REVIEW

CURRENT OPINION

Predicting of excess body fat in children

Diana Paola Córdoba-Rodríguez[a,b], *Gerardo Rodriguez*[b,c,d,e]
Luis A. Moreno[b,c,f]

Purpose of review
Approximately 370 million children and adolescents worldwide showed overweight or obesity in 2016. The risk of developing severe comorbidities depends on the age of onset and the duration of obesity. This review discusses available methodologies to detect excess body fat in children as well as the early life factors that predict excess body fat and its development.

Recent findings
Factors, such as parental nutritional status, maternal weight gain during pregnancy, maternal malnutrition, maternal smoking during pregnancy, low and high birth weight, rapid weight gain, and short infant sleep duration have been independently and positively associated with neonatal, infant, and children adiposity. Early detection of excess body fat in children through the use of various tools is the first step in preventing nutrition-related diseases in adulthood.

Summary
The early detection of excess body fat and the implementation of efficient interventions to normalize the weight of children and adolescents at obesity risk are essential to prevent diseases in adult life.

Keywords
body composition, children, fat mass, obesity, perinatal factors

INTRODUCTION

According to the WHO, in 2016, 40 million children under 5 years of age and 330 million children and adolescents worldwide, aged 5–19 years, showed overweight or obese [1]. Predicting excess body fat in children is the first step in preventing nutrition-related diseases as early obesity can persist into adulthood. Early obesity prevention may also reduce the risk of developing comorbidities, enhancing the success of interventions to normalize body fat composition [2].

DIAGNOSIS AND MONITORING OF EXCESS ADIPOSITY IN CHILDREN AND ADOLESCENTS

Obesity is an 'abnormal or excessive fat accumulation that poses a risk to health' [3]. Children under 5 years of age are overweight when their weight for length/height falls between +2 and +3 standard deviations (SD) of the WHO Child Growth Standards median (99.9th percentile > overweight ≥ 97th percentile) and are regarded as having obesity when their weight for length/height is at least +3SD (≥99.9th percentile) of the WHO Child Growth Standards median [1], as established by WHO Multicentre Growth Reference Study [4]. In children and adolescents aged 5–19 years, one of the most widely used tools for detecting overweight and obesity is the BMI (BMI = weight/height-squared). Within this age range, overweight occurs when BMI for age is greater than 1 SD above the WHO growth reference mean and obesity with a BMI greater than 2 SD above the WHO growth reference median [5].

In the case of the cut-off points recommended by the International Obesity Task Force (IOTF, currently World Obesity) [6], overweight and obesity

[a]Departamento de Nutrición y Bioquímica, Facultad de Ciencias, Pontificia Universidad Javeriana, Bogotá DC, Colombia, [b]Growth, Exercise, Nutrition and Development (GENUD) Research Group, Instituto Agroalimentario de Aragón (IA2)Universidad de Zaragoza, Zaragoza, Spain, [c]Instituto de Investigación Sanitaria Aragón (IIS Aragón), Zaragoza, Spain, [d]Red de Salud Materno Infantil y del Desarrollo (SAMID), Instituto de Salud Carlos III, Madrid, Spain, [e]Área de Pediatría, Universidad de Zaragoza, Zaragoza, Spain and [f]Centro de Investigación Biomédica en Red de Fisiopatología de la Obesidad y Nutrición (CIBERObn), Instituto de Salud Carlos III Madrid, Madrid, Spain

Correspondence to Luis A. Moreno, Universidad de Zaragoza, Zaragoza, Spain. Tel: +34 616215067; e-mail: lmoreno@unizar.es

Curr Opin Clin Nutr Metab Care 2020, 23:000–000
DOI:10.1097/MCO.0000000000000848

KEY POINTS

- BMI does not differentiate between fat mass content and fat-free mass, which is a disadvantage when evaluating children.
- Accurate direct methods should be used to identify excess body fat in children and adolescents.
- Prenatal and postnatal factors, such as maternal BMI before pregnancy, maternal weight gain during pregnancy, gestational diabetes, maternal malnutrition, and maternal smoking have been independently and positively associated with childhood obesity.
- According to the context and available resources, the early detection of children with high levels of fat mass based on the use of the different techniques currently available is the starting point for efficient interventions aiming to normalize fat mass.

correspond, respectively, to BMI values equivalent to greater than 25 and 30 kg m^2, for each age and sex.

