

Nestlé Nutrition Institute

THE ROLE OF MICRONUTRIENTS FOR HEALTHY LONGEVITY

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THE ROLE OF MICRONUTRIENTS FOR HEALTHY LONGEVITY

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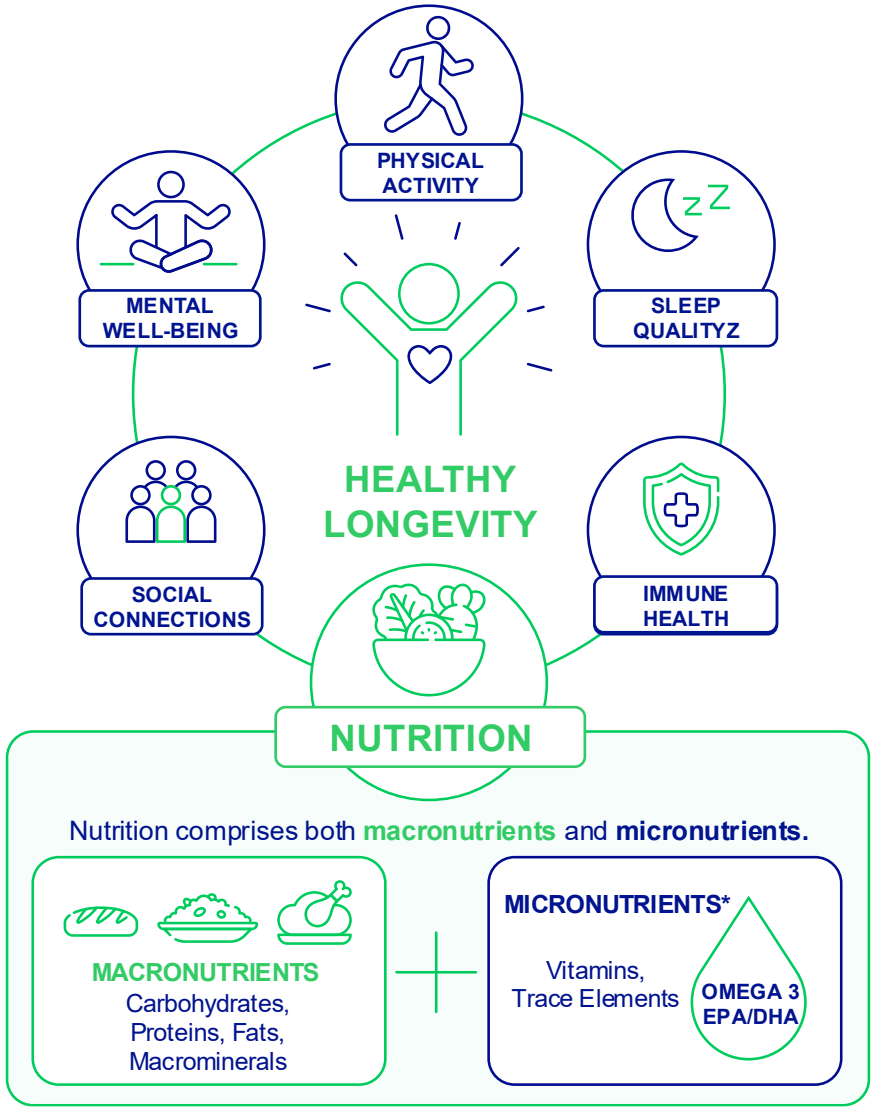
HEALTHY LONGEVITY

Introduction
Key determinants of healthy ageing
Healthy longevity though nutrition

Introduction

- Population ageing is a major public health challenge, driven by increasing age and a growing burden of age-related diseases.[1]
- Emerging evidence highlights the central **role** of **nutrition** in promoting **healthy longevity** through its effects on mitochondrial function, inflammation, immunity, and cognitive health.[1]
- This module reviews the evidence on micronutrients and omega-3 fatty acids, providing practical recommendations to support health span and healthy longevity with optimized approaches.[1]

*This module applies the ESPEN clinical-nutrition definition, in which micronutrients = vitamins + trace elements only. The major minerals calcium, magnesium, sodium, potassium, phosphorus and chloride are excluded and treated as electrolytes / macrominerals.[2]



1. Garmany A, et al. Global Healthspan-Lifespan Gaps Among 183 World Health Organization Member States. JAMA Netw Open. 2024;7(12):e2450241.
2. Berger M, et al. ESPEN micronutrient guideline. Clin Nutr. 2022 Jun;41(6):1357-1424.

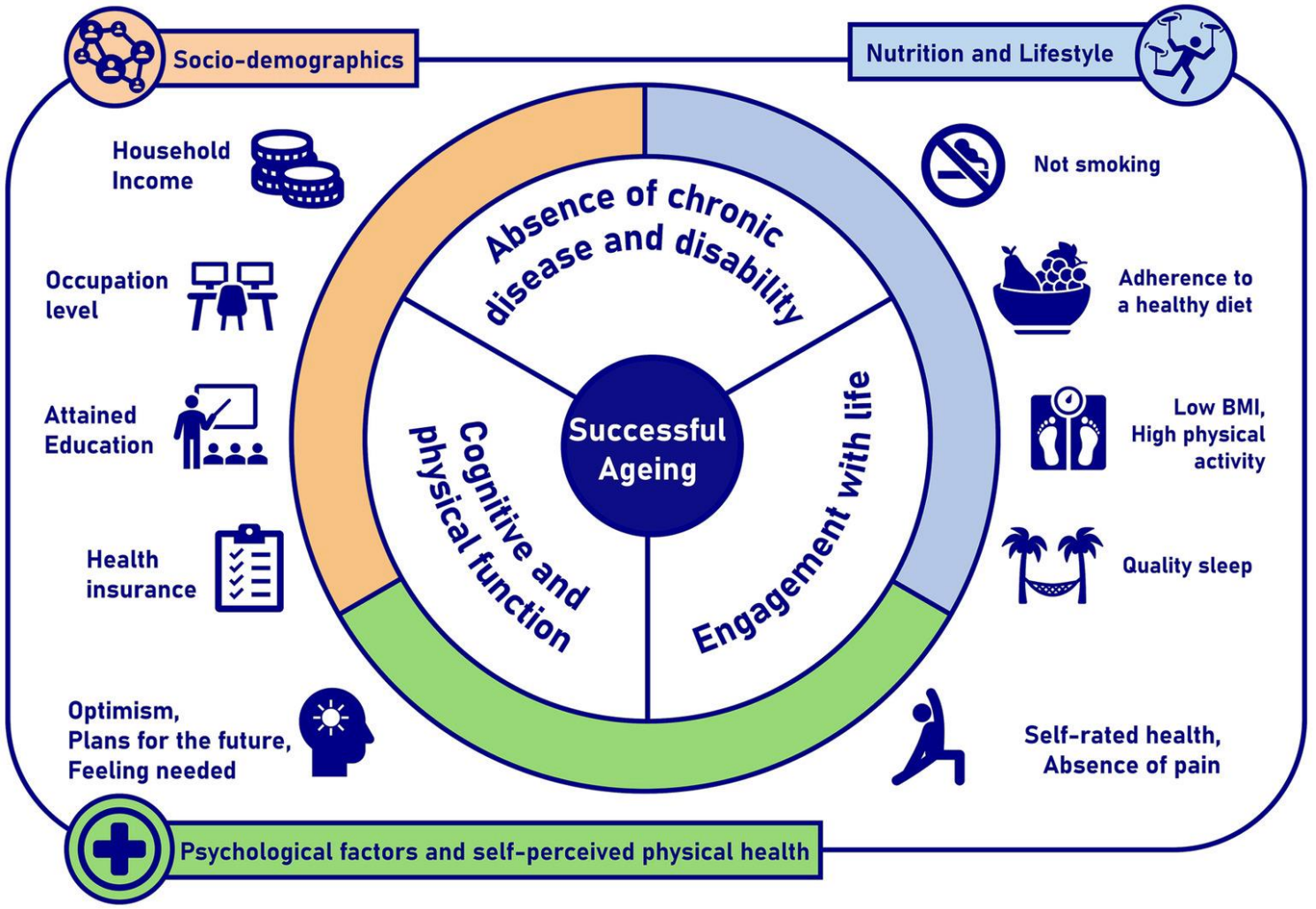
Key determinants of healthy longevity

- **Successful ageing** is considered a multidimensional outcome, encompassing physical health, cognitive function, and social well-being
- Key factors associated with successful ageing include:
  - **Healthy dietary patterns** (especially the Mediterranean diet)
  - Regular physical activity
  - Non-smoking
  - Good metabolic health
  - Higher socioeconomic status
- Emerging evidence highlights the importance of **psychological well-being.**

Click here for more information

1. Rodrigues C, et al. Determinants and indicators of successful aging as a multidimensional outcome: a systematic review of longitudinal studies. Front Public Health. 2023 Nov 21;11:1258280.

Multidimensional model of successful ageing and its determinants (Rodrigues_2023)



1. Rodrigues C, et al. Determinants and indicators of successful aging as a multidimensional outcome: a systematic review of longitudinal studies. Front Public Health. 2023 Nov 21;11:1258280.

Healthy longevity through nutrition

- Different nutritional approaches have shown benefits in healthy longevity.

