Olyaei *et al.*
Journal of Health, Population and Nutrition (2025) 44:151
https://doi.org/10.1186/s41043-025-00868-5

Journal of Health, Population and Nutrition

RESEARCH **Open Access**

Repeated cross-sectional and longitudinal study of dietary mineral intake status in Iranian adults: Tehran lipid and glucose study

Hadi Pourmirzaei Olyaei[1,2], Zahra Bahadoran[2*], Parvin Mirmiran[1] and Fereidoun Azizi[3]

Abstract

Background Mineral deficiencies are significant public health concerns worldwide, contributing to the development and progression of non-communicable diseases (NCDs). We evaluated longitudinal adequacy of mineral intakes among Iranian adults.

Methods Adult (aged ≥ 18) participants were included in the repeated cross-sectional analysis from 2006–2008 to 2018–2022. Dietary intake was assessed using a validated Food Frequency Questionnaire (FFQ). Adequacy of minerals intake, including calcium, iron, magnesium, zinc, copper, manganese, selenium, and chromium, were evaluated against the European Society for Clinical Nutrition and Metabolism (ESPEN) guidelines. Longitudinal trends of mineral intakes were evaluated using repeated measures analysis of variance in a cohort of 4384 participants (42% men; mean age 40.8 ± 12.8 years).

Results Calcium inadequacy increased markedly from 39.6% in 2006–2008 to 68.6% in 2018–2022, with higher rates among women (74.1%) and older adults (75.0%). Iron inadequacy, mainly affecting women, increased from 14.5 to 39.1% over the same period. Although magnesium inadequacy remained high overall, it reached 34.2% in 2018–2022. In contrast, manganese intake was rarely inadequate. Zinc, copper, selenium, and chromium inadequacies showed fluctuations, but mean levels were generally closer to recommended values despite notable gender disparities.

Conclusions The study indicates significant and worsening mineral intake inadequacies among Iranian adults, particularly for calcium and iron. Further long-term studies are needed to guide interventions, such as dietary education, food fortification, and policy measures aimed at improving micronutrient intake across diverse age and gender groups.

Keywords Mineral intake, Calcium, Iron, Magnesium, Non-communicable diseases

*Correspondence:
Zahra Bahadoran
z.bahadoran@sbmu.ac.ir; zahrabahadoran@yahoo.com
Full list of author information is available at the end of the article

© The Author(s) 2025. **Open Access** This article is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License, which permits any non-commercial use, sharing, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if you modified the licensed material. You do not have permission under this licence to share adapted material derived from this article or parts of it. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by-nc-nd/4.0/.

Introduction

Mineral deficiencies remain a significant public health challenge worldwide, often stemming from poor dietary intake, low nutrient bioavailability, or increased physiological demands [1–3]. Key minerals—such as calcium, iron, magnesium, zinc, copper, selenium, and chromium—are essential for myriad biological processes, including bone health, neuromuscular function, oxygen transport, energy metabolism, enzymatic reactions, immune function, wound healing, antioxidant defense, thyroid function, and insulin action [4–11]. Inadequate intake of these micronutrients can lead to serious health complications, ranging from anemia and osteoporosis to immune dysfunction and metabolic disorders.

Despite their importance, many populations including those in developing countries are experiencing a shift away from traditional, nutrient-rich diets toward more processed, calorie-dense foods. In Iran, for instance, rising urbanization and changes in food preferences have contributed to a nutrition transition in which refined carbohydrates, fats, and sugars are displacing micronutrient-rich foods [12, 13]. Additionally, lifestyle factors such as tobacco use, consumption of high-fat or high-sugar diets, reduced physical activity, and harmful alcohol consumption further compound the risk of nutrient inadequacies [14, 15]. Socioeconomic constraints can exacerbate this situation, as individuals of lower income may be forced to rely on less expensive, energy-dense foods rather than higher-quality, nutrient-rich options [16, 17]. Together, these developments intensify the likelihood of mineral deficiencies across various demographic groups.

Mineral inadequacies can also contribute to the burden of non-communicable diseases (NCDs), including cardiovascular diseases, diabetes, osteoporosis, and hypertension [18]. NCDs currently account for 74% of all deaths globally, with a particularly rapid rise in developing countries [19]. Nutritional factors, notably micronutrient status, play a pivotal role in both the onset and progression of these chronic conditions [20, 21].

The European Society for Clinical Nutrition and Metabolism (ESPEN) has developed comprehensive guidelines that provide evidence-based recommendations for nutrient intake, particularly focusing on clinical nutrition and metabolism in adults. The ESPEN guidelines are widely recognized and offer a standardized framework for evaluating dietary intake against established reference values [22]. These guidelines allow for a consistent assessment of mineral intake adequacy, facilitating comparisons across different populations and studies.

The Tehran Lipid and Glucose Study (TLGS), a large-scale prospective cohort study investigating risk factors for NCDs among Tehran's urban population, offers a unique opportunity to evaluate dietary patterns and nutrient intake over time in a representative sample [23]. While previous phases have focused on various health outcomes, there is a lack of data specifically addressing trends in mineral intake and their adequacy relative to dietary recommendations. Addressing this gap, our study evaluates the adequacy of dietary mineral intake among adult TLGS participants from 2006 to 2022. By analyzing data across multiple phases and following participants over time, we aim to determine the prevalence of inadequate intake of key minerals— calcium, iron, magnesium, zinc, copper, manganese, selenium, and chromium—based on the ESPEN guidelines. Understanding these patterns is essential for developing effective nutritional interventions and public health policies. In Iran, there has been limited large-scale investigation into long-term trends in mineral intake. One notable national endeavor was the National Integrated Micronutrient Survey II (NIMS-II) (2011–2015), which focused on the status of iron, zinc, and vitamins A and D through direct measures of blood levels and anthropometric indexes [24]. Although valuable, NIMS-II did not fully capture longitudinal patterns of other minerals, such as calcium, magnesium, copper, selenium, manganese, or chromium, nor did it examine long-term dietary trends in detail. Therefore, the primary objective of this study was to evaluate the adequacy of dietary mineral intakes among Iranian adults using both cross-sectional (Phases 3–7) and longitudinal analyses within the Tehran Lipid and Glucose Study (TLGS). By examining 16 years of data (2006–2022), we aimed to identify trends in mineral intake and provide evidence-based insights for public health strategies—such as dietary modifications, supplementation programs, or food fortification—to reduce micronutrient deficiencies at both local and national levels.

Methods

Study population

The TLGS was a prospective cohort study that investigated risk factors for non-communicable diseases in Tehran, Iran [25]. The present study utilizes data from phases 3–7 of the TLGS, covering the period from 2006–2008 to 2018–2022. The TLGS was conducted in district-13 of Tehran, selected due to its stable population and demographic characteristics representative of the overall Tehran population. Initiated in 1999, the TLGS collected data every three years to monitor changes in lifestyle, nutritional status, and various health outcomes. The original TLGS used a multi-stage cluster random sampling approach to recruit participants from different households within the district.

For this research, both cross-sectional and longitudinal data were examined to evaluate dietary intake and mineral inadequacy. The sample included adult participants (age was categorized by WHO including adults: 18–50 years, and older adults: > 50 years) with complete dietary, demographic, and anthropometric data for at least one phase. In each phase, participants with implausible total daily energy intake (< 800 or > 4200 kcal/day) or with missing dietary or anthropometric information were excluded. Specifically, the number of participants excluded due to implausible energy intake was 207 in Phase 3, 612 in Phase 4, 403 in Phase 5, 320 in Phase 6, and 260 in Phase 7. Further exclusions were made if essential variables (e.g., food intake, weight, height, or age) were missing.