BMI, however, entails some limitations. The most relevant being the fact of not differentiating between fat mass and fat-free mass (FFM) content or between different patterns of fat mass distribution. This is a disadvantage when assessing children as their proportions of fat and lean tissue masses are variable, depending on age, gender, ethnicity, and maturity level [7]. BMI does not always reflect an increase in fat mass at adiposity rebound or at early puberty [8▪▪]. Thus, identifying each of the components of body composition is of great importance as excess adipose tissue is associated with a predisposition to health conditions in adulthood, such as cardiovascular disease and type 2 diabetes mellitus [9], also having an impact on quality of life, productivity, and life expectancy [10]. On the other hand, low FFM contributes to adverse health outcomes in childhood, such as insulin resistance, glucose intolerance, metabolic syndrome [11▪], and reduced bone parameters [12▪▪].

Assessing obesity and related diseases, requires accurate body fat measurements. Currently, there are various tools to determine body fat in children, both in clinical and research settings [13▪▪], these include anthropometric measurements, bioimpedance analysis (BIA), air displacement plethysmography (ADP), dual-energy X-ray absorptiometry (DXA), computed tomography (CT), and MRI, among others. However, each of these methods has advantages and disadvantages (Table 1).

All of the fat mass measurements obtained with these techniques are often reported in absolute or relative values (kg or %), both of which can lead to misinterpretation; for instance, tall children with protein-energy malnutrition may have fat mass values similar to shorter but well nourished children. To avoid such estimation errors, it is possible to construct indices, such as the normalized index for height FMI = fat mass (kg)/height $(m)^2$. FMI values can be interpreted in the light of ethnicity-matched reference values [14]. Recently, other fat mass indicators have been suggested, such as the triponderal mass index (TMI), which is calculated as weight (kg)/height (m^3). TMI has been said to be a better body fat predictor in children and adolescents better than BMI [15] but this is still under discussion.

The localization of excess body fat is also paramount in childhood and adolescence. An excess of visceral adipose tissue (VAT) is associated with high metabolic [16] and cardiovascular risks [17], possibly because of an increase of VAT lipolytic activity leading to a rise in circulating free fatty acids. Fat in additional body locations may also lead to other health implications, such as the subcutaneous adipose tissue (SAT), which acts as a reservoir for excess energy and triglycerides and impedes the flow of lipids to other tissues. It is likely that when SAT capacity is exceeded, VAT growth and fat accumulation in nonadipose tissues (perihepatic, intramuscular, epicardial, and perivascular) is favored [18].

Currently, several anthropometric indicators have been described that provide information on the disposition of body fat at different body locations, namely, waist circumference [19], neck circumference [20], waist-to-height ratio (WHtR) [19,21], waist-to-hip ratio (WHR) [19], and A Body Shape Index [ABSI = $WC/(BMI^{2/3} \times height^{1/2})$ [22]. Other techniques offer specific information on the distribution of both VAT and SAT and measurements of localized fat deposits (Table 1) [9].

Early risk factors for childhood obesity

Obesity risk factors may appear from the very early stages of life, even at conception. Thus, maternal BMI before pregnancy, maternal weight gain during pregnancy, gestational diabetes, maternal malnutrition and maternal smoking during pregnancy have been independently and positively associated with neonatal, infant and children adiposity. Apart from the nutritional status of the mother, studies have shown that the father's BMI is also associated with childhood obesity [23]. After birth, other factors have also been related to a higher risk of adiposity and obesity, such as birth weight, namely, low birth weight ($<$2500 g) and high birth weight ($>$4000 g), rapid postnatal weight gain during the first months of age, and formula feeding [23] (Fig. 1).

