Supplementary Materials

Associations Between Hair Element Concentrations and Height-Percentile Status in Mongolian Children and Adolescents: A Retrospective Cross-Sectional ICP-MS Study

Corrected master dataset: 1,000 records; percentile models: n=998. This supplement accompanies the revised manuscript.

Table S1. Clinical context and available covariates (N=1,000).

Characteristic	n	%	Interpretation
Clinical diagnosis code absent/0	761	76.1	No standardized testing indication was available.
E34.3 short-stature code	139	13.9	136/154 in the lowest percentile category.
F84.0 code	90	9.0	Diagnostic code, not a test-order indication.
E66 code	10	1.0	Diagnostic code, not a test-order indication.
Any diagnosed disease	454	45.4	Separate binary clinical-history field.
Growth-delay/short-stature flag	97	9.7	Separate symptom/history field.
No general symptoms	316	31.6	Not evidence of a population-screening indication.
Residence in Ulaanbaatar	861	86.1	129 other locations; 10 missing/invalid.
Dyed hair	7	0.7	993 untreated; cosmetic-treatment timing unavailable.
Paternal smoking: yes	296	29.6	Recorded questionnaire/history response.
Paternal smoking: no	377	37.7	Recorded questionnaire/history response.
Paternal smoking: missing/invalid	327	32.7	Missing category used in the extended model.
Maternal smoking: yes	53	5.3	Recorded questionnaire/history response.
Maternal smoking: no	626	62.6	Recorded questionnaire/history response.
Maternal smoking: missing/invalid	321	32.1	Missing category used in the extended model.
Selective eating: yes	404	40.4	Recorded questionnaire/history response.
Selective eating: no	273	27.3	Recorded questionnaire/history response.
Selective eating: missing/invalid	323	32.3	Missing category used in the extended model.

Note: Percentages use N = 1,000. Clinical codes and symptom fields are not standardized indications for ordering hair analysis and are not mutually exclusive. Explicit missing categories preserve observations but do not ensure unbiased confounder adjustment.

Table S2. Primary age-group- and sex-adjusted ordinal models (n=998).

Element	n	aOR (95% CI)	p	FDR q
Mercury (Hg)	998	0.72 (0.63–0.81)	<0.001	<0.001
Lead (Pb)	998	0.80 (0.70–0.92)	0.0012	0.0046
Aluminum (Al)	998	0.84 (0.73–0.96)	0.0134	0.0317
Barium (Ba)	998	0.74 (0.65–0.84)	<0.001	<0.001
Cadmium (Cd)	998	0.84 (0.73–0.96)	0.0105	0.0273
Arsenic (As)	998	0.87 (0.76–0.99)	0.0307	0.0603
Uranium (U)	998	0.97 (0.85–1.10)	0.5900	0.6669
Bismuth (Bi)	998	0.96 (0.85–1.09)	0.5381	0.6359
Thallium (Tl)	998	1.04 (0.92–1.18)	0.5073	0.6281
Cesium (Cs)	998	0.90 (0.80–1.02)	0.0888	0.1282
Sodium (Na)	998	1.16 (1.01–1.32)	0.0325	0.0603
Potassium (K)	998	0.88 (0.78–1.00)	0.0547	0.0948
Calcium (Ca)	998	1.12 (0.98–1.27)	0.0876	0.1282
Magnesium (Mg)	998	1.00 (0.87–1.14)	0.9543	0.9543
Zinc (Zn)	998	1.04 (0.85–1.27)	0.6804	0.7371
Sulfur (S)	998	0.76 (0.67–0.85)	<0.001	<0.001
Phosphorus (P)	998	1.06 (0.93–1.20)	0.3894	0.5063
Chromium (Cr)	998	0.71 (0.62–0.81)	<0.001	<0.001
Manganese (Mn)	998	0.84 (0.73–0.95)	0.0073	0.0237
Cobalt (Co)	998	0.92 (0.81–1.03)	0.1558	0.2132
Iron (Fe)	998	0.78 (0.67–0.90)	0.0011	0.0046
Copper (Cu)	998	1.21 (1.05–1.40)	0.0094	0.0271
Selenium (Se)	998	0.98 (0.86–1.11)	0.7270	0.7561
Lithium (Li)	998	0.89 (0.79–1.01)	0.0664	0.1079
Vanadium (V)	998	0.75 (0.66–0.86)	<0.001	<0.001
Molybdenum (Mo)	998	0.86 (0.75–0.98)	0.0220	0.0477

Note: Each aOR is per one SD higher natural-log-transformed concentration. aOR, adjusted odds ratio; CI, confidence interval; FDR, false discovery rate; SD, standard deviation. Nominal 95% CIs are not multiplicity adjusted. FDR q values are Benjamini–Hochberg adjusted within the specified 26-element model family. Exposure standardization uses the primary n=998 cohort and is held fixed in subset analyses. Models use zero-only substitution. An aOR <1 indicates lower odds of a higher recorded percentile category. Global proportional-odds violations are documented in S6A; threshold-specific estimates are in S6B.

Table S3. Recorded zeros and element-specific preprocessing parameters (N=1,000).

Element	Zero, n (%)	Smallest positive (µg/g)	Half-minimum constant (µg/g)
Mercury (Hg)	0 (0.0)	0.148	0.074
Lead (Pb)	0 (0.0)	0.102	0.051
Aluminum (Al)	0 (0.0)	0.032	0.016
Barium (Ba)	0 (0.0)	0.087	0.0435
Cadmium (Cd)	10 (1.0)	0.001	0.0005
Arsenic (As)	0 (0.0)	0.012	0.006
Uranium (U)	0 (0.0)	0.003	0.0015
Bismuth (Bi)	0 (0.0)	0.003	0.0015
Thallium (Tl)	163 (16.3)	0.001	0.0005
Cesium (Cs)	169 (16.9)	0.001	0.0005
Sodium (Na)	0 (0.0)	5.21	2.61
Potassium (K)	0 (0.0)	2.35	1.18
Calcium (Ca)	0 (0.0)	11.3	5.63
Magnesium (Mg)	0 (0.0)	3.19	1.6
Zinc (Zn)	0 (0.0)	27.3	13.6
Sulfur (S)	0 (0.0)	30,900	15,400
Phosphorus (P)	0 (0.0)	10.4	5.2
Chromium (Cr)	0 (0.0)	0.126	0.063
Manganese (Mn)	0 (0.0)	0.185	0.0925
Cobalt (Co)	0 (0.0)	0.002	0.001
Iron (Fe)	0 (0.0)	0.041	0.0205
Copper (Cu)	0 (0.0)	1.08	0.542
Selenium (Se)	0 (0.0)	0.056	0.028
Lithium (Li)	0 (0.0)	0.002	0.001
Vanadium (V)	0 (0.0)	0.02	0.01
Molybdenum (Mo)	0 (0.0)	0.003	0.0015

Note: Recorded zeros are not known to be true zeros, below-MDL values, below-LOQ values, or rounded results. Half-minimum constants are numerical values, not laboratory detection limits. Concentrations and constants are rounded for display; calculations used unrounded values. Positive concentrations are unchanged. The nonzero-derived constant is listed for every element because the alternative add-to-all analysis uses it even when no zeros are recorded. MDL, method detection limit; LOQ, limit of quantification.

Table S4. Sensitivity analysis with continuous age modeled using cubic B-splines (n=998).

Element	Primary aOR (95% CI)	Primary q	Sensitivity aOR (95% CI)	Sensitivity q
Mercury (Hg)	0.72 (0.63–0.81)	<0.001	0.71 (0.63–0.80)	<0.001
Lead (Pb)	0.80 (0.70–0.92)	0.0046	0.81 (0.70–0.92)	0.0069
Aluminum (Al)	0.84 (0.73–0.96)	0.0317	0.84 (0.73–0.97)	0.0430
Barium (Ba)	0.74 (0.65–0.84)	<0.001	0.74 (0.65–0.84)	<0.001
Cadmium (Cd)	0.84 (0.73–0.96)	0.0273	0.84 (0.73–0.96)	0.0381
Arsenic (As)	0.87 (0.76–0.99)	0.0603	0.87 (0.77–0.99)	0.0773
Uranium (U)	0.97 (0.85–1.10)	0.6669	0.95 (0.84–1.08)	0.5360
Bismuth (Bi)	0.96 (0.85–1.09)	0.6359	0.96 (0.85–1.10)	0.6418
Thallium (Tl)	1.04 (0.92–1.18)	0.6281	1.05 (0.93–1.18)	0.5360
Cesium (Cs)	0.90 (0.80–1.02)	0.1282	0.91 (0.81–1.03)	0.1888
Sodium (Na)	1.16 (1.01–1.32)	0.0603	1.14 (1.00–1.31)	0.1032
Potassium (K)	0.88 (0.78–1.00)	0.0948	0.90 (0.79–1.02)	0.1454
Calcium (Ca)	1.12 (0.98–1.27)	0.1282	1.09 (0.96–1.25)	0.2594
Magnesium (Mg)	1.00 (0.87–1.14)	0.9543	0.96 (0.84–1.11)	0.6574
Zinc (Zn)	1.04 (0.85–1.27)	0.7371	1.00 (0.82–1.23)	0.9639
Sulfur (S)	0.76 (0.67–0.85)	<0.001	0.76 (0.67–0.85)	<0.001
Phosphorus (P)	1.06 (0.93–1.20)	0.5063	1.05 (0.92–1.20)	0.5360
Chromium (Cr)	0.71 (0.62–0.81)	<0.001	0.71 (0.62–0.82)	<0.001
Manganese (Mn)	0.84 (0.73–0.95)	0.0237	0.84 (0.74–0.96)	0.0306
Cobalt (Co)	0.92 (0.81–1.03)	0.2132	0.91 (0.81–1.03)	0.2000
Iron (Fe)	0.78 (0.67–0.90)	0.0046	0.78 (0.67–0.91)	0.0069
Copper (Cu)	1.21 (1.05–1.40)	0.0271	1.18 (1.02–1.36)	0.0528
Selenium (Se)	0.98 (0.86–1.11)	0.7561	0.98 (0.86–1.11)	0.7419
Lithium (Li)	0.89 (0.79–1.01)	0.1079	0.89 (0.79–1.01)	0.1438
Vanadium (V)	0.75 (0.66–0.86)	<0.001	0.75 (0.66–0.86)	<0.001
Molybdenum (Mo)	0.86 (0.75–0.98)	0.0477	0.86 (0.76–0.99)	0.0700

Note: Sensitivity models replace age groups with four cubic B-spline basis terms (one internal knot at 11 years; boundary knots at 1 and 18 years) and retain sex. The basis was constructed using the full cohort. Recorded age is in completed years; birth and measurement dates were unavailable. Each aOR is per one SD higher natural-log-transformed concentration. aOR, adjusted odds ratio; CI, confidence interval; FDR, false discovery rate; SD, standard deviation. Nominal 95% CIs are not multiplicity adjusted. FDR q values are Benjamini–Hochberg adjusted across the 26 models. Exposure standardization uses the primary n = 998 cohort and is held fixed in subset analyses.

Table S5. Sensitivity analysis with additional recorded covariates (n=998).

Element	Primary aOR (95% CI)	Primary q	Sensitivity aOR (95% CI)	Sensitivity q
Mercury (Hg)	0.72 (0.63–0.81)	<0.001	0.73 (0.65–0.83)	<0.001
Lead (Pb)	0.80 (0.70–0.92)	0.0046	0.82 (0.71–0.94)	0.0179
Aluminum (Al)	0.84 (0.73–0.96)	0.0317	0.86 (0.75–0.99)	0.0975
Barium (Ba)	0.74 (0.65–0.84)	<0.001	0.79 (0.69–0.90)	0.0030
Cadmium (Cd)	0.84 (0.73–0.96)	0.0273	0.85 (0.74–0.97)	0.0640
Arsenic (As)	0.87 (0.76–0.99)	0.0603	0.88 (0.77–1.00)	0.1060
Uranium (U)	0.97 (0.85–1.10)	0.6669	0.99 (0.87–1.13)	0.9339
Bismuth (Bi)	0.96 (0.85–1.09)	0.6359	0.98 (0.86–1.11)	0.7515
Thallium (Tl)	1.04 (0.92–1.18)	0.6281	1.07 (0.94–1.21)	0.3846
Cesium (Cs)	0.90 (0.80–1.02)	0.1282	0.90 (0.80–1.02)	0.1643
Sodium (Na)	1.16 (1.01–1.32)	0.0603	1.13 (0.98–1.29)	0.1554
Potassium (K)	0.88 (0.78–1.00)	0.0948	0.89 (0.78–1.01)	0.1150
Calcium (Ca)	1.12 (0.98–1.27)	0.1282	1.15 (1.01–1.31)	0.0975
Magnesium (Mg)	1.00 (0.87–1.14)	0.9543	1.07 (0.93–1.24)	0.3955
Zinc (Zn)	1.04 (0.85–1.27)	0.7371	1.05 (0.86–1.28)	0.7086
Sulfur (S)	0.76 (0.67–0.85)	<0.001	0.78 (0.68–0.88)	<0.001
Phosphorus (P)	1.06 (0.93–1.20)	0.5063	1.09 (0.96–1.24)	0.2661
Chromium (Cr)	0.71 (0.62–0.81)	<0.001	0.75 (0.65–0.86)	<0.001
Manganese (Mn)	0.84 (0.73–0.95)	0.0237	0.88 (0.77–1.00)	0.1150
Cobalt (Co)	0.92 (0.81–1.03)	0.2132	0.96 (0.84–1.09)	0.5861
Iron (Fe)	0.78 (0.67–0.90)	0.0046	0.80 (0.69–0.93)	0.0179
Copper (Cu)	1.21 (1.05–1.40)	0.0271	1.12 (0.97–1.30)	0.1998
Selenium (Se)	0.98 (0.86–1.11)	0.7561	0.97 (0.85–1.10)	0.6812
Lithium (Li)	0.89 (0.79–1.01)	0.1079	0.92 (0.81–1.05)	0.3027
Vanadium (V)	0.75 (0.66–0.86)	<0.001	0.77 (0.66–0.88)	0.0015
Molybdenum (Mo)	0.86 (0.75–0.98)	0.0477	0.86 (0.75–0.99)	0.0851

Note: Sensitivity models retain age group and sex and additionally include residence (Ulaanbaatar/other/missing), diagnosed disease, paternal and maternal smoking, selective eating, and dyed-hair status. Smoking/eating fields use yes/no/missing-or-invalid categories. Missing-data proportions are reported in S1. These proxies do not substitute for detailed nutritional, socioeconomic, parental-height, or environmental data. Each aOR is per one SD higher natural-log-transformed concentration. aOR, adjusted odds ratio; CI, confidence interval; FDR, false discovery rate; SD, standard deviation. Nominal 95% CIs are not multiplicity adjusted. FDR q values are Benjamini–Hochberg adjusted within the specified 26-element model family. Exposure standardization uses the primary n=998 cohort and is held fixed in subset analyses.

Table S6A. Proportional-odds diagnostics for the corrected dataset (n=998).

Element	Element × threshold p	Element FDR q	All slopes p	All slopes FDR q
Mercury (Hg)	0.6400	0.7924	<0.001	<0.001
Lead (Pb)	0.0454	0.3693	<0.001	<0.001
Aluminum (Al)	0.3212	0.5567	<0.001	<0.001
Barium (Ba)	0.1666	0.3980	<0.001	<0.001
Cadmium (Cd)	0.1031	0.3693	<0.001	<0.001
Arsenic (As)	0.4523	0.6917	<0.001	<0.001
Uranium (U)	0.9150	0.9516	<0.001	<0.001
Bismuth (Bi)	0.0119	0.2672	<0.001	<0.001
Thallium (Tl)	0.7042	0.8017	<0.001	<0.001
Cesium (Cs)	0.2430	0.4786	<0.001	<0.001
Sodium (Na)	0.6377	0.7924	<0.001	<0.001
Potassium (K)	0.7551	0.8180	<0.001	<0.001
Calcium (Ca)	0.1684	0.3980	<0.001	<0.001
Magnesium (Mg)	0.2577	0.4786	<0.001	<0.001
Zinc (Zn)	0.7092	0.8017	<0.001	<0.001
Sulfur (S)	0.1667	0.3980	<0.001	<0.001
Phosphorus (P)	0.3508	0.5700	<0.001	<0.001
Chromium (Cr)	0.0206	0.2672	<0.001	<0.001
Manganese (Mn)	0.1136	0.3693	<0.001	<0.001
Cobalt (Co)	0.9878	0.9878	<0.001	<0.001
Iron (Fe)	0.5972	0.7924	<0.001	<0.001
Copper (Cu)	0.2085	0.4517	<0.001	<0.001
Selenium (Se)	0.5177	0.7477	<0.001	<0.001
Lithium (Li)	0.0649	0.3693	<0.001	<0.001
Vanadium (V)	0.0983	0.3693	<0.001	<0.001
Molybdenum (Mo)	0.0872	0.3693	<0.001	<0.001

Note: Stacked cumulative binary logistic models included threshold interactions for the element and all age-group/sex covariates; participant-clustered sandwich covariance accounted for dependence between the two cut points. Wald tests examine the element slope alone or all slopes jointly. FDR correction is separate across 26 element tests and across 26 global tests. Global nonproportionality was detected for every model; nonsignificant adjusted element tests do not prove proportionality. FDR, false discovery rate.

Table S6B. Threshold-specific associations allowing all slopes to differ (n=998).

Element	>3rd vs ≤3rd aOR (95% CI)	p	FDR q	>50th vs ≤50th aOR (95% CI)	p	FDR q
Mercury (Hg)	0.70 (0.59–0.82)	<0.001	<0.001	0.73 (0.63–0.84)	<0.001	<0.001
Lead (Pb)	0.70 (0.58–0.85)	<0.001	0.0013	0.86 (0.74–1.00)	0.0473	0.1106
Aluminum (Al)	0.76 (0.58–0.98)	0.0338	0.0628	0.86 (0.75–0.98)	0.0255	0.0828
Barium (Ba)	0.68 (0.57–0.82)	<0.001	<0.001	0.78 (0.67–0.90)	<0.001	0.0066
Cadmium (Cd)	0.74 (0.61–0.90)	0.0019	0.0084	0.88 (0.75–1.03)	0.1032	0.1936
Arsenic (As)	0.82 (0.70–0.96)	0.0160	0.0377	0.88 (0.76–1.03)	0.1233	0.2138
Uranium (U)	0.96 (0.80–1.16)	0.6769	0.7652	0.97 (0.84–1.12)	0.6876	0.7492
Bismuth (Bi)	0.83 (0.71–0.98)	0.0256	0.0512	1.03 (0.90–1.18)	0.6613	0.7492
Thallium (Tl)	1.02 (0.86–1.21)	0.8352	0.8686	1.05 (0.92–1.21)	0.4494	0.5842
Cesium (Cs)	0.97 (0.81–1.16)	0.7509	0.8135	0.87 (0.76–1.00)	0.0422	0.1097
Sodium (Na)	1.12 (0.93–1.35)	0.2317	0.3543	1.18 (1.01–1.37)	0.0382	0.1097
Potassium (K)	0.90 (0.72–1.12)	0.3399	0.4418	0.87 (0.76–1.00)	0.0510	0.1106
Calcium (Ca)	1.23 (1.03–1.47)	0.0256	0.0512	1.07 (0.93–1.24)	0.3319	0.4794
Magnesium (Mg)	0.92 (0.76–1.11)	0.3777	0.4676	1.03 (0.88–1.21)	0.6989	0.7492
Zinc (Zn)	1.08 (0.79–1.47)	0.6324	0.7474	1.02 (0.82–1.26)	0.8595	0.8595
Sulfur (S)	0.83 (0.69–1.00)	0.0491	0.0851	0.73 (0.63–0.84)	<0.001	<0.001
Phosphorus (P)	1.11 (0.97–1.26)	0.1360	0.2210	1.02 (0.91–1.14)	0.7204	0.7492
Chromium (Cr)	0.61 (0.51–0.73)	<0.001	<0.001	0.77 (0.66–0.90)	0.0012	0.0080
Manganese (Mn)	0.75 (0.61–0.93)	0.0074	0.0242	0.88 (0.76–1.03)	0.1043	0.1936
Cobalt (Co)	0.91 (0.78–1.07)	0.2635	0.3806	0.91 (0.79–1.05)	0.2109	0.3226
Iron (Fe)	0.74 (0.59–0.94)	0.0123	0.0326	0.79 (0.67–0.93)	0.0053	0.0196
Copper (Cu)	1.11 (0.90–1.36)	0.3325	0.4418	1.28 (1.08–1.51)	0.0045	0.0196
Selenium (Se)	1.01 (0.83–1.24)	0.8956	0.8956	0.96 (0.85–1.09)	0.5457	0.6756
Lithium (Li)	0.79 (0.65–0.95)	0.0125	0.0326	0.94 (0.82–1.08)	0.3666	0.5017
Vanadium (V)	0.67 (0.56–0.81)	<0.001	<0.001	0.80 (0.69–0.93)	0.0048	0.0196
Molybdenum (Mo)	0.75 (0.62–0.92)	0.0051	0.0191	0.90 (0.78–1.04)	0.1703	0.2767

Note: Each threshold model adjusts for age group and sex without imposing common slopes across thresholds. CIs and p values use participant-clustered sandwich covariance from the stacked model. FDR correction is applied separately across 26 elements at each cut point. Each aOR is per one standard deviation (SD) higher log concentration. An aOR <1 indicates lower odds of exceeding the stated cut point. aOR, adjusted odds ratio; CI, confidence interval; FDR, false discovery rate.

Table S7. Age-restricted sensitivity analysis among participants aged ≥3 years (n=980).

Element	Primary aOR (95% CI)	Primary q	Sensitivity aOR (95% CI)	Sensitivity q
Mercury (Hg)	0.72 (0.63–0.81)	<0.001	0.73 (0.64–0.82)	<0.001
Lead (Pb)	0.80 (0.70–0.92)	0.0046	0.80 (0.69–0.91)	0.0042
Aluminum (Al)	0.84 (0.73–0.96)	0.0317	0.83 (0.73–0.96)	0.0264
Barium (Ba)	0.74 (0.65–0.84)	<0.001	0.75 (0.66–0.86)	<0.001
Cadmium (Cd)	0.84 (0.73–0.96)	0.0273	0.83 (0.73–0.96)	0.0264
Arsenic (As)	0.87 (0.76–0.99)	0.0603	0.84 (0.74–0.97)	0.0293
Uranium (U)	0.97 (0.85–1.10)	0.6669	0.97 (0.86–1.11)	0.7709
Bismuth (Bi)	0.96 (0.85–1.09)	0.6359	0.96 (0.85–1.10)	0.6930
Thallium (Tl)	1.04 (0.92–1.18)	0.6281	1.03 (0.92–1.17)	0.6930
Cesium (Cs)	0.90 (0.80–1.02)	0.1282	0.91 (0.80–1.02)	0.1658
Sodium (Na)	1.16 (1.01–1.32)	0.0603	1.16 (1.01–1.33)	0.0667
Potassium (K)	0.88 (0.78–1.00)	0.0948	0.88 (0.77–1.00)	0.0783
Calcium (Ca)	1.12 (0.98–1.27)	0.1282	1.12 (0.98–1.27)	0.1576
Magnesium (Mg)	1.00 (0.87–1.14)	0.9543	1.00 (0.87–1.15)	0.9998
Zinc (Zn)	1.04 (0.85–1.27)	0.7371	1.03 (0.84–1.26)	0.7840
Sulfur (S)	0.76 (0.67–0.85)	<0.001	0.75 (0.66–0.85)	<0.001
Phosphorus (P)	1.06 (0.93–1.20)	0.5063	1.06 (0.93–1.21)	0.4691
Chromium (Cr)	0.71 (0.62–0.81)	<0.001	0.71 (0.62–0.82)	<0.001
Manganese (Mn)	0.84 (0.73–0.95)	0.0237	0.84 (0.74–0.96)	0.0264
Cobalt (Co)	0.92 (0.81–1.03)	0.2132	0.92 (0.81–1.04)	0.2219
Iron (Fe)	0.78 (0.67–0.90)	0.0046	0.77 (0.66–0.90)	0.0042
Copper (Cu)	1.21 (1.05–1.40)	0.0271	1.21 (1.04–1.40)	0.0264
Selenium (Se)	0.98 (0.86–1.11)	0.7561	0.98 (0.86–1.11)	0.7709
Lithium (Li)	0.89 (0.79–1.01)	0.1079	0.90 (0.79–1.02)	0.1576
Vanadium (V)	0.75 (0.66–0.86)	<0.001	0.75 (0.66–0.87)	<0.001
Molybdenum (Mo)	0.86 (0.75–0.98)	0.0477	0.86 (0.75–0.98)	0.0541

Note: The restricted model uses only participants with InBody J50-derived percentile bands and available outcomes; age groups are 3–4, 5–9, 10–14, and 15–18 years. The three >97th-percentile records remain in the >50th category. Restriction does not validate the underlying reference algorithm. Each aOR is per one SD higher natural-log-transformed concentration. aOR, adjusted odds ratio; CI, confidence interval; FDR, false discovery rate; SD, standard deviation. Nominal 95% CIs are not multiplicity adjusted. FDR q values are Benjamini–Hochberg adjusted within the specified 26-element model family. Exposure standardization uses the primary n=998 cohort and is held fixed in subset analyses.

Table S8. Continuous measured-height sensitivity analysis among participants aged ≥3 years (n=979).

Element	n	β (95% CI), cm	p	FDR q
Mercury (Hg)	979	−1.23 (−1.85 to −0.61)	<0.001	<0.001
Lead (Pb)	979	−1.10 (−1.75 to −0.44)	0.0011	0.0048
Aluminum (Al)	979	−1.11 (−1.97 to −0.24)	0.0120	0.0275
Barium (Ba)	979	−1.13 (−1.68 to −0.58)	<0.001	<0.001
Cadmium (Cd)	979	−1.05 (−1.73 to −0.37)	0.0025	0.0081
Arsenic (As)	979	−0.76 (−1.35 to −0.17)	0.0115	0.0275
Uranium (U)	979	0.34 (−0.26 to 0.93)	0.2709	0.3522
Bismuth (Bi)	979	0.04 (−0.54 to 0.62)	0.8945	0.9303
Thallium (Tl)	979	0.01 (−0.60 to 0.61)	0.9838	0.9838
Cesium (Cs)	979	−0.23 (−0.78 to 0.33)	0.4203	0.4967
Sodium (Na)	979	0.89 (0.25 to 1.52)	0.0063	0.0183
Potassium (K)	979	−0.56 (−1.14 to 0.02)	0.0602	0.0874
Calcium (Ca)	979	0.65 (0.03 to 1.28)	0.0414	0.0674
Magnesium (Mg)	979	0.24 (−0.43 to 0.91)	0.4783	0.5407
Zinc (Zn)	979	0.34 (−0.72 to 1.40)	0.5318	0.5761
Sulfur (S)	979	−1.35 (−1.89 to −0.81)	<0.001	<0.001
Phosphorus (P)	979	0.36 (−0.26 to 0.98)	0.2538	0.3473
Chromium (Cr)	979	−1.12 (−1.73 to −0.50)	<0.001	0.0020
Manganese (Mn)	979	−0.87 (−1.56 to −0.19)	0.0127	0.0275
Cobalt (Co)	979	−0.76 (−1.38 to −0.14)	0.0162	0.0325
Iron (Fe)	979	−1.30 (−2.12 to −0.47)	0.0020	0.0075
Copper (Cu)	979	0.79 (0.09 to 1.48)	0.0267	0.0496
Selenium (Se)	979	0.71 (−0.03 to 1.45)	0.0605	0.0874
Lithium (Li)	979	−0.24 (−0.81 to 0.32)	0.4010	0.4964
Vanadium (V)	979	−1.58 (−2.26 to −0.91)	<0.001	<0.001
Molybdenum (Mo)	979	−0.65 (−1.26 to −0.04)	0.0354	0.0614

Note: β is the difference in measured height (cm) per 1-SD higher log concentration. CI, confidence interval; FDR, false discovery rate; SD, standard deviation. Nominal 95% CIs use heteroscedasticity-consistent type 3 (HC3) standard errors. FDR correction covers the 26 models. Models include four cubic age-spline terms, sex, and age-by-sex spline interactions. The spline basis was constructed in the full cohort, with an internal knot at 11 years and boundary knots at 1 and 18 years, and was held fixed in this analysis. Two missing heights and one implausible age–height record are excluded from the age-eligible cohort. This is a within-sample analysis in centimeters, not a World Health Organization (WHO) height-for-age z-score analysis.

Table S9. Alternative handling of zero-valued observations (n=998).

Element	Primary aOR (95% CI)	Primary q	Sensitivity aOR (95% CI)	Sensitivity q
Mercury (Hg)	0.72 (0.63–0.81)	<0.001	0.72 (0.64–0.81)	<0.001
Lead (Pb)	0.80 (0.70–0.92)	0.0046	0.80 (0.70–0.92)	0.0046
Aluminum (Al)	0.84 (0.73–0.96)	0.0317	0.84 (0.73–0.96)	0.0343
Barium (Ba)	0.74 (0.65–0.84)	<0.001	0.74 (0.65–0.84)	<0.001
Cadmium (Cd)	0.84 (0.73–0.96)	0.0273	0.84 (0.73–0.97)	0.0349
Arsenic (As)	0.87 (0.76–0.99)	0.0603	0.86 (0.76–0.98)	0.0518
Uranium (U)	0.97 (0.85–1.10)	0.6669	0.97 (0.85–1.10)	0.6682
Bismuth (Bi)	0.96 (0.85–1.09)	0.6359	0.96 (0.84–1.09)	0.6229
Thallium (Tl)	1.04 (0.92–1.18)	0.6281	1.06 (0.94–1.19)	0.4775
Cesium (Cs)	0.90 (0.80–1.02)	0.1282	0.90 (0.80–1.02)	0.1309
Sodium (Na)	1.16 (1.01–1.32)	0.0603	1.16 (1.02–1.33)	0.0518
Potassium (K)	0.88 (0.78–1.00)	0.0948	0.88 (0.78–1.00)	0.0918
Calcium (Ca)	1.12 (0.98–1.27)	0.1282	1.12 (0.99–1.27)	0.1265
Magnesium (Mg)	1.00 (0.87–1.14)	0.9543	1.00 (0.87–1.15)	0.9991
Zinc (Zn)	1.04 (0.85–1.27)	0.7371	1.04 (0.85–1.27)	0.7405
Sulfur (S)	0.76 (0.67–0.85)	<0.001	0.76 (0.67–0.85)	<0.001
Phosphorus (P)	1.06 (0.93–1.20)	0.5063	1.06 (0.93–1.20)	0.5203
Chromium (Cr)	0.71 (0.62–0.81)	<0.001	0.71 (0.62–0.81)	<0.001
Manganese (Mn)	0.84 (0.73–0.95)	0.0237	0.84 (0.73–0.95)	0.0254
Cobalt (Co)	0.92 (0.81–1.03)	0.2132	0.92 (0.81–1.04)	0.2279
Iron (Fe)	0.78 (0.67–0.90)	0.0046	0.78 (0.67–0.90)	0.0046
Copper (Cu)	1.21 (1.05–1.40)	0.0271	1.21 (1.05–1.40)	0.0255
Selenium (Se)	0.98 (0.86–1.11)	0.7561	0.97 (0.85–1.10)	0.6869
Lithium (Li)	0.89 (0.79–1.01)	0.1079	0.89 (0.78–1.01)	0.1033
Vanadium (V)	0.75 (0.66–0.86)	<0.001	0.75 (0.66–0.86)	<0.001
Molybdenum (Mo)	0.86 (0.75–0.98)	0.0477	0.85 (0.75–0.98)	0.0428

Note: The primary analysis replaces only zeros with one-half of the smallest positive concentration. The alternative adds that element-specific constant to every observation before log transformation. Each transformed exposure is standardized using its own mean and sample SD in the primary n = 998 cohort. The two approaches yield the same FDR-significance classification for all 26 elements; potassium does not meet the FDR criterion under either approach (zero-only, q = 0.0948; add-to-all, q = 0.0918). This agreement does not establish the analytical meaning of recorded zeros. Each aOR is per one SD higher natural-log-transformed concentration. aOR, adjusted odds ratio; CI, confidence interval; FDR, false discovery rate; SD, standard deviation. Nominal 95% CIs are not multiplicity adjusted. FDR correction is applied separately across the 26 models for each approach.

Table S10. Sensitivity analysis excluding two unresolved age–height inconsistencies (n=996).

Element	Primary aOR (95% CI)	Primary q	Sensitivity aOR (95% CI)	Sensitivity q
Mercury (Hg)	0.72 (0.63–0.81)	<0.001	0.72 (0.63–0.81)	<0.001
Lead (Pb)	0.80 (0.70–0.92)	0.0046	0.80 (0.70–0.92)	0.0051
Aluminum (Al)	0.84 (0.73–0.96)	0.0317	0.84 (0.73–0.96)	0.0319
Barium (Ba)	0.74 (0.65–0.84)	<0.001	0.74 (0.65–0.84)	<0.001
Cadmium (Cd)	0.84 (0.73–0.96)	0.0273	0.83 (0.72–0.95)	0.0253
Arsenic (As)	0.87 (0.76–0.99)	0.0603	0.86 (0.76–0.99)	0.0574
Uranium (U)	0.97 (0.85–1.10)	0.6669	0.97 (0.86–1.10)	0.7324
Bismuth (Bi)	0.96 (0.85–1.09)	0.6359	0.96 (0.85–1.09)	0.6527
Thallium (Tl)	1.04 (0.92–1.18)	0.6281	1.04 (0.92–1.18)	0.6213
Cesium (Cs)	0.90 (0.80–1.02)	0.1282	0.90 (0.80–1.02)	0.1373
Sodium (Na)	1.16 (1.01–1.32)	0.0603	1.16 (1.01–1.32)	0.0661
Potassium (K)	0.88 (0.78–1.00)	0.0948	0.89 (0.78–1.00)	0.1015
Calcium (Ca)	1.12 (0.98–1.27)	0.1282	1.12 (0.98–1.27)	0.1409
Magnesium (Mg)	1.00 (0.87–1.14)	0.9543	0.99 (0.86–1.14)	0.8892
Zinc (Zn)	1.04 (0.85–1.27)	0.7371	1.03 (0.84–1.26)	0.7916
Sulfur (S)	0.76 (0.67–0.85)	<0.001	0.76 (0.67–0.86)	<0.001
Phosphorus (P)	1.06 (0.93–1.20)	0.5063	1.05 (0.93–1.20)	0.5449
Chromium (Cr)	0.71 (0.62–0.81)	<0.001	0.71 (0.62–0.81)	<0.001
Manganese (Mn)	0.84 (0.73–0.95)	0.0237	0.83 (0.73–0.95)	0.0207
Cobalt (Co)	0.92 (0.81–1.03)	0.2132	0.92 (0.81–1.04)	0.2248
Iron (Fe)	0.78 (0.67–0.90)	0.0046	0.78 (0.67–0.90)	0.0045
Copper (Cu)	1.21 (1.05–1.40)	0.0271	1.20 (1.04–1.39)	0.0297
Selenium (Se)	0.98 (0.86–1.11)	0.7561	0.98 (0.86–1.11)	0.7916
Lithium (Li)	0.89 (0.79–1.01)	0.1079	0.89 (0.79–1.01)	0.1074
Vanadium (V)	0.75 (0.66–0.86)	<0.001	0.75 (0.65–0.86)	<0.001
Molybdenum (Mo)	0.86 (0.75–0.98)	0.0477	0.86 (0.75–0.98)	0.0490

Note: The sensitivity analysis excludes records with height 145.4 cm at age 2 and height 173 cm at age 6, without assigning corrected ages or heights. They remain in the primary ordinal analysis because their supplied percentile categories were not missing. FDR classification is unchanged for all 26 elements. The previously zero-valued height corrected to 109 cm in the supplied master export is retained. Each aOR is per one SD higher natural-log-transformed concentration. aOR, adjusted odds ratio; CI, confidence interval; FDR, false discovery rate; SD, standard deviation. Nominal 95% CIs are not multiplicity adjusted. FDR q values are Benjamini–Hochberg adjusted within the specified 26-element model family. Exposure standardization uses the primary n=998 cohort and is held fixed in subset analyses.

Table S11. Available analytical information and explicit reporting limitations.

Component	Information available	Qualification
Collection and basic preparation	Occipital proximal hair, approximately 2–3 cm; deionized-water wash; 50 °C for 30 min.	Detailed wash counts, durations, volumes, and agitation settings are not disclosed at the laboratory's request.
Digestion	50 mg dried hair; 5 mL ultrapure nitric acid; microwave-assisted digestion; final volume 50 mL.	No study-batch records of additional dilution or out-of-range remeasurement were available.
Measurement	Agilent 7700x ICP-MS; rhodium specified at 500 µg/L in the method summary.	Instrument and internal-standard details are reported from the method summary; study-batch instrument records were unavailable.
Calibration	Panel-wide span of 0.01–5000 µg/L; R^2 >0.999.	Per-element working intervals and study-batch calibration results were unavailable.
Detection and quantification	MDL range 0.002–6.607 µg/L; 3.14 × SD of seven spiked-blank replicates.	Per-element MDL mappings, LOQs, censoring flags, and validation of very low exported values were unavailable.
Precision and recovery	Method-summary RSD <8% (n=7); reference-material recoveries 85–115%.	No element-by-element or study-batch precision/recovery results were available.
Blank and reference material	Method blank; RM-YSIET-Human hair-01 processed with samples.	Blank results, assigned/measured values, uncertainty, and independent certification documentation were unavailable; it is described as a reference material, not asserted to be a certified material.
Zero-valued and high-range results	Zeros retained as recorded in source; sulfur values corrected to a consistent exported scale.	Zero origin and additional-dilution/remeasurement procedures could not be verified. Scale correction does not establish sulfur analytical validity.

Note: This table summarizes the analytical information available for the retrospective study. Element-specific and study-batch validation records were unavailable. ICP-MS, inductively coupled plasma mass spectrometry; KOLAS, Korea Laboratory Accreditation Scheme; YSIET, YS Institute of Environmental Technology; MDL, method detection limit; LOQ, limit of quantification; RSD, relative standard deviation. With 50 mg of hair diluted to 50 mL and no additional dilution, 1 µg/L in the test solution corresponds to 1 µg/g of hair. Additional dilution cannot be assumed to reconcile reported concentrations with the calibration range.

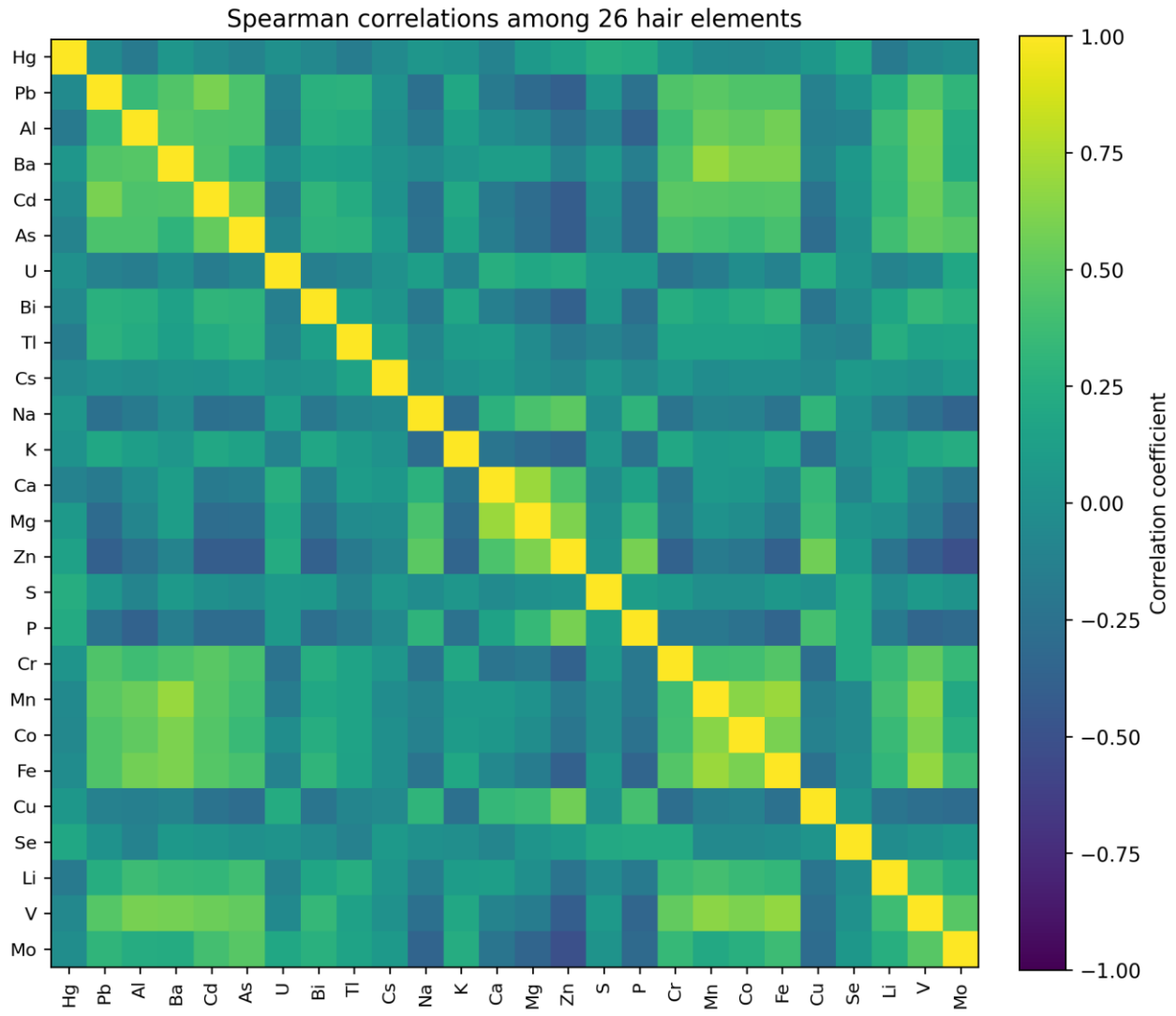


Figure S1. Spearman rank correlations among all 26 hair elements (N=1,000). Each cell shows the correlation of the unmodified laboratory-reported concentrations; recorded zeros are retained as tied ranks. Sulfur uses the corrected export values. The complete numeric matrix is provided in Supplementary Data S1. Correlations do not identify exposure sources or mutually independent effects.

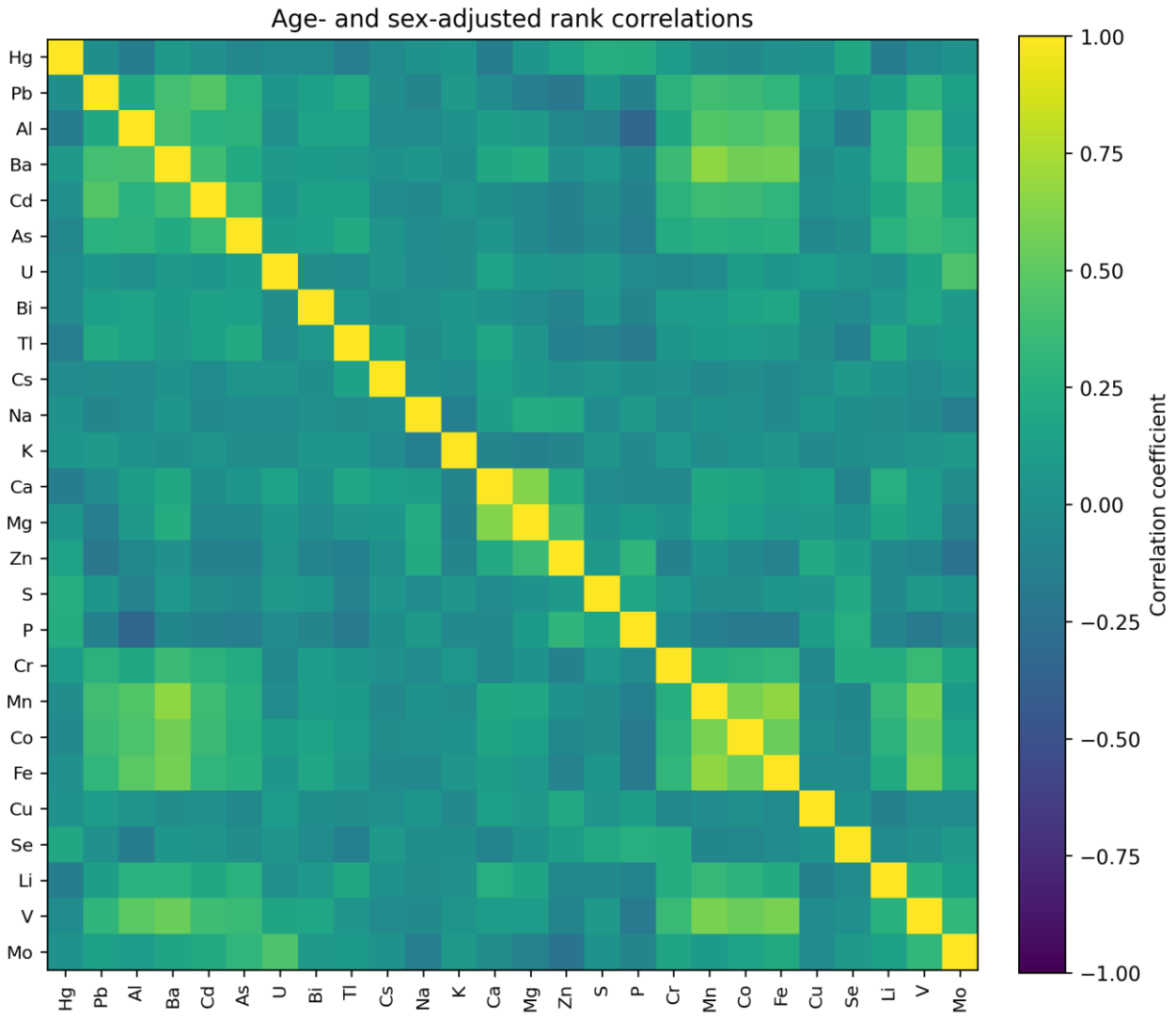


Figure S2. Partial rank correlations after adjustment for sex and continuous age represented by four cubic B-spline terms (N=1,000). Each element was ranked, its ranks regressed on the adjustment terms, and the residuals correlated. This descriptive adjustment does not eliminate residual confounding or validate a mixture mechanism. Numerical coefficients are provided in Supplementary Data S1.