conducted a pilot cross-sectional survey to determine how factors and nutrients in the diet influence the facial skin status using non-invasive skin analysis.⁶ That study demonstrated that subjects with high levels of coffee polyphenol consumption had lower levels of skin hyperpigmentation measured according to a VISIA™ UV Pigmented Spot (PS) score using a digital imaging technique.⁷ Coffee is the largest source of polyphenols in the Japanese diet and supplies a large amount of antioxidants in daily life.^{8,9}

We have accumulated a basic knowledge about facial hyperpigmented spots and factors that influence them.¹⁰ Japanese women are well aware of the harmful effects of UV exposure and most of them use sun protection every day. Their previous sun exposure times were usually very short showing that the UV exposure time was not an influential factor in the PS score. Hyperpigmented spots typically appear initially in Japanese women around 18 years of age and their PS scores remarkably increase in their 20s and then gradually increase further with age. Not only coffee polyphenol consumption but also age and genetic factors are significant influential factors in the PS score. The skin type is genetically determined by melanin formation after sun exposure and was identified as an independent strong influential factor in the PS score. Subjects with skin type I, one of the three grades of Japanese skin type (JST), whose melanin formation is genetically lower, showed higher PS scores.¹¹

To further understand the influence of consuming polyphenols from coffee and from other sources, especially green tea (the second largest source of polyphenols in the Japanese diet), on skin conditions, we conducted an additional cross-sectional study to explore the influence of polyphenol consumption as well as genetic and environmental factors on facial skin hyperpigmentation in healthy Japanese women.

Materials and Methods

Study Design and Subjects

This cross-sectional survey was conducted in accordance with the principles of the Declaration of Helsinki. This study was approved by the Shirogane EXE Clinic Ethics Committee, and all subjects provided written informed consent for their data to be used in the study. As described in

our previous study,⁶ we recruited 131 subjects in the summer, and 113 subjects were newly added in the winter for this expanded study. Briefly, we collected subjects using an internet website of a contract research organization. Inclusion factors were healthy, non-smoking Japanese women, aged 30–60 years, and exclusion factors were subjects who had chronic diseases, who were taking medications, who had skin diseases or skin complaints (e.g. nevus, melasma and macules) or who had undergone artificial treatments such as chemical peeling, laser and/or light treatment, and injection of hyaluronic acid. We also excluded pregnant or lactating women, as well as subjects who had regular activities that potentially exposed them to sunburns, such as tennis, golf, body boarding, skiing, snowboarding (at least once a month), or outdoor activities in the summer, including climbing mountains and sea bathing (at least once a year) every year after 25 years of age. Subjects were also excluded who intentionally suntanned without a sunscreen, e.g. sea bathing, swimming in an outdoor pool or attending an outdoor athletic festival. The profile of the subjects in this study is shown in Table 1.

Non-Invasive Measurement of Skin Conditions

Skin condition measurements were conducted under the control of a physician. After washing her face, each subject was completely sedentary for 20 mins in an environmentally controlled room at $22 \pm 1^\circ\text{C}$ and $50 \pm 10\%$ relative humidity. PS scores and PS counts were measured using a VISIA™ Evolution facial image analysis system (Canfield Inc., Fairfield, NJ, USA). Examples of UV photos and PS scores are shown in Figure 1. The PS score/count (PS score divided by the PS count) was also calculated as an indicator of the average area of pigmented spots. The PS score divided by the number of years after becoming 18 years old is expressed as the rate of UV pigmented spot development. Skin color is expressed as L^* (lightness) value and the melanin index measured using a CM-2600d spectrophotometer (Konica-Minolta, Tokyo, Japan).

Questionnaires on Lifestyle, Diet and Environmental Conditions

A food questionnaire was conducted using a brief, self-administered Diet History Questionnaire (BDHQ) to calculate energy and nutritional intake, and alcohol consumption.¹² The lifestyle of each subject, including their smoking and sun exposure habits, and actions geared towards any usual