Table 1. Comparative analysis of the methods to evaluate fat mass in children

Technique	**Principle/fat mass estimation**	**Advantages**	**Disadvantages**	**Reference**
Anthropometr/ skinfolds	Measurement of subcutaneous fat and equations to determine fat mass.	Quick Minimal material requirements Portable Simple Adapted to most age groups Noninvasive	In children with obesity and children with edema these techniques are less accurate and precise Intra-observer and inter-observer variability Predictive equations may not be valid in populations other than those from which they were derived.	[41]
Bioelectric impedance analysis (BIA)	Measurement of the impedance of different tissues, according to their different water content. BIA assumes that 73% of fat free mass is body water, which is a good electrical conductor, whereas fat mass is a poor conductor because of its lower hydration Equations developed for specific populations are used to predict total body water, then fat-free mass and finally fat mass	Fast, Simple Low cost Portable	Susceptible to changes in a patient's fasting and hydration status	[42]
Dual-energy X ray absorptiometry	High-energy and low-energy beams pass through the body to differentiate between soft tissues and bone Fat mass, visceral adipose tissue and subcutaneous adipose tissue	Fast Relatively well tolerated (requires minimal radiation exposure, similar to a single day's background radiation at the sea level) Relatively cost-effective compared with other assessment modalities, such as computed tomography and MRI	Requires trained staff. Bidimensional assessment. Assumption of constant hydration of the lean soft tissues. Impossibility to determine the fat fraction in solid organs, such as liver or muscle.	[43,44]
Air displacement Plethysmography	Measurement of body density and then body fat % using Siri's equation. From the calculated percentage of fat, the software estimates the fat mass.	Noninvasive It does not require patient radiation exposure Excellent adherence to measurement protocol Can be used even in newborns and infants.	High cost Error susceptibility because of the approximation of the density of different tissues.	[45]
Ultrasound	Reflection of ultrasound waves at the interface between tissues of different densities. Visceral adipose tissue, subcutaneous adipose tissue.	Noninvasive Accurate Reproducible Fast Available Low cost	Operator-dependence Lack of standardized measurement protocol Insufficient data in children	[9,44]
Computed tomography (CT)	High-resolution three-dimensional image of each structure in a selected area, based on differences in attenuation of fat and lean tissues. Total adipose tissue, subcutaneous adipose tissue, visceral adipose tissue and interstitial adipose tissue.	High accuracy	High X-ray exposure	[9,44]
MRI	On the basis of behavior of protons under the influence of high-intensity electromagnetic field. Total adipose tissue, subcutaneous adipose tissue, visceral adipose tissue, interstitial adipose tissue and fat fraction of brown adipose tissue.	No radiation	High cost	[9,44]
Deuterium dilution	Measurement of total body water based on concentration of deuterium in the collected samples; by total body water, the fat free mass can be calculated assuming that the fat free mass is constantly hydrated at 73.2%, and the fat mass is calculated from this value.	No radiation Reference method	Time-intensive protocol Specialized equipment/technical training. Error susceptibility because of the approximation of the water content of different tissues.	[9,45]