For the cross-sectional analysis, after exclusions, the number of participants varied across phases, with 2933 individuals in Phase 3 (2006–2008), 5126 in Phase 4 (2009–2011), 4423 in Phase 5 (2012–2014), 4854 in Phase 6 (2015–2017), and 7147 in Phase 7 (2018–2022). These samples were used to estimate the prevalence of inadequate mineral intake in each period. In the longitudinal analysis, participants with dietary data for at least three phases were included, resulting in a baseline cohort of 4384 individuals. This complete-case approach allowed for consistent assessment of within-subject changes in dietary mineral intake over time. Potential bias from exclusions was minimized by comparing baseline characteristics (e.g., age, gender) between excluded and included participants, with no significant differences observed.

Dietary intake assessment

Dietary intake was assessed using validated 168- and 147-item Food Frequency Questionnaire (FFQ) designed to capture participant's usual dietary intake over the previous year. The FFQ used in the TLGS is semi-quantitative, comprising food items commonly consumed by Iranians. Participants reported both the frequency (on a daily, weekly, or monthly basis) and approximate portion size of each food item, which were then converted to grams using standardized household measures. [26, 27]. Trained dietitians conducted face-to-face interviews with participants to ensure accurate reporting. The FFQ collected comprehensive data on the frequency and portion sizes of various foods and beverages consumed [26, 27]. The mineral content of the reported foods was calculated using the United States Department of Agriculture (USDA) Food Composition Table and the Iranian Food Composition Table for local foods not listed in the USDA database [28].

Anthropometric, demographic, and lifestyle measurements

Standardized TLGS protocols were used to measure height, weight, and waist circumference [29]. Weight was recorded with a digital scale sensitive to 100 g, and height was measured with a stadiometer to a precision of 0.1 cm. Body Mass Index (BMI) was calculated as weight (kg) divided by height squared (m^2). Demographic data (age, gender), lifestyle factors (physical activity, smoking), and medical history (medication use) were also gathered. Medication history was specifically defined as the use of medications for diabetes, hypertension, and/or hyperlipidemia and was collected through structured questionnaires administered during face-to-face interviews [29].

Physical activity was assessed using a structured questionnaire administered during face-to-face interviews. Participants were asked the question: "Are you physically active? Yes or no." Based on their response, physical activity levels were categorized as follows: A score of "0" was assigned to participants reporting less than 600 MET-minutes per week (indicating insufficient physical activity). A score of "1" was assigned to participants reporting 600 MET-minutes or more per week (indicating sufficient physical activity). The MET (Metabolic Equivalent of Task) calculation was based on standard values for various physical activities, as defined by the Compendium of Physical Activities. The total MET-minutes per week were estimated by multiplying the duration (in minutes) and frequency (per week) of each reported activity by its corresponding MET value. This approach allowed us to quantify physical activity levels in a standardized manner.

Blood pressure (BP) measurements were implemented between 8:00 and 12:00 AM by the trained TLGS staff, manually using an appropriate-sized cuff using Omron M7 sphygmomanometer (HEM-780-E), i.e., calibrated by the Institute of Standards and Industrial Research of Iran [30]. Participants rested seated for 15 min before two BP readings, separated by a 30-s interval. The average of these readings constituted the final BP value.

Definition of inadequate mineral intake

Inadequate mineral intake was defined as a daily intake below the recommended dietary allowance (RDA), adequate intake (AI) or dietary references intake (DRI) values specified in the ESPEN guidelines [22]. For each mineral, the ESPEN thresholds were used to classify participants as having inadequate intake if their reported daily intake was lower than the corresponding EAR or RDA. This approach ensured a standardized and consistent assessment of mineral inadequacy across all study phases.

Statistical analyses

For the cross-sectional analysis, the number and percentage of participants with inadequate mineral intake were assessed in each phase. Mineral inadequacy was determined based on the ESPEN guidelines [22]. Descriptive statistics were calculated to independently summarize the prevalence of inadequate intake for each phase.

For the longitudinal analysis, participants with dietary data from at least three phases (Phases 3–7) were included. A repeated-measures ANOVA was performed to examine within-subject changes in mineral intake (calcium, iron, magnesium, zinc, copper, manganese, selenium, and chromium), total energy and macronutrients intake over the five phases. Before conducting each repeated-measures ANOVA, we assessed the assumption of sphericity using Mauchly's Test. If the assumption was violated ($p < 0.05$), the Greenhouse–Geisser was applied to adjust the degrees of freedom, and the corrected F-values and p-values were reported. Post-hoc pairwise comparisons were conducted to identify which phases differed significantly.

All statistical analyses were conducted using SPSS software version 26. A p-value of < 0.05 was considered statistically significant.

Results

Participant's characteristics of repeated cross-sectional study

The mean age and gender distribution of the study population across different phases varied slightly. In Phase 3, participants had an average age of 40.5 ± 14.6 years, with 44.1% being men. Phase 4 saw a slight increase in the average age to 44.4 ± 14.5 years, with 42.0% men participants. In Phase 5, the average age rose further to 47.4 ± 14.3 years, with 42.9% of the participants being men. Phase 6 showed an average age of 50.8 ± 14.1 years, maintaining the same men proportion of 42.9%. Finally, in Phase 7, the average age was 49.7 ± 16.1 years, with a slightly higher representation in men (44.5%).

Participant's characteristics of longitudinal study

The baseline characteristics of participants in the longitudinal who participated in at least three phases are summarized in Supplementary Table 1. The overall mean BMI was 27.5 ± 4.90 kg/m^2, with men averaging 26.9 ± 4.17 kg/m^2 and women 27.9 ± 5.34 kg/m^2. Mean waist circumference was higher in men than women (95.6 ± 10.9 cm *vs.* 89.3 ± 13.4 cm). Men also exhibited higher mean systolic (118 ± 16.2 mmHg) and diastolic blood pressure (77.8 ± 10.5 mmHg) compared to women (111 ± 17.7 mmHg and 73.1 ± 10.6 mmHg, respectively). The prevalence of smoking was significantly higher in men (17.4%) than women (1.5%). Medication use for diabetes, lipid disorders, and hypertension was more common among women.

Table 1 presents the proportion of participants with insufficient mineral intake in the TLGS across phases 3–7, highlighting the prevalence of inadequate mineral consumption over time within the study population. Figure 1 illustrates the overall trend of dietary intake of minerals over 16 years of follow-up. As indicated, all minerals exhibited significant trends over time (P for all < 0.05). Table 2 represents the trend (as mean ± SD) of mineral intakes over 16 years of follow-up, stratified for age group and gender, providing a detailed overview of the average intake and its variability over time. Supplementary Table 1 shows the trend (as mean ± SD) of total energy and macronutrients intake across phases 3–7. This table provides a detailed overview of the average intake and variability over time.

Calcium (Ca)

Calcium inadequacy was prevalent throughout all study phases, showing a concerning increase over time. In Phase 3, 39.6% of participants had inadequate calcium intake, which initially improved to 24.6% in Phase 4. However, the inadequacy rates worsened in Phases 5 (34.0%) and 6 (33.9%), culminating in a significant rise to 68.6% in Phase 7. This issue was more pronounced among women, with 74.1% exhibiting insufficient intake in Phase 7, compared to 61.2% of men. Older adults (aged ≥ 50 years) also showed higher inadequacy rates (75.0%) than younger adults (65.2%) in the same phase (Table 1).

The mean calcium intake reflected these trends, starting at 1201 ± 463 mg in Phase 3 and slightly increasing to 1398 ± 530 mg in Phase 4. Subsequently, a gradual decline was observed, with mean intake dropping to 903 ± 351 mg in Phase 7. The decrease was more pronounced among women, and older adults consistently had higher calcium intake than younger participants throughout the study (Table 2).