Mediterranean diet	Intermittent fasting / caloric restriction
• Reduces CVD risk.[1,2] • Associated with slower cognitive decline and reduced dementia incidence.[3,4] • Supplementation with vitamin D further reduces age-related disease risk[5]	• Activates autophagy → cellular renewal and reduced oxidative damage.[6] • Reduces IGF-1 (tumour progression accelerator), improves metabolic function.[7] • Delays immunosenescence and inflammation.[6] • A shorter eating window may make it harder to reach adequate nutrient intake.[8]

- Other specifically designed diets have been proposed to increase longevity.[6] (Longo_2022)
  - Plant-based: 45–60% complex carbohydrates, 10–15% plant proteins, 25–35% plant fats
  - Emphasis on fresh, unrefined foods; legumes, nuts, whole grains
  - Includes time-restricted eating (11–13 h daily eating window)

1. Estruch R. et al. PREDIMED Study Investigators. Primary Prevention of Cardiovascular Disease with a Mediterranean Diet Supplemented with Extra-Virgin Olive Oil or Nuts. N Engl J Med. 2018 Jun 21;378(25):e34.
2. Salas-Salvadó J, et al. Effect of a Lifestyle Intervention Program With Energy-Restricted Mediterranean Diet and Exercise on Weight Loss and Cardiovascular Risk Factors: One-Year Results of the PREDIMED-Plus Trial. Diabetes Care 1 May 2019; 42 (5): 777–788.
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4. Dhana K, et al. MIND Diet, Common Brain Pathologies, and Cognition in Community-Dwelling Older Adults. J Alzheimers Dis. 2021;83(2):683-692.
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8. Dashti H, et al. Promise and Uncertainty of Intermittent Fasting for Aging Populations. Adv Nutr. 2026 Jul;17(7):100643.

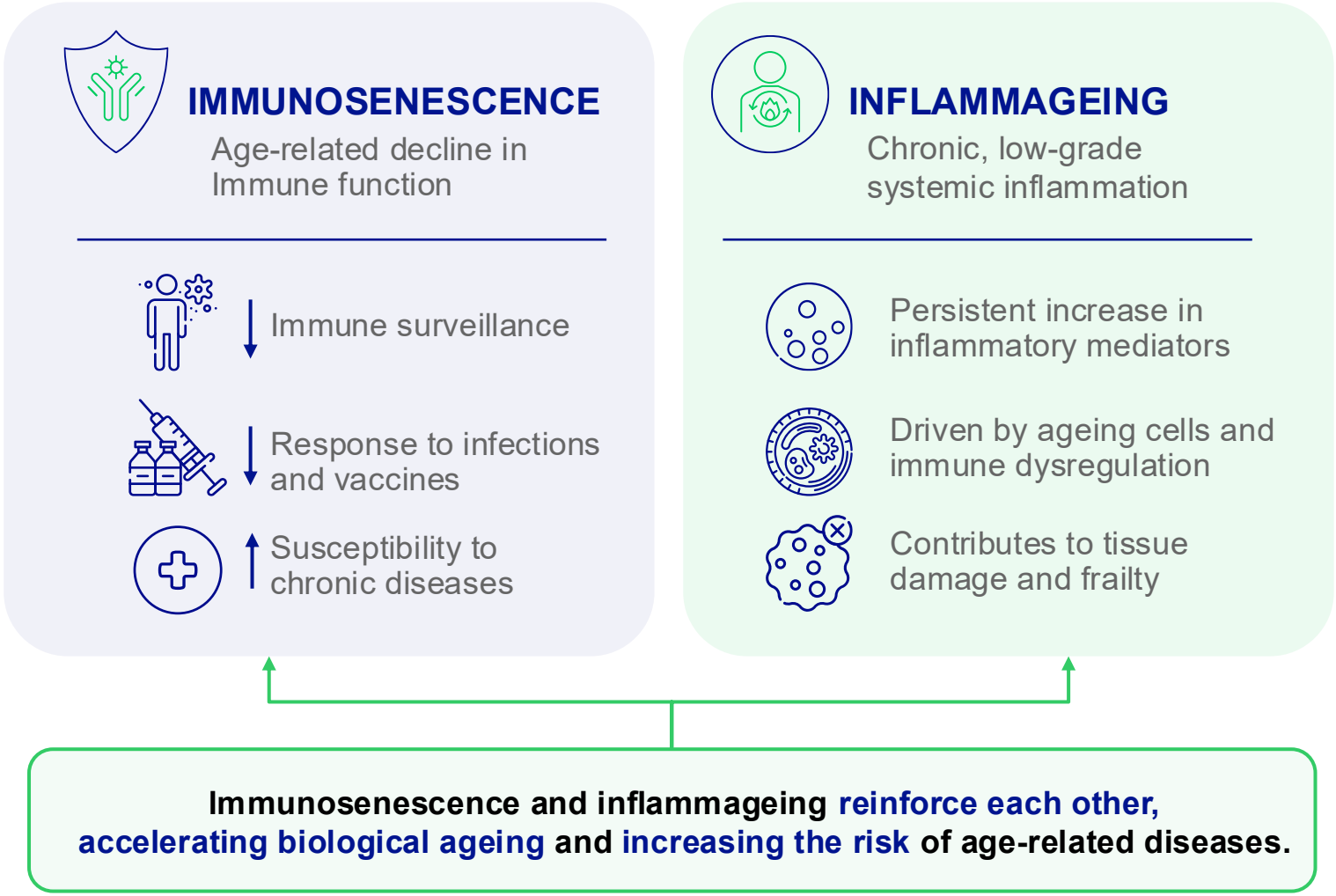


AGE-RELATED TRAJECTORIES IN BODY SYSTEMS

Inflammageing and immunosenescence
Critical periods of accelerated ageing
Nutrients associated with biological systems functionality

Inflammageing and immunosenescence

- With advancing age, many physiological systems undergo gradual declines.
- In the immune system, this is reflected by **immunosenescence**[1] (a decline in immune function) and **inflammageing**[2] (chronic low-grade inflammation related with age) that can affect its efficiency
- These are two interconnected key processes that contribute to age-related changes in health.



1. Liu Z, et al. Immunosenescence: molecular mechanisms and diseases. Signal Transduct Target Ther. 2023 May 13;8(1):200.
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AGE-RELATED TRAJECTORIES IN BODY SYSTEMS

Critical periods of accelerated ageing

- There are **two critical periods of accelerated biological** ageing, occurring at approximately **44 and 60 years of age**.[1]
- The first is associated with changes in cardiovascular risk and lipid metabolism, while the second involves alterations in immune function and carbohydrate metabolism.[1]
- The **early 40s** may represent a **key window** for implementing **preventive health measures**.[2]

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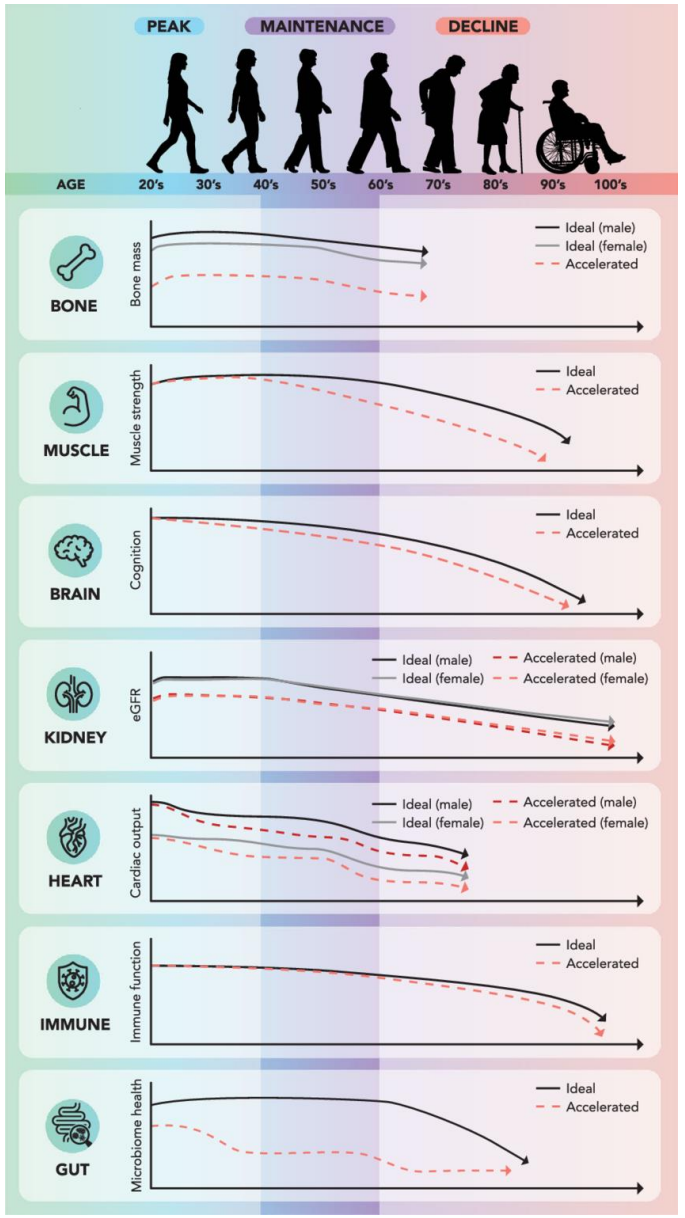

Trajectory of functional decline across the lifespan. Dashed red lines illustrate accelerated decline trajectories driven by inadequate nutrition, physical inactivity, and micronutrient insufficiency.[2]

1. Berger MM, et al. Micronutrients and omega-3 PUFAs to promote healthy ageing: informing a physiology-based complementation strategy. Geroscience. 2026 Jul 23.
2. Shen X, et al. Nonlinear dynamics of multi-omics profiles during human aging. Nat Aging. 2024 Nov;4(11):1619-1634.

Nutrients associated with biological systems functionality

- Organ function peaks between the 20s and 30s, enters a maintenance plateau through the 40s–50s, and declines progressively from the 5th–6th decade onward.[1] The table summarizes key nutrients associated with the maintenance of each system.

Organ	Peak	Decline onset	Nutritional link
Bone	20–30 yrs	~50 yrs (accelerated in women post-menopause)	Vitamin D, calcium
Muscle	~25 yrs	Progressive; −3%/yr after age 60	Protein, vitamin D, selenium
Brain / Cognition	20–30 yrs	50–60 yrs	B6, B9, B12, vitamin D, EPA+DHA
Heart	Peak in 20s–30s	Progressive; accelerated in both sexes	Antioxidant MNs, omega-3
Kidney (eGFR)	Stable to ~60 yrs	Steeper in women after 60	Vitamin B3
Immune system	Develops in childhood	Decline with age (immunosenescence)	Zinc, selenium, vitamin D, iron
Gut microbiome	Peaks in adulthood	Gradual decrease in Bifidobacteria	B vitamins, EPA+DHA

1. Berger MM, et al. Micronutrients and omega-3 PUFAs to promote healthy ageing: informing a physiology-based complementation strategy. Geroscience. 2026 Jul 23.