Table I Profile of the Subjects and Their Consumption of TPs

Number of Subjects		Summer	Winter	Total
		131	113	244
Age	Years	44.4±8.0	48.7±5.3	46.4±7.2
Body weight	kg	51.8±6.5	50.9±6.1	51.4±6.3
BMI	kg/m ²	20.8±2.2	20.6±2.1	20.7±2.2
Energy consumption	kcal/day	1649±481	1552±479	1604±482
Exercise	METs – h/week	6.2±15.2	3.7±9.7	5.1±13.0
Total polyphenol consumption	mg/day	1279±864	1163±781	1225±827
Beverage consumption	mL/day	1566±783	1160±665	1378±757
Coffee consumption	mL/day	334±356	319±347	327±351
Alcohol consumption	g/day	2.7±5.2	3.0±5.2	2.8±5.2
Ex-smoker	N(%)	25(19.1%)	0(0.0%)	25(10.2%)
Usage for UV protection				
Sunscreen/Sun protection cosmetics	N(%)	126(96.2%)	100(88.5%)	226(92.6%)
Sunshade or hat/cap	N(%)	108(82.4%)	74(65.5%)	182(74.6%)
Long sleeves	N(%)	28(21.4%)	34(30.1%)	62(25.4%)
Activity with sun exposure in the past				
Outdoor sports ^a	N(%)	12(9.2%)	8(7.1%)	20(8.2%)
Outdoor activities in the summer ^b	N(%)	13(9.9%)	4(3.5%)	17(7.0%)

Notes: Mean±SD. ^aNumber of subjects who did the outdoor sports including tennis, golf, bodyboarding, snowboarding and ski at least 5 years before. ^bNumber of subjects who did outdoor activities in the summer including mountain climbing and sea bathing once in a few years.

Abbreviation: MET, metabolic equivalents.

sun protection were recorded using the questionnaire. The exercise level of each subject was expressed as metabolic equivalents (METs) calculated by information from the same questionnaire.¹³ The consumption of foods and beverages containing polyphenols was recorded through questionnaires aimed at calculating polyphenol intake.⁸ The consumption of total polyphenols (TPs) was estimated using the consumption data of food and beverage items in this survey and the polyphenol content database developed for Japanese foods and beverages, whose TP contents were holistically measured using a modified Folin Ciocalteu method.⁸ JSTs were classified based on questionnaires as Skin Type I reddens in response to UV exposure but unlikely to suntan (lower melanin producer), Type II modestly reddens in response to UV but

able to suntan (average melanin producer), and Type III unlikely to redden or sunburn in response to UV exposure but easily suntans (higher melanin producer).¹¹

Data Analysis

Numerical data are presented as means ± SD. Subject groups were divided based on arbitrary cut-off points, such as median or tertile. Correlations among survey items were evaluated by the partial correlation coefficient based on the product-moment Pearson's correlation coefficient using the control variable as age, whereas age alone and the combination of other factors such as BMI, energy intake, alcohol consumption and skin type delivered similar results on the partial correlations when they were used

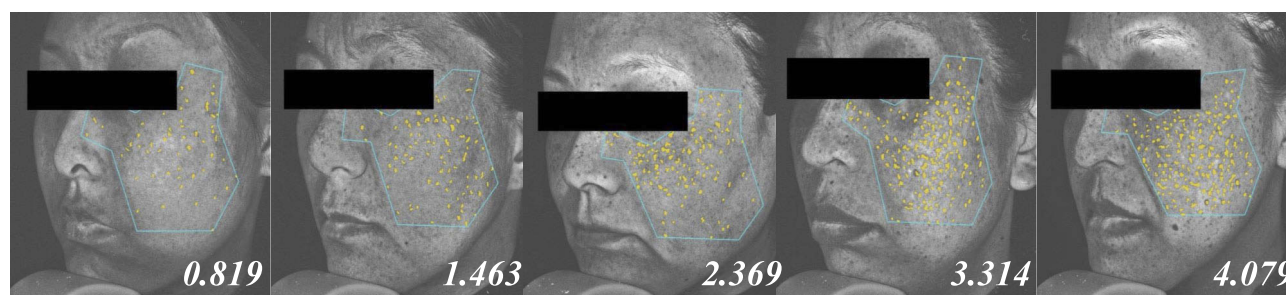


Figure 1 Examples of VISIA UV photoimages and UV Pigmented Spot scores. Images of five subjects in the study; the number at the bottom of each image is the PS score.

Table 2 Partial Correlations Between the Consumption of TPs and UV Pigmented Spot (PS) Score

	Summer (n=131)		Winter (n=113)		Total (n=244)	
Total polyphenol vs.	R	p	R	p	R	p
PS score	-0.218	0.013	-0.216	0.022	-0.224	<0.001
PS count	-0.190	0.031	-0.192	0.043	-0.196	0.002
PS score/count	-0.211	0.016	-0.188	0.048	-0.212	0.001

Note: Control variable: age

as the control variable. Comparisons among groups were first analyzed using analysis of variance (ANOVA); then, Dunnett's test for multiple comparisons, or were directly analyzed using Welch's *t*-test between two groups. IBM® SPSS® Statistics 19 (SPSS Japan Inc., Tokyo, Japan) was used and a *p*-value <0.05 is considered as significant.