Iron (Fe)

Iron inadequacy was primarily observed among women in all phases. In Phase 3, 14.5% of participants had inadequate iron intake, decreasing to 7.1% in Phase 4 but rising again to 10.3% in Phase 5. By Phase 7, the inadequacy rate had increased substantially to 22.3%, with a significant gender disparity: 39.1% of women had insufficient iron intake compared to only 2.2% of men (Table 1).

The mean iron intake showed an upward trend in the middle phases, increasing from 25.8 ± 11.6 mg in Phase 3 to a peak of 37.7 ± 18.9 mg in Phase 6. However, a sharp decline was noted in Phase 7, where the mean intake

Table 1 Prevalence of inadequate mineral intake among Tehran Lipid and Glucose Study (TLGS) participants across study phases (Phases 3–7)

		2006–2008 (n = 2933) N (%)	2009–2011 (n = 5126) N (%)	2012–2014 (n = 4423) N (%)	2015–2017 (n = 4854) N (%)	2018–2022 (n = 7147) N (%)
Ca (mg/day)	Total	1160 (39.6)	1263 (24.6)	1503 (34)	1646 (33.9)	4901 (68.6)
	Men	472 (36.6)	494 (23)	576 (30.4)	562 (27)	1964 (61.7)
	Women	688 (42)	769 (25.9)	927 (36.7)	1084 (39.1)	2937 (74.1)
	Adult	818 (37.6)	823 (22.8)	841 (30.6)	721 (28.7)	2370 (62.8)
	Older adult	342 (45.5)	440 (29.1)	662 (39.6)	925 (39.5)	2531 (75)
Fe (mg/day)	Total	424 (14.5)	359 (7.1)	449 (10.3)	216 (4.5)	1567 (22.3)
	Men	17 (1.3)	7 (0.3)	8 (0.4)	8 (0.4)	70 (2.2)
	Women	407 (25)	352 (12.1)	441 (18)	208 (7.7)	1497 (39.1)
	Adult	409 (18.9)	346 (9.6)	427 (15.5)	205 (8.2)	1396 (37.4)
	Older adult	15 (2)	13 (0.9)	22 (1.4)	11 (0.5)	171 (5.2)
Mg (mg/day)	Total	1504 (51.3)	1432 (27.9)	1334 (30.2)	1467 (30.2)	2447 (34.2)
	Men	777 (60.1)	793 (36.8)	731 (38.6)	797 (38.3)	1278 (40.2)
	Women	727 (44.3)	639 (21.5)	603 (23.9)	670 (24.2)	1169 (29.5)
	Adult	1102 (50.5)	988 (27.3)	816 (29.7)	723 (28.8)	1224 (32.5)
	Older adult	402 (53.5)	444 (29.4)	518 (31)	744 (31.8)	1223 (36.2)
Zn (mg/day)	Total	636 (21.7)	542 (10.6)	550 (12.4)	673 (13.9)	1713 (24)
	Men	219 (16.9)	174 (8.1)	170 (9)	189 (9.1)	517 (16.2)
	Women	417 (25.4)	368 (12.4)	380 (15)	484 (17.4)	1196 (30.2)
	Adult	449 (20.6)	357 (9.9)	308 (11.2)	306 (12.2)	794 (21.1)
	Older adult	187 (24.9)	185 (12.2)	242 (14.5)	367 (15.7)	919 (27.2)
Cu (mg/day)	Total	934 (27)	878 (12)	823 (12.4)	955 (12.2)	1236 (17.2)
	Men	271 (21)	184 (8.6)	162 (8.5)	186 (8.9)	355 (11.2)
	Women	531 (32.4)	458 (15.4)	403 (15.9)	442 (15.9)	877 (22.1)
	Adult	579 (26.5)	422 (11.7)	328 (11.9)	285 (11.3)	567 (15)
	Older adult	223 (29.7)	220 (14.6)	237 (14.2)	343 (14.7)	665 (19.7)
Mn (mg/day)	Total	10 (0.3)	6 (0.1)	5 (0.1)	5 (0.1)	26 (0.4)
	Men	5 (0.4)	2 (0.1)	3 (0.2)	2 (0.1)	10 (0.3)
	Women	5 (0.3)	4 (0.1)	2 (0.1)	3 (0.1)	16 (0.4)
	Adult	10 (0.5)	4 (0.1)	1 (0)	2 (0.1)	13 (0.3)
	Older adult	0 (0)	2 (0.1)	4 (0.2)	3 (0.1)	13 (0.4)
Se (µg/day)	Total	137 (4)	118 (1.6)	124 (1.9)	173 (2.2)	270 (3.8)
	Men	26 (2)	16 (0.7)	22 (1.2)	24 (1.2)	50 (1.6)
	Women	94 (5.7)	74 (2.5)	65 (2.6)	88 (3.2)	219 (5.5)
	Adult	78 (3.6)	45 (1.2)	40 (1.5)	49 (1.9)	106 (2.8)
	Older adult	42 (5.6)	45 (3)	47 (2.8)	63 (2.7)	163 (4.8)
Cr (mg/day)	Total	767 (26.2)	585 (11.4)	362 (8.2)	403 (8.3)	617 (8.6)
	Men	341 (26.4)	228 (10.6)	134 (7.1)	148 (7.1)	259 (8.1)
	Women	426 (26)	357 (12)	228 (9)	255 (9.2)	358 (9)
	Adult	593 (27.2)	418 (11.6)	240 (8.7)	238 (9.5)	357 (9.5)
	Older adult	174 (23.1)	167 (11)	122 (7.3)	165 (7.1)	260 (7.7)

Values are presented as percentages (%) of participants with inadequate intake for each mineral (calcium, iron, magnesium, zinc, copper, manganese, selenium, and chromium), stratified by gender and age group

dropped to 17.7 ± 7.6 mg. Men consistently had higher iron intake than women, and the gap between genders widened in the later phases (Table 2).

Magnesium (Mg)

Magnesium inadequacy affected a significant portion of participants, especially in Phase 3, where 51.3% had