MICRONUTRIENTS

Definition
Key functions of micronutrients
Can micronutrient supplementation support healthy longevity?

Definition

- **Micronutrients*** (MNs) comprise vitamins and trace elements.[1,2]
  - **Vitamins** are organic compounds that are required in small amounts for normal physiological function and that must be obtained from the diet because they cannot be synthesized in sufficient quantities by the body.[3]
  - **Trace elements**, also known as trace minerals, are minerals required by adults in daily amounts ranging from 1 to 100 mg, or that constitute less than 0.01% of total body mass.[4] Trace minerals include chromium, copper, fluoride, iodine, iron, manganese, molybdenum, selenium and zinc.[5]
- **Omega-3 fatty acids** are polyunsaturated fatty acids (PUFAs) that have their first double bond located at the third carbon from the methyl end of the chain**. Omega-3 fatty acids EPA** (eicosapentaenoic acid) and **DHA** (docosahexaenoic acid), though not classically classified as MN, share common characteristics: consumed in small amounts, not synthesized sufficiently by the body, and typically below recommended intakes in older adults.[6]

*This module applies the ESPEN clinical-nutrition definition, in which micronutrients = vitamins + trace elements only. The major minerals calcium, magnesium, sodium, potassium, phosphorus and chloride are excluded and treated as electrolytes / macrominerals.

1. Berger M, et al. ESPEN micronutrient guideline. Clin Nutr. 2022 Jun;41(6):1357-1424.
2. Overview of Nutritrion. MSD Manual. Available from: https://www.msdmanuals.com/professional/nutritional-disorders/nutrition-general-considerations/overview-of-nutrition [Accessed 15/07/2026].
3. Hahn A, et al. What Is a Vitamin? Towards a Contemporary Definition. Nutrients. 2025 Dec 12;17(24):3890.
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5. Overview of Minerals. MSD Manual. Available from: https://www.msdmanuals.com/professional/nutritional-disorders/mineral-deficiency-and-toxicity/overview-of-minerals [Accessed 15/07/2026].
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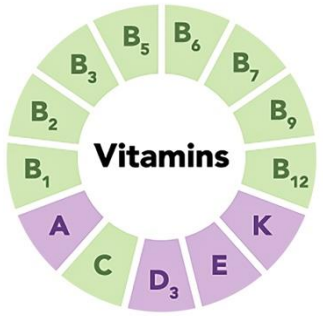
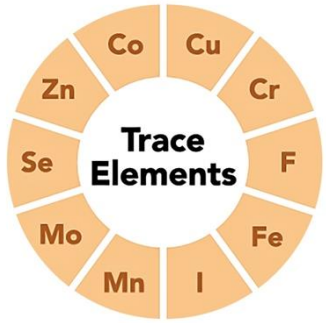
Key functions of micronutrients

- **Micronutrients** are essential for metabolism, immunity, antioxidant defence and endocrine function processes, all of which **play critical roles in the ageing process.**[1,2]
- Vitamins and trace elements diverge widely in mechanism: some act as direct **antioxidants**, others as **enzymatic cofactors** or **hormonal precursors**.[1,2]
- **Micronutrient deficiencies** are widespread and have been **linked to** a range of adverse health outcomes and **unhealthy ageing**.[1]



Click here to know more about vitamin functions



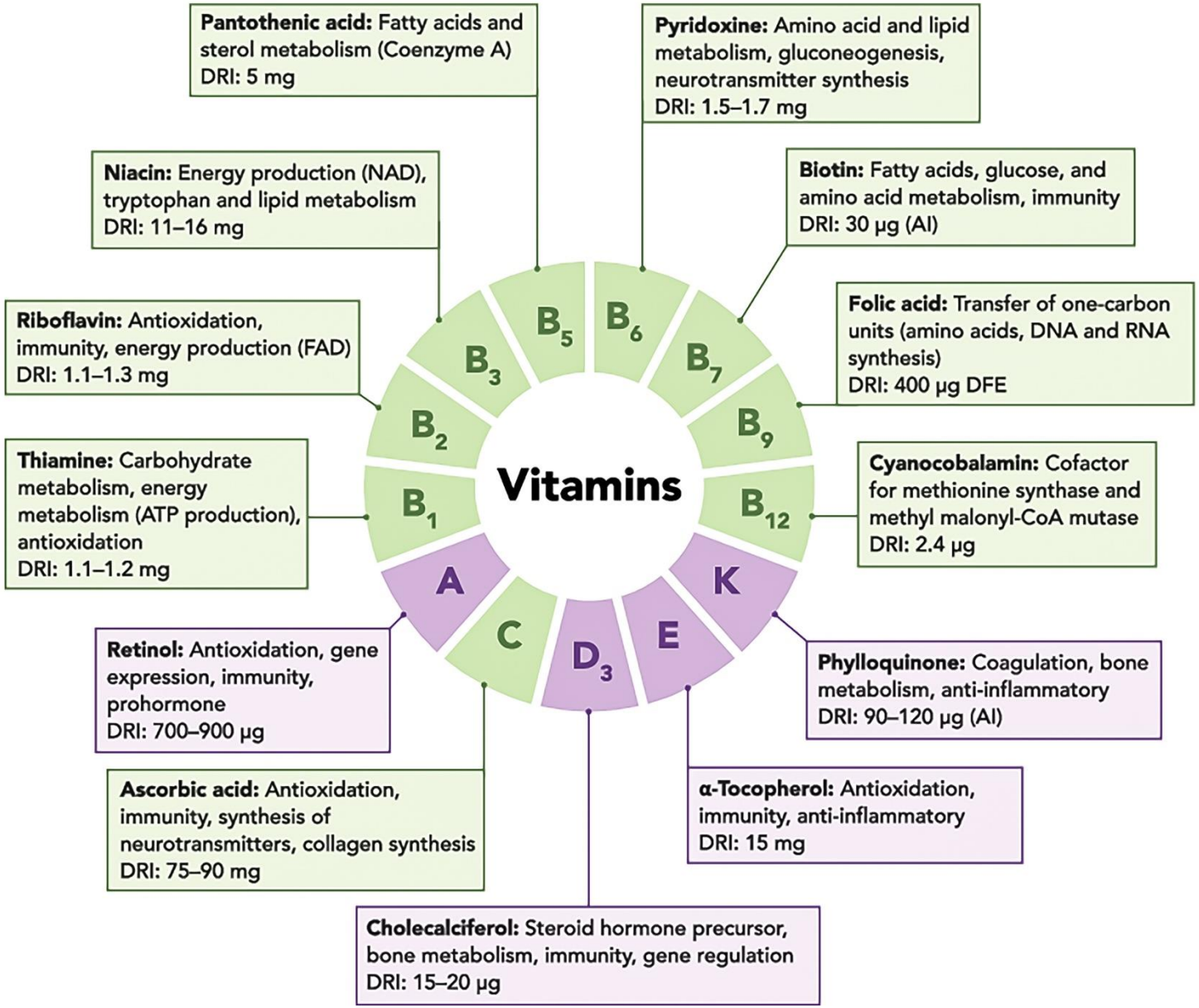
Click here to know more about trace elements functions



Click here to know more about omega-3 functions

Essential trace elements and vitamins according to ESPEN-micronutrient guidelines.
Green, water-soluble vitamins; violet, lipid-soluble vitamins; orange, trace elements.[2]

1. Berger MM, et al. Micronutrients and omega-3 PUFAs to promote healthy ageing: informing a physiology-based complementation strategy. Geroscience. 2026 Jul 23.
2. Berger M, et al. ESPEN micronutrient guideline. Clin Nutr. 2022 Jun;41(6):1357-1424.



1. Berger MM, et al. Micronutrients and omega-3 PUFAs to promote healthy ageing: informing a physiology-based complementation strategy. Geroscience. 2026 Jul 23.
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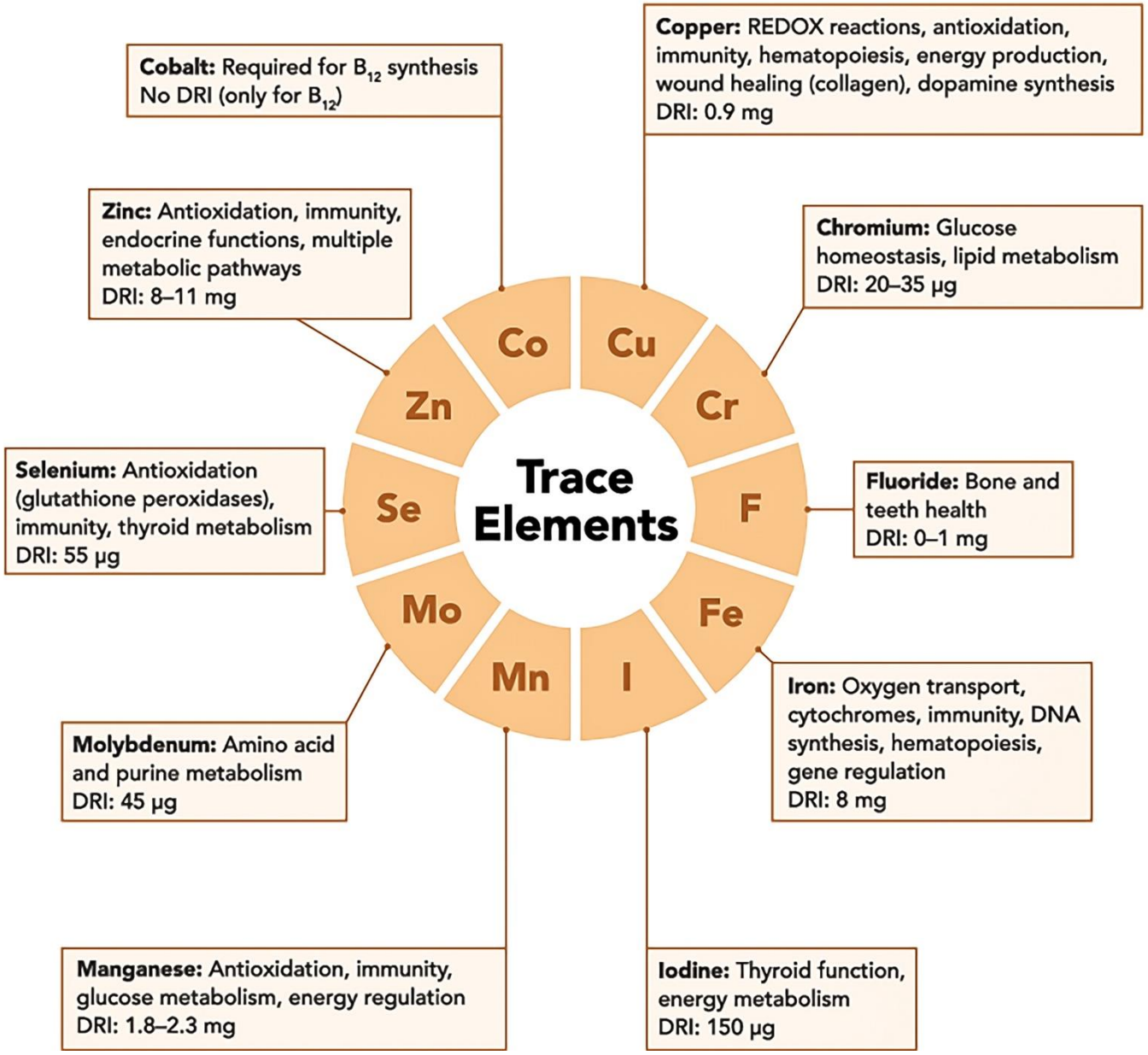
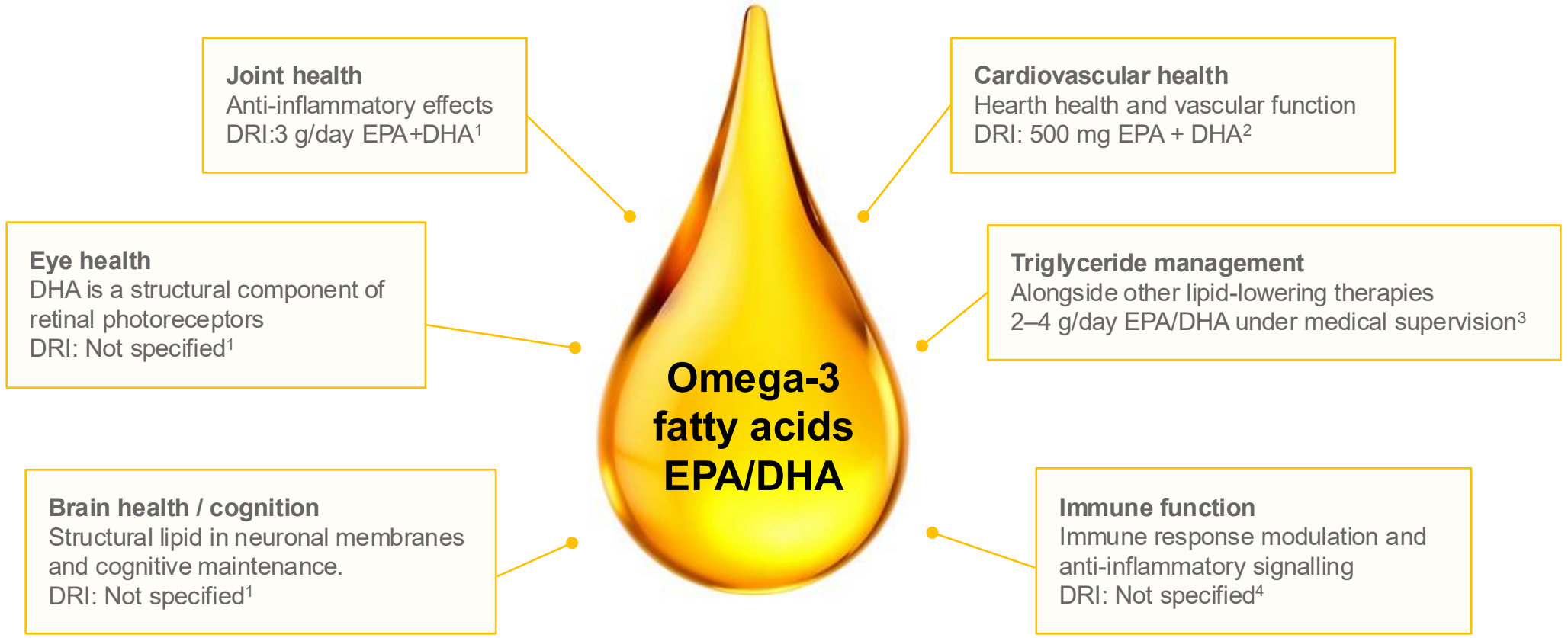


1. Berger MM, et al. Micronutrients and omega-3 PUFAs to promote healthy ageing: informing a physiology-based complementation strategy. Geroscience. 2026 Jul 23.



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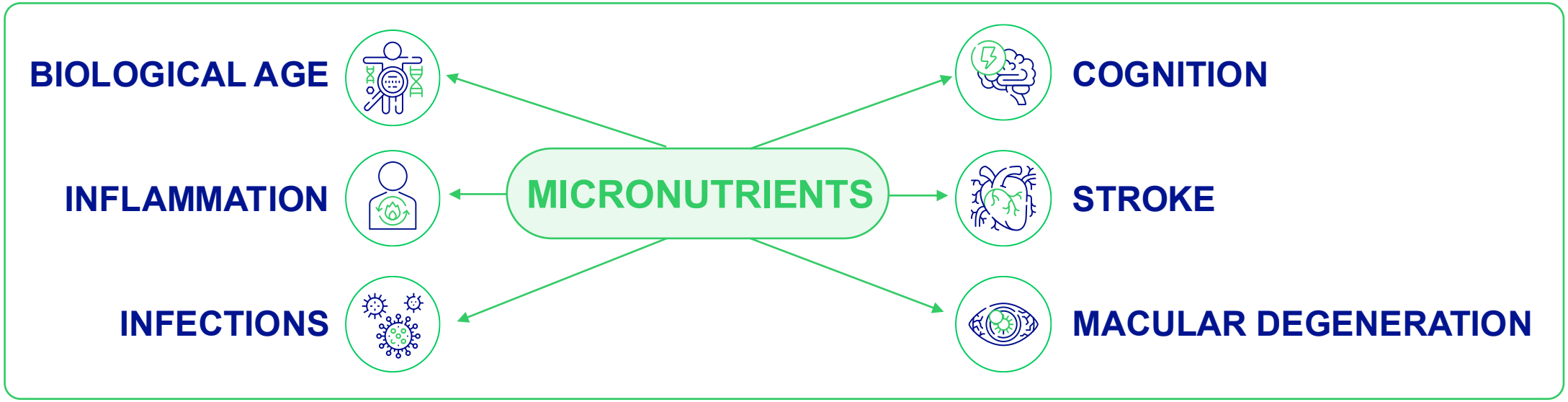
3. Skulas-Ray AC, et al. American Heart Association Council on Arteriosclerosis, Thrombosis and Vascular Biology; Council on Lifestyle and Cardiometabolic Health; Council on Cardiovascular Disease in the Young; Council on Cardiovascular and Stroke Nursing; and Council on Clinical Cardiology. Omega-3 Fatty Acids for the Management of Hypertriglyceridemia: A Science Advisory From the American Heart Association. Circulation. 2019 Sep 17;140(12):e673-e691.
4. Bodur M, et al. Immunomodulatory Effects of Omega-3 Fatty Acids: Mechanistic Insights and Health Implications. Mol Nutr Food Res. 2025 May;69(10):e202400752.

Can micronutrient supplementation support healthy longevity?

- Many studies have assessed the effect of micronutrient supplementation on healthy longevity.[1]
- Different interventions with single MNs or mixed formulations have shown benefits on:[1]



1. Berger MM, et al. Micronutrients and omega-3 PUFAs to promote healthy ageing: informing a physiology-based complementation strategy. Geroscience. 2026 Jul 23.



CAUSES OF LOW MICRONUTRIENTS STATUS

Inadequate nutritional intake
Impact of gut microbiome on micronutrients
Drug-nutrient interactions
Common medications that compromise micronutrient status

Inadequate nutritional intake (1/3)

- Micronutrient inadequacy remains a common nutritional challenge in middle-aged and older adults.
- It has been estimated that **more than half of the global population** has **inadequate dietary intakes** of iodine, vitamin E, calcium, iron, riboflavin, folate, and vitamin C from unfortified foods alone, highlighting the widespread global burden of micronutrient inadequacy.[1]
- In Europe, inadequate intakes of vitamin C, **vitamin D**, folate, **selenium, iodine**, iron and riboflavin are common among adults and older adults, iron and riboflavin inadequacy being a concern among women.[2,3]
- Given their importance for bone, cognitive, and metabolic health,[4-7] these inadequacies may have important health implications.

1. Passarelli S, Free C, Shepon A et al. Global estimation of dietary micronutrient inadequacies: a modelling analysis The Lancet Global Health, 2024; 12, e1590-e1599
2. Mensink GB, et al. Mapping low intake of micronutrients across Europe. Br J Nutr. 2013 Aug;110(4):755-73.
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7. da Silva-Araújo ER, et al. Effects of deficiency or supplementation of riboflavin on energy metabolism: a systematic review with preclinical studies. Nutr Rev. 2025 Feb 1;83(2):e332-e342.

Inadequate nutritional intake (2/3)

Overview of micronutrients with >5% of intakes below the lower reference nutrient intake (LRNI) among adults (18–60 Years) across European countries.[2]

	Belgium	Denmark	France	Germany	Poland	Spain	Netherlands	UK
I	N/A		X	X	X	N/A	N/A	X
Fe		♀	♀		♀		♀	♀
Se		X	X	N/A	N/A	N/A	X	X
Zn								X
Vitamin A					♀			X
Vitamin B2		♀			♀		♀	♀
Folate					♀			
Vitamin B12					♀			
Vitamin D		X	X	X	X	X	X	X
Vitamin E		♀						

X: >5% of intakes below the LRNI among adults (adults and females)
♀: >5% of intakes below the LRNI among adult females
N/A: no data available
Cu, vitamin B1, vitamin B6, and vitamin C were also assessed but not shown in the table as no country showed >5% of intakes below the LRNI in the given population.

1. Mensink GB, et al. Mapping low intake of micronutrients across Europe. Br J Nutr. 2013 Aug;110(4):755-73.

Inadequate nutritional intake (3/3)

In the general population

- **Low** consumption of **fruit** and **vegetables** → reduced intake of **antioxidant vitamins.**[1,2]
- **Strict plant-based** diets → deficiency in **vitamins B12** and **D, iron, and zinc,** and **EPA + DH.**[1,3,4]
- Intake of ultra-processed foods → deficiency in vitamins A, C, D, E, B-family, iron and zinc.[1,5]

In older adults

Older adults have a **reduced dietary intake** conditioned by:

- Reduced appetite, taste and smell perception.[1,6,7]
- Chewing and swallowing difficulties due to loss of teeth.[1,7]
- Frailty and depression.[1,8]

It is associated with reduced intake of **vitamins C, D, E, riboflavin, folate, iodine, iron, zinc** and **selenium**.[9]

In disease

Disease-related malnutrition is frequently accompanied by inadequate micronutrient intake due to:

- Reduced appetite
- Treatment-related adverse effects

Patients with chronic diseases commonly report deficiencies of **vitamin D, C** and **B**, as well as **iron, zinc, selenium**.[10]

1. Berger MM, et al. Micronutrients and omega-3 PUFAs to promote healthy ageing: informing a physiology-based complementation strategy. Geroscience. 2026 Jul 23.
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9. Passarelli S, et al. Global estimation of dietary micronutrient inadequacies: a modelling analysis. Lancet Glob Health. 2024 Oct;12(10):e1590-e1599.
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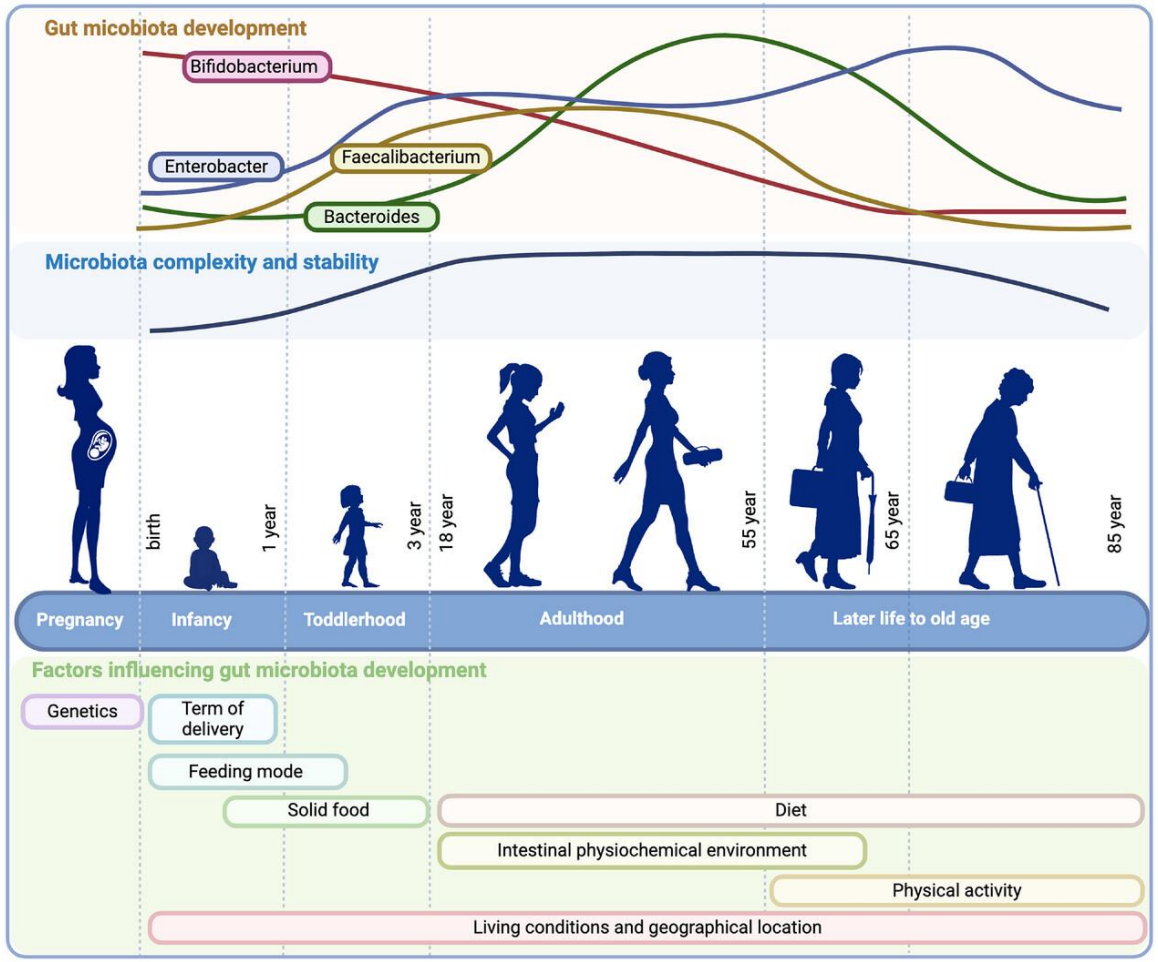
Impact of gut microbiome on micronutrients (1/2)

- Gut microbial communities evolve throughout life, becoming more variable in early life, stable in adulthood, and **variable again in old age**.
- The **Bacteroides-to-Prevotella** ratio has been proposed as a biomarker of healthy longevity, reflecting dietary and lifestyle patterns.[1]
- Healthy longevity is associated with higher abundances of beneficial gut microbes such as ***Akkermansia***, ***Bifidobacterium***, and ***Christensenella***[2], whereas ageing is commonly characterized by an increased abundance of pathobionts, particularly members of the **Proteobacteria phylum**.[3]

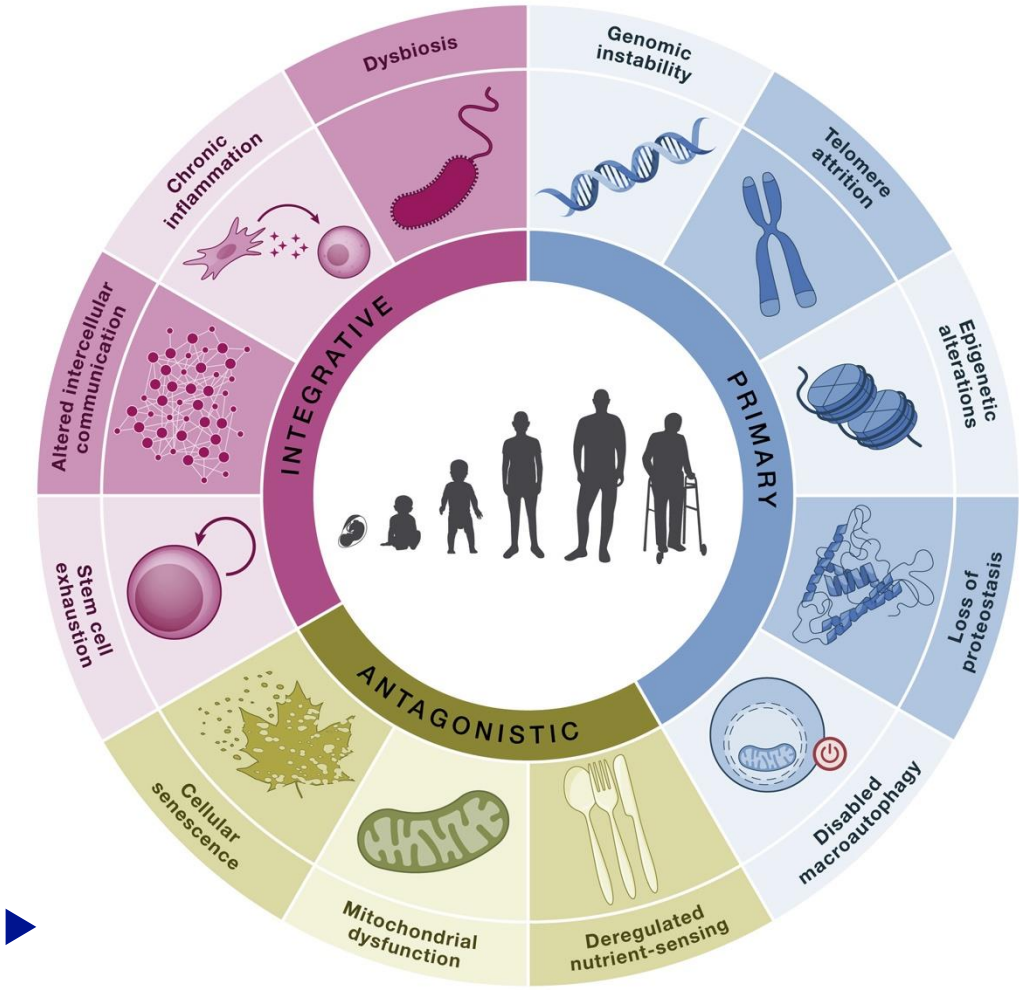


Development of microbiota from infancy to old age. Modified from[4]

1. Gorvitovskaia A, et al. Interpreting Prevotella and Bacteroides as biomarkers of diet and lifestyle. Microbiome. 2016 Apr 12;4:15.
2. Biagi E, et al. Gut Microbiota and Extreme Longevity. Curr Biol. 2016 Jun 6;26(11):1480-5.
3. Vemuri R. Gut Microbial Changes, Interactions, and Their Implications on Human Lifecycle: An Ageing Perspective. Biomed Res Int. 2018 Feb 26;2018:4178607.
4. Schoultz I, et al. Gut microbiota development across the lifespan: Disease links and health-promoting interventions. J Intern Med. 2025 Jun;297(6):560-583.

