# The Double Burden of Undernutrition and Overnutrition in Children and Adolescents

## Epidemiological aspects & Nutritional deficiencies

*R Caleyachetty , MBBS PhD, University of Warwick, UK*
*ML Frelut , MD, MSc, ECOG, Albi, France*

# Authors

Rishi Caleyachetty is a physician and epidemiologist who focuses on improving women and children's health. Dr Caleyachetty was a Fulbright Scholar at Columbia University and served as an Advisor to the Minister of Health in the Republic of Mauritius. He has published several studies relating to the double burden of malnutrition, obesity and obesity-related complications, and written textbook chapters on preventing childhood obesity and eating disorders. He sits on the Strategic Council of the UK All-Party Parliamentary Group on Obesity.

# Authors

Marie-Laure Frelut, MD, MSc, is a pediatrician specialising in nutrition and childhood obesity. She has spent most of her career in Paris Children University Hospitals. She is a founding member of SCOPE, Past President of the European Childhood Obesity Group (ECOG), Editor of ECOG's first Free Obesity eBook on pediatric obesity, and was awarded the French Academy of Medicine's Nutrition Award. She is Deputy Chair of World Obesity's Clinical Care Committee.

# The double burden of malnutrition in children and adolescents

- This course describes two major contemporary nutritional problems in children and adolescents: undernutrition and overnutrition.
- Both epidemiological and clinical aspects of the double burden of malnutrition will be considered.
- Micronutrient deficiencies among children and adolescents who have overweight or obesity are also considered.

# Objectives of this module

At the end of this module, you should:

1. Be able to define the double burden of malnutrition in children and adolescents
2. Be able to describe the measures used to characterise the double burden of malnutrition among children and adolescents
3. Understand the causes of and geographical distribution of the double burden of malnutrition among children and adolescents
4. Know which nutrient deficiencies are most common in child and adolescent obesity
5. Understand the pitfalls in the interpretation of nutrient status in children and adolescents

# Part I

## Defining and measuring the double burden of malnutrition among children and adolescents

# DEFINING THE DOUBLE BURDEN OF MALNUTRITION

The double burden of malnutrition among children and adolescents refers to the co-existence of levels of under- and overnutrition that can exist at the individual, household, or population level.

Individuals may experience a double burden of malnutrition, with overweight and obesity coupled with micronutrient deficiencies, or stunting coupled with high levels of central adiposity.

At the household level, a mother may have obesity while her child is stunted.

At the population level, there may be a prevalence of both undernutrition and overnutrition in the same community, region or nation.

**Undernutrition** is characterised by deficient intake of macronutrients (protein, carbohydrates and fat) or micronutrients.

Macronutrient deficiencies are defined by stunting (height-for-age z-score [HAZ]) or wasting (weight-for-height z-score [WHZ] or body mass index (BMI) for age z-score [BAZ]) based on the WHO Child Growth Standards for children 0-5 years and WHO Reference 2007 for children and adolescents 5-19 years.

**Overnutrition** is characterised by excess intake of macronutrients (fat and carbohydrates) and defined by overweight or obesity.

Overweight and obesity (excess adiposity) are commonly classified based on BMI for age z-scores from WHO Reference 2007 for children and adolescents 5-19 years.

There are no accepted standards to identify clinically significant excess adiposity in infants < 2 years of age.

Weight-for-length is the predominant standard used globally but doesn't reflect age-based changes in weight and length.

Currently recommended that weight status assessed by WFL in children <2 years of age, and then use BMI-for-age in children ≥ 2 years of age.

# TYPES OF MALNUTRITION AMONG CHILDREN AND ADOLESCENTS

| Nutritional condition | Classification | Age: Birth to 5 years cut off points | Age: 5 to 19 years cut off points | Example health consequences |
|---|---|---|---|---|
| Stunted* | Based on weight and height indices | Length/height-for-age <–2SD to –3SD | Height-for-age <–2SD to –3SD | Diminished cognition and learning capacity, poor school performance. Girls of reproductive age have an elevated risk of perinatal mortality mostly related to obstructed labour resulting from a narrower pelvis. |
| Wasted | Based on weight and height indices | Weight-for-height <–2SD to –3SD | | Increase in morbidity and mortality |
| Thin | Based on BMI | | BMI-for-age < –2 to –3 SD | Delayed maturation, poor muscle strength leading to constraints in capacity for physical work, and reduced bone density later in life |
| Micronutrient deficiency (e.g. vitamin A, zinc, iron, iodine) | Based on biochemical tests on blood/urine | NA | NA | Decreased immunity, impaired cognitive performance, stunted growth, and increased morbidity and mortality. |
| Overweight | Based on BMI | BMI-for-age (or weight-for-height) > 2SD | BMI-for-age >1SD(equivalent to BMI 25 kg/$m^2$ at 19 y) | |
| Obese* | Based on BMI | BMI-for-age (or weight-for-height) > 3SD | BMI-for-age >2SD (equivalent to BMI 30 kg/$m^2$ at 19 y) | Insulin resistance, impaired fasting glucose/glucose tolerance, type 2 diabetes, precious puberty, hypertension dyslipdaemia, non-alcoholic fatty liver disorder, poor psychological health, musculoskeletal problems |

*The consequences of concurrent stunting and obesity in adolescents is likely to compound health issues in children and later in adulthood.