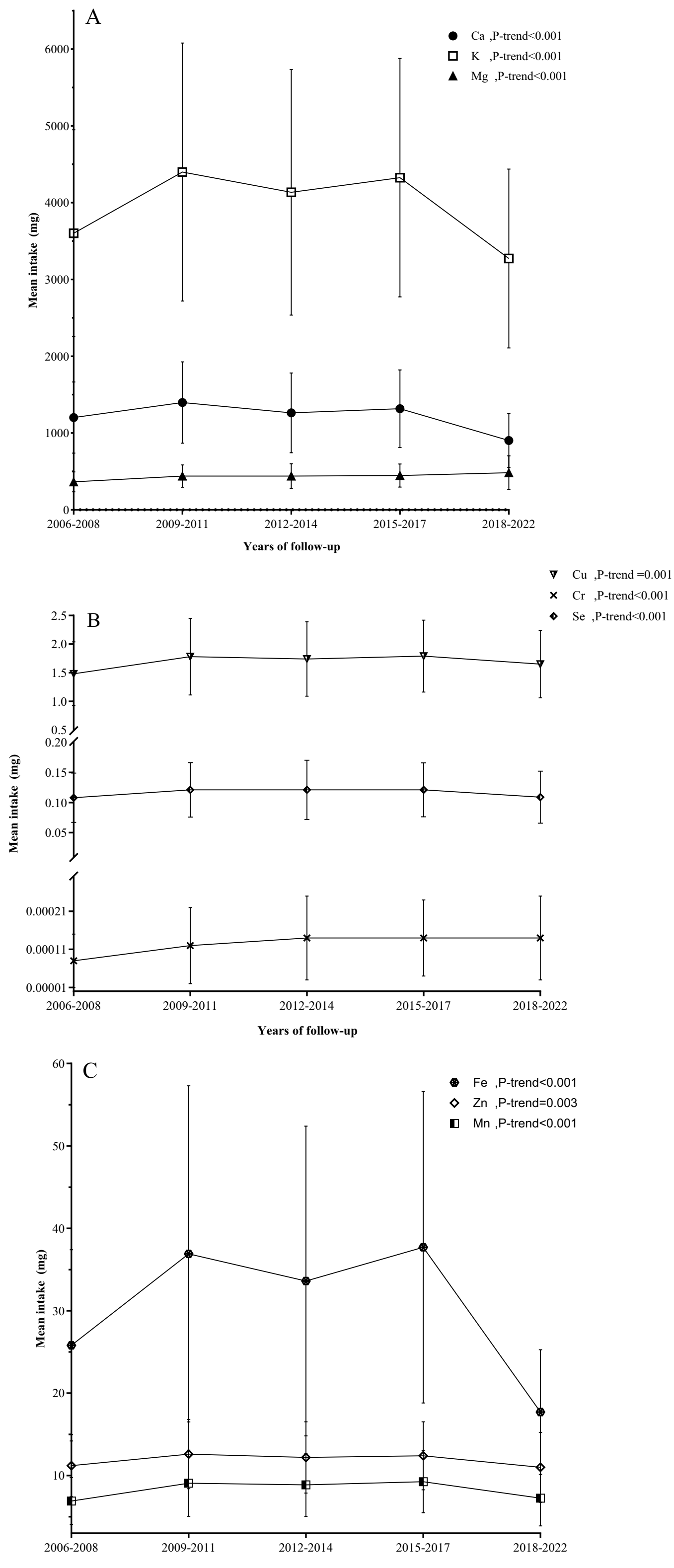

Fig. 1 Trend of dietary mineral intake over 16 years of follow-up. As indicated, all minerals exhibited significant trends over time (*P* for all < 0.05). (**A**) Calcium (Ca), Potassium (K), and Magnesium (Mg) intake over 16 years of follow-up. (**B**) Copper (Cu), Chromium (Cr), and Selenium (Se) intake over 16 years of follow-up. (**C**) Iron (Fe), Zinc (Zn), and Manganese (Mn) intake across phases 3–7

Table 2 Trends in mean mineral intake (mean ± SD) among TLGS participants over 16 years of follow-up (Phases 3–7)

		2006–2008	2009–2011	2012–2014	2015–2017	2018–2022	P_{group}
Ca (mg/day)	Men	1192 ± 454	1353 ± 511	1273 ± 494	1394 ± 522	925 ± 354	0.511
	Women	1208 ± 471	1431 ± 543	1255 ± 540	1259 ± 484	886 ± 349	
	Adult	1206 ± 470	1385 ± 511	1265 ± 523	1310 ± 503	898 ± 350	0.586
	Older	1179 ± 430	1461 ± 621	1253 ± 511	1354 ± 515	926 ± 359	
K (mg/day)	Men	3565 ± 1306	4264 ± 1645	4186 ± 1501	4523 ± 1564	3344 ± 1178	0.590
	Women	3630 ± 1383	4501 ± 1703	4094 ± 1670	4174 ± 1529	3220 ± 1154	
	Adult	3538 ± 1315	4338 ± 1648	4123 ± 1609	4291 ± 1549	3253 ± 1164	0.074
	Older	3931 ± 1481	4713 ± 1817	4189 ± 1555	4500 ± 1564	3378 ± 1172	
Fe (mg/day)	Men	26.0 ± 11.5	36.0 ± 20.3	34.3 ± 17.9	40.8 ± 19.5	18.6 ± 7.01	0.127
	Women	25.7 ± 11.7	37.6 ± 20.5	33.0 ± 19.5	35.3 ± 18.1	17.1 ± 7.93	
	Adult	25.7 ± 11.6	35.8 ± 19.3	33.2 ± 18.6	37.3 ± 18.9	17.7 ± 7.50	0.036
	Older	26.8 ± 11.5	42.5 ± 24.7	35.4 ± 19.7	39.7 ± 18.6	17.9 ± 8.01	
Mg (mg/day)	Men	389 ± 139	448 ± 150	469 ± 153	488 ± 156	521 ± 220	0.001
	Women	345 ± 117	432 ± 141	417 ± 166	416 ± 140	454 ± 217	
	Adult	357 ± 122	436 ± 146	438 ± 163	444 ± 152	479 ± 219	0.089
	Older	398 ± 152	456 ± 143	448 ± 159	464 ± 146	502 ± 231	
Zn (mg/day)	Men	12.0 ± 4.12	12.8 ± 4.25	13.1 ± 4.28	13.4 ± 4.21	11.9 ± 4.40	0.001
	Women	10.6 ± 3.35	12.5 ± 4.16	11.5 ± 4.25	11.6 ± 3.90	10.3 ± 3.99	
	Adult	11.1 ± 3.65	12.6 ± 4.11	12.3 ± 4.36	12.4 ± 4.16	11.0 ± 4.22	0.869
	Older	11.4 ± 4.27	12.7 ± 4.67	12.0 ± 4.19	12.7 ± 4.03	10.9 ± 4.39	
Cu (mg/day)	Men	1.60 ± 0.61	1.84 ± 0.66	1.85 ± 0.61	1.94 ± 0.63	1.80 ± 0.63	0.001
	Women	1.39 ± 0.50	1.74 ± 0.66	1.65 ± 0.66	1.67 ± 0.61	1.53 ± 0.52	
	Adult	1.45 ± 0.53	1.78 ± 0.66	1.74 ± 0.65	1.77 ± 0.64	1.63 ± 0.57	0.143
	Older	1.62 ± 0.65	1.81 ± 0.68	1.74 ± 0.64	1.87 ± 0.58	1.72 ± 0.64	
Mn (mg/day)	Men	7.65 ± 3.05	9.39 ± 3.98	9.63 ± 3.59	10.3 ± 3.73	8.22 ± 3.57	< 0.001
	Women	6.34 ± 2.56	8.82 ± 4.03	8.27 ± 3.91	8.49 ± 3.62	6.51 ± 3.01	
	Adult	6.71 ± 2.71	8.84 ± 3.85	8.73 ± 3.79	9.13 ± 3.76	7.16 ± 3.30	0.001
	Older	7.91 ± 3.32	10.2 ± 4.62	9.53 ± 3.98	9.89 ± 3.77	7.69 ± 3.66	
Se (µg/day)	Men	121 ± 43.7	128 ± 45.6	134 ± 46.5	139 ± 45.4	124 ± 45.0	0.001
	Women	97.7 ± 35.4	116 ± 44.6	111 ± 49.2	107 ± 39.6	97.8 ± 38.2	
	Adult	108 ± 39.1	121 ± 44.7	121 ± 49.1	121 ± 45.1	109 ± 42.4	0.961
	Older	108 ± 48.8	123 ± 49.3	120 ± 50.6	121 ± 44.1	107 ± 47.5	
Cr (mg/day)	Men	0.09 ± 0.07	0.13 ± 0.09	0.16 ± 0.10	0.16 ± 0.10	0.17 ± 0.12	0.001
	Women	0.06 ± 0.06	0.11 ± 0.10	0.12 ± 0.10	0.12 ± 0.09	0.12 ± 0.10	
	Adult	0.07 ± 0.06	0.12 ± 0.10	0.13 ± 0.10	0.14 ± 0.10	0.14 ± 0.11	0.036
	Older	0.09 ± 0.08	0.14 ± 0.10	0.15 ± 0.11	0.15 ± 0.10	0.15 ± 0.12	

Data are stratified by gender and age group, with intake values reported in milligrams (mg) or micrograms (µg) per day

insufficient intake. The deficiency improved markedly in Phase 4 (27.9%) and remained relatively steady in Phases 5 and 6 (both at 30.2%). A slight increase to 34.2% was observed in Phase 7. Men consistently exhibited higher inadequacy rates than women across all phases (Table 1).

The mean magnesium intake increased steadily over time, from 364 ± 129 mg in Phase 3 to 483 ± 221 mg in Phase 7. Men had consistently higher magnesium intake than women, and older adults generally consumed more magnesium than younger adults throughout the study (Table 2).

Zinc (Zn)

Zinc inadequacy remained relatively stable but showed an uptick in the final phase. In Phase 3, 21.7% of participants had inadequate zinc intake, which improved to 10.6% in Phase 4 and remained low in Phase 5 (12.4%). However, by Phase 7, the inadequacy rate increased to 24.0%. Women consistently exhibited higher inadequacy rates than men, with 30.2% of women showing insufficient intake in Phase 7 compared to 16.2% of men (Table 1).

The mean zinc intake was relatively stable, starting at 11.2 ± 3.76 mg in Phase 3 and experiencing slight fluctuations before settling at 11.0 ± 4.25 mg in Phase 7. Men consistently had higher zinc intake than women across all phases (Table 2).

Copper (Cu)

Copper inadequacy was notable in Phase 3, affecting 27.0% of participants. Substantial improvements were observed in Phases 4 (12.0%) and 5 (12.4%), but a slight increase to 17.2% occurred by Phase 7. Women consistently had higher inadequacy rates than men, with 22.1% of women showing insufficient intake in Phase 7 compared to 11.2% of men (Table 1).

The mean copper intake showed an upward trend from Phase 3 (1.28 ± 0.43 mg) to Phase 6 (1.79 ± 0.63 mg), followed by a slight decrease in Phase 7 (1.65 ± 0.59 mg). Men had higher copper intake than women throughout the study, and older adults consumed slightly more copper than younger adults (Table 2).

Manganese (Mn)

Manganese inadequacy was rare across all phases, affecting only 0.1–0.4% of participants. No significant gender differences were observed, and the deficiency remained minimal throughout the study period (Table 1).

Mean manganese intake increased significantly from Phase 3 (6.90 ± 2.85 mg) to Phase 6 (9.25 ± 3.77 mg), before declining to 7.25 ± 3.36 mg in Phase 7. Men consistently consumed more manganese than women, with the highest intake observed among older men (Table 2).

Selenium (Se)

Selenium inadequacy was relatively low, starting at 4.0% in Phase 3 and decreasing to 1.6% in Phase 4. A slight increase was noted by Phase 7, with inadequacy rates rising to 3.8%. Women consistently showed higher inadequacy rates than men, particularly in Phase 7, where 5.5% of women had insufficient intake compared to 1.6% of men (Table 1).

The mean selenium intake remained stable, with slight fluctuations. It started at 108 ± 40.8 µg in Phase 3, peaked at 121 ± 49.3 µg in Phase 5, and stabilized at 109 ± 43.2 µg in Phase 7. Men generally had higher selenium intake than women across all phases (Table 2).

Chromium (Cr)

Chromium inadequacy was relatively high in Phase 3, affecting 26.2% of participants. Significant improvements were observed in subsequent phases, with the inadequacy rate decreasing to 8.6% in Phase 7. Both men and women showed similar improvements in chromium intake over time (Table 1).

Mean chromium intake steadily increased from 0.08 ± 0.07 mg in Phase 3 to 0.14 ± 0.11 mg in Phase 7. Men consistently had higher chromium intake than women throughout the study period (Table 2).

Discussion

This study aimed to assess the adequacy of mineral intake among adults in Tehran over a 16-year period, utilizing data from the TLGS. The prevalence of calcium inadequacy rose significantly from 39.6% during 2006–2008 to 68.6% in 2018–2022, with women (74.1%) and older adults (75.0%) experiencing even higher rates. Similarly, iron inadequacy, which predominantly affects women, increased from 14.5 to 39.1% over the same period. Magnesium inadequacy remained consistently high, reaching 34.2% in 2018–2022. In contrast, manganese intake was rarely insufficient. While zinc, copper, selenium, and chromium inadequacies showed some fluctuations, average levels generally remained closer to recommended values, despite notable differences between genders. Women and older adults exhibited notably higher rates of mineral inadequacy in our study, and several factors may explain this trend. First, older adults often experience reduced appetite and may have decreased absorption efficiency due to age-related physiological changes, leading to overall lower nutrient intake. Second, women of reproductive age require more iron to compensate for menstrual blood loss and thus are more vulnerable to iron deficiency if dietary intake is insufficient. Additionally, cultural norms and household roles can influence food choices. In some settings, women may prioritize feeding other family members before themselves, potentially compromising their own dietary quality. Socioeconomic factors further compound these vulnerabilities; for instance, limited budgets can restrict access to mineral-rich foods (such as dairy, lean meats, or fresh produce), disproportionately affecting older adults and women in certain communities. These combined physiological, cultural, and economic elements help account for the heightened mineral deficiencies observed in these groups [31–33]. These trends were observed alongside fluctuations in the intake of other minerals such as magnesium, zinc, copper, and chromium.

Comparing our results with the National Integrated Micronutrient Survey II (NIMS-II) conducted in Iran between 2011 and 2015, similar patterns emerge. The NIMS-II highlighted substantial nutritional challenges, including a high prevalence of overweight and obesity among both men (61.6%) and women (77.3%), and significant micronutrient deficiencies across various age groups [24]. While our study focused on adults aged 18 and above, the persistent issues with mineral intake reflect broader nutritional inadequacies within the Iranian population identified by NIMS-II. The alarming rise in calcium inadequacy observed in our study, escalating to 68.6% in Phase 7, mirrors global concerns about insufficient calcium intake. This inadequacy was more pronounced among women and older adults, groups that are particularly vulnerable to conditions like osteoporosis. A meta-analysis focusing on Iranian individuals aged 50 and above found elevated rates of osteoporosis, especially among women [34]. This correlation underscores the potential long-term impact of inadequate calcium intake on bone health in this population.

International studies also reflect similar patterns. Many countries in Asia report average daily calcium intakes below 500 mg, significantly lower than recommended levels [35]. The implications of inadequate calcium extend beyond bone health, including increased risks of preeclampsia in pregnant women and a potential protective effect against breast cancer in premenopausal women [36, 37]. Given the high prevalence of breast cancer and rising rates of preeclampsia among Iranian women [38, 39], addressing calcium deficiency is critical.

Iron inadequacy in our study was predominantly a concern among women, with 39.1% exhibiting insufficient intake in Phase 7. This gender disparity is consistent with findings from other studies, which have documented higher rates of iron deficiency among women, particularly those of reproductive age [40]. The inadequate iron intake among women could contribute to higher rates of anemia and related health complications.