Impact of gut microbiota on micronutrients (2/2)

- The gut microbiota is an important determinant of micronutrient status by producing vitamin K[1] and B-group vitamins[2] and enhancing the intestinal absorption of minerals including iron.[3,4]
- **Dysbiosis**, now recognized as one of the 12 **hallmarks of ageing**, arises from disruption of the bacteria–host crosstalk and contributes to a wide range of pathological conditions, including obesity, type 2 diabetes, ulcerative colitis, neurological disorders, cardiovascular diseases (CVDs), and cancer.[5]
- Dysbiosis can **impair microbial pathways** involved in micronutrient metabolism.[6]



Hallmarks of ageing[5] ▶

1. Chen S, et al. Consistent signatures in the human gut microbiome of longevous populations. Gut Microbes 2024 Jan-Dec;16(1):2393756.
2. Hossain KS, et al. B Vitamins and Their Roles in Gut Health. Microorganisms. 2022 Jun 7;10(6):1168.
3. Hadadi N, et al. Intestinal microbiota as a route for micronutrient bioavailability. Curr Opin Endocr Metab Res. 2021 Sep 4;20:100285.
4. Barone M, et al. Gut microbiome-micronutrient interaction: The key to controlling the bioavailability of minerals and vitamins? Biofactors. 2022 Mar;48(2):307-314..
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6. Richards JD, et al. Micronutrient bioavailability: concepts, influencing factors, and strategies for improvement. Front Nutr. 2025 Nov 19;12:1646750.

Drug-nutrient interactions

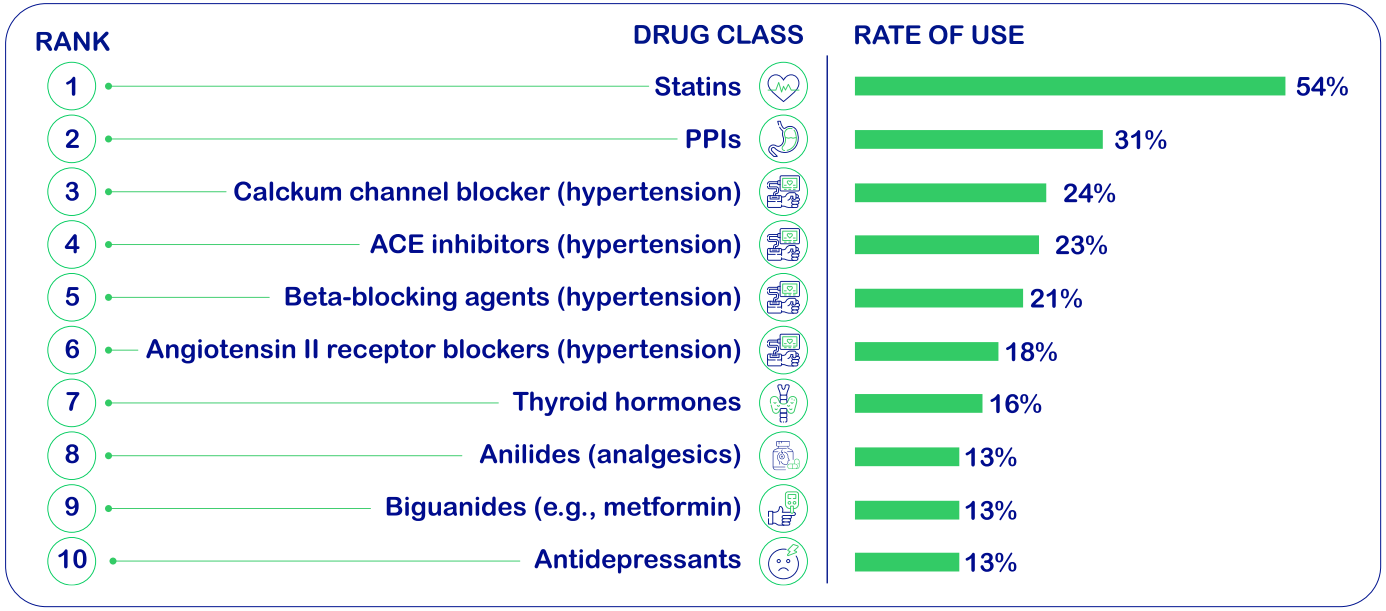
Polypharmacy is common in adults, and many commonly prescribed medications can interfere with nutrient absorption, metabolism, or excretion.[1]

Common drug–micronutrient interactions

- Proton pump inhibitors → Vitamin B12, iron, vitamin C, calcium or magnesium[2]
- Metformin → Vitamin B12[3]
- Diuretics → Zinc[4]

Clinical implications

- Increased risk of subclinical deficiencies
- Potential contribution to frailty,[5] and cognitive decline.[6]



Top 10 most prescribed medication classes among Canadian seniors.[7]

1. Berger MM, et al. Micronutrients and omega-3 PUFAs to promote healthy ageing: informing a physiology-based complementation strategy. Geroscience. 2026 Jul 23.
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Common medications that compromise micronutrient status

Vitaminsa	Drugs compromising status
Vitamin A	Bile acid sequestrants, statins
Vitamin B1 – Thiamine	Antibiotics, diuretics
Vitamin B2 – Riboflavin	Antibiotics, estrogens
Vitamin B3 – Niacin	Antibiotics
Vitamin B6 – Pyridoxine	Antibiotics, anticonvulsants, diuretics, oestrogens, isoniazide
Vitamin B7	Antibiotics, anticonvulsants
Vitamin B9 – Folate & folic acid	Antacids, anticonvulsants, bile acid sequestrants, estrogens, folic acid, metformin, methotrexate, NSAIDs, opioids
Vitamin B12 – Cobalamin	Antacids, antibiotics, anticonvulsants, oestrogens, H2-receptor antagonists, metformin (biguanides), methotrexate, PPIs
Vitamin C	Antacids, diuretics, oestrogens, PPIs, opioids
Vitamin D	Anticonvulsants, antiretroviral treatments, bile acid sequestrants, corticosteroids
Vitamin E	Bile acid sequestrants, statins
Vitamin K	Antibiotics, vitamin K-dependent anticoagulants, bile acid sequestrants, corticosteroids
Coenzyme Q10	Statins
Trace elements	**Drugs compromising status**
Iron	Antacids, bile acid sequestrants, lipid lowering drugs, NSAIDs, opioids, PPIs
Selenium	Diuretics, statins (interfere with selenoprotein synthesis)
Zinc	Diuretics, oestrogens, lipid lowering drugs, RAAS inhibitors
Abbreviations: NSAIDs = non-steroidal anti-inflammatory agents, PPI = proton pump inhibitors, RAAS = Renin-Angiotensin-Aldosterone-System	

1. Berger MM, et al. Micronutrients and omega-3 PUFAs to promote healthy ageing: informing a physiology-based complementation strategy. Geroscience. 2026 Jul 23.

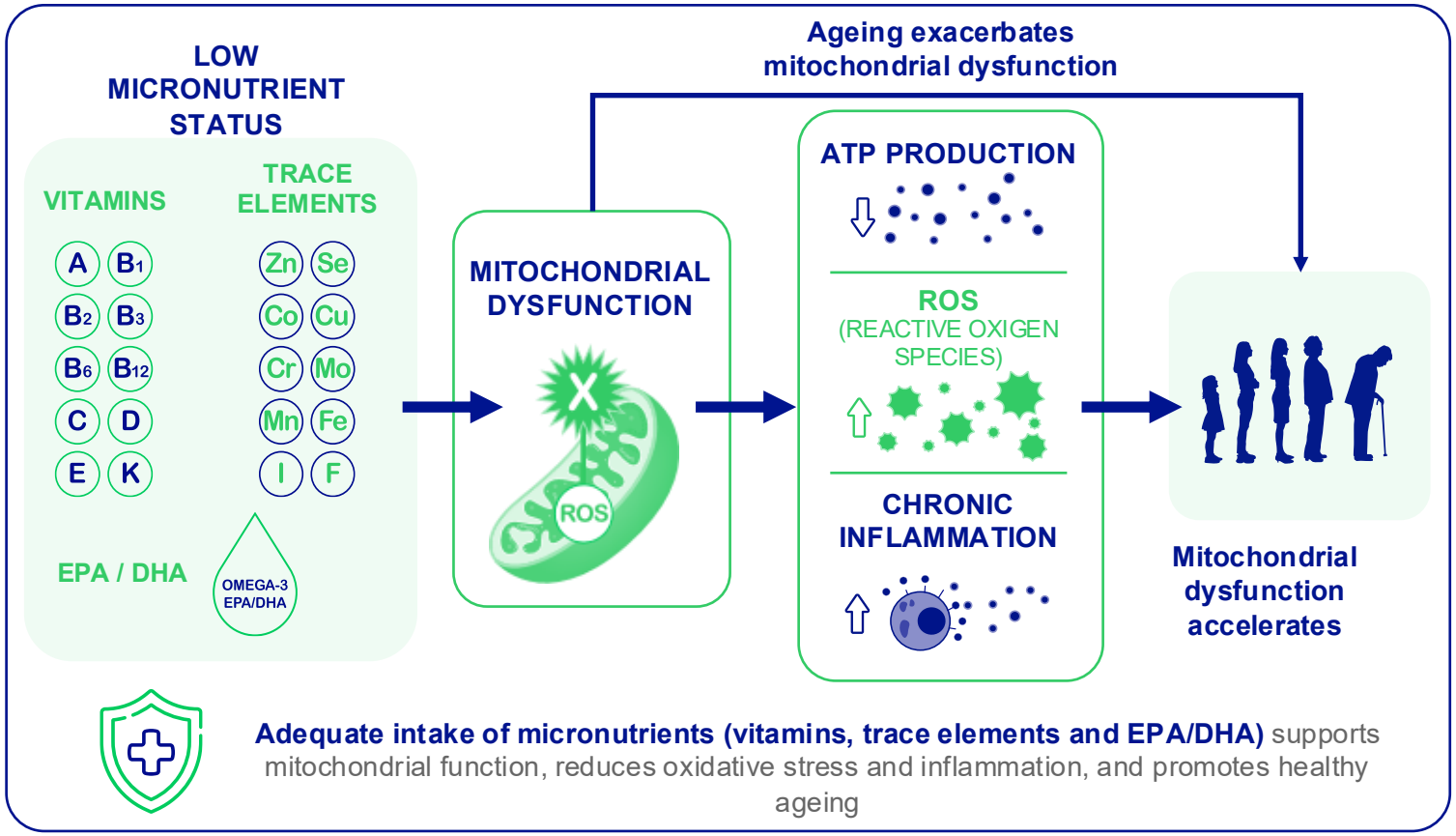


CONSEQUENCES OF LOW MICRONUTRIENTS STATUS

Mitochondrial disfunction and oxygen stress
Attenuated vaccine response
Risk of infections