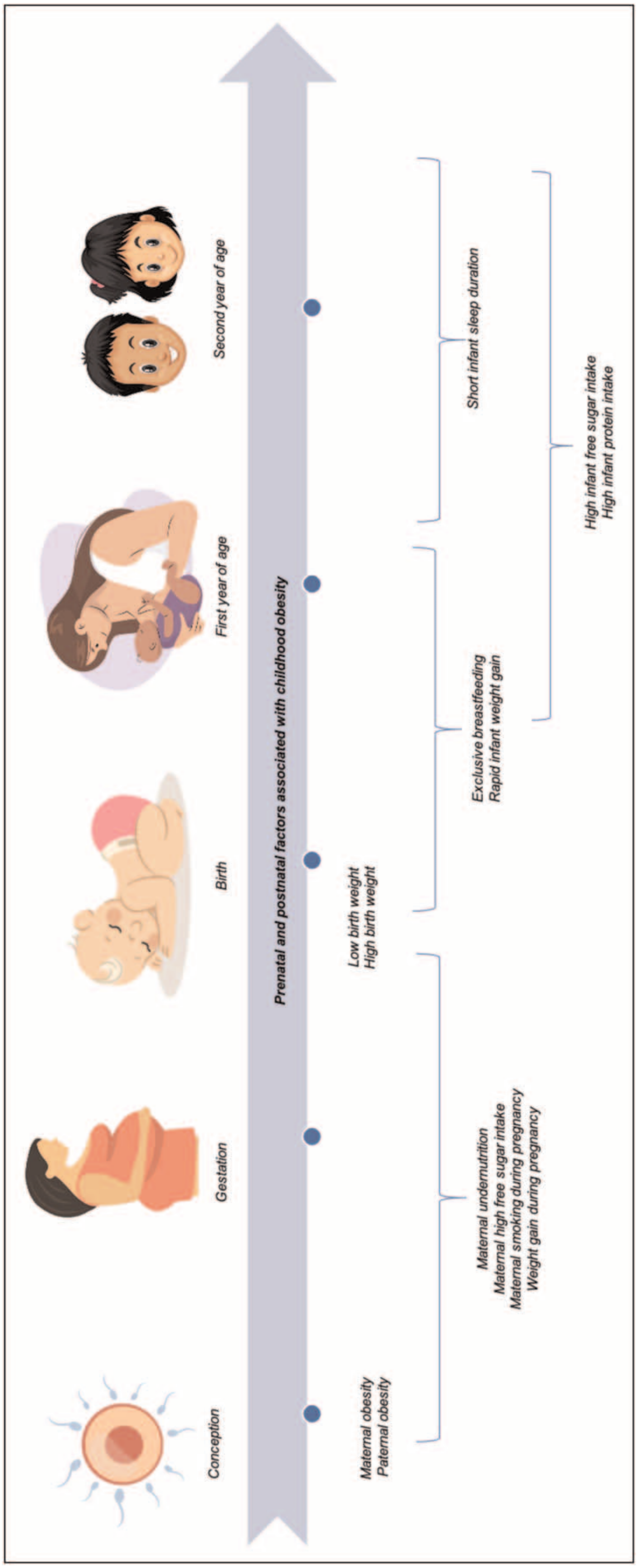

FIGURE 1. Prenatal and postnatal factors associated with childhood obesity.

Maternal and paternal BMI before pregnancy

A systematic review with a subsequent meta-analysis aimed at understanding the association between maternal prepregnancy weight and childhood obesity identified a significant increase in the odds of childhood obesity with increasing maternal BMI; this association was strongest when the mother had obesity, which increased the odds of childhood obesity by 264%, followed by maternal overweight, which increased the odds by 89% [24]. Three theories have explained the intergenerational transmission of body adiposity: first, a genetic component; second, epigenetic processes in the womb that may contribute to obesity in the offspring, including alterations in DNA methylation; and the third mechanism concerns exposure to obesogenic environments, promoting less healthy lifestyles [25].

Some studies also associate paternal BMI with excess fat and obesity in the offspring [23]. Although the mechanisms are still unclear, biological (epigenetic factors in sperm, such as DNA methylation, chromatin modifications and noncoding RNAs) and social factors (influence of the father on the mother's environment, for example, by passive exposure to smoke, stress, emotional support, etc.) [26] are currently being investigated.

Maternal undernutrition

Maternal undernutrition can also lead to childhood obesity. Although malnourished mothers frequently have small-for-gestational-age babies, limited nutrient supply *in utero* has been reported to lead to metabolic adaptations to optimize extrauterine growth, characterized by excessive nutrient storage when nutrient supply is not limited after birth [27▪].

Maternal weight gain during pregnancy

Excessive maternal weight gain leads to an altered intrauterine environment that influences fetal growth and can also lead to persistent child weight programming with consequent poor health outcomes in the offspring. Children of mothers with excess gestational weight gain have more adiposity at 3 years; similarly, maternal gestational weight gain is associated with obesity risk in adolescence and early adulthood. In addition, the timing of gestational weight gain influences the future health of the offspring: significant gestational weight gain in the first and second trimesters but not in the third trimester, is associated with higher BMI and adiposity at birth [28]. This significant excess weight gain during pregnancy is related to an altered balance between energy intake and expenditure because of high intake of refined sugars and an inadequate distribution of polyunsaturated fatty acids (high omega-6 content fatty acids and low intake of omega-3 fatty acids), accompanied by insufficient physical activity levels during pregnancy [9].

Although the mechanisms whereby maternal weight gain at pregnancy are linked to child weight are yet unclear, it may be because of both increased lipid transfusion and increased glucose delivery from the mother to the fetus [29]. This may result in increased fetal insulin secretion, which promotes adipogenesis and fat cell hypertrophy [30] and leads to epigenetic alterations that include changes in DNA methylation, histone modifications and changes in noncoding RNA expression [27▪].

Maternal smoking during pregnancy

Similarly, intrauterine exposure to tobacco smoke has been associated with an increased risk of obesity in the offspring. It is likely that nicotine and other components of tobacco cross the placenta and impair fetal growth, leading to low birth weight in infants and subsequent rapid postnatal weight gain associated with increased adiposity later in life [31].

Low and high birth weight

Low birth weight (LBW) is mainly induced by intrauterine growth restriction. LBW is associated with an increased risk of obesity later in life, likely because of a more significant accumulation of visceral [23], hepatic, and pancreatic fat when later catch-up growth occurs, accompanied by low lean mass and increased peripheral resistance to nutrient utilization programed from the intrauterine stage. Other theories point to a lower number of adipocytes, which could be associated with the overload of individual adipocytes and impaired expansion capacity of adipose tissue [32].

On the other hand, high birth weight (i.e. weighing more than 4000 g at birth) has been associated with greater total and truncal adiposity in adults [33] and an increased risk of subsequent obesity [34]. Hypernutrition during pregnancy can cause an increase in fat mass or FFM because of hyperglycemia and hyperinsulinemia, accompanied by increased levels of insulin-like growth factors I and II and changes in DNA methylation, as well as modification of genetic predisposition [35].

Rapid infant weight gain

Rapid infant weight gain (RIWG), defined as a change of more than 0.67 standard deviations in weight-for-age *z* score between two-time points during childhood, has been associated with overweight and obesity in childhood and adulthood [36]. Although the mechanisms of this relationship remain unclear, this may be as infants experiencing rapid weight gain have high levels of insulin resistance and total and central fat [37], as well as alterations in their microbiota [38]. RIWG in periods with positive energy balance, and consequent tissue storage, triggers a body mass increase characterized by a greater fat mass than FFM.

The exact RIWG period during childhood that predicts overweight and obesity is subject of discussion. Although some studies indicate that the period between birth and 2 years of age may be decisive, others favor the period between birth and the first week of life [38].

As for the risk factors associated with RIWG, low birth weight, which as previously mentioned, is related with a more significant accumulation of fat, and therefore, a greater risk of overweight and obesity. Likewise, formula feeding, and higher protein intake have also been described as RIWG risk factors [38].

The adverse effect of early high protein intake on overweight and obesity risk later in life, may be because of increased intake of insulinogenic amino acids, which in turn stimulate secretion of insulin and insulin-like growth factor 1 (IGF-1), and increase adipogenic activity [39,40]. This situation is exacerbated by a regular intake of high-energy foods, the consumption of sugary drinks, and the lack of regular physical activity [40].

Short infant sleep duration

Some studies have shown a relationship between the hours of sleep in infancy and the risk of overweight and obesity later in life. Children who slept less than 12 h a day were twice as likely to have overweight at age 3 years [40].

CONCLUSION

Finally, in the prevention of childhood obesity, healthcare professionals, public health policymakers, and society, in general, will have to pay more attention to those prenatal and postnatal factors that predispose to excess body fat in childhood and adolescence. Early childhood is a crucial time to establish positive behaviors that prevent excess weight in the future. Therefore, healthy eating practices, regular physical activity, and changes away from a sedentary lifestyle should be encouraged. In addition, we should ensure early detection of excess body fat and the implementation of efficient interventions to normalize the weight of our children and adolescents at risk.

Acknowledgements

None.

Financial support and sponsorship

None.

Conflicts of interest

There are no conflicts of interest.

REFERENCES AND RECOMMENDED READING

Papers of particular interest, published within the annual period of review, have been highlighted as:
■ of special interest
■■ of outstanding interest

1. Khadilkar V, Shah N. Evaluation of children and adolescents with obesity. Indian J Pediatr 2021; 88:1214–1221.
2. Malhotra S, Sivasubramanian R, Singhal V. Adult obesity and its complications: a pediatric disease? Curr Opin Endocrinol Diabetes Obes 2021; 28:46–54.
3. World Health Organization. Obesity overview [Internet] [cited 16 March 2022]. Available at: https://www.who.int/health-topics/obesity#tab=tab_1. Accessed 16 Mar 2022.
4. World Health Organization. WHO child growth standards: length/height-for-age, weight-for-age, weight-for-length, weight-for-height and body mass index-for-age: methods and development [internet]. World Health Organization; 2006. 336 p. Available at: https://www.who.int/publications/i/item/924154693X. Accessed 16 Mar 2022.
5. World Health Organization. Obesity and overweight [Internet]. [cited 2022 Mar 17]. Available at: https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight. Accessed 17 Mar 2022.
6. Cole TJ, Lobstein T. Extended international (IOTF) body mass index cut-offs for thinness, overweight and obesity. Pediatr Obes 2012; 7:284–294.
7. Van Eyck A, Eerens S, Trouet D, *et al.* Body composition monitoring in children and adolescents: reproducibility and reference values. Eur J Pediatr 2021; 180:1721–1732.
8. ■■ Bosy-Westphal A, Müller MJ. Diagnosis of obesity based on body composition-associated health risks—Time for a change in paradigm. Obes Rev 2021; 22(Suppl 2):1–7.
This systematic review summarizes the importance of lean mass for diagnosis of obesity-associated risk across the life cycle and in health and disease.
9. Negrea MO, Neamtu B, Dobrotă I, *et al.* Causative mechanisms of childhood and adolescent obesity leading to adult cardiometabolic disease: a literature review. Appl Sci 2021; 11:11565.
10. Tiwari A, Balasundaram P. Public Health Considerations Regarding Obesity [Internet]. StatPearls [Internet]. StatPearls Publishing; 2021 [cited 2022 Mar 16]. Available from: https://www.ncbi.nlm.nih.gov/books/NBK572122/.
11. ■ Córdoba-Rodríguez DP, Iglesia I, Gomez-Bruton A, *et al.* Fat-free/lean body mass in children with insulin resistance or metabolic syndrome: a systematic review and meta-analysis. BMC Pediatr 2022; 22:1–23.
This systematic review and meta-analysis is the first to examine differences in lean mass/lean body mass based on the presence of insulin sensitivity/insulin resistance/glucose tolerance/metabolic syndrome in children.
12. ■■ Orsso CE, Tibaes JRB, Oliveira CLP, *et al.* Low muscle mass and strength in pediatrics patients: why should we care? Clin Nutr 2019; 38:2002–2015.
This review summarizes the influences on skeletal muscle development, the impact of low muscle mass and strength in pediatrics, and the importance of measuring and monitoring skeletal muscle mass and function from infancy through early adulthood in clinical settings.
13. ■■ Orsso CE, Silva MