Zirconium

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Abstract

This page draws on 18 peer-reviewed studies. The complete citation list is at the bottom of the page.

1 | Overview

The evidence reviewed for this page is mostly about zirconium as a material, not as a contaminant. Of 23 papers, one measured zirconium in a food matrix (wild mushrooms) alongside contextual topsoil samples 1, one detected trace zirconium in oral mucosa samples around dental implants 2, one tested zirconium toxicity to oat plants in spiked soil 3, one used a zirconium-containing drug in a clinical trial 4, and one developed a method for detecting zirconium in water 5. The other 18 use zirconium compounds as adsorbents, catalysts, sensor materials, ice-shaping additives or dental crowns and contain no exposure data.

The mushroom study describes zirconium as a lithogenic element whose distribution in soils follows parent material and resistant accessory minerals, particularly zircon, so that only a small fraction is released by aqua regia type extraction 1. The oat study lists nuclear fuel cladding, ceramics, refractories, electronics and zirconia dental implants among its uses 3.

2 | Toxicology

The cited evidence does not establish human toxicity, a no-effect level or a tolerable intake for zirconium. No paper reviewed here tested zirconium toxicity in people or mammals.

In a greenhouse experiment, oat grown in soil spiked with 400 mg/kg zirconium (as zirconium sulfate) for 8 weeks lost biomass, and chlorophyll a, chlorophyll b, total chlorophyll and photosynthetic rate fell by 61%, 71%, 50% and 62% compared with uncontaminated plants, with signs of oxidative damage 3. This is phytotoxicity at a single high spiked dose and cannot be read across to human health.

The papers disagree in their framing. The oat study calls zirconium and its compounds toxic to human health, citing earlier literature 3, while two water-treatment studies describe zirconium as non-toxic, also citing earlier literature 6 7. None of these statements rests on data in the papers themselves.

In a 6-week trial of 26 patients with advanced chronic kidney disease taking the potassium binder sodium zirconium cyclosilicate, 10 mild and transient gastrointestinal events were recorded, and the physician rated 6 as probably or possibly related to the drug 4. The trial did not measure zirconium in blood or urine, so it says nothing about zirconium absorption.

3 | Typical exposure routes

The cited evidence does not establish dietary intake, drinking water exposure or body burden of zirconium in any population. Three possible routes appear in the papers, each with limited data.

- Diet: zirconium was detected in every wild mushroom sampled in one English city 1, but the study did not address which taxa are eaten or how much.
- Dental materials: zirconium was detected near the detection limit in oral mucosa samples around zirconia implants 2.
- Medication: sodium zirconium cyclosilicate was given at 30 g/d for the first 48 to 72 hours and then 5 to 10 g/d, most often 10 g/d 4. How much zirconium, if any, is absorbed from this dose was not studied.

Zirconium-based adsorbents are being developed to remove fluoride and lead from drinking water and soil 6 7 8 9 10. None of these papers reported whether zirconium leaches into the treated water or soil, so whether this use adds to exposure is unknown.

Trace detections in oral mucosa are summarized below. Values are concentrations in the prepared sample solution, not per mass of tissue.

STUDY / LOCATION	MATERIAL / DESIGN	METAL SPECIES	VALUE (UNITS AND BASIS)	N	INTERPRETATION / LIMITATION
2, Geneva, Switzerland	Brush cytology of peri-implant mucosa, zirconia implants, semi-quantitative ICP-MS (Phase I)	total zirconium	0.07 (two subjects), 0.08 and 0.24 µg/L in sample solution; LOD 0.07 µg/L	5	Detected in 4 of 5 subjects, at or just above the LOD
2, Geneva, Switzerland	Same method, quantitative mode, after controlled titanium dioxide intake (Phase II)	total zirconium	0.07 and 0.15 ppb at two implant sites; 0.12 ppb at one contralateral tooth	7	All below the stated LOQ of 2 ppb; the paper also gives the LOQ as 0.5 or 1 µg/L

2, Geneva, Switzerland	Gingival cells of control subjects without metallic devices (Phase III)	total zirconium	Detected in two samples, below LOQ (values not given)	10	Conflicts with the paper's conclusion that zirconium appeared only around zirconia implants

4 | Food sources

The only food measurements in the cited evidence come from wild mushrooms. In 121 fruiting bodies collected in autumn 2019 from urban and peri-urban green spaces in Leicester and Leicestershire, England, acid-recoverable zirconium was detected in every sample, with a median of 170 ng/g dry weight (equal to 170 µg/kg) and a range of 28 to 3200 ng/g 1. Concentrations differed by taxon and site, but taxon and site could not be separated because most taxa came from one park. The study did not state which taxa are edible and did not estimate intake, so these values describe occurrence in wild mushrooms, not dietary exposure.

STUDY / LOCATION	MATERIAL / DESIGN	METAL SPECIES	VALUE (UNITS AND BASIS)	N	INTERPRETATION / LIMITATION
1, Leicester and Leicestershire, England	Wild mushroom fruiting bodies, all taxa, opportunistic collection, acid-recoverable	total zirconium (acid-recoverable)	median 170 ng/g (IQR 61 to 380), range 28 to 3200, mean 320, P95 1100, dry weight	121	Detected in all samples; no reference material; edibility and intake not addressed
1, Abbey and Braunstone Parks	Panaeolina foenisecii	total zirconium (acid-recoverable)	median 390 ng/g (IQR 220 to 660), range 32 to 3200, dry weight	28	Highest values in the set; taxon and site confounded
1, Victoria Park	Mycena citrinomarginata	total zirconium (acid-recoverable)	median 390 ng/g (IQR 300 to 500), range 120 to 2000, dry weight	22	Single site
1, Bradgate Park	Coprinopsis atramentaria	total zirconium (acid-recoverable)	median 260 ng/g (IQR 79 to 450), range 44 to 850, dry weight	8	Small group, single site
1, St Augustine Road	Agaricus bitorquis	total zirconium (acid-recoverable)	median 56 ng/g (IQR 50 to 62), range 38 to 140, dry weight	22	Lowest and least variable group; single site
1, Leicester and Leicestershire, 26 sites	Contextual topsoil composites, 0 to 5 cm, reverse aqua regia	total zirconium (acid-recoverable)	median 11.0 mg/kg (IQR 9.68 to 12.7), range 6.65 to 17.7, dry weight	26	Pseudo-total, not full silicate dissolution; not paired with individual mushrooms

The same study found that soil and mushroom comparisons for zirconium were inconclusive and supported no inference about soil-to-mushroom transfer 1. In the oat experiment, zirconium accumulated in plants grown in spiked soil, but tissue values appear only in a figure and refer to whole plants, not to oat grain 3.

Several papers use zirconium compounds in food processing or food testing without measuring zirconium in the food: zirconium phosphate to isolate a polyphenol fraction from green tea extract 11, zirconium frameworks to purify astaxanthin from an algal extract 12, and zirconium acetate compounds proposed as ice-growth inhibitors with possible frozen food uses 13 14. Whether zirconium residues carry over into these products was not studied.

5 | Regulatory limits

The cited evidence does not establish any regulatory limit, guideline value or tolerable intake for zirconium in food, water or consumer products. The only regulatory value used in the papers is a fluoride benchmark of 1.5 mg/L, which two water-treatment studies apply as a breakthrough point 6 7; it concerns fluoride, not zirconium.

6 | Testing

Zirconium in mushrooms, soils, oral samples and plants was measured by ICP-MS. In the mushroom study, zirconium-90 was read in helium collision mode with indium-115 as internal standard; the working detection limit was 0.294 ng/g dry weight for mushrooms and 0.0131 mg/kg for soils, and an independent aqueous check standard recovered about 102% 1. That study had no certified reference material, matrix spikes or procedural blanks, and its digestions do not fully dissolve zircon, so results are acid-recoverable rather than total.

For brush cytology samples, the detection limit for zirconium was 0.07 µg/L in solution, and recovery from spiked micro-brushes at 2 µg/L was 86% to 87% 2. A microwave plasma torch ion trap method detected zirconium in water standards at 20 µg/L, with a linear range of 20 to 100 µg/L; the same paper lists 0.04 µg/L for ICP-MS for comparison, so the newer method is far less sensitive 5.

Several sensor papers use zirconium frameworks or oxides as the sensing material for other analytes, not to measure zirconium: oxytetracycline in milk and malachite green in fish by fluorescence sensing 15 16, and vanillin and rutoside by electrochemical detection 17 18.

7 | Microbiome effects

The cited evidence does not establish any effect of zirconium on the gut or other microbiomes. None of the 23 papers studied microbial communities.

8 | Vulnerable populations

The cited evidence does not identify populations at higher risk from zirconium. Two groups have documented contact with zirconium materials: people with zirconia dental implants, in whom trace zirconium was found in oral mucosa 2, and patients with advanced kidney disease taking sodium zirconium cyclosilicate 4. Neither study assessed harm from zirconium itself.

9 | Mitigation

The cited evidence does not establish any method for removing zirconium from food or water. The only reduction reported is experimental: in the greenhouse study, raising carbon dioxide to 710 ppm lowered zirconium in oat grown in spiked soil by about 40% compared with 420 ppm 3. This is not a practical control measure.

Zirconium appears in the remaining papers as a tool for removing other contaminants. Zirconium-coated pumice and scoria, zirconium-loaded tea waste and a zirconium framework removed fluoride from water 6 7 8 9, and a zirconium-loaded tannin foam immobilized fluoride and lead in tea garden soil 10.

10 | Open questions

- Toxicology: no human or mammalian toxicity data, no tolerable intake.
- Typical exposure routes: no dietary intake, drinking water or biomonitoring data for any population.
- Food sources: only wild mushrooms from one English city; no data on cultivated mushrooms, cereals, other crops, seafood or processed foods; edibility of the sampled taxa not addressed.
- Regulatory limits: no limit or guideline value for zirconium in the cited evidence.
- Whether zirconium leaches from zirconium-based water and soil treatment materials.
- Whether zirconium residues carry over from zirconium phosphate or zirconium framework adsorbents into food extracts.
- Systemic absorption of zirconium from sodium zirconium cyclosilicate.
- Microbiome effects: not studied.
- Vulnerable populations: not identified.
- Mitigation: no removal or processing method for zirconium in food.
- Total versus acid-recoverable zirconium in food and soil, given incomplete dissolution of zircon.

11 | What remains uncertain

The occurrence data rest on one opportunistic survey of wild mushrooms in one city, without certified reference materials, and on a small pilot of oral brush samples where nearly every detection sat near the detection limit and the paper is internally inconsistent about whether zirconium appeared in people without zirconia implants. Neither supports a population exposure estimate.

Statements in the papers about zirconium toxicity point in opposite directions and come from earlier literature rather than from the studies themselves. The oat experiment used a single spiked soil dose far above the acid-recoverable topsoil levels measured in Leicester, so its phytotoxicity findings do not indicate what happens in ordinary agricultural soils.

Most of the evidence reviewed here concerns zirconium as an engineered material. That use is growing in water treatment and food analysis, but none of those papers measured zirconium release, so the contribution of these materials to exposure is unknown.

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