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Skin aging associated with chromium among rural housewives in northern China

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ABSTRACT

Previous studies have found associations between chromium exposure and skin damage. However, few studies have focused on both chromium and skin aging. This study aimed to assess the degree of skin aging symptoms and estimate the relationship between hair chromium and skin aging among rural housewives. We recruited 405 subjects in Shanxi Province of northern China and analyzed 397 eligible hair samples with inductively coupled plasma–mass spectrometry (ICP–MS). The subjects' skin aging symptoms were assessed with SCINEXA™ (SCore of INtrinsic and EXtrinsic skin Aging). After adjusting for age and other important covariates, the regression results showed more severe skin aging symptoms in women with a higher level of hair chromium and presented an increasing linear trend. Vegetables, fruits, and beans might be a source of chromium exposure. We concluded that skin aging might be positively associated with hair chromium. It is necessary to take measures to reduce chromium exposure to prevent skin aging.

1. Introduction

Chromium (Cr) is an essential trace element for life and plays an irreplaceable role in the metabolism of carbohydrates, proteins, and lipids (Kobla and Volpe, 2000). As a toxic heavy metal element, however, excessive chromium exposure, especially hexavalent chromium exposure, may lead to health damage (Alvarez et al., 2021). Skin lesions are a major manifestation of chromium poisoning. It was reported that exposure to high hexavalent chromium concentrations caused skin irritation, anaphylaxis, contact dermatitis, and ulcers (Moretto, 2015; Shelnutt et al., 2007). Increasing chromium concentration in urine was found to be a risk factor for skin barrier disruption and skin diseases such as hand eczema among cement workers (Chen et al., 2008; Chou et al., 2016). Moreover, hair chromium was considered to be correlated with skin hyperpigmentation in male tannery workers (Al Hossain et al., 2019). However, most of the existing studies focus on a high level of occupational chromium exposure and cannot explain the dermatological manifestations among the general population.

Skin aging is a series of symptoms, including two separate processes, of which intrinsic skin aging is determined by genes, extrinsic skin aging is induced by environmental factors, and environmental factors can accelerate the intrinsic process (Vierkotter et al., 2016). Rather than acute skin symptoms, skin aging has a chronic appearance over time in the population but easily causes severe complications such as vascular disorders and skin injuries (Farage et al., 2009). Known possible environmental risk factors for skin aging involve sunshine, tobacco and alcohol consumption, and air pollution (Goodman et al., 2019; Li et al., 2015a; Rittie and Fisher, 2015), whereas these findings fail to illustrate specific environmental pollutants. In addition, the relationship between chromium and skin aging is still unclear. Hence, more evidence is needed.

We hypothesized that chromium exposure was a crucial factor in skin aging and conducted this research. Our previous study recruited rural housewives in northern China and collected hair samples, which

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enabled us to further explore the association between hair chromium and skin aging.

2. Method

2.1. Study design and population

This cross-sectional study was performed from August 2012 to May 2013 to assess the effects of indoor air pollution on the health of local rural housewives in Pingding County Hospital of Shanxi Province. In short, the women were recruited when the following criteria were met: (1) they were the native inhabitant of Pingding County rather than the migrant; (2) their living situations were not markedly changed in the past decade; and (3) they were aged 30 or over. If they consented to participate, the well-trained investigators would shear a strand of the hair sample from them for laboratory analysis and the local physicians would make the physical examination for them such as measurements of height and weight according to standard protocols. The characteristics of our study population were collected by a structured questionnaire, which mainly included demographical data such as age, occupation, education, alcohol consumption (hard wine and weak drinks), and smoking status; further covariates of skin aging such as sun exposure and sunburn history; dietary frequency; and so on.

We recruited 405 subjects with 397 eligible hair samples. More information regarding the questionnaires and physical examinations can be acquired in our previous studies (Li et al., 2015b). This study was approved by the Institutional Review Board of Peking University. All participants read and signed the Informed and Consent Form.

2.2. Assessment of skin aging symptoms

We applied the skin aging score SCINEXA™ (SCore of INtrinsic and EXtrinsic skin Aging) to evaluate skin aging symptoms (Vierkotter et al., 2010). Briefly, we used scores from 0 (not present) to 5 (very severely present) to describe the severity of coarse wrinkles, telangiectasia, laxity of eyelids, and laxity of cheeks; used scores 0 (0 pigment spots), 1 (1–10 pigment spots), 2 (11–50 pigment spots), or 3 (more than 50 pigment spots) to appraise the number of pigment spots larger than 3 mm in diameter; and used scores 0 (not present) or 1 (present) to distinguish the manifestation of solar elastosis, cutis rhomboidalis nuchae, Morbus Favre Racouchot, uneven pigmentation on the bottom side of arms, and fine wrinkles on the back of hands.

Two trainers, A. V. and M. L., the developer and the proficient of SCINEXA™, were responsible for utilizing SCINEXA™ correctly, including personnel training and quality control. When a woman was recruited, after facial cleanliness and adaptation to room temperature for 15 min, she was asked to close her eyes and relax her face, and a trained dermatologist or investigator assessed the skin aging score according to a strict protocol. A trained photographer took the color digital photos of subjects, and then another independent dermatologist or investigator performed a secondary evaluation of the skin aging score based on the photograph. If the two scores of the same participant differed larger than 1 or if no agreement was reached, the trainers of SCINEXA™ would decide the final result.

2.3. Analysis of hair samples

We assumed that the hair sample close to 24 cm could indicate a woman's 2-year accumulated chromium exposure. Therefore, we collected the subject's eligible hair cut from as near as possible to the scalp of the back of the head and then kept the sample into a closed labeled polyethylene zip-lock bag to send to the laboratory. The 24-cm hair sample was cut into 1-cm pieces and weighed to 80 mg for analysis. These samples and the corresponding blank vials were orderly washed with 1 ml Triton X-100 (Sigma–Aldrich, USA) 1 time, with 1 ml deionized water 3 times, and with 1 ml acetone (J.T. Baker®, USA) 3 times. All of the above washes were vortexed for 5 min each time. Subsequently, these samples were digested with 1 ml nitric acid under a microwave for 50 min. The concentrations of the metal elements were detected using inductively coupled plasma–mass spectrometry (ICP–MS; ELAN DRC II, PerkinElmer, USA). Each sample corresponded to three procedural blanks and one reagent blank, and the concentration was computed by subtracting the means of the corresponding blanks from the detected concentration. More detailed information on this analysis method can be found in our previous study (Li et al., 2016).

We finally analyzed a total of 397 samples, and the distribution of chromium concentrations is presented in Fig. 1. The median and the quartile was 118.09 (79.50, 171.42), and the range was from 35.38 to 908.44 (unit: ng/g hair). The concentrations of chromium in the hair can be further divided into three exposure levels according to the 33rd and 66th percentages: 35.38–92.29, 92.60–141.55, 141.97–908.44 (unit: ng/g hair).

2.4. Statistical analysis

We compared the demographic information of the subjects grouped by the median chromium concentration. Continuous variables were shown as the mean ± standard deviation (SD) and tested using the t test, and the categorical variables were shown as number (percentage) and tested using the chi-square test. We estimated the effects of chromium exposure on skin aging symptoms using linear and logistic regression. We used two models, and chromium exposure was bisected by the median (the 50th percentage, P_{50}) of concentrations as the independent variable. In the first model, we adjusted for age, and in the second model, we further adjusted for age, BMI, education, occupation, active and passive smoking status, alcohol consumption, staying up, physical exercise, menopause status, sun exposure, sunburn history, and sun protection. The regression coefficient with 95% confidence interval (CI) was transformed to arithmetic mean ratio (AMR) for scores with normal distribution, geometric mean ratio (GMR) for scores with log-normal distribution, or odds ratio (OR) for scores as categorical variables. The AMR and GMR were comparable to the OR in their meaning (Vierkotter et al., 2010). Then, we explored the linear tendency of the significant effects in three different intervals of the concentrations that were cut off with the 33rd and 66th percentages. We further evaluated the correlations between numerous exposure sources and chromium