Mitochondrial dysfunction and oxygen stress

- Micronutrients support mitochondrial function, energy metabolism, and redox balance.[1]
- B vitamins, selenium, zinc, vitamin D, and EPA and DHA have been linked to greater mitochondrial respiratory capacity through improvements in mitochondrial membrane composition.[2]
- Mitochondrial dysfunction is a feature of ageing,[3] and is exacerbated by MN deficiency.[4]
- Mitochondrial dysfunction results in impaired ATP production, increased reactive oxygen species (ROS) accumulation and chronic inflammation.[1]
- **Inadequate intake of MNs may promote oxidative stress and contribute to unhealthy ageing**.



Click here to know more about the role of micronutrients in mitochondrial health and ageing

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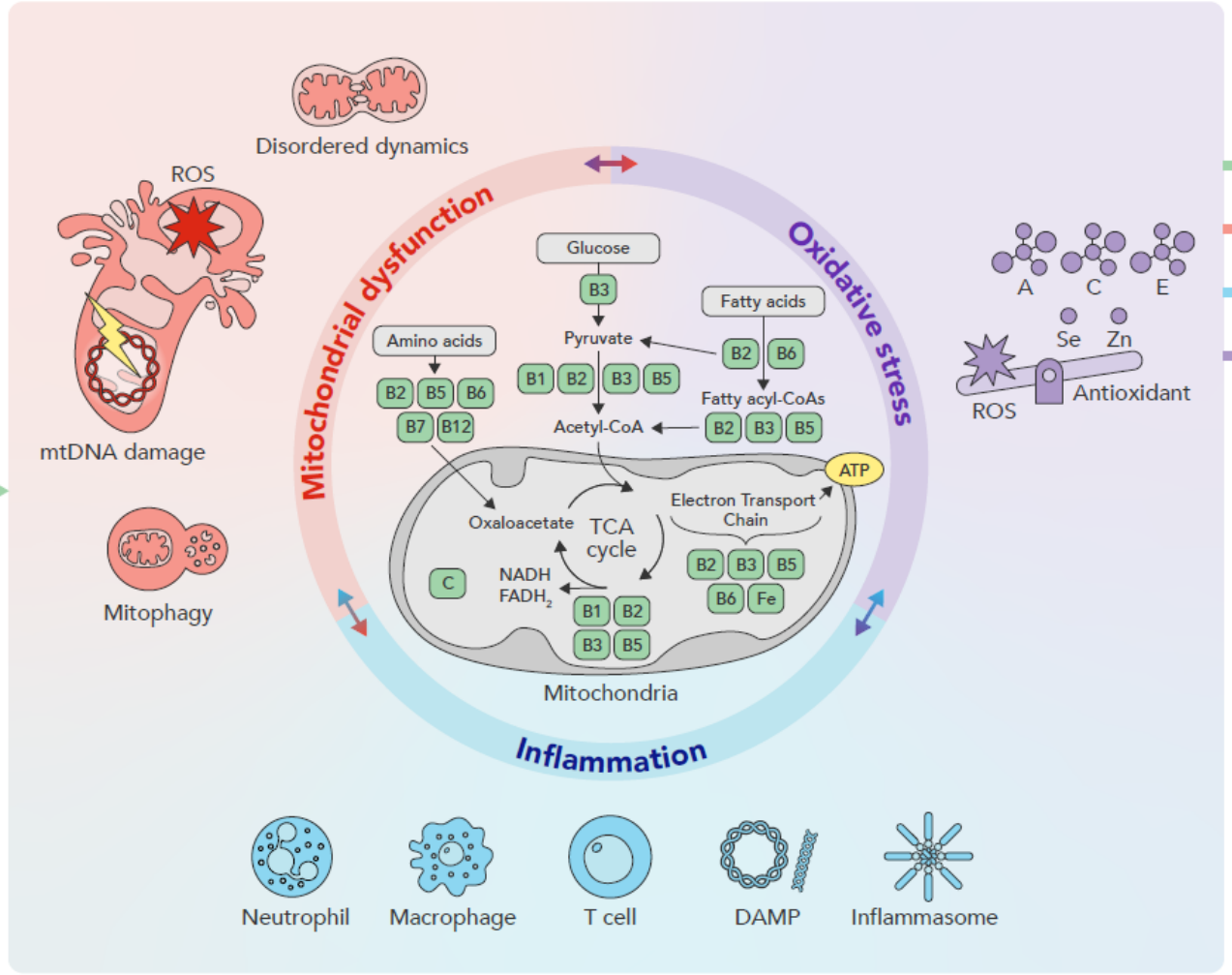
Intake < DRI or global malnutrition

Rapidly impacting:
- B-vitamins,
- Cu, Fe, Zn

Antioxidants:
- A, C, E, D
- Se, Mn, Zn



Consequences

- ATP production
- ROS accumulation
- Oxidative stress
- Mitophagy
- mtDNA mutations
- Disordered mitochondrial dynamics

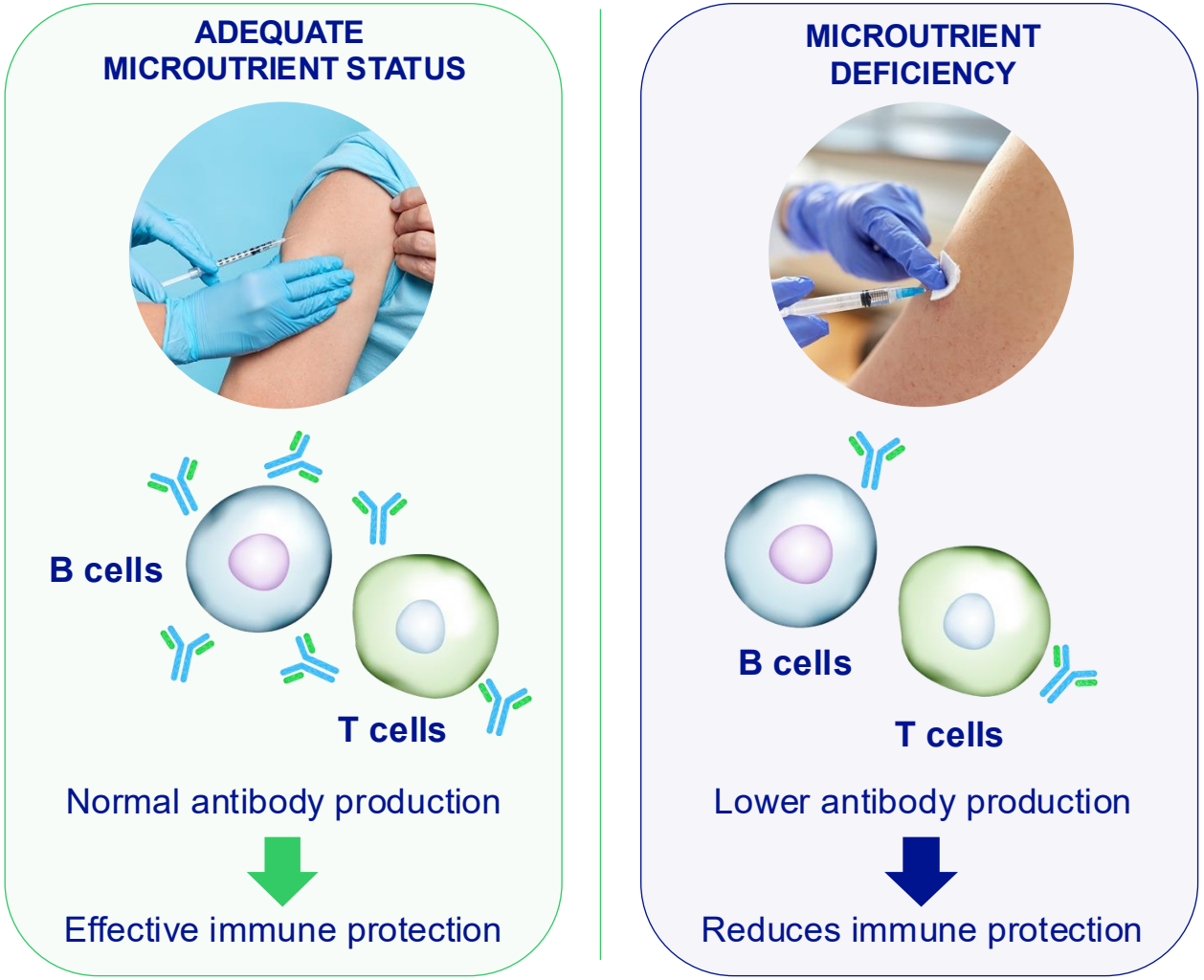
Unhealthy aging

- Osteoporosis
- Sarcopenia
- Cognitive disorders
- Function decline
  - Kidney
  - Heart
- Immuno-senescence
- Frailty
- Pressure sores
- Etc …

1. Berger MM, et al. Micronutrients and omega-3 PUFAs to promote healthy ageing: informing a physiology-based complementation strategy. Geroscience. 2026 Jul 23.

Attenuated vaccine response

- Immunosenescence reduces T and B cell output and antibody production, weakening responses to vaccination,[1] and MN deficiency further amplifies this impairment.[2]
- **Vitamin D**: low levels associated with weaker responses to hepatitis B and COVID-19 vaccines.[3]
- **Iron**: iron deficiency impairs IgG production by B cells *in vivo*.[4]



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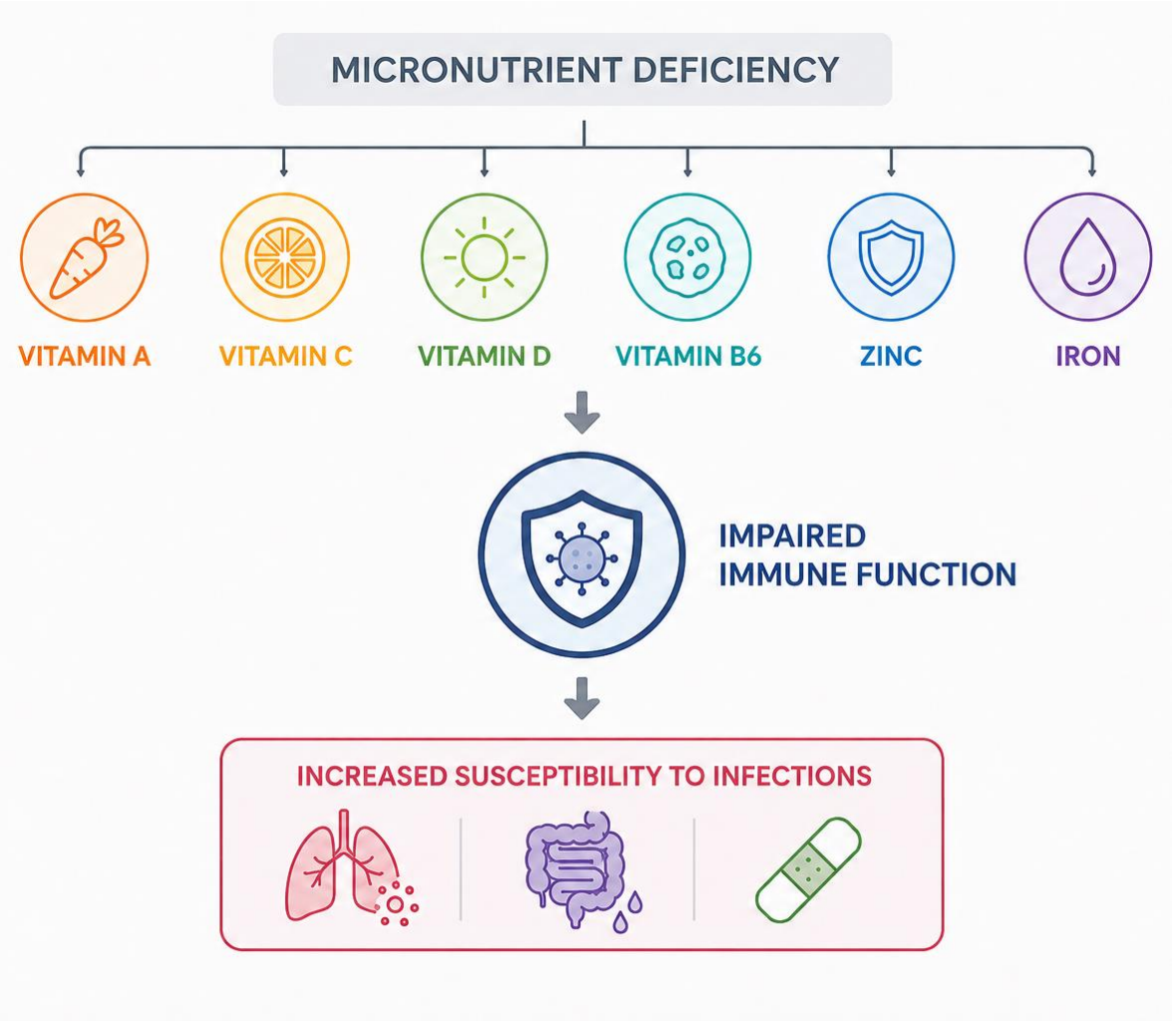
Risk of infections

- Micronutrient deficiency impacts negatively on the immune system and therefore predispose to infections.[1]
- Impact of deficiency:[1]
  - **Vitamin C**: Increased incidence of pneumonia
  - **Vitamin D**: Increased risk of RTIs and autoimmune diseases
  - **Vitamin A**: Increased risk of RTIs and diarrhea
  - **Vitamin B6**: reduced response to pathogens
  - **Zinc**: increased risk of inflammatory diseases and infections, reduced wound healing.
  - **Iron**: Increased duration of RTIs



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PERSONALISED MICRONUTRIENT DEFICIENCY MANAGEMENT

Suboptimal micronutrient status in ageing
Screening & correction strategy

Suboptimal micronutrient status in ageing

- **Malnutrition and micronutrient deficiencies** are major drivers of frailty and age-related health decline. Reflecting this link, the WHO proposes assessing **vitality** through **appetite** and **weight loss**, two key markers of nutritional status, although no consensus has yet been reached on the clinical operationalization of vitality.[1,2]
- Correcting micronutrient and EPA+DHA insufficiency may slow inflammageing, immunosenescence, and related disease.[3]
- While the optimal intake of individual micronutrients for slowing biological age remains unclear, combined micronutrient strategies show greater promise, as demonstrated by the DO-HEALTH trial, which evaluated vitamin D, omega-3, and exercise together in older adults.[4]

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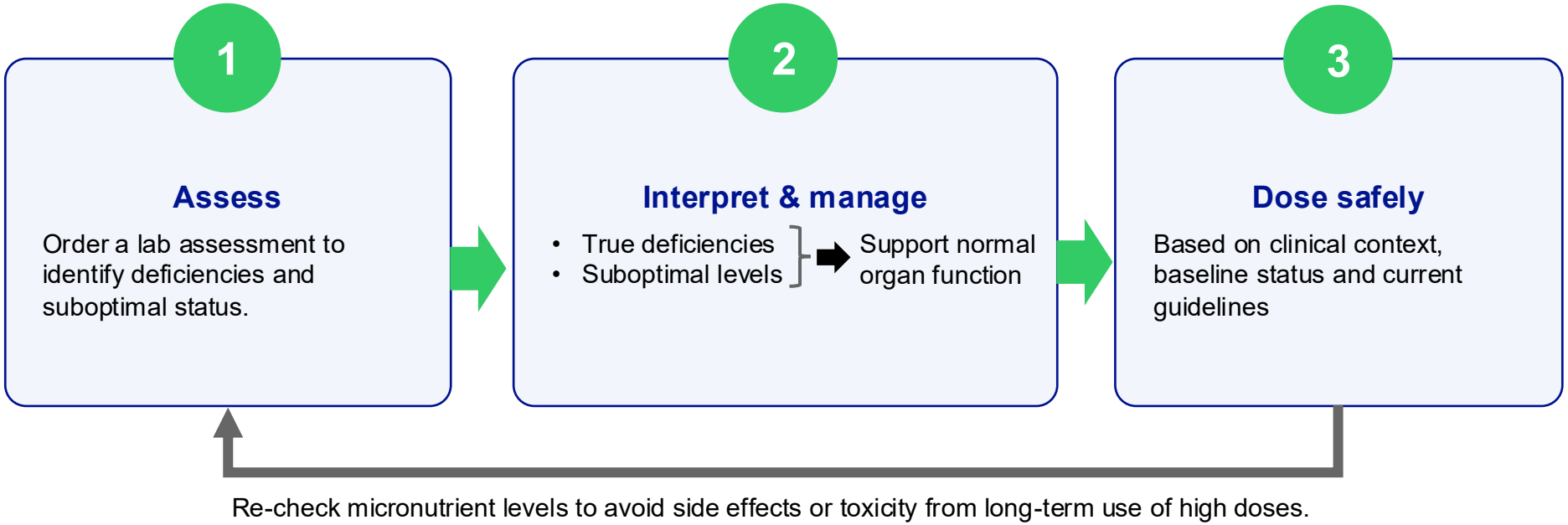
Screening & correction strategy

A three-step guided path to correct micronutrient deficiency in adults 50+: from testing to safe, individualized supplementation.[1]



Encourage your patients to consult an HCP to prevent overconsumption from multiple sources and prioritize high-quality products from reputable manufacturers.

1. Berger MM, et al. Micronutrients and omega-3 PUFAs to promote healthy ageing: informing a physiology-based complementation strategy. Geroscience. 2026 Jul 23.



CONCLUSIONS

Conclusions

- **Healthy longevity is strongly influenced by nutritional status**. Both macro- and micronutrients, together with omega-3 fatty acids, support mitochondrial function, immune function, cognitive health, musculoskeletal integrity, and cardiometabolic health.
- **Micronutrient insufficiency is common during ageing** due to inadequate intake, chronic disease, inflammation, gut dysbiosis, and drug–nutrient interactions.
- **Low micronutrient status may accelerate key hallmarks of ageing**, including oxidative stress, immunosenescence, inflammageing, reduced vaccine responsiveness, and increased susceptibility to infections.
- **Benefits of supplementation are most consistent when correcting documented deficiencies or insufficiencies**, highlighting the importance of a personalised rather than universal approach.
- **From midlife onwards** (~50 years), **laboratory assessment** may help **identify at-risk individuals** and guide targeted correction strategies, including selected micronutrients and EPA+DHA.
- A **physiology-based**, **individualized nutritional strategy** may contribute to preserving organ function, supporting health span, and **promoting healthy longevity**.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