Results

The VISIA™ UV Pigment Spot (PS) score had a negative partial correlation with the consumption of TPs in both surveys conducted in the summer and in the winter at $R=-0.218$

($p=0.013$) and $R=-0.216$ ($p=0.022$), respectively (Table 2), and we combined those two survey results for the following analysis. The consumption of TPs had negative partial correlations not only against the PS score ($R=-0.224$, $p<0.001$) but also against both the PS count, an indicator of the number of pigmented spots ($R=-0.196$, $p=0.002$), and the PS score/count, an indicator of the average area of pigmented spots ($R=-0.212$, $p=0.001$) (Table 2). The PS score per age after each subject became 18 years-old, which estimates the rate of hyperpigmented spot development, was suppressed by the consumption of TPs, and its rate in the highest tertile TP group was significantly lower in the rate of hyperpigmented spot development ($p=0.001$) (Figure 2).

Skin type was a significant influential factor in the PS score, and subjects with Skin Type III, who have a higher production of melanin after UV exposure, showed a significantly lower PS score while subjects with Skin Type I, who have a lower production of melanin after UV exposure, showed the highest PS score ($p<0.001$, Table 3). For each skin type, subjects with a higher consumption of TPs (≥ 1064 mg/day) tended to show lower PS scores. The PS

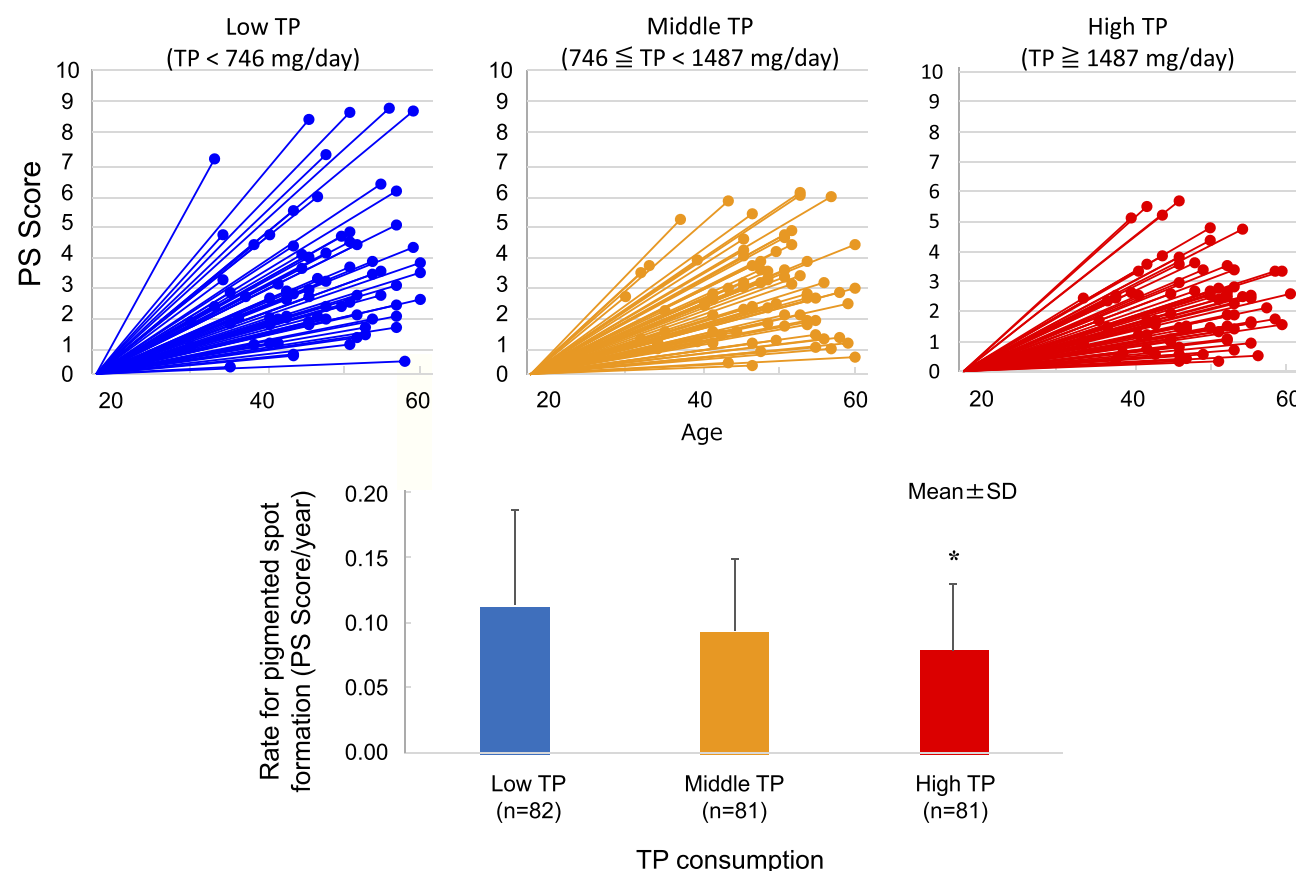


Figure 2 Distribution of UV Pigmented Spot scores and age of subjects in tertile groups divided by TP consumption, and UV Pigmented Spot development rate (PS score per year after reaching 18 years of age) and consumption of TPs. ANOVA *p*-value was $p=0.002$; * $p=0.001$ compared with the low TP consumption group.

Table 3 PS Scores in Low and High TP Groups According to Skin Type, Skin Color and Melanin Index

		All Subjects		Low TP		High TP		p-value ^a
		n	PS Score	n	PS Score	n	PS Score	
Skin type	I	65	3.12±1.64	36	3.44±1.89	29	2.72±1.18	0.068
	II	136	2.74±1.61	72	2.88±1.78	64	2.58±1.38	0.276
	III	43	1.56±1.08 ^b p<0.001	14	1.62±1.01 ^c p=0.005	29	1.53±1.14 ^d p<0.001	0.785
L* value	Low	122	2.20±1.42	61	2.43±1.62	61	2.05±1.22	0.154
	High	122	3.06±1.69 p<0.001	61	3.37±1.88 p=0.004	61	2.67±1.42 p=0.011	0.023
Melanin index	Low	122	3.20±1.79	61	3.61±2.05	61	2.70±1.41	0.006
	High	122	2.06±1.18 p<0.001	61	2.19±1.18 p<0.001	61	2.02±1.22 p=0.005	0.445

Notes: Mean±SD. ^ap-value between high TP and low TP groups. ^bp<0.001. ^cp=0.002. ^dp=0.001 vs Skin type I.

score showed a partial correlation with skin color (L* value) and melanin index (control variable: age) at $R=-0.434$ ($p<0.001$) and $R=0.523$ ($p<0.001$), respectively. Subjects with a high L* value, a lighter skin color and a lower melanin index had higher PS scores ($p<0.001$ and $p<0.001$, respectively, Table 3). The consumption of TPs suppressed the PS score in subjects with a light skin color (high L* value) or low melanin index ($p=0.023$ and 0.006 , respectively, Table 3).

The consumption of TPs from different sources and the relationship between TP sources and PS scores are shown in Table 4. The consumption of TPs in all subjects was 1225 ± 827 mg/day, and coffee and green tea, the top 2 TP sources, greatly contributed to total consumption at 53% and 8%, respectively. Daily TP consumption from all foods was 300 ± 203 mg (25% of the total) but was not associated with the PS score. The intake of TPs from all beverages was 925 ± 784 mg (75% of the total), which showed a significant negative correlation against the PS score ($p<0.001$). TPs from other beverages showed a negative association against the PS score; however, there were no beverage items other than coffee and green tea that associated with the PS score significantly. Subjects with a high consumption of TPs from coffee (≥ 400 mg/day, corresponding to 1.5 cups of coffee) showed significantly lower PS scores than subjects with a low consumption of TPs from coffee ($p<0.001$, Table 5). Green tea did not have as much of an impact as coffee but subjects with a high consumption of TPs from green tea (≥ 41 mg/day, corresponding to a half cup of green tea) showed lower PS scores than subjects with a low

consumption of TPs from coffee ($p<0.001$, Table 5). Green tea did not have as much of an impact as coffee but subjects with a high consumption of TPs from green tea (≥ 41 mg/day, corresponding to a half cup of green tea) showed lower PS scores than subjects with a low

Table 4 Partial Correlations Between PS Scores and the Consumption of TPs from Different Sources of Food and Beverages

Sources	TP Consumption (mg/day)	% Contribution	TP Consumption vs PS Score	
			R	P
Cereals and noodles	10.4±10.2	1%	0.034	0.602
Fruits and vegetables	87.9±59.9	7%	-0.024	0.709
Other foods	202±179	17%	-0.024	0.708
Total foods	300±203	25%	-0.027	0.680
Coffee	655±703	53%	-0.191	0.003
Green tea	103±174	8%	-0.136	0.034
Other beverages	167±152	14%	-0.144	0.024
Total beverages	925±784	75%	-0.230	<0.001
Total food and beverages	1225±827	100%	-0.224	<0.001
All food and beverages except for coffee and green tea	467±270	38%	-0.101	0.115

Note: Control variable: age

Table 5 PS Scores and the Consumption of TPs in Groups of Subjects with High and/or Low Consumption of Coffee and Green Tea

Group		n	PS Score		TPs from Coffee		TPs from Green Tea		TPs from All Foods and Beverages	
				p-value ^a	mg/day	p-value ^a	mg/day	p-value ^a	mg/day	p-value ^a
Coffee	Low	118	3.01±1.79		108±114		84±134		639±357	
	High	126	2.28±1.36	<0.001	1166±634	<0.001	121±203	0.091	1774±763	<0.001
Green tea	Low	118	2.85±1.79		611±679		13±14		1053±773	
	High	126	2.40±1.39	0.029	701±727	0.319	198±211	<0.001	1405±846	0.001
Coffee (C) and Green tea (GT) ^b	Group 1 (low in both)	56	3.22±2.06		70±98		9±11		491±273	
	Group 2 (low C and high GT)	62	2.81±1.49	0.361	143±117	0.719	151±157	<0.001	773±372	0.027
	Group 3 (high C and low GT)	62	2.43±1.21	0.019	1157±572	p<0.001	13±13	0.998	1636±678	<0.001
	Group 4 (high in both)	64	2.13±1.49	0.001	1176±693	p<0.001	226±243	<0.001	1907±820	<0.001

Notes: Mean±SD. ^aComparisons were made between low TP and high TP groups or vs Group 1 (low in both). ^bANOVA p-values were p=0.001 for PS Score and p<0.001 for TPs from coffee, TPs from green tea, and TPs from all foods and beverages.

consumption of TPs from green tea (p=0.029, Table 5). Four groups were created with different combinations of coffee and green tea consumption, where Group 3 (high in coffee and low in green tea) and Group 4 (both high in coffee and green tea) showed significantly lower PS scores than Group 1 (both low in coffee and green tea) (p=0.019 and p=0.001, respectively, Table 5).

Discussion

We conducted a cross-sectional survey of healthy middle-aged Japanese women aged from 30 to 60 years (n=244) to examine if there is a relationship between the consumption of TPs and the hyperpigmentation of facial skin. The results show that a higher consumption of TPs contributed to suppress skin hyperpigmentation measured using a VISIA™ facial image analyzer. The UV Pigmented Spot (PS) count and its ratio (the PS score divided by the PS count), which indicates the average area of hyperpigmented spots, were similarly suppressed by the consumption of TPs, suggesting that TPs suppressed both the number of pigmented spots and the area of pigmented spots. This study showed that not only coffee, the largest source of TP in the Japanese diet representing half of the total consumption of TPs,⁹ but also green tea, the second highest source of TPs, contributed to suppress hyperpigmentation. Subjects with a high consumption of TPs in both beverages showed the lowest PS scores. Our previous study showed that there are no seasonal changes in PS scores.¹⁰ In the present study, we combined two sets of cross-sectional surveys recruiting subjects in the summer and in the winter, after confirming that both groups of subjects had similar PS scores and that TPs similarly suppressed their PS scores. This finding confirmed that the PS score is not

influenced by the season and that the findings are reproducible; thus, the suppression of hyperpigmentation by the consumption of TPs was confirmed.

Facial hyperpigmentation can occur at any age depending on etiological factors but our previous study showed that its intensity increases in Japanese females from adolescence around 18 years of age and then gradually develops further in adults.¹⁰ Individual differences in PS scores were large but there were no trends in the distribution of PS score in each age segment between 30 and 60 years of age. We estimated the rate of hyperpigmented spot development (PS score/years after 18 years of age) and showed that the rate was suppressed by the consumption of TPs, which also meant that the suppression of hyperpigmentation was observed after adjusting for the age difference in subjects. Hyperpigmented spots, once they occur, are stable and the location and intensity of each hyperpigmented spot do not usually change within a few years.¹⁰ This study is a cross-over survey and the causal association of hyperpigmented spot development and the consumption of TPs can not be conclusively established, which is a limitation of this study. As a pilot trial, we conducted a follow-up survey using the same set of questionnaires and VISIA™ analyses in some subjects 2.5 years after this survey (n=132, 32–62 years old).^{14,15} Visual analysis of UV photos showed that the area of existing pigmented spots slightly expanded in 61% of those subjects, but such small changes cannot be detected by VISIA™ as the PS score. None of the subjects had developed new hyperpigmented spots in those 2.5 years. Lower scores of hyperpigmented spots remained in subjects who maintained high consumption of coffee TPs. A longitudinal study is required to determine a causal effect, and at least a 5- to 10-year observation period would be required.