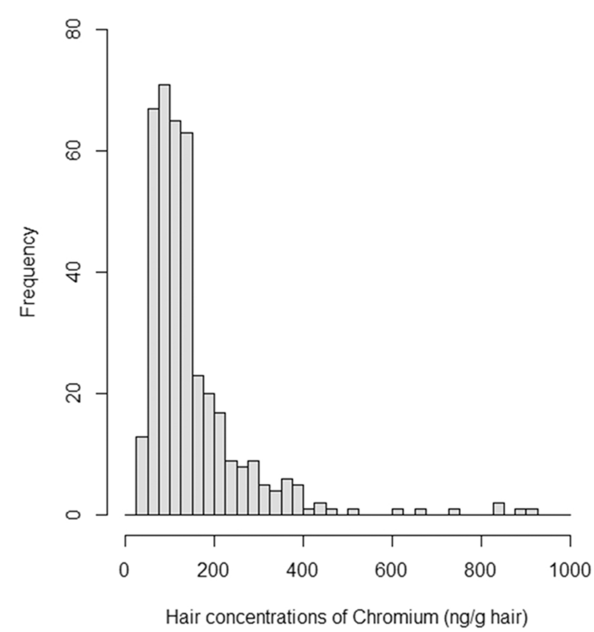

Fig. 1. The frequency distribution histogram of chromium concentrations in hair.

concentrations using Spearman's rank correlation analysis.

All data were analyzed with R software (version 4.0.2; R Development Core Team). Two-sided probability was used in all statistical tests. The criterion for significance was p value < 0.05.

3. Result

3.1. Study population characteristics

A total of 397 subjects were divided into two groups according to the median hair chromium concentrations, and their characteristics are compared in Table 1. Compared with the $\leq P_{50}$ group, the $> P_{50}$ group had more nonfarmers and used more skincare products. Except for the above two features, no other obvious differences were found in sociodemographic or behavioral characteristics between the two groups. Thus, the two populations were comparable overall.

Table 1
Characteristics grouped by the median chromium concentrations.

Characteristics	Total (n = 397) No. (%)	$\leq P_{50}$ (n = 199) No. (%)	$> P_{50}$ (n = 198) No. (%)	P
Age (years)	52.87 ± 10.40	52.90 ± 10.68	52.83 ± 10.15	0.95
BMI (kg/m^2)	24.87 ± 3.02	24.89 ± 3.12	24.84 ± 2.92	0.87
Occupation				
Farmer	310 (78.28)	165 (83.33)	145 (73.23)	0.02
Not farmer	86 (21.72)	33 (16.67)	53 (26.77)	
Education				
Junior high school or lower, or unknown	212 (53.54)	109 (55.05)	103 (52.02)	0.61
High school or higher	184 (46.46)	89 (44.95)	95 (47.98)	
Smoking				
Not smoker	373 (94.19)	184 (92.93)	189 (95.45)	0.09
Smoker	11 (2.78)	9 (4.55)	2 (1.01)	
Ever smoker	12 (3.03)	5 (2.53)	7 (3.54)	
Passive smoking				
Yes	272 (68.69)	132 (66.67)	140 (70.71)	0.45
No	124 (31.31)	66 (33.33)	58 (29.29)	
Hard wine (> 50 g) (times/week)				
Never	373 (94.19)	189 (95.45)	184 (92.93)	0.39
> 1	23 (5.81)	9 (4.55)	14 (7.07)	
Weak drinks (> 50 ml) (times/week)				
Never	382 (96.36)	192 (96.97)	190 (95.96)	0.79
> 1	14 (3.54)	6 (3.03)	8 (4.04)	
Staying up (times/week)				
< 1	356 (89.90)	179 (90.40)	177 (89.39)	0.93
1–3	28 (7.07)	13 (6.57)	15 (7.58)	
> 3	12 (3.03)	6 (3.03)	6 (3.03)	
Physical exercise (times/week)				
< 1	254 (64.30)	125 (63.45)	129 (65.15)	0.21
1–3	109 (27.59)	60 (30.46)	49 (24.75)	
> 3	32 (8.10)	12 (6.09)	20 (10.10)	
Menopause status				
Yes	233 (58.84)	119 (60.10)	114 (57.58)	0.68
No	163 (41.16)	79 (39.90)	84 (42.42)	
Sunburn history				
Yes	8 (2.02)	4 (2.02)	4 (2.02)	1.00
No	388 (97.98)	194 (97.98)	194 (97.98)	
Sun exposure				
Yes	292 (73.92)	151 (76.65)	141 (71.21)	0.26
No	103 (26.08)	46 (23.35)	57 (28.79)	
Using sunshade				
Yes	23 (5.8)	9 (4.5)	14 (7.1)	0.39
No	373 (94.2)	189 (95.5)	184 (92.9)	
Using sunscreen				
Yes	23 (5.81)	10 (5.05)	13 (6.57)	0.67
No	373 (94.19)	188 (94.95)	185 (93.43)	
Using skincare products				
Yes	51 (12.88)	18 (9.09)	33 (16.67)	0.04
No	345 (87.12)	180 (90.91)	165 (83.33)	

Abbreviations: P_{50}, the 50th percentage (median); BMI, body mass index. Total values for certain characteristics may not be equal to "n" because of few missing data; the total percentage for certain characteristics may not be equal to 100% because of rounding.

3.2. Association of hair chromium with skin aging

Table 2 shows the effect values of the two regression models. We found that the increasing concentration of hair chromium was significantly associated with pigmentation, especially with pigment spots (diameter > 3 mm) on the forehead, arms, and back of the hands, as well as uneven pigmentation on the bottom side of arms, whether in the first or second model. After adjusting for age and other considered covariates, high exposure to hair chromium increased the risk of these symptoms by approximately 1.2- to 2.3-fold. However, we did not observe any statistical associations between hair chromium and cheek pigment spots. We also found no associations of hair chromium on

Table 2
Associations between chromium in hair and skin aging symptoms.

Skin aging symptom	Index[a]	Model 1[b]	Model 2[b]
Score of number of pigment spots (diameter > 3 mm)			
On forehead	GMR (95% CI)	1.16 (1.04, 1.29)	1.15 (1.03, 1.28)
On cheeks	GMR (95% CI)	1.11 (0.98, 1.26)	1.07 (0.95, 1.21)
On the back of hands	GMR (95% CI)	1.15 (1.02, 1.30)	1.16 (1.02, 1.31)
On arms	GMR (95% CI)	1.22 (1.08, 1.37)	1.23 (1.09, 1.39)
Score of coarse wrinkles			
On forehead	AMR (95% CI)	1.01 (0.94, 1.07)	1.03 (0.97, 1.09)
Frown lines	AMR (95% CI)	1.00 (0.93, 1.07)	1.01 (0.94, 1.08)
Crow's feet	AMR (95% CI)	0.99 (0.92, 1.05)	1.00 (0.94, 1.07)
Under the eyes	AMR (95% CI)	1.01 (0.95, 1.08)	1.04 (0.97, 1.10)
On upper lip	AMR (95% CI)	0.99 (0.91, 1.07)	1.01 (0.93, 1.09)
Nasolabial	AMR (95% CI)	0.98 (0.92, 1.04)	1.00 (0.94, 1.06)
Score of further skin aging symptoms			
Facial telangiectasia	AMR (95% CI)	0.89 (0.76, 1.03)	0.93 (0.80, 1.07)
Laxity of eyelids	AMR (95% CI)	0.98 (0.92, 1.04)	1.00 (0.94, 1.06)
Laxity of cheeks	AMR (95% CI)	0.99 (0.93, 1.05)	1.01 (0.95, 1.06)
Presence of further skin aging symptoms			
Solar elastosis on cheeks	OR (95% CI)	1.13 (0.69, 1.85)	1.27 (0.74, 2.16)
Cutis rhomboidalis nuchae	OR (95% CI)	1.01 (0.65, 1,58)	1.18 (0.73, 1.91)
Morbus favre racouchot	OR (95% CI)	1.30 (0.34, 4.97)	1.47 (0.30, 7.21)
Uneven pigmentation on the bottom side of arms	OR (95% CI)	1.93 (1.16, 3.22)	2.34 (1.34, 4.09)
Fine wrinkles on the back of hands	OR (95% CI)	0.91 (0.60, 1.39)	0.75 (0.48, 1.19)

Abbreviations: GMR, geometric mean ratio; AMR, arithmetic mean ratio; OR, odds ratio; CI, confidence interval.