Despite remaining high overall, magnesium deficiency showed improvement over time, and men consistently had higher mean intakes than women. This pattern suggests that certain dietary habits such as consuming more legumes, nuts, and whole grains may be more prevalent among men, leading to relatively better magnesium status. Another possibility is that broader public health awareness campaigns or gradual shifts in Iranian food culture encouraged moderate increases in consumption of magnesium-rich items, thereby raising average intakes. Meanwhile, cultural practices or personal food preferences among women could contribute to persistently lower magnesium intake. Future investigations might focus on delineating how dietary patterns, cooking practices, and the availability of fortified products influence magnesium consumption, and whether tailored interventions can further reduce deficiencies. Similar trends were observed in studies from other countries, such as Mexico and China, where magnesium inadequacy was prevalent among adolescents and adults [40, 41]. Zinc inadequacy in our study remained relatively stable but was consistently higher among women. This finding contrasts with other research, such as the study conducted in São Paulo, which indicated that men aged over 19 were more susceptible to inadequate zinc intakes than women, with inadequacy worsening with age [42]. The differing patterns between studies suggest that gender-related dietary habits, cultural practices, and nutritional awareness may vary across populations, affecting zinc intake differently. In Iran, traditional dietary practices or socio-economic factors might contribute to lower zinc intake among women. This highlights the importance of considering local dietary habits and gender roles when developing nutritional interventions.

Copper intake showed fluctuations, with women consistently exhibiting higher inadequacy rates. Although copper deficiency is less commonly discussed, it has been linked to cardiovascular health, and both deficiency and excess can have adverse effects [10, 43]. Selenium inadequacy was relatively low, but increased slightly by the end of the study period, particularly among women. Selenium plays a crucial role in antioxidant defense and thyroid function, and both inadequate and excessive intake can impact health [10, 44]. Chromium intake demonstrated a distinct improvement over the course of the study, likely reflecting increasing awareness of metabolic health and glycemic control in the population. Healthcare providers may have recommended chromium supplementation or foods rich in chromium such as brewer's yeast, whole grains, nuts, and certain vegetables to individuals at risk for impaired glucose metabolism. Moreover, inadvertent fortification or changes in local food production practices might also have contributed to higher chromium levels in commonly consumed staples. While our data cannot pinpoint the exact source of this positive trend, it underscores the potential impact of evolving dietary knowledge and public health messaging on micronutrient status. Further research to identify the primary dietary contributors to chromium intake would help clarify this mechanism.

The inadequacies observed in our study are not isolated to Iran. Studies from China and Mexico have reported high prevalence rates of inadequate intake of minerals like calcium, magnesium, zinc, and selenium among adults [40, 41]. These deficiencies have significant health implications, including increased risks of osteoporosis, cardiovascular diseases, and impaired immune function.

Inconsistent findings exist regarding the relationship between mineral intake and cardiovascular health. While deficiencies in iron, copper, and selenium have been associated with increased cardiovascular risk, excessive levels can also be harmful [10]. This highlights the importance of achieving a balanced intake of these essential minerals.

Several factors may explain the observed mineral deficiencies. First, cultural dietary practices in Iran, while traditionally rich in nutrient-dense foods, have shifted toward increased consumption of refined carbohydrates and energy-dense, processed items [45, 46]. This shift can crowd out more nutritious choices. Moreover, certain cultural norms such as prioritizing staple foods over high-protein or calcium-rich options may exacerbate nutrient gaps for subpopulations, particularly among women. Second, socioeconomic barriers and availability issues play a significant role [47, 48]. Rising food prices and economic fluctuations often limit access to higher quality, nutrient-rich foods such as dairy, lean meats, and fresh produce. Therefore, individuals of lower socioeconomic status may rely on cheaper, calorie-dense foods, which are relatively low in essential minerals. A third factor involves lifestyle shifts, wherein rapid urbanization and sedentary behaviors reduce overall energy needs, often leading to the consumption of fewer nutrient-dense foods [49, 50].

It is important to consider that Phase 7 of our study coincided with the COVID-19 pandemic. The pandemic may have influenced dietary habits due to lockdowns, reduced physical activity, and changes in food availability. The sharp decline in calcium and iron intake during this phase could be partially attributed to these unprecedented circumstances. A shift towards more processed and less nutrient-dense foods during the pandemic has been reported in various studies, which could explain the worsening mineral intake [51–53]. The pandemic has had profound global impacts on dietary habits and food accessibility. Lockdowns, restrictions, and disruptions in supply chains limited access to fresh, nutrient-rich foods such as fruits, vegetables, and dairy products, which are primary sources of essential minerals. Concurrently, economic challenges, including job losses and financial instability, exacerbated food insecurity, leading many individuals to prioritize affordable, calorie-dense foods over nutrient-dense options. Additionally, reduced physical activity and heightened stress levels during the pandemic further contributed to shifts in dietary patterns, potentially affecting mineral intake.

Addressing these persistent and, in some cases, worsening deficiencies requires a comprehensive public health approach. Nutrition education initiatives can help households balance traditional dietary patterns with healthier modern options, particularly those that emphasize calcium- and iron-rich foods. In parallel, fortifying common staples, such as flour and dairy products, with minerals like calcium and iron could substantially improve overall intakes. Supplementation strategies are also crucial, especially for high-risk groups such as women of reproductive age and older adults who face a greater burden of deficiencies. Finally, policies that ensure access and affordability including subsidies or other interventions to lower the cost of nutrient-dense product are essential to guarantee that financial constraints do not hinder adequate mineral intake.

A major strength of our study is the longitudinal design, which allowed us to assess trends in mineral intake over an extended period. The large sample size and the use of validated dietary assessment tools enhance the reliability of our findings. However, some limitations should be acknowledged. Dietary intake was assessed using a FFQ, which, despite being validated, may be subject to recall bias. The use of the USDA Food Composition Table and the Iranian Food Composition Table might not capture all variations in local food composition. Also, this study did not assess data on participant's supplement intake, as the assessment focused solely on dietary intake of mineral. Additionally, we did not explicitly adjust for variations in energy intake across different time points. However, we acknowledge that energy intake can influence nutrient intake patterns and may confound the results. Moreover the manuscript does not include an analysis of the food sources of the minerals studied, which a significant limitation is given the impact of food composition and bioavailability on mineral absorption and utilization. As well as, while we used the ESPEN guidelines for assessing mineral adequacy, variations in individual requirements were not accounted for, which could affect the classification of inadequacy. Also, this study used the ESPEN micronutrient guidelines, which are designed for clinical practice and may not fully reflect the needs of the general healthy population. Moreover, the bioavailability of minerals can vary widely depending on dietary composition (e.g., the presence of enhancers or inhibitors such as vitamin C or phytates), yet we lacked specific measures of mineral bioavailability. Finally, the COVID-19 pandemic may have compounded dietary changes in the last phase, and not all related lifestyle shifts could be fully captured or adjusted for in our analysis.

This study highlights significant inadequacies in mineral intake among adults in Tehran, with particularly concerning trends for calcium and iron. These deficiencies pose serious public health risks, including increased susceptibility to osteoporosis, anemia, cardiovascular diseases, and other chronic conditions. Notably, the observed gender disparities, with women being disproportionately affected, underscore the need for targeted interventions. Addressing these nutritional gaps requires a multifaceted approach, including public health education, dietary modifications, strategic supplementation, and policy initiatives aimed at improving access to nutrient-rich foods. Such efforts have the potential to significantly enhance mineral intake and reduce the burden of

NCDs in this population. Future research should focus on identifying the underlying causes of these inadequacies, such as socioeconomic, cultural, and lifestyle factors, and evaluate the effectiveness of targeted interventions to inform evidence-based strategies for improving nutritional health.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s41043-025-00868-5.

Additional file1 (DOCX 15 KB)

Acknowledgements

We thank the Tehran Lipid and Glucose Study participants and the field investigators of the Tehran Lipid and Glucose Study for their cooperation and assistance in physical examinations, biochemical evaluation and database management. This study, was supported by Research Institute for Endocrine Sciences.

Author contributions

All authors read and approved the final manuscript. Z.B, P.M and H.P designed the study and analyzed the data. Z.B and H.P wrote the manuscript. F.A supervised the work. All authors read and approved the final manuscript.