# How to measure weight, length and height

The WHO Training Course on Child Growth Assessment is a tool for the application of the WHO Child Growth Standards. It teaches how to measure weight, length and height and how to interpret nutrition status.

https://www.who.int/childgrowth/training/en/

# Calculating children's nutritional status

Two different systems are used to measure a child's or a group of children's weight, height or weight-for-length/height and compare them to the reference population: Z-scores and percentiles.

For both population-based and individual assessment, the Z-score is widely used for analysis and presentation of anthropometric data.

The Z-score is a statistical measure that reflects the relative deviance from the median value and measured as a SD (Standard Deviation) in statistical terms. For example, weight-for-age z score should be understood as the number of SD of the actual weight of a child from the median weight of the children of his/her age as determined from the standard sample.

Z-score= (observed value - median value of the reference population) / SD value of reference population.

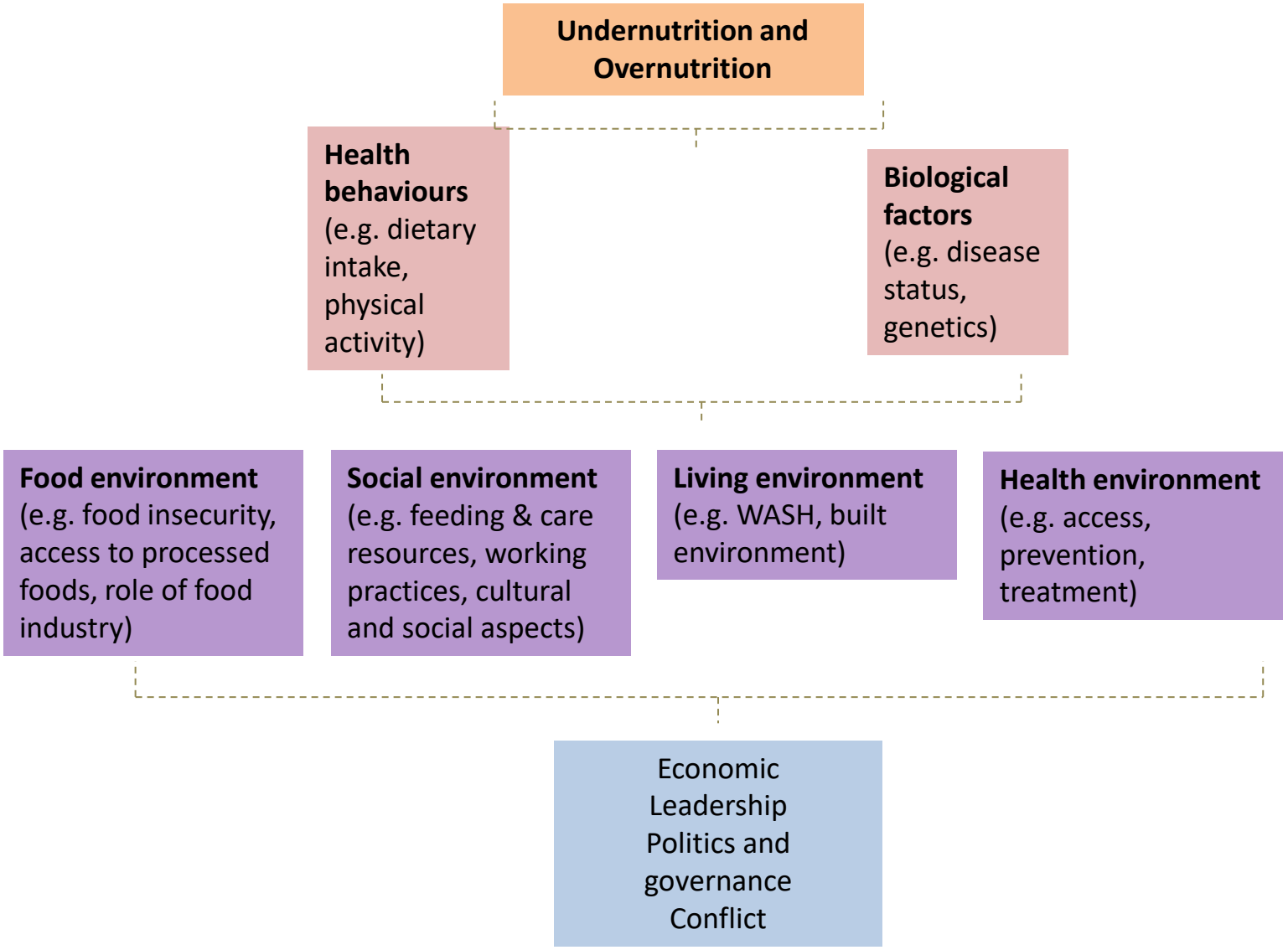
Children's nutritional status can be calculated and monitored using WHO software (for Windows PC or mobile) or macros for statistical software (e.g. R, SAS and Stata)

WHO Anthro is a software for the global application of the WHO Child Growth Standards for children 0-5 years https://www.who.int/childgrowth/software/en/

WHO AnthroPlus is a software for the global application of the WHO Reference 2007 for 5-19 years (https://www.who.int/growthref/tools/en/)

# Part II

## Understanding the causes of and the geographical distribution of the double burden of malnutrition among children and adolescents

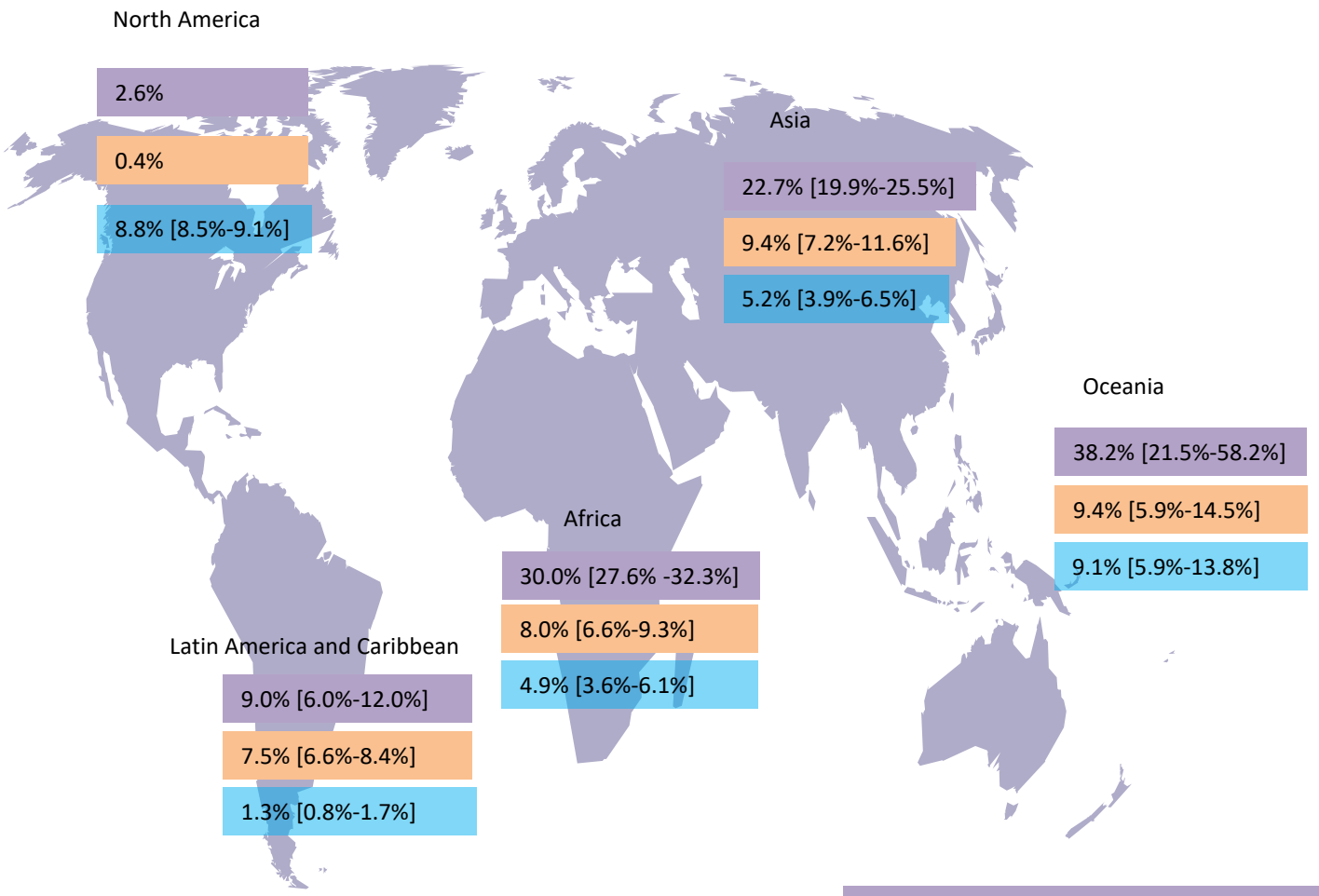



Conceptual framework for determinants of the double burden of malnutrition among children and adolescents

WASH: Water, Sanitation and Hygiene

Source: Adapted from Haddad L, Cameron L, Barnett I. The double burden of malnutrition in SE Asia and the Pacific: priorities, policies and politics. Health Policy Plan. 2015;30(9):1193-206

# DISTRIBUTION OF THE DOUBLE BURDEN OF MALNUTRITION AMONGST CHILDREN < 5 YEARS*




**Stunted**. < -2 (moderate and severe) SD from median height for age of the WHO Child Growth Standards.

**Wasted**. < -2 (moderate and severe) SD from median weight for height for age of the WHO Child Growth Standards.

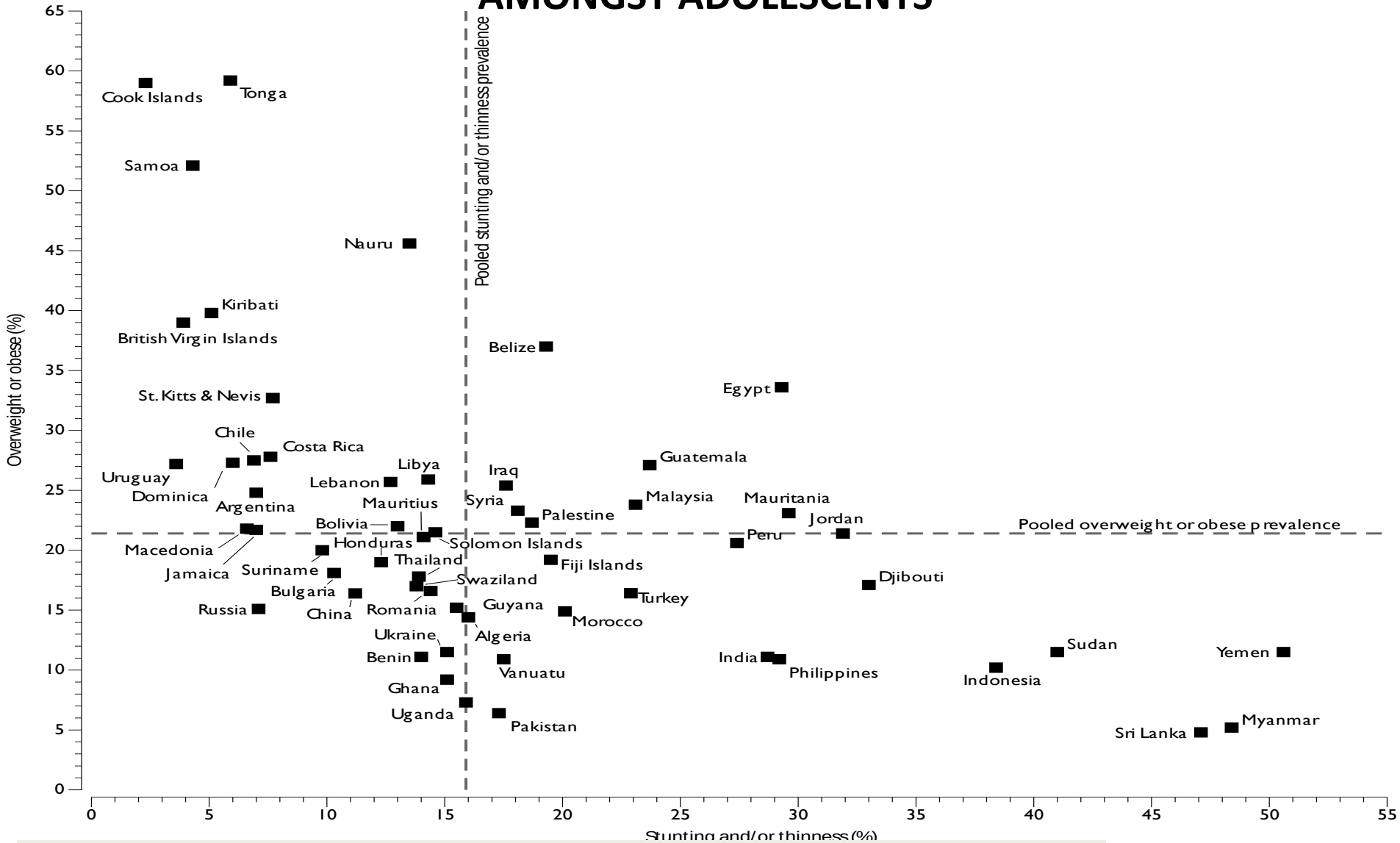
**Overweight**. > 2 (moderate and severe) SD from median weight for age of the WHO Child Growth Standards

Trends in child malnutrition estimates can be found here:
http://apps.who.int/gho/tableau-public/tpc-frame.jsp?id=402

Source: Adapted from UNICEF / WHO / World Bank Group Joint Child Malnutrition Estimates 2019 edition.

* Confidence intervals are not available when estimate based on single country.

# MAPPING THE DOUBLE BURDEN OF MALNUTRITION AMONGST ADOLESCENTS




Adolescent overweight or obesity prevalence by stunting and/or thinness prevalence

Source: Adapted from Caleyachetty R, Thomas GN, Kengne AP, Echouffo-Tcheugui JB, Schilsky S, Khodabocus J, Uauy R. The double burden of malnutrition among adolescents: analysis of data from the Global School-Based Student Health and Health Behavior in School-Aged Children surveys in 57 low- and middle-income countries. Am J Clin Nutr. 2018 Aug 1;108(2):414-424

# MAPPING THE DOUBLE BURDEN OF MALNUTRITION AMONGST ADOLESCENTS

| | Stunting (% 95 CI) | Thinness (% 95 CI) | Overweight or obesity (% 95 CI) | Concurrent stunting and overweight or obesity (% 95 CI |
|---|---|---|---|---|
| Africa | 9.7 (6.0-14.1) | 6.6 (4.7-8.8) | 14.1 (10.2-18.6) | 1.2 (0.5- 2.3) |
| Americas | 7.2 (4.1-11.2) | 2.5 (1.7-3.4) | 27.6 (24.5-30.9) | 1.9 (1.2-2.7) |
| Eastern Mediterranean | 16.4 (12.2-21.1) | 8.4 (6.1-10.9) | 19.1 (13.9-24.9) | 3.4 (2.1- 5.1) |
| South-East Asia | 19.8 (13.9-26.5) | 15.0 (9.5-21.4) | 11.1 (5.0-18.9) | 1.8 (1.1- 2.8) |
| Western Pacific | 6.2 (2.9-10.5) | 2.4 (0.4-5.6) | 33.7 (21.0-47.7) | 1.7 (1.0-2.6) |
| Europe | 5.5 (2.4-9.7) | 6.4 (4.6-8.6) | 16.2 (13.7-18.9) | 1.6 (0.9- 2.4) |

Regional prevalence of adolescent malnutrition by WHO region

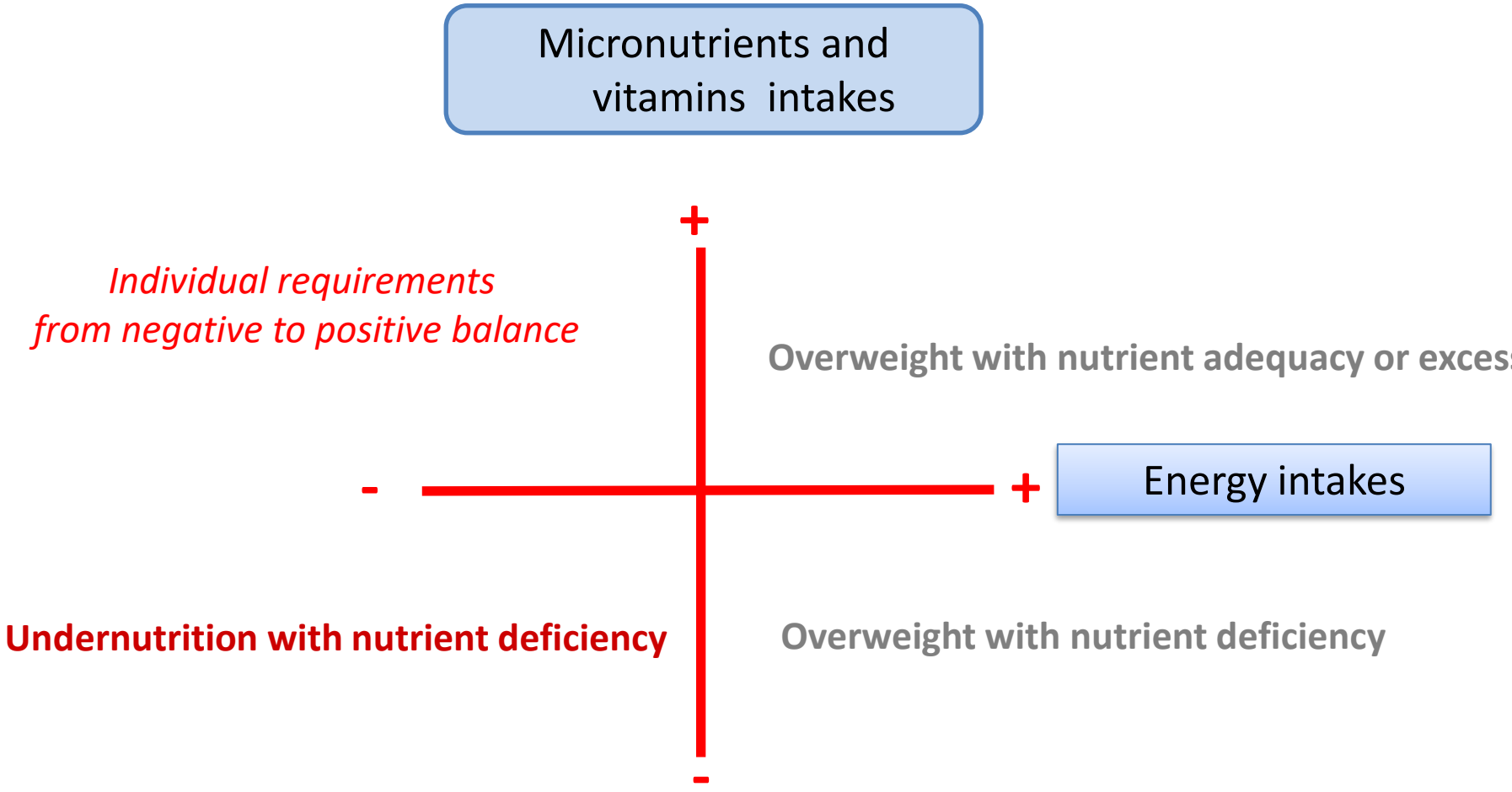
CI: Confidence interval

Source: Adapted from Caleyachetty R, Thomas GN, Kengne AP, Echouffo-Tcheugui JB, Schilsky S, Khodabocus J, Uauy R. The double burden of malnutrition among adolescents: analysis of data from the Global School-Based Student Health and Health Behavior in School-Aged Children surveys in 57 low- and middle-income countries. Am J Clin Nutr. 2018 Aug 1;108(2):414-424

Part III

# Common nutritional deficiencies among children and adolescents with obesity

# The spectrum of malnutrition from undernutrition to overnutrition




✓*Energy intake should fit energy needs for activity, metabolism and growth*

✓*A balanced diet should cover individual requirements for macronutrients, i.e. protein, carbohydrates, fibres, lipids, quality and quantity and micronutrients such as vitamins and minerals.*

✓***Nutrient or vitamin deficiency occurs when energy is provided by "empty calories" of low nutritional***

# Obesity nutritional facts

**Key points : some characteristics of obesity**

- Excess fat mass
- Common high sugar, high fat, low nutrients  imbalanced diets
- Differences in lifestyle: e.g. exposure to sunlight, physical activity
- Massive storage in adipose tissue of fat soluble vitamins
- Mild chronic inflammation
- Modulation by genetic and epigenetic background

## Consequences

1. **Nutritional deficiencies arise from imbalanced nutrient intake**
2. **Interpretation of nutritional status linked to**
   - **Fat storage of fat soluble vitamins**
   - **Consequences of mild inflammation on various  aspects of metabolism**

# The most common vitamin and nutrient deficiencies

| Nutrients | Fat soluble vitamins | Water soluble vitamins |
| --- | --- | --- |
| • Iron<br>• Zn ?* | • Vit D<br>• Vit A<br>• Vit E | Folate (B9)<br>• B12<br>• B1?*<br>• B2?* |

* Evidence in Zn, vitamin B1 and B2 is weak or limited to specific circumstances such as bariatric surgery; therefore these deficiencies won't be further described in this module.

# Evidence of an increased prevalence of iron deficiency in children with obesity vs. children with a healthy weight

## *Review (Hutchinson 2016)*

48 papers

More iron deficiency or anaemia in children with overweight or obesity than in children with a healthy weight

Little difference in nutrient and antinutrients (e.g. phytates) intakes

Information lacking about heme vs. non heme iron intakes

## *Healthy Growth study (Greece)*

| | | | |
|---|---|---|---|
| n = 2500 | 9-13 yrs old | 42 % OW or OB | |
| Iron deficiency adjusted for other RF | | OR = 2.5 in boys | 2.1 in girls |
| Iron deficiency anaemia | | 5-8 % % in OB<br>OR = 3.1 in boys | 1.5-2 % NWt<br>3.3 in girls |

## *NHANES IIII (USA)*

| | | |
|---|---|---|
| n = 9700 | 2-16 yrs old | 24 % OW or OB |
| Iron deficiency | 9.1 % in OW or OB vs 4.7 % in Nl Wt in 12-16 yrs | |

# Pitfalls in interpretation of iron status in obesity

**OBESITY = MILD CHRONIC INFLAMMATION**

*Hepcidin is a protein produced by the liver, regulating iron absorption by the duodenum and its release by macrophages.*

*Mild inflammation increases liver protein synthesis, including hepcidin and ferritin*.

- **Increased circulating hepcidin**

.

-> decreased duodenal iron absorption

-> sequestration of iron into the reticuloendothelial system

- **Ferritin over synthesis**

-> but ferritin is the best marker of iron stores in the normal weight population

**Underestimation of iron deficiency in obesity ?**

**Short and long term consequences of altered markers unknown**

*Use a combination of markers rather than ferritin alone*

*Nutritional surveys focusing on iron and antinutrients are required*

# Fat soluble vitamins
# Pitfalls in the interpretation of the nutritional status and evidence for deficiencies

1. **Pitfalls in the interpretation of vitamin D status**
2. **Broad range of metabolic disorder associated to vitamin D deficiencies**
    1. Bone health
    2. Cardiovascular risk factors
    3. Non alcoholic fatty liver disease (NAFLD)
3. **Vitamin E and associated nutrients deficiencies may trigger NAFLD**
4. **Pitfalls in vitamin A status assessment**
    1. Food sources vary widely around the world : animal vs. vegetal
    2. Lack of agreement on the biological criteria of deficiency
5. **Metabolic consequences of biological vitamin A deficiencies are still poorly studied**

# Pitfalls in interpretation of vitamin D status

- **Meta-analysis** (*Pereira Santos 2015*)
  - Children and adolescents
  - Criteria : plasma 25(OH)D concentration
  - Deficiency

    + 35 % in OB group  + 24 % in OW group vs. NL Wt

    Irrespective of age, latitude, 25(OH)D cut offs

- **Causes of low plasma 25(OH)D concentration**
  - **Vitamin D = Fat soluble**
  - Storage in adipose tissue
  - Impaired vitamin D release from adipose tissue
  - Reduced bioavailability from skin synthesis
  - *Genuine deficiency*
    - Insufficient exposure to sunshine (latitude, covering cloth, psychological reason)
    - Insufficient intakes

# Broad range of vitamin D deficiency associated metabolic disorders in child and adolescent obesity

## 1. Bone health

- Bone mineralization adequate
- No association with fracture nor slipped femoral capita epiphysis
- Lower plasma 25(OH)D concentration
    - seldom associated to increased PTH
    - counteracted by increased IGF1, androgens aromatisation into oestrogen in adipose tissue?

## 2. Cardiovascular risk factors

- 25(OH) D deficiency is an independent risk factor of increased blood glucose

(OR = 2.3, 95 % CI 1.0-7.9) irrespective of age and season *(Ekbom, 2016)*

- 25(OH)D is negatively associated to markers of visceral adiposity, insulin resistance *(Cediel, 2015)*

## 3. Non alcoholic fatty liver disease (NAFLD)

# Non Alcoholic Fatty Liver Disease (NAFLD) and nutrition in childhood obesity

## NAFLD : a common situation but a difficult diagnosis

- NAFLD : *a major cause of escalating rates of chronic liver disease stemming from childhood*
- Prevalence : 12 to 70 % in OW or OB groups
- Large differences due to diagnosis method (Gold standard: liver biopsy)
  - All methods of evaluation are indirect
  - Biochemical algorithms used in adults do not apply in children
- Complication: liver fibrosis (non alcoholic steatohepatitis, NASH) : **25 %**
- **positive association with Western type diet and high fructose intake**

## Vitamin D status and NAFLD *(Nobili, 2014)*

- Low 25(OH)D in 74 % of NASH vs 46 % of elevation of ALT
  - ➢ Independent correlation between HOMA index*, metabolic syndrome feature

## Positive impact of treatment with vitamin D

- RCT with correction of low vitamin D Status in adolescents : decrease in fasting insulin and insulin resistance markers *(Cediel, 2015)*
- RCT of vitamin D + docosahexaenoïc acid (DHA) *(Della Corte, 2016)*

**HOMA index (homeostatic assessment for insulin resistance) allows to estimate insulin resistance on the basis of fasting values ([glycaemia (mmol/L)x insulin]/22.5)*

# Obesity, non alcoholic fatty liver disease (NAFLD) and nutrition

**First positive studies on the beneficial role of some natural nutrients** *(Panera 2018)*

- Vitamin E + hydroxytyrosol (HXT, a simple phenol of extra virgin olive oil)
- Combination of polyunsaturated fatty acids (PUFA): eicosapentaenoïc acid (EPA) + DHA
- Choline + Vitamin E + DHA

**Next steps ?**

- Probiotics (which mixture?)
- Polyphenols ?

***The occurrence of fatty liver is partly dependent upon poor eating pattern***

**Improving nutrition allows to reduce its incidence and severity through :**

- **Avoidance of high fat high sugar low nutrient "Western diets"**
- **A reduction of fructose intakes**
- **An adequate vitamin D and vitamin E status**
- **Consumption of sources of DHA an EPA (fish, vegetable oils...)**
- **Consumption of sources of antioxidants**

**But reducing BMI Z-score will also reduce NAFLD**

# Vitamin A = retinol + carotenoids

- **Fat soluble – no direct evaluation of the stores**
- Key additional role of retinol in adipose tissue metabolism and insulin resistance
- **Sources of vitamin A :** Retinol (animal origin) Carotenoids (vegetal origin)

  *30 % carotenoids in Western diet vs. 70 % in developing countries*

**Prevalence of biological deficiency vary widely among regions and subpopulations, e.g.**

**America**

- Low β carotene in 50 % of OB vs 25 % in lean children (NHANES III 1988-94))
- 12 % α carotene deficiency in Mexican American children (NHANES 2001-2004)

**Europe**

- No difference for retinol and carotene between lean and OB groups in Hungary (1997)
- Retinol deficiency in 3 % of the children (Switzerland)

**Asia**

- China : Vit A deficiency increased in obesity (OR = 2.37 , 95% CI 1,59-3.55)

**India and Eastern Mediterranean Region**

- Triple burden of undernutrition, OW and OB micronutrient deficiences but no data about overlap

➢ ***Vitamin A deficiency may coexist with overweight or obesity in children***

# Folate (vit B9) and vit B12

**Folate status specific interest :**

- **Folate is a key contributor in energy metabolism and epigenetic determinant of cardiovascular risk and obesity in association with vit B12**
- Common gene variant of the methylenetetrahydrofolate reductase (MTHFR) confer higher CV risks level
- Low intakes below RDAs are reported in the general population (e.g. 68.3% of children and 90.8 % of adolescents in Spain)

- **Folate dosage :** Red blood cell = stores (EF); plasma = recent intakes (PF)
- **Main sources:**
  - green leafy vegetables, nuts, dairies, liver meat
  - Fortified foods in some countries
- **Impaired folate status**
  - **Intakes below RDAs**: 80 % of a group of 57 French adolescents with severe obesity
  - **NHANES 2002-2004**: serum concentrations of vitamin B-12 and folate inversely associated with BMI ($\beta$: -2.68, $P < 0.01$; $\beta$ = -1.33, $P < 0.01$) in Mexican American children
  - **Affluent Indian school children**: nearly all group below EF threshold
- **An endangered group**
  - In commonly unplanned adolescent pregnancy both mother and child will share the consequences of folate deficiency
  - spina bifida is the severest complication of folate deficiency at the time of conception

# Key messages

The double burden of malnutrition (DBM) among children and adolescents is the coexistence of undernutrition (including macronutrient and micronutrient deficiencies) and overnutrition, within individuals, households and populations.

Health consequences of macronutrient deficiencies (i.e. protein, carbohydrates and fat) are stunting or wasting.

Over nutrition is characterised by excess intake of some macronutrients (i.e. fat and carbohydrates).

Children > 2 years are classified as either underweight/thin, overweight or obese by BMI thresholds .

Weight-for-length is used to assess weight status of children < 2 years.

# Key messages

The most common nutrient deficiencies in children with overweight or obesity are fat soluble vitamins A, D, E , water soluble vitamin B9 (folate) and B12, and iron.

Overweight and obesity are characterized by an enlarged fat mass in which fat soluble vitamins (A, D, E) may be stored and a mild inflammation inducing ferritin over synthesis. Therefore, caution is required when interpreting the nutritional status of fat soluble vitamins and iron.

The UNICEF conceptual framework can be used as a basis for exploring the causes of the double burden among children and adolescents

# References


Haddad L, Cameron L, Barnett I. The double burden of malnutrition in SE Asia and the Pacific: priorities, policies and politics. Health Policy Plan. 2015;30(9):1193-206

Caleyachetty R, Thomas GN, Kengne AP, Echouffo-Tcheugui JB, Schilsky S, Khodabocus J, Uauy R. The double burden of malnutrition among adolescents: analysis of data from the Global School-Based Student Health and Health Behavior in School-Aged Children surveys in 57 low- and middle-income countries. Am J Clin Nutr. 2018 Aug 1;108(2):414-424

De Onis M (2015). World Health Organization Reference Curves. In M.L. Frelut (Ed.), The ECOG's eBook on Child and Adolescent Obesity. Retrieved from ebook.ecog-obesity.eu

Rolland-Cachera, MF, Akrout, M, Péneau S (2015). History And Meaning Of The Body Mass Index. Interest Of Other Anthropometric Measurements. In M.L. Frelut (Ed.), The ECOG's eBook on Child and Adolescent Obesity. Retrieved from ebook.ecog-obesity.eu

Frelut ML et al. Committee on Nutrition of the French Society of Paediatrics. Impact of obesity on biomarkers of iron and vitamin D status in children and adolescents: The risk of misinterpretation. Arch Pediatr. 2018 Jan;25(1):3-5.

Panera N et al. A review of the pathogenic and therapeutic role of nutrition in pediatric nonalcoholic fatty liver disease. Nutr Res. 2018 Oct;58:1-16

Nobili V et al. The Antioxidant Effects of Hydroxytyrosol and Vitamin E on Pediatric Nonalcoholic Fatty Liver Disease, in a Clinical Trial: A New Treatment? Antioxid Redox Signal. 2019 Feb 11. doi: 10.1089/ars.2018.7704. [Epub ahead of print]

Nasreddine LM et al. Nutritional status and dietary intakes of children amid the nutrition transition: the case of the Eastern Mediterranean region. Nutr Res 2018;57:12-27.

Wei X. Serum vitamin A status is associated with obesity and the metabolic syndrome among school-age children in Chongqing, China. Asia Pac J Clin Nutr 2016;25(3):563-10.

Shrihari G et al . Nutritional status of affluent Indian school children. How much do we know? Indian Paediatrics 2007;44:204-213

# The double burden of obesity and malnutrition in children and adolescents

## Questions

1. At what levels do we observe the double burden of malnutrition in children and adolescents?

Molecular (F)
Individual (T)
Household (T)
Nationally (T)

2. What nutritional outcomes can be used to measure the double burden of malnutrition in children and adolescents?

Underweight (F)
Stunting (T)
Wasting (T)
Obese (T)
Iron deficiency (T)

3. What factors play a role in the double burden of malnutrition in children and adolescents?

Food insecurity (T)
Dietary intake (T)
Gross Domestic Product (T)
Recurrent respiratory infections (T)
War/Conflict (T)

4. Which are the most common vitamin deficiencies in child and adolescents obesity? Vitamin B6 (F), Vitamin B9 (T), Vitamin K (F), Vitamin E (T), vitamin A (T), Vitamin A (T)

5. Which of the below are among the most common nutrient deficiencies ? Iron (T), calcium (F), phosphorus (F), iodine (F)

6. Which factor(s) makes iron status difficult to interpret in obesity: storage (F), inflammation (T), vegetal rather than animal sources (F), age (F) ?

7. Is Vitamin D stored in adipose tissue (Y/N)? Y