[a] The concentrations of chromium were grouped by the median, and the $\leq P_{50}$ group was the control.

[b] The covariates in model 1 involved age, and those in model 2 involved age, BMI, education, occupation, active and passive smoking status, alcohol consumption (hard wine and weak drinks), staying up, physical exercise, menopause status, sun exposure, sunburn history, and sun protection (using sunshade, sunscreen, and skincare products).

coarse wrinkles and other further skin aging symptoms.

We further subdivided hair chromium into three levels to test its dose–response relationship with the above pigmentation symptoms. The results indicated obvious linear upward trends in the risk of pigmentation when the hair chromium concentrations increased (Table 3).

3.3. Correlation between dietary frequency plus other potential sources and hair chromium

We calculated Spearman's correlation coefficients between nine dietary frequencies plus other potential sources and the concentrations of chromium in hair (Table 4). The results indicated that eating vegetables, fruits, and beans was significantly correlated with chromium exposure, which suggested that plant foods might be a source of chromium exposure among rural housewives in Shanxi. We also analyzed the correlation of hair chromium with other potential sources including passive smoking, tea drinking, and coal-burning-related indoor air pollution; however, no significant association was found.

4. Discussion

In this study, we estimated the association between hair chromium concentrations and skin aging symptoms among rural women in northern China. We observed that women with higher concentrations of hair chromium had more severe skin pigmentation, which represented uneven pigmentation on the bottom side of the arms and more pigment spots on the forehead, arms, and back of the hands. The increasing trend of effect values with the addition of levels of hair chromium further strengthened this association. We also discovered correlations of dietary frequencies of vegetables, fruits, and beans with hair chromium accumulation. In summary, our results supported the assumption that skin aging, especially pigmentation, was associated with chronic exposure to chromium, and eating plant foods might be a reason for chromium exposure among rural housewives.

Table 3
Associations between different levels of hair chromium concentrations and skin aging symptoms.

Skin aging symptom	Levels[a]	Index	Model 1[b]	P for trend	Model 2[b]	P for trend
Reference	1	GMR or OR	1.00	-	1.00	-
Number of pigment spots						
On forehead	2	GMR (95% CI)	1.14 (1.00, 1.30)	0.01	1.12 (0.98, 1.28)	0.02
	3	GMR (95% CI)	1.18 (1.03, 1.34)		1.17 (1.03, 1.34)	
On the back of hands	2	GMR (95% CI)	1.19 (1.03, 1.39)	0.02	1.21 (1.03, 1.41)	0.01
	3	GMR (95% CI)	1.20 (1.03, 1.39)		1.21 (1.04, 1.42)	
On arms	2	GMR (95% CI)	1.24 (1.07, 1.43)	< 0.01	1.27 (1.09, 1.48)	< 0.01
	3	GMR (95% CI)	1.26 (1.09, 1.45)		1.27 (1.09, 1.47)	
Presence of further skin aging symptoms						
Uneven pigmentation on the bottom side of arms	2	OR (95% CI)	1.96 (1.02, 3.76)	0.02	2.17 (1.07, 4.37)	0.01
	3	OR (95% CI)	2.16 (1.16, 4.02)		2.64 (1.35, 5.18)	

Abbreviations: GMR, geometric mean ratio; OR, odds ratio; CI, confidence interval.

[a] The concentrations of chromium were cut off by the 33rd and 66th percentages, and the $\le P_{33}$ group (level 1) was the control.

[b] The covariates in model 1 involved age, and those in model 2 involved age, BMI, education, occupation, active and passive smoking status, alcohol consumption (hard wine and weak drinks), staying up late, physical exercise, menopause status, sun exposure, sunburn history, and sun protection (using sunshade, sunscreen, and skincare products).

Table 4
Spearman correlation analysis between hair chromium concentrations and dietary frequencies of various foods plus other sources.

	n	r_s	P
Dietary frequency			
Meat	396	0.05	1.00
Eggs	396	0.08	0.57
Vegetables	396	0.25	< 0.01
Fruits	395	0.18	< 0.01
Beans	395	0.14	0.03
Sauerkrauts	396	-0.04	1.00
Barbecue	396	0.01	1.00
Fried foods	396	0.06	1.00
Vinegar	396	0.06	1.00
Others			
Passive smoking	396	-0.11	0.10
Tea drinking	396	0.00	0.97
Indoor air pollution	351	0.10	0.11

People are vulnerable to exposure to chromium from the environment due to its wide distribution (Zhao et al., 2020), which can enter the human body through the digestive tract, respiratory tract, and skin (Bregnbak et al., 2015). China is an agricultural large country, and the application of fertilizer may increase the accumulation of soil chromium (Li et al., 2020), which can be enriched in the human body through food. Dietary exposure to chromium was considered to be related to rice and vegetables (Hu et al., 2019), and we further found that fruits and beans might also be the source of chromium exposure. Thus, the health effect of chromium among people living in rural areas needs more attention. The method of using hair samples to determine chromium that is less harmful to humans has been established, and the correlation between hair chromium and serum chromium is strong (correlation coefficient = 0.52) (Randall and Gibson, 1989), which indicates that hair chromium can be regarded as a biomarker of chromium exposure in a certain period. The median concentrations of hair chromium among our subjects are several times lower than those among workers exposed to high levels of chromium (Al Hossain et al., 2019; Randall and Gibson, 1989), similar to those among general northern Finns (Soininen et al., 2003). In addition, our subjects were recruited in the countryside far from the mining area and mainly engaged in housework. Therefore, our study is applicable to explore the association between chromium exposure and skin aging in the general population.

Many studies have stated the association between chromium exposure and skin damage (Chen et al., 2008; Chou et al., 2016; Moretto, 2015; Shelnutt et al., 2007). Specifically, few studies have reported the relationship of chromium with skin aging. Al Hossain et al. found hair chromium associated with face and feet hyperpigmentation among male tannery workers (Al Hossain et al., 2019), which was similar to our results. In contrast, the pigmentation of our subjects mainly occurred on the forehead and upper limbs. Compared with their study, we focused more on nonoccupational exposure and women's health. In addition, we used SCINEXA™ to systematically distinguish and assess the degrees of skin aging, although except for pigment spots and uneven pigmentation, no significant associations of other symptoms with chromium were observed. As a result, our study might further reveal the effect of a lower dose of chromium on skin aging. Unfortunately, except for the above studies, we have not obtained any other similar epidemiological or animal studies on chromium and skin aging to provide more evidence for our conclusions.

Several possible mechanisms may explain the reason for skin aging. As age increases, the proliferation ability of skin cells in the basal layer naturally decreases, namely cellular senescence (Zhang and Duan, 2018); along this process, environmental factors can arise reactive oxygen, induce complex cascade reactions in the skin and eventually lead to skin damage (McDaniel et al., 2018). High levels of chromium exposure can increase the production of reactive oxygen and hydroxyl radicals in the human body and enhance oxidative stress (Junaid et al., 2016), and oxidative stress may play an important role in skin pigmentation (Lee, 2021). In addition, chromium can change the lipopolysaccharide-induced inflammatory response (Jin et al., 2016); high concentrations of hexavalent chromium are also considered to be related to skin irritation and contact dermatitis (Moretto, 2015; Shelnutt et al., 2007). Chromium causes inflammation, which can stimulate the melanocytes in the basal layer of the epidermis, resulting in skin pigmentation (Hossain et al., 2021). Unfortunately, the specific mechanism for chromium exposure developing skin aging including pigmentation is still unclear. Therefore, studies need to pay more attention to the mechanism of this association and supplement more epidemiological evidence in the future.

Our study had three main limitations. Because of the relatively weak causal reference of the cross-sectional study, we failed to directly identify the causal relationship between hair chromium and skin aging and failed to observe the time-effect change. In addition, our subjects were all Han women, so it might hinder the extrapolation of the conclusion to other populations such as men, children, and other ethnicities. Moreover, we cannot distinguish the valence state of chromium, which is a common limitation of ICP–MS; therefore, further studies should focus on improving the specificity of chromium detection.

However, our study also had several strengths. First, we analyzed chromium in hair samples, which were less harmful and more acceptable than other methods. Second, the highly stable living environment of our subjects reduced the latent significant impact of other interferents. Third, the questionnaire collection and outcome evaluation were performed by uniformly trained healthcare workers for quality control and assurance. Fourth, we used two regression models to confirm the association between hair chromium and skin aging, and the second model involved enough important covariates to control their confounding effects, so the conclusion was reliable.

To our knowledge, this is the first study to systematically examine the associations between chromium and skin aging scores among general women. Skin aging such as pigmentation is general, but high chromium exposure might accelerate and aggravate this process. It might arise the risk of dermatological diseases and lead to negative esthetic influence. Hence, the effect of chromium on skin aging needs to be taken seriously.

5. Conclusion

We found that skin aging, especially pigmentation, was associated with a high level of hair chromium, and vegetative foods might be a source of chromium among rural housewives in northern China. We deem that it is necessary to take some measures to reduce chromium exposure to prevent skin aging.

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CRediT authorship contribution statement

Jigen Na: Conceptualization, Data curation, Formal analysis, Writing – original draft. **Nan Li:** Conceptualization, Data curation, Writing – review & editing. **Lailai Yan:** Laboratory analysis. **Tamara Schikowski:** Investigation, Supervision. **Rongwei Ye:** Investigation, Project administration, Funding acquisition, Supervision. **Jean Krutmann:** Investigation, Supervision. **Zhiwen Li:** Investigation, Project administration, Funding acquisition, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Author contributions

Rongwei Ye, Jean Krutmann, Tamara Schikowski, and Zhiwen Li conceived and designed the study and supervised the whole project; Nan Li helped conduct the field study and collect data; Rongwei Ye and Zhiwen Li obtained funding; Lailai Yan performed the laboratory analysis; Jigen Na analyzed data and drafted the manuscript; Nan Li polished the manuscript. All authors reviewed and approved the final version of the manuscript.

Institutional review board statement

The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board of Peking University (protocol code: IRBIRB00001052-12045, 4 September 2012).

Informed consent statement

Informed consent was obtained from all subjects involved in the study.

References

Al Hossain, M.M.A., Yajima, I., Tazaki, A., Xu, H., Saheduzzaman, M., Ohgami, N., Kato, M., 2019. Chromium-mediated hyperpigmentation of skin in male tannery workers in Bangladesh. Chemosphere 229, 611–617.
Alvarez, C.C., Bravo Gomez, M.E., Hernandez Zavala, A., 2021. Hexavalent chromium: regulation and health effects. J. Trace Elem. Med. Biol. Vol. 65, 126729.
Bregnbak, D., Johansen, J.D., Jellesen, M.S., Zachariae, C., Menné, T., Thyssen, J.P., 2015. Chromium allergy and dermatitis: prevalence and main findings. Contact Dermat. Vol. 73, 261–280.
Chen, C.J., Shih, T.S., Chang, H.Y., Yu, H.S., Wu, J.D., Sheu, S.C., Chou, T.C., 2008. The total body burden of chromium associated with skin disease and smoking among cement workers. Sci. Total Environ. Vol. 391, 76–81.
Chou, T.C., Wang, P.C., Wu, J.D., Sheu, S.C., 2016. Chromium-induced skin damage among Taiwanese cement workers. Toxicol. Ind. Health Vol. 32, 1745–1751.
Farage, M.A., Miller, K.W., Berardesca, E., Maibach, H.I., 2009. Clinical implications of aging skin: cutaneous disorders in the elderly. Am. J. Clin. Dermatol. Vol. 10, 73–86.
Goodman, G.D., Kaufman, J., Day, D., Weiss, R., Kawata, A.K., Garcia, J.K., Gallagher, C. J., 2019. Impact of smoking and alcohol use on facial aging in women: results of a

large multinational, multiracial, cross-sectional survey. J. Clin. Aesthet. Dermatol. Vol. 12, 28–39.

Hossain, M.R., Ansary, T.M., Komine, M., Ohtsuki, M., 2021. Diversified stimuli-induced inflammatory pathways cause skin pigmentation. Int. J. Mol. Sci. Vol. 22.

Hu, Y., Zhou, J., Du, B., Liu, H., Zhang, W., Liang, J., Zhou, J., 2019. Health risks to local residents from the exposure of heavy metals around the largest copper smelter in China. Ecotoxicol. Environ. Saf. 329–336.

Jin, Y., Liu, L., Zhang, S., Tao, B., Tao, R., He, X., Fu, Z., 2016. Chromium alters lipopolysaccharide-induced inflammatory responses both in vivo and in vitro. Chemosphere Vol. 148, 436–443.

Junaid, M., Hashmi, M.Z., Malik, R.N., Pei, D.S., 2016. Toxicity and oxidative stress induced by chromium in workers exposed from different occupational settings around the globe: a review. Environ. Sci. Pollut. Res. Int. Vol. 23, 20151–20167.

Kobla, H.V., Volpe, S.L., 2000. Chromium, exercise, and body composition. Crit. Rev. Food Sci. Nutr. Vol. 40, 291–308.

Lee, A.Y., 2021. Skin pigmentation abnormalities and their possible relationship with skin aging. Int. J. Mol. Sci. Vol. 22.

Li, M., Vierkotter, A., Schikowski, T., Huls, A., Ding, A., Matsui, M.S., Wang, S., 2015a. Epidemiological evidence that indoor air pollution from cooking with solid fuels accelerates skin aging in Chinese women. J. Dermatol. Sci. Vol. 79, 148–154.

Li, N., Li, Z., Chen, S., Yang, N., Ren, A., Ye, R., 2015b. Effects of passive smoking on hypertension in rural Chinese nonsmoking women. J. Hypertens. Vol. 33, 2210–2214.

Li, X., Zhang, J., Ma, J., Liu, Q., Shi, T., Gong, Y., Wu, Y., 2020. Status of chromium accumulation in agricultural soils across China (1989-2016). Chemosphere Vol. 256, 127036.

Li, Z., Wang, B., Ge, S., Yan, L., Liu, Y., Li, Z., Ren, A., 2016. A simultaneous analysis method of polycyclic aromatic hydrocarbons, nicotine, cotinine and metals in human hair. Environ. Pollut. Vol. 219, 66–71.

McDaniel, D., Farris, P., Valacchi, G., 2018. Atmospheric skin aging-contributors and inhibitors. J. Cosmet. Dermatol. Vol. 17, 124–137.

Moretto, A., 2015. Hexavalent and trivalent chromium in leather: what should be done? Regul. Toxicol. Pharmacol. Vol. 73, 681–686.

Randall, J.A., Gibson, R.S., 1989. Hair chromium as an index of chromium exposure of tannery workers. Br. J. Ind. Med. Vol. 46, 171–175.

Rittie, L., Fisher, G.J., 2015. Natural and sun-induced aging of human skin. Cold Spring Harb. Perspect. Med. Vol. 5, a015370.

Shelnutt, S.R., Goad, P., Belsito, D.V., 2007. Dermatological toxicity of hexavalent chromium. Crit. Rev. Toxicol. Vol. 37, 375–387.

Soininen, L., Mussalo-Rauhamaa, H., Lehto, J., 2003. Hair chromium concentration of northern Finns. Int. J. Circumpolar Health Vol. 62, 276–283.

Vierkotter, A., Schikowski, T., Ranft, U., Sugiri, D., Matsui, M., Kramer, U., Krutmann, J., 2010. Airborne particle exposure and extrinsic skin aging. J. Investig. Dermatol. Vol. 130, 2719–2726.

Vierkotter, A., Huls, A., Yamamoto, A., Stolz, S., Kramer, U., Matsui, M.S., Schikowski, T., 2016. Extrinsic skin ageing in German, Chinese and Japanese women manifests differently in all three groups depending on ethnic background, age and anatomical site. J. Dermatol. Sci. Vol. 83, 219–225.

Zhang, S., Duan, E., 2018. Fighting against skin aging: the way from bench to bedside. Cell Transpl. Vol. 27, 729–738.

Zhao, M., Xu, J., Li, A., Mei, Y., Ge, X., Liu, X., Xu, Q., 2020. Multiple exposure pathways and urinary chromium in residents exposed to chromium. Environ. Int. Vol. 141, 105753.