Funding

This work was not supported by any funding agency.

Availability of data and materials

Data will be available upon forwarding the request to the corresponding author (z.bahadoran@sbmu.ac.ir) and confirmation of the director of RIES (azizi@sbmu.ac.ir).

Declarations

Ethics approval and consent to participate

Written informed consent was obtained from all participants. The ethics research committee of the Research Institute for Endocrine Sciences, Shahid Beheshti University of Medical Sciences, Tehran, Iran, approved the study protocol (IR.SBMU.ENDOCRINE.REC.1403.098). The study protocol was carried out according to the relevant guidelines expressed in the Declaration of Helsinki.

Competing interests

The authors declare no competing interests.

Author details

[1]Nutrition and Endocrine Research Center, Research Institute for Endocrine Disorders, Research Institute for Endocrine Sciences, Shahid Beheshti University of Medical Sciences, Tehran, Iran. [2]Micronutrient Research Center, Research Institute for Endocrine Disorders, Research Institute for Endocrine Sciences, Shahid Beheshti University of Medical Sciences, No 23, A'rabi St, Yeman Av, Velenjak, Tehran, Iran. [3]Endocrine Research Center, Research Institute for Endocrine Disorders, Research Institute for Endocrine Sciences, Shahid Beheshti University of Medical Sciences, Tehran, Iran.

Received: 22 October 2024 Accepted: 8 April 2025
Published online: 10 May 2025

References

1. Kirichuk AA, Skalny AV, Schaumlöffel D, Kovaleva IA, Korobeinikova TV, Kritchenkov AS, et al. Assessment of trace element and mineral levels in students from Turkmenistan in comparison to Iran and Russia. J Trace Elem Med Biol. 2024;84:127439.
2. Babaali E, Rahmdel S, Berizi E, Akhlaghi M, Götz F, Mazloomi SM. Dietary intakes of zinc, copper, magnesium, calcium, phosphorus, and sodium by the general adult population aged 20–50 years in Shiraz, Iran: a total diet study approach. Nutrients. 2020;12(11):3370.
3. Bahramy P, Mohammad-Alizadeh-Charandabi S, Ramezani-Nardin F, Serum MM. Levels of vitamin D, calcium, magnesium, and copper, and their relations with mental health and sexual function in pregnant Iranian adolescents. Biol Trace Elem Res. 2020;198(2):440–8. https://doi.org/10.1007/s12011-020-02109-8.
4. Wu Q, Gao Z-J, Yu X, Wang P. Dietary regulation in health and disease. Signal Transduct Target Ther. 2022;7(1):252. https://doi.org/10.1038/s41392-022-01104-w.
5. Dai Q, Zhu X, Manson JE, Song Y, Li X, Franke AA, et al. Magnesium status and supplementation influence vitamin D status and metabolism: results from a randomized trial. Am J Clin Nutr. 2018;108(6):1249–58.
6. Altarelli M, Ben-Hamouda N, Schneider A, Berger MM. Copper deficiency: causes, manifestations, and treatment. Nutr Clin Pract. 2019;34(4):504–13. https://doi.org/10.1002/ncp.10328.
7. Chan L-N, Mike LA. The science and practice of micronutrient supplementations in nutritional anemia. J Parenter Enter Nutr. 2014;38(6):656–72. https://doi.org/10.1177/0148607114533726.
8. De Benedictis CA, Vilella A, Grabrucker A 2023 The role of trace metals in Alzheimer's disease [Internet]. Available from: https://researchrepository.ul.ie/articles/chapter/The_role_of_trace_metals_in_Alzheimer_s_disease/19816417
9. Zhou D, Zhao Z, Wu W, Li Z, Wei S, Gao Q, et al. Dietary chromium promotes growth performance, immunity response, antioxidant capacity, insulin signaling pathways, and glucolipid metabolism in juvenile oriental river prawn (*Macrobrachium* nipponense). Aquac Reports. 2024;35:101960.
10. Mohammadifard N, Humphries KH, Gotay C, Mena-Sánchez G, Salas-Salvadó J, Esmaillzadeh A, et al. Trace minerals intake: risks and benefits for cardiovascular health. Crit Rev Food Sci Nutr. 2019;59(8):1334–46. https://doi.org/10.1080/10408398.2017.1406332.
11. De Jong N, Gibson RS, Thomson CD, Ferguson EL, Green TJ, Horwath CC, et al. Selenium and zinc status are suboptimal in a sample of older New Zealand women in a community-based study. J Nutr. 2001;131(10):2677–84.
12. Abdi F, Atarodi KZ, Mirmiran P, Esteki T. 2015 Surveying global and Iranian food consumption patterns: a review of the literature.
13. Mohammadifard N, Sarrafzadegan N, Ghassemi GR, Nouri F, Pashmi R. Alteration in unhealthy nutrition behaviors in adolescents through community intervention: Isfahan healthy heart program. ARYA Atheroscler. 2013;9(1):89.
14. Uddin R, Lee E-Y, Khan SR, Tremblay MS, Khan A. Clustering of lifestyle risk factors for non-communicable diseases in 304,779 adolescents from 89 countries: a global perspective. Prev Med (Baltim). 2020;131: 105955.
15. Benziger CP, Roth GA, Moran AE. The global burden of disease study and the preventable burden of NCD. Glob Heart. 2016;11(4):393–7.
16. Lago S, Cantarero D, Rivera B, Pascual M, Blázquez-Fernández C, Casal B, et al. Socioeconomic status, health inequalities and non-communicable diseases: a systematic review. J Public Health. 2018;26:1–14.
17. Cano-Ibáñez N, Gea A, Ruiz-Canela M, Corella D, Salas-Salvadó J, Schröder H, et al. Diet quality and nutrient density in subjects with metabolic syndrome: Influence of socioeconomic status and lifestyle factors. A cross-sectional assessment in the PREDIMED-Plus study. Clin Nutr. 2020;39(4):1161–73.
18. World Health Organization. Noncommunicable diseases [Internet]. 2023. Available from: https://www.who.int/news-room/fact-sheets/detail/noncommunicable-diseases
19. Wagner K-H, Brath H. A global view on the development of non communicable diseases. Prev Med. 2012;54:S38-41.
20. Tuomilehto J. How to prevent non-communicable diseases?: A continuous need for a better understanding of the role of nutritional factors through scientific research. Eur J Clin Nutr. 2022;76(10):1357–63. https://doi.org/10.1038/s41430-021-00997-0.
21. Musaiger AO, Al-Hazzaa HM. Prevalence and risk factors associated with nutrition-related noncommunicable diseases in the Eastern