This study evaluated how much of an influence the consumption of TPs has on the suppression of the PS score. We reconfirmed that the skin type is a significant influential factor in hyperpigmentation, and subjects with Skin Type III, who can efficiently produce melanin after UV exposure, were the most protected against skin hyperpigmentation. Subjects with higher consumption of TPs tended to have lower PS scores in each skin type, which suggests that the suppressive effect of TP consumption on hyperpigmentation is independent of the skin type. Dark skin color, which has a low L^* value and a higher melanin index, was also a suppressive factor for skin hyperpigmented spots. The skin type determines the ability to suntan after UV exposure, which is responsible for the efficacy of melanin production. Skin color and the melanin index show stable states of melanin pigment distribution that work as a protective factor for the skin against UV exposure. The response to sun exposure and the constitutive production level of melanin are different; however, skin color and the melanin index are correlated with the skin type, which influences hyperpigmentation.¹⁰ We showed in this study that those factors are not correlated with the consumption of TPs, which suggests that the consumption of TPs is an independent suppressive factor of skin hyperpigmentation.

Clinical observations of an abnormally early onset of solar lentigines in Xeroderma pigmentosum patients indicate that DNA repair defects result in DNA damage induced by solar UV light and cause severe hyperpigmentation spot development.¹⁶ Even in the healthy normal population, it is hypothesized that the development of hyperpigmented spots may also occur through gene mutations of keratinocytes and/or melanocytes following UV exposure for a few decades. Mutations in genes encoding stem cell factor, endothelin-1 and proopiomelanocortin in keratinocytes have been suggested to be responsible for the development of solar lentigines in healthy subjects.^{17,18} Mutagenesis via UV damage is due to the production of cyclobutane pyrimidine dimers (CPDs) in DNA strands by the absorption of UV and also by indirect effects of ROS.¹⁹ Recently, Premi et al. showed that CPDs are generated for more than 3 hrs after exposure to UVA, a major component of the radiation in sunlight, and not only ROS but also reactive nitrogen species play roles in the UV-associated DNA damage.²⁰ Antioxidants, such as green tea polyphenol, show photoprotective effects to decrease DNA damage and have anti-carcinogenic and anti-inflammation properties.⁴ The oral intake of green tea polyphenols at a high dose of 1.4 g for 12 weeks was shown to have protective effects against UV-induced erythema and structural characteristics of the skin such as elasticity, and skin density was maintained after UV

exposure in humans.²¹ However, the underlying mechanism by which polyphenols contribute to suppress hyperpigmentation is still not clear, especially for coffee polyphenols. Coffee and green tea deliver more than half of TPs consumed in the Japanese diet as shown in this study and in previous studies.⁹ Polyphenols are a major source of antioxidants and foods rich in polyphenols, such as coffee and tea, have protective effects against oxidative-stress-related diseases such as cardiovascular diseases, type 2 diabetes and some cancers.²² At least one-third of polyphenols from coffee and green tea are absorbed through the intestines and appear in the circulation,^{23,24} and oxidative damage to macromolecules including DNA has been shown to be suppressed by coffee and green tea consumption in humans.^{25,26} These considerations, which may contribute to reduce oxidative stress in humans, may play a role in the suppression of hyperpigmentation shown in this study.

Conclusion

The consumption of TPs may be beneficial for reducing photoaging of the skin, and not only coffee but also green tea contribute to suppress skin hyperpigmentation through providing large amounts of TPs in the Japanese diet. Further study is required to understand the underlying mechanism(s) of the suppressive effect of TPs on hyperpigmentation and studying younger subjects could be helpful for further understanding of that process.

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Disclosure

YF is affiliated with Wellness Communications Section, Nestlé Japan Ltd., Tokyo, Japan. YT is affiliated with Inary Corp., Tokyo, Japan. The authors report no other conflicts of interest in this work.

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