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Heavy Metal and Trace Element Levels in Hair Samples from Fishermen in Turkey: The Fish/Ermen Heavy Metal Study (FHMS)

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Abstract

Toxic chemicals from polluted seas can enter the human body through seafood consumption and cause health problems. The aim of this study was to evaluate the levels of selected heavy metals and trace elements among fishermen who frequently consumed seafood and controls who consumed seafood less frequently in four provinces on the shores of the Sea of Marmara, which is heavily polluted by industrial activities. Fourteen elements (antimony, arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, selenium, strontium, vanadium, and zinc) were analyzed in hair samples using the inductively coupled plasma-mass spectrometer method. Levels of arsenic (0.147 ± 0.067 μg/g vs. 0.129 ± 0.070 μg/g, $p = 0.025$), chromium (0.327 ± 0.096 μg/g vs. 0.269 ± 0.116 μg/g, $p < 0.01$), nickel (0.469 ± 0.339 μg/g vs. 0.403 ± 0.368 μg/g, $p = 0.015$), strontium (1.987 ± 1.241 μg/g vs. 1.468 ± 1.190 μg/g, $p < 0.01$), and zinc (103.3 ± 43.1 μg/g vs. 92.7 ± 37.4 μg/g, $p = 0.047$) were higher in the fisherman group than in the control group. No difference was found between the groups in terms of other elements. The findings suggest that heavy metal-trace element contamination in the Sea of Marmara may increase the exposure levels of individuals to some chemicals through seafood consumption.

Keywords Heavy metal · Trace element · Hair · Seafood consumption · Fishermen

Introduction

Seafood is an important food source because it is rich in proteins with high biological value, essential fatty acids, some vitamins, and minerals [1, 2]. Marine pollution has been increasing for a long time, and these pollutants potentially threaten marine life [3]. Accumulation of pollutants in the aquatic environment has become a global problem due to industrial expansion and affects life forms due to their strong bioaccumulation potential and toxicity [4]. Chemicals introduced to receiving environments can be transported through the chain of phytoplankton–zooplankton–small fish–large fish [3, 5]. Humans who consume seafood living in these contaminated waters may experience increased heavy metal and trace element exposure due to bioaccumulation and biomagnification mechanisms and may face serious health problems [6, 7].

Some heavy metals and trace elements that are taken into the body through the consumption of seafood are essential for the continuation of human life and play important roles in various reactions in the human body (such as iron, zinc, and selenium). Some elements have no known role in

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human physiology and can be toxic even at low levels (such as lead). However, even essential elements are known to be toxic above certain levels. It is therefore important that the concentrations of these substances taken into the body from various sources are within specific ranges [8].

Minamata disease was identified in 1956 with the occurrence of widespread neurological disorders, congenital diseases, and deaths due to the consumption of seafood containing high amounts of mercury caught from a gulf contaminated with mercury-containing industrial wastes for many years and is one of the most well-known examples of health problems caused by this way [9, 10]. Heavy metals such as arsenic and cadmium can also cause systemic toxic changes in the body and are classified as carcinogens by the International Agency for Research on Cancer [11–13]. Therefore, exposure due to frequent consumption of seafood living in waters contaminated with heavy metals and trace elements is a public health concern. Levels in hair samples can be used to assess past exposure to these elements [14, 15].

In Turkey, a peninsula surrounded by sea on three sides, marine pollution has been increasing in recent years. The Sea of Marmara Sea has been polluted with various wastes, especially heavy metals, for many years due to the fact that it is an inland sea located in the region where the industry is densely clustered and which hosts a significant part of the country's population [16–20]. In 2018, 18.4 percent of the seafood caught in Turkey was caught in the Marmara region, which is equivalent to 52338 tons of seafood [21]. The effects of this pollution on seafood have been examined in studies, and arsenic, cadmium, lead, mercury, and zinc levels in different species of seafood caught in the Sea of Marmara were found to be above the safe upper limits [22–25]. In a study conducted as part of this project, the levels of arsenic, cadmium, chromium, and lead in seafood caught in the Sea of Marmara were found to be above permissible limits [26]. In two recent studies on various species of fish in the Sea of Marmara, the levels of many toxic metals were found to be above the safe limits [27, 28]. This makes it essential to investigate whether or not there is an increase in elemental levels in individuals consuming seafood in the region.

Research examining levels of trace elements and heavy metals in individuals who frequently consume seafood has focused on a few elements, particularly mercury [e.g., 29–31]. Increasing environmental pollution of industrial origin and the growing spectrum thereof mean that a larger number of elements now require investigation [32]. The studies on this subject conducted in Turkey are also limited in number and cover three elements in total [33–35].

The aim of this study was to evaluate the levels of 14 heavy metals and trace elements (antimony, arsenic, cadmium, chromium, chromium, copper, iron, lead, manganese, mercury, nickel, selenium, strontium, vanadium, and zinc) in hair samples collected from fishermen who frequently consumed seafood and a control group who consumed seafood less frequently in four provinces on the shores of the Sea of Marmara.

Materials and Methods

Study Design and Participants

This research is part of the "Heavy Metal-Trace Element Load and Risk Mapping in Sea Products and Fishermen" project conducted between July 2017 and August 2019. As part of this project, whole blood levels indicating recent exposure to various elements were evaluated in the previous article [36]. In this study, heavy metal and trace element levels were analyzed in hair samples to assess chronic exposure. The study was carried out in the provinces of Istanbul, Kocaeli, Tekirdağ, and Yalova, all on the shores of the Sea of Marmara and heavily affected by industrial pollution (Fig. 1).

Fishermen who frequently consumed seafood they caught in the Sea of Marmara were selected as the experimental group. The inclusion criteria for the fishermen group were having been actively engaged in fishing for at least five years, being 25 years of age or older, being male and consuming seafood at least twice a week. The control group was established from among male individuals living in the same provinces as the fishermen and of similar age to them, not working in fishing and consuming seafood less than once every 15 days.

Raposo et al.'s study from Spain assessing the hair levels of various elements was adopted as a reference study in calculating the sample size [37]. The reported hair mercury level in the normal population in this study was 5.38 mg/kg. Estimating that the standard deviation for that value would be 20% and that hair mercury levels in fishermen would be approximately 10% higher than that value, investigation using Power and Precision Version 3.2.0 software with 80% power showed that at least 64 fishermen and 20 controls would need to be included from each province. In order to establish contact with fishermen, cooperatives in the provinces of Istanbul, Kocaeli, Tekirdağ, and Yalova were visited, fishermen registered with these were interviewed, and the date and time of the field study were determined. Research commenced with the fishermen groups in the provinces, after which controls of similar ages to the fishermen in the same provinces were selected. A total of 263 fishermen and 89 controls were included in the research.

Sampling and Analytical Methods

A questionnaire prepared by the authors was applied to the participants in the fishermen and control groups at face-to-face

Fig. 1 The Sea of Marmara and the provinces where the research was conducted

interviews, after which hair samples were collected. This consisted of questions concerning participants' various sociodemographic and personal characteristics, seafood consumption and the type, amount, period, and frequency of that consumption. Metal-free, ceramic scissors were used to collect the hair samples. Care was taken to ensure that there was no dye or hairspray on the hair. Samples were then collected from the occipital region as close to the scalp as possible, at a length of 1 cm, a diameter of 0.5 cm, and a weight of approximately 0.8–1.0 g. The collected hair samples were placed in lockable plastic bags and stored at − 18 °C until analysis.

Hair samples were first washed with distilled water for 15 min in an ultrasonic bath according to the method described by Rodushkin and Axelsson [38]. They were then washed again with acetone–water-water-water–acetone, placed in glass containers, and dried in an oven at 50 °C overnight. The samples were subsequently subjected to microwave digestion. For this purpose, 0.05 ml of 65% suprapure HNO_3 and 0.5 ml of 30% suprapure H_2O_2 were added to 0.05 g hair samples placed in dry, clean teflon microwave chambers, digestion being performed under the conditions shown in Table 1. Samples removed from the device were allowed to cool to room temperature and then transferred to 15 ml Falcon tubes. Next, the samples were made ready for analysis on an ICP-MS device with the addition of ultrapure water for a final volume of 10 ml.

Laboratory analyses were carried out at the Zonguldak Bülent Ecevit University Science and Technology Application and Research Center. Antimony (Sb), arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), lead (Pb), manganese (Mn), mercury (Hg), nickel (Ni), selenium (Se), strontium (Sr), vanadium (V), and zinc (Zn) levels in the hair samples were measured using an inductively coupled plasma-mass spectrometer (Perkin-Elmer, New York, USA). ICP-MS working conditions were set at an RF power of 1000 W, a nebulizer gas flow

Table 1 Microwave device working conditions

Temperature (°C)	Pressure (bar)	Increase speed (s)	Duration (min)	Power (W)
150	50	10	10	70
220	50	5	20	80
200	50	5	5	80
150	50	1	5	60
100	50	1	1	0

rate of 0.99 ml/min, an auxiliary gas flow rate of 1.2 ml/min, a lens voltage of −9.75 V, and an oxide rate of 0.021%. Internal calibrations of the device were performed using the appropriate device setup solution and stock standards (V^{51}, Cr^{52}, Mn^{55}, Fe^{56}, Ni^{60}, As^{75}, Cu^{63}, Zn^{66}, Se^{82}, Sr^{88}, Cd^{111}, Sb^{123}, Hg^{202}, and Pb^{208}). Five-point calibration curves were used for element readings. Two certificated reference materials were employed for the external calibration of the device (NCS DC73347a (GSH-1a) and NCS ZC 81002b [Beijing, China]). Sample preparation and analysis processes for both the samples and the reference material were performed following the method described by Rodushkin and Axelsson [39]. All solutions and reactives in the experiments were prepared with ultrapure water (18.3 MΩ-cm), while ultrapure nitric acid and hydrogen peroxide were employed in the sample preparation procedures. Results are based upon dry weight. The limit of detection (LOD) and limit of quantification (LOQ) values in hair are presented in Table 2.

Statistical Analysis

Statistical analyses were performed with SPSS 23.0 software. Descriptive statistics were expressed as mean (AM (arithmetic mean)), standard deviation (SD), minimum (min), and maximum (max) for quantitative variables and as number (n) and percentage (%) for qualitative variables. The Kolmogorov–Smirnov test and Shapiro–Wilk test were used to assess the normality of data distribution. Student's t-test was used in the comparison of measurement variables between two independent groups when normal distribution conditions were met, while the Mann–Whitney U test was used in case of nonnormal distribution. A chi-square test was used to compare qualitative data between independent groups. Spearman's correlation test was used to evaluate correlations between measurement variables. The statistical significance level was accepted as $p<0.05$.

Table 2 Limit of detection and limit of quantification values in hair

Element	LOD (μg/g)	LOQ (μg/g)
Antimony (Sb)	0.002	0.004
Arsenic (As)	0.01	0.02
Cadmium (Cd)	0.001	0.004
Chromium (Cr)	0.02	0.06
Copper (Cu)	0.01	0.03
Iron (Fe)	0.12	0.18
Lead (Pb)	0.02	0.07
Manganese (Mn)	0.001	0.008
Mercury (Hg)	0.003	0.007
Nickel (Ni)	0.01	0.016
Selenium (Se)	0.02	0.06
Strontium (Sr)	0.01	0.03
Vanadium (V)	0.006	0.01
Zinc (Zn)	0.02	0.09

LOD limit of detection, *LOQ* limit of quantification

Ethics Approval and Consent to Participate

This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Bülent Ecevit University Clinical Research Ethical Committee (Date 24 February 2016, no. 2016/04). The aims and scope of the study were explained to all participants. Written informed consent was obtained from individuals agreeing to participate prior to commencement. Participation was completely voluntary.

Results

352 people participated in the study, 263 in the fishermen group, and 89 in the control group. The mean consumption of seafood in the last month was 6234.6 ± 4856.3 g in the fishermen group and 363.5 ± 310.5 g in the control group ($p<0.001$). Some sociodemographic and personal characteristics of fishermen and control groups are presented in Table 3.

Among the 14 heavy metals and trace elements measured in hair samples, arsenic, chromium, nickel, strontium, and zinc levels were significantly higher in the fishermen group than in the control group. The levels determined in the fishermen and control groups were 0.147 ± 0.067 μg/g and 0.129 ± 0.070 μg/g for arsenic ($p=0.025$), 0.327 ± 0.096 μg/g and 0.269 ± 0.116 μg/g for chromium ($p<0.01$), 0.469 ± 0.339 μg/g and 0.403 ± 0.368 μg/g for nickel ($p=0.015$), 1.987 ± 1.241 μg/g and 1.468 ± 1.190 μg/g for strontium ($p<0.01$), and 103.3 ± 43.1 μg/g and 92.7 ± 37.4 μg/g for zinc ($p=0.047$), respectively (Table 4 and Fig. 2). No significant difference was observed between the groups in terms of antimony, cadmium, copper, iron, lead, manganese, mercury, selenium, or vanadium levels (Table 4).

The fishermen and control groups' hair cadmium and nickel levels according to smoking status and hair mercury levels according to the presence of amalgam fillings are shown in Table 5. Hair cadmium levels of fishermen group and control group were found to be similar when considering nonsmokers/quitters ($p=0.396$). Hair cadmium levels were similar between fishermen and controls who smoke ($p=0.249$). Hair nickel levels of fishermen who do not smoke or quit smoking were found to be higher than controls who do not smoke or quit smoking ($p=0.009$). No difference in hair nickel levels was found between smoking fishermen and controls ($p=0.693$). Hair mercury levels of both fishermen and controls without dental amalgam fillings and fishermen and controls with dental amalgam fillings did not differ between the groups ($p=0.399$ and $p=0.127$, respectively) (Table 5).

Table 3 Some sociodemographic and personal characteristics of fishermen and control groups

Characteristic	Fishermen group ($n = 263$)		Control group ($n = 89$)		p
	n	%	n	%	
Age (mean ± SD)	53.5 ± 13.3		52.0 ± 12.8		0.331
Marital status					0.384
Married	215	81.7	77	86.5	
Single	48	18.3	12	13.5	
Education					< 0.001
Illiterate/literate	6	2.3	3	3.4	
Elementary school	126	47.9	29	32.6	
Middle school	48	18.3	5	5.6	
High school	63	24.0	16	18.0	
University and above	20	7.6	36	40.4	
Smoking status					< 0.001
Current smoker	163	62.0	37	41.6	
Quitter	60	22.8	23	25.8	
Nonsmoker	40	15.2	29	32.6	
Amalgam tooth filling					0.694
Yes	52	19.8	20	22.5	
No	211	80.2	69	77.5	
Seafood consumption in the last month (g) (mean ± SD)	6234.6 ± 4856.3		363.5 ± 310.5		< 0.001

Table 4 Heavy metal and trace element levels in hair samples of fishermen and control groups (μg/g)

Element	Fishermen ($n = 263$)				Control ($n = 89$)				p
	AM	SD	min	max	AM	SD	min	max	
Antimony (Sb)	0.057	0.030	0.008	0.132	0.058	0.030	0.008	0.124	0.853
Arsenic (As)	0.147	0.067	0.023	0.308	0.129	0.070	0.024	0.288	0.025
Cadmium (Cd)	0.099	0.079	0.005	0.343	0.098	0.076	0.008	0.286	0.857
Chromium (Cr)	0.327	0.096	0.082	0.533	0.269	0.116	0.058	0.530	< 0.001
Copper (Cu)	34.4	15.0	10.8	89.3	35.9	15.2	7.100	78.1	0.322
Iron (Fe)	10.6	5.302	1.000	28.0	10.5	5.144	2.000	21.0	0.971
Lead (Pb)	2.897	1.969	0.190	7.250	3.251	1.839	0.430	6.990	0.076
Manganese (Mn)	0.918	0.525	0.088	2.505	0.987	0.575	0.129	2.188	0.394
Mercury (Hg)	0.139	0.119	0.011	0.716	0.114	0.085	0.011	0.469	0.146
Nickel (Ni)	0.469	0.339	0.020	1.660	0.403	0.368	0.020	1.590	0.015
Selenium (Se)	1.024	0.296	0.490	1.960	0.969	0.384	0.270	1.920	0.132
Strontium (Sr)	1.987	1.241	0.250	5.760	1.468	1.190	0.180	5.490	< 0.001
Vanadium (V)	0.047	0.031	0.006	0.130	0.042	0.028	0.007	0.125	0.236
Zinc (Zn)	103.3	43.1	26.0	203.0	92.7	37.4	20.0	214.0	0.047

AM arithmetic mean, *SD* standard deviation

Correlations between participants' seafood consumption and hair heavy metal/trace element levels were examined. Elements with significant correlation are shown in Table 6. Monthly seafood consumption was positively correlated with hair chromium, nickel, selenium, strontium, and zinc levels, while no correlation was determined with other elements (Table 6 and Fig. 3).

Discussion

This study employed a large panel to investigate whether fishermen who frequently consumed seafood in four provinces around the Sea of Marmara were exposed to an increased element load compared to controls who consumed smaller amounts of such foods. Arsenic, chromium, nickel, strontium, and zinc levels

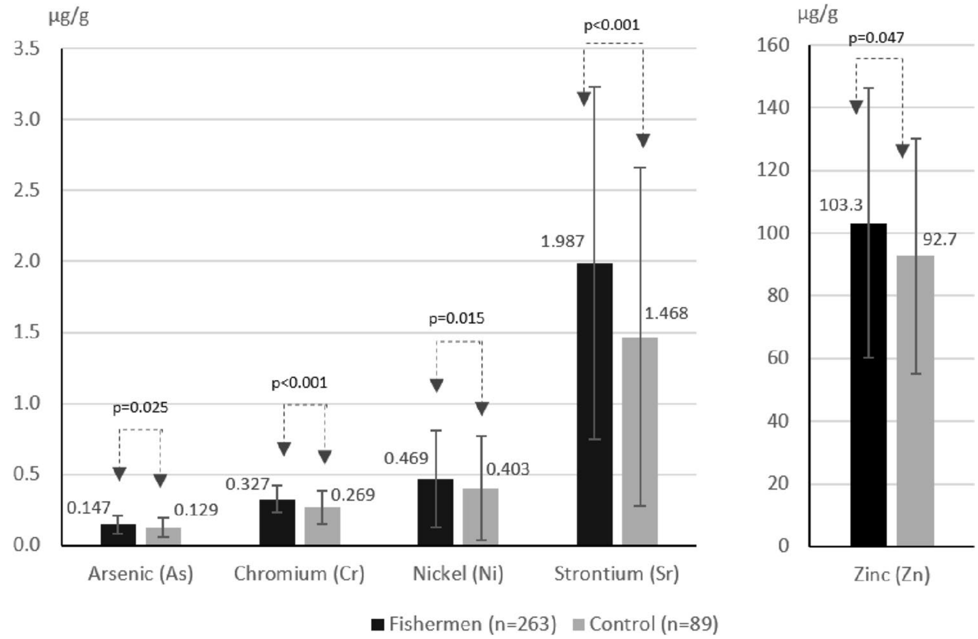

Fig. 2 Hair arsenic, chromium, nickel, strontium, and zinc levels in the fishermen and control groups (µg/g)

Table 5 Cd, Hg and Ni levels according to some characteristics of fishermen and control groups (µg/g)

Element	Fishermen			Control			*p*
	n	AM	SD	*n*	AM	SD	
Cadmium (Cd)							
Nonsmokers/quitters	100	0.104	0.081	52	0.092	0.075	0.396
Smokers	163	0.098	0.078	37	0.107	0.078	0.249
Mercury (Hg)							
No amalgam fillings	211	0.136	0.120	69	0.116	0.902	0.399
With amalgam fillings	52	0.151	0.116	20	0.104	0.067	0.127
Nickel (Ni)							
Nonsmokers/quitters	100	0.463	0.358	52	0.329	0.293	0.009
Smokers	163	0.473	0.329	37	0.507	0.438	0.693

AM arithmetic mean, *SD* standard deviation

Table 6 Correlations between participants' monthly seafood consumption and element levels ($n = 352$)

Element	*r*	*p*
Chromium (Cr)	0.233	< 0.001
Nickel (Ni)	0.141	0.008
Selenium (Se)	0.120	0.024
Strontium (Sr)	0.157	0.003
Zinc (Zn)	0.115	0.031

r correlation coefficient

were higher in hair samples from the fishermen group than in the control group.

Although people are exposed to various amounts of arsenic through the air they breathe and drinking water, the main source of arsenic exposure is the consumption of food, particularly seafood [11]. Several studies have examined the relationship between individuals' seafood consumption and arsenic levels. A study of 100 individuals from Egypt reported that the average weekly amount of fish consumed was correlated with hair arsenic levels [40]. Two other studies, one from Norway and one from Italy and Croatia revealed correlation between the amounts of fish consumed and blood arsenic levels, which are more likely to reflect recent exposure [11, 41, 42]. However, studies involving 52 individuals from Puerto Rico and 160 from Pakistan observed no difference in hair arsenic levels between groups with high frequencies of fish consumption and groups with low frequencies of consumption [43, 44]. Studies from Japan and Brazil investigating arsenic levels in nail and blood samples, respectively, from individuals consuming seafood at varying frequencies also observed no association [45, 46]. These findings may be attributable to the studies being conducted in different regions. Since arsenic levels are higher in seafood from waters

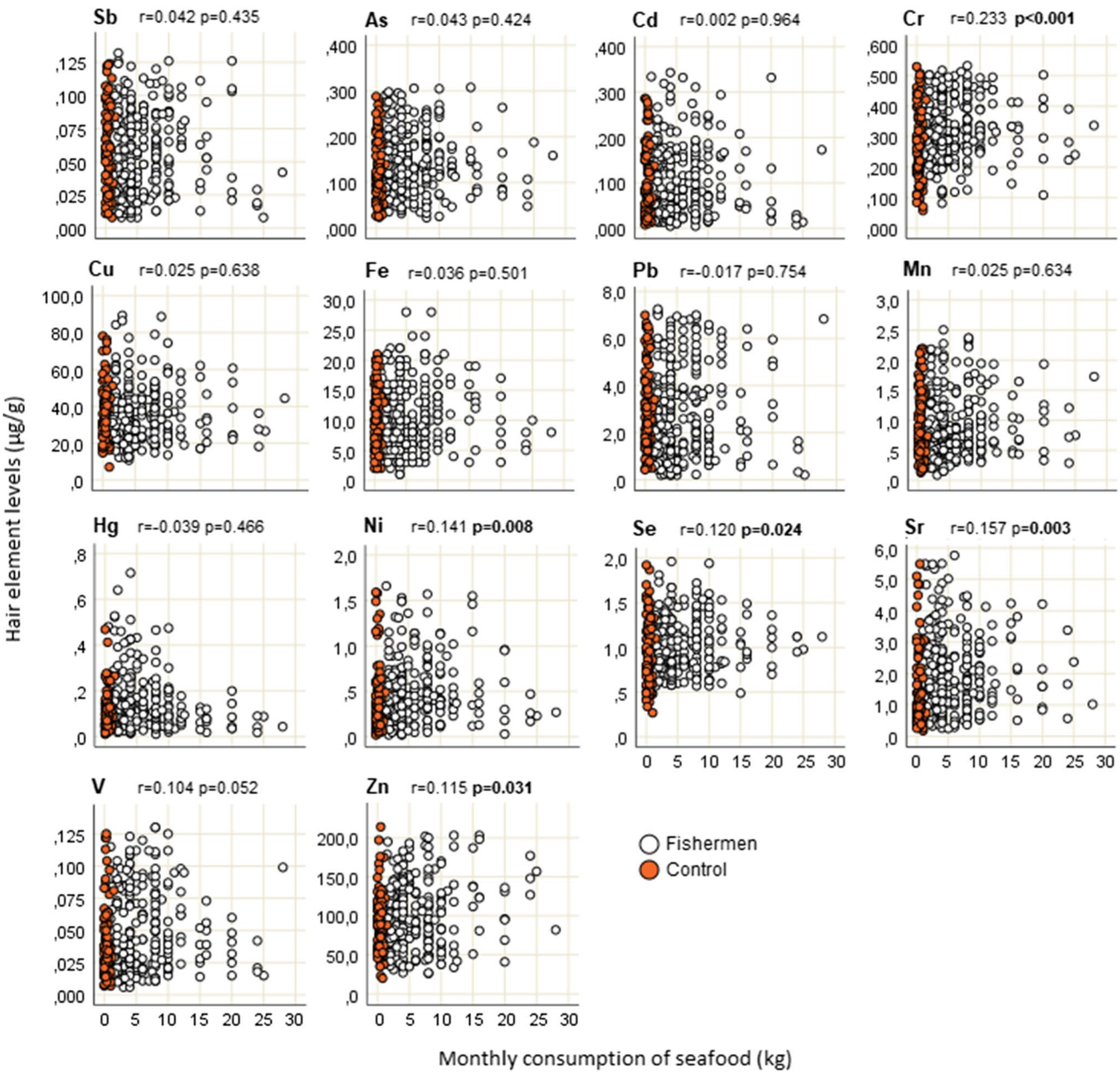

Fig. 3 Correlations between participants' monthly seafood consumption and heavy metal/trace element levels measured in hair samples

contaminated with arsenic, individuals who frequently consume such food will also have higher arsenic exposure [47]. In a study conducted in Turkey using the atomic absorption spectrometry method, the mean hair arsenic level in 94 participants in the control group was found to be 0.115 ± 0.006 mg/kg, which is similar to the control group in our study. It was found to be higher as 1.81 ± 1.79 mg/kg in 95 metal workers with occupational exposure [48]. In the present study, hair arsenic levels were higher among the fishermen who frequently consumed seafood compared to the control group. This shows that individuals' arsenic loads may increase in line with frequent consumption of seafood caught in the region. Although less toxic forms of arsenic are known to be found in seafood, with increased seafood consumption, inorganic arsenic exposure, with proven adverse health effects, will also increase and pose a risk to health [11, 49].

Chromium exposure in the general population generally derives from food [50]. Due to its roles in glucose and lipid metabolism, chromium is an essential element for the human body, albeit at low levels [51]. However, high levels can lead to toxic effects [50]. The relationship between frequent seafood consumption and chromium levels has not been sufficiently investigated. A study involving 350 participants from Tunisia determined no difference in blood chromium levels between a high-frequency fish consumption group and a low-frequency consumption group [52]. In the present study, however, hair chromium levels were higher in the fishermen group than in the control group. In addition, participant's monthly seafood consumption was also positively correlated with hair chromium levels. These findings suggest that frequent consumption of seafood caught in the region may cause an increase in exposure to chromium.

Studies evaluating nickel levels in frequent consumers of seafood are very limited. In a study conducted in 423 children and adolescents in Spain, urinary nickel levels were evaluated and it was found that the consumption of fresh fish in the week before the measurement and urinary nickel levels of those living in the intense industrial area Ria of Huelva were positively related. However, urinary nickel levels and consumption were found to be unrelated in those living in other less industrialized Andalusian regions, which were taken as the reference group [53]. This study is important in terms of showing that those who consume fish caught from contaminated waters in industrialized regions may face an increased risk of nickel exposure.

Another study on this subject evaluated blood nickel levels in 350 participants from Tunisia and reported no difference between high- and low-frequency consumption groups [52]. In the present study, hair nickel levels were higher in the fishermen group than in the control group. The monthly amount of seafood consumed by the participants was positively correlated with hair nickel levels. This suggests that frequent consumption of seafood caught from this region may increase nickel exposure. Although food is the primary source of nickel exposure for humans, smoking is also known to have a significant positive effect on nickel levels [54]. When the hair nickel levels of the participants were stratified according to smoking status, it was observed that the mean hair nickel levels of fishermen and controls who smoked were higher and the difference in nickel levels between fishermen and control groups disappeared when only smoking participants were evaluated. However, hair nickel levels of nonsmoker/quitter fishermen were still statistically significantly higher compared to nonsmoker/quitter controls.

Strontium is another element that can enter the human body through the food chain by accumulating in seafood [55]. A study from Italy involving 46 individuals determined no difference in serum strontium levels between a group that consumed fish frequently and a group that consumed fish less frequently [56]. However, research from China involving 452 women reported that the frequency of meat or fish consumption was positively correlated with hair strontium levels [57]. In the present study, hair strontium levels were higher in the fishermen group than in the control group. At the same time, these levels were positively correlated with the monthly amount of seafood consumed. It should not be forgotten that strontium can be absorbed into the body through various food and environmental sources. Our findings suggest that seafood consumption can also contribute to exposure.

Zinc is an important essential element that needs to be present in the body at certain concentrations. However, it can have toxic effects at high levels [58, 59]. Some studies have reported an association between seafood consumption and zinc levels, while others have reported no such association [34, 60–63]. In the present study, hair zinc levels were higher in the fishermen group compared to the control group. Frequent consumption of seafood may have caused this, but people can get zinc into the body from many different dietary sources [58]. Therefore, it is difficult to identify the source of the detected difference as seafood containing high amounts of zinc. The existence of numerous sources of exposure makes it difficult to establish a clear cause and effect relationship. In addition, frequent consumption may affect exposure since seafood is generally rich in zinc. However, the participants' hair zinc levels were not above those reported in the general population and were far from being toxic [58].

Mercury is an element toxic to the human body and with high bioaccumulation and biomagnification potential [64]. It is also one of the elements whose association with seafood consumption has been most investigated. A large proportion of studies have reported higher hair mercury levels among individuals who frequently consume seafood [29, 30, 34, 35, 65]. However, in our study, no significant difference was determined in terms of hair mercury levels between the fishermen and control groups. In addition, mercury concentrations in hair samples from the fishermen and controls were similar or lower than in the previous literature [64, 66]. This suggests that frequent consumption of seafood caught in the region has no significant effect on hair mercury levels. The release of mercury can also contribute to exposure to mercury among individuals with amalgam fillings [64]. Rates of presence of amalgam fillings were similar among the participants in the fishermen and control groups included in this study. Furthermore, no difference was observed when the groups' hair mercury levels were stratified on the basis of presence of amalgam fillings. Although the findings of this study differ from those reported in the literature, they are important in terms of showing that the frequent consumption of seafood from the region causes no significant increase in mercury exposure.

Cadmium is a heavy metal that is highly toxic to humans [12]. Research has reported inconsistent results concerning the association between frequent seafood consumption and cadmium levels [44, 62, 67–70]. No difference in hair cadmium levels was determined between the fishermen and control groups in this study. Smoking is also known to affect cadmium exposure. Since cadmium absorption from the lungs is greater than that from the gastrointestinal system, smoking can make a significant contribution to total exposure [71]. However, when smoker and nonsmoker/quitter participants were evaluated separately, hair cadmium levels were found to be similar between fishermen and control groups. All these findings suggest that the frequent consumption of seafood did not contribute significantly to participants' exposure to cadmium.

Lead is a toxic heavy metal with no known function in the human body [71]. Several studies have investigated the relationship between individuals' seafood consumption and lead levels, with some reporting an association and others not [34, 44, 62, 67, 72, 73]. No difference was found in hair lead levels between the two groups in the present study. Humans can be exposed to lead through various environmental sources. Although it is difficult to identify the source of that exposure, the findings of the present study suggest that frequent consumption of seafood caught in the region results in no additional exposure.

Copper and selenium are essential elements for human metabolism [74, 75]. The results of studies assessing the relationship between the seafood consumption and levels of these elements are inconsistent [42, 60, 61, 63, 72, 76–79]. Similar to zinc, since these two elements can be taken into the body through various foods, dietary content can affect exposure levels [80, 81]. However, the frequent consumption of seafood containing high levels of these elements can result in increased exposure. In our study, no difference was found between the fishermen and control groups in terms of copper levels. There was an increase in selenium levels as the amount of seafood consumption increased, but this increase was not enough to create a significant difference between two groups.

The relationships between seafood consumption and antimony, iron, manganese, and vanadium levels have been the subject of limited investigation for each element, and no increase was found in the levels of any element due to seafood consumption [46, 61, 72, 79, 82–84]. Similarly, in our study, there was no difference between fishermen and controls in terms of hair levels of these elements.

Conclusion

This study, conducted in four provinces bordering the Sea of Marmara, found increased levels of arsenic, chromium, nickel, strontium, and zinc exposure in fishermen who consumed seafood frequently compared to controls who consumed seafood less frequently. Considering that fishermen consume seafood they catch from the Sea of Marmara, it has been revealed that the pollution in seawater in terms of various elements can reach individuals through the consumption of seafood, creating exposure and causing health risks. This study is particularly important in that it involved the analysis of numerous elements in hair samples indicating chronic exposure.

The Sea of Marmara, which is located in a region with intensive industrial production, needs to be evaluated in terms of pollution, especially the elements for which risk is determined, and necessary precautions should be taken. It will be useful for a system to be established involving continuous and systematic monitoring of elemental levels in seawater, seafood and humans. It will also be highly beneficial for public health for the system to be established to detect the changes in element levels in the early stages and to take appropriate action quickly when required. There is an urgent need for similar studies to be conducted in other regions with a high risk of contamination. There is also a need for studies in which all of the different variables such as air, water, food, and drugs that may affect exposure are evaluated together.

Author Contribution All authors contributed to the study design. Data collection and sampling were carried out by Yusuf Demirtaş, Murat Topbaş, Büşra Parlak Somuncu, and Fatih Aydın. Analyses were performed by Yusuf Demirtaş, Murat Topbaş, Murat Can, and Büşra Parlak Somuncu. Derya Çamur, Meriç Albay, Hüseyin İlter, Ferruh Niyazi Ayoğlu, Ahmet Altın, and Bilgehan Açıkgöz were involved in the conceptualization, methodology, and revision. Murat Topbaş carried out the project administration. The first draft of the manuscript was written by Yusuf Demirtaş, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Data Availability The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics Approval This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Bülent Ecevit University Clinical Research Ethical Committee (date: 24 February 2016/No. 2016/04).

Consent to Participate Informed consent was obtained from all individual participants included in the study.

Competing Interests The authors declare no competing interests.

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