Mediterranean region. Int J Gen Med. 2012;295:199–217. https://doi.org/10.2147/IJGM.S29663.
22. Berger MM, Shenkin A, Schweinlin A, Amrein K, Augsburger M, Biesalski H-K, et al. ESPEN micronutrient guideline. Clin Nutr. 2022;41(6):1357–424.
23. Azizi F, Madjid M, Rahmani M, Emami H, Mirmiran P, Hadjipour R. Tehran lipid and glucose study (TLGS): rationale and design. Iran J Endocrinol Metab. 2000;2(2):77–86.
24. Pouraram H, Djazayery A, Mohammad K, Parsaeian M, Abdollahi Z, Motlagh AD, et al. Second national integrated micronutrient survey in Iran: study design and preliminary findings. Arch Iran Med. 2018;21(4):137–44.
25. Azizi F, Takyar M, Zadeh-Vakili A. Contributions and Implications of the Tehran lipid and glucose study. Int J Endocrinol Metab. 2018. https://doi.org/10.5812/ijem.84792.
26. Esfahani FH, Asghari G, Mirmiran P, Azizi F. Reproducibility and relative validity of food group intake in a food frequency questionnaire developed for the Tehran lipid and glucose study. J Epidemiol. 2010;20(2):150–8.
27. Mirmiran P, Esfahani FH, Mehrabi Y, Hedayati M, Azizi F. Reliability and relative validity of an FFQ for nutrients in the Tehran lipid and glucose study. Public Health Nutr. 2010;13(5):654–62.
28. Rad AH, Esmaeili M, Abdollahi M, Azar M. Compiling and validation of Iranian food composition tables. In: ANNALS OF NUTRITION AND METABOLISM. KARGER ALLSCHWILERSTRASSE 10, CH-4009 BASEL, SWITZERLAND; 2007. p. 125.
29. Gaeini Z, Bahadoran Z, Mirmiran P, Azizi F. Tea, coffee, caffeine intake and the risk of cardio-metabolic outcomes: findings from a population with low coffee and high tea consumption. Nutr Metab. 2019;16:1–10.
30. Ramezankhani A, Hosseini-Esfahani F, Mirmiran P, Azizi F, Hadaegh F. The association of priori and posteriori dietary patterns with the risk of incident hypertension: Tehran lipid and glucose study. J Transl Med. 2021;19:1–11.
31. de Souto BP, Cesari M, Morley JE, Roberts S, Landi F, Cederholm T, et al. Appetite loss and anorexia of aging in clinical care: an ICFSR task force report. J frailty aging. 2022;11(2):129–34.
32. Story M, Neumark-Sztainer D, French S. Individual and environmental influences on adolescent eating behaviors. J Am Diet Assoc. 2002;102(3):S40-51.
33. Monge-Rojas R, Colón-Ramos U, Chinnock A, Smith-Castro V, Reyes-Fernández B. Gender-based eating norms, the family environment and food intake among Costa Rican adolescents. Public Health Nutr. 2021;24(15):4840–50.
34. Fahimfar N, Hesari E, Mansourzadeh MJ, Khalagi K, Sanjari M, Hajivalizadeh S, et al. Prevalence of osteoporosis in the Iranian population: a systematic review and meta-analysis. J Diabetes Metab Disord. 2024;23(1):229–37. https://doi.org/10.1007/s40200-023-01352-9.
35. Balk EM, Adam GP, Langberg VN, Earley A, Clark P, Ebeling PR, et al. Global dietary calcium intake among adults: a systematic review. Osteoporos Int. 2017;28(12):3315–24. https://doi.org/10.1007/s00198-017-4230-x.
36. Shlisky J, Mandlik R, Askari S, Abrams S, Belizan JM, Bourassa MW, et al. Calcium deficiency worldwide: prevalence of inadequate intakes and associated health outcomes. Ann N Y Acad Sci. 2022;1512(1):10–28. https://doi.org/10.1111/nyas.14758.
37. Ebrahimpour-Koujan S, Benisi-Kohansal S, Azadbakht L, Esmaillzadeh A. The association between dietary calcium intake and breast cancer risk among Iranian women. Nutr Cancer. 2022;74(5):1652–9. https://doi.org/10.1080/01635581.2021.1957135.
38. Kazeminia M, Salari N, Hosseinian-Far A, Akbari H, Bazrafshan M-R, Mohammadi M. The prevalence of breast cancer in Iranian women: a systematic review and meta-analysis. Indian J Gynecol Oncol. 2022;20(1):14. https://doi.org/10.1007/s40944-022-00613-4.
39. Abdollahpour S, Khadivzadeh T, Shafeei M, Arian M. Prevalence of preeclampsia and eclampsia in Iran: an updated systematic review and meta-analysis. Iran J Nurs Midwifery Res. 2024;29(5):495–502. https://doi.org/10.4103/ijnmr.ijnmr_299_23.
40. Huang K, Fang H, Yu D, Guo Q, Xu X, Ju L, et al (2022) Usual intake of micronutrients and prevalence of inadequate intake among chinese adults: data from CNHS 2015–2017. Vol. 14, Nutrients.
41. Ramírez-Silva I, Rodríguez-Ramírez S, Barragán-Vázquez S, Castellanos-Gutiérrez A, Reyes-García A, Martínez-Piña A, et al. Prevalence of inadequate intake of vitamins and minerals in the Mexican population correcting by nutrient retention factors, Ensanut 2016. Salud Publica Mex. 2020;62(5):521–31.
42. Sales CH, de Fontanelli MM, Vieira DAS, Marchioni DM, Fisberg RM. Inadequate dietary intake of minerals: prevalence and association with socio-demographic and lifestyle factors. Br J Nutr. 2017;117(2):267–77.
43. Saari JT. Copper deficiency and cardiovascular disease: role of peroxidation, glycation, and nitration. Can J Physiol Pharmacol. 2000;78(10):848–55.
44. Joseph J, Loscalzo J. Selenistasis: epistatic effects of selenium on cardiovascular phenotype. Nutrients. 2013;5(2):340–58. https://doi.org/10.3390/nu5020340.
45. Asghari G, Yuzbashian E, Mirmiran P, Bahadoran Z, Azizi F. Prediction of metabolic syndrome by a high intake of energy-dense nutrient-poor snacks in Iranian children and adolescents. Pediatr Res. 2016;79(5):697–704. https://doi.org/10.1038/pr.2015.270.
46. Yari Z, Cheraghpour M, Aghamohammadi V, Alipour M, Ghanei N, Hekmatdoost A. Energy-dense nutrient-poor snacks and risk of non-alcoholic fattyliver disease: a case–control study in Iran. BMC Res Notes. 2020;13(1):221. https://doi.org/10.1186/s13104-020-05063-9.
47. Arzhang P, Abbasi SH, Sarsangi P, Malekahmadi M, Nikbaf-Shandiz M, Bellissimo N, et al. Prevalence of household food insecurity among a healthy Iranian population: a systematic review and meta-analysis. Front Nutr. 2022;9:1006543.
48. Pakravan-Charvadeh MR, Savari M, Khan HA, Gholamrezai S, Flora C. Determinants of household vulnerability to food insecurity during COVID-19 lockdown in a mid-term period in Iran. Public Health Nutr. 2021;24(7):1619–28.
49. Mirmiran P, Bahadoran Z, Delshad H, Azizi F. Effects of energy-dense nutrient-poor snacks on the incidence of metabolic syndrome: a prospective approach in Tehran Lipid and Glucose Study. Nutrition. 2014;30(5):538–43.
50. Balaghi S, Faramarzi E, Mahdavi R, Ghaemmaghami J. Fluids intake and beverage consumption pattern among university students. Heal Promot Perspect. 2011;1(1):54.
51. Mattioli AV, Sciomer S, Cocchi C, Maffei S, Gallina S. Quarantine during COVID-19 outbreak: changes in diet and physical activity increase the risk of cardiovascular disease. Nutr Metab Cardiovasc Dis. 2020;30(9):1409–17.
52. Mattioli AV, Ballerini Puviani M, Nasi M, Farinetti A. COVID-19 pandemic: the effects of quarantine on cardiovascular risk. Eur J Clin Nutr. 2020;74(6):852–5. https://doi.org/10.1038/s41430-020-0646-z.
53. Ruíz-Roso MB, de Carvalho P, Padilha DC, Matilla-Escalante PB, Ulloa N, Acevedo-Correa D, et al. Changes of physical activity and ultra-processed food consumption in adolescents from different countries during covid-19 pandemic: an observational study. Nutrients. 2020;12(8):2289. https://doi.org/10.3390/nu12082289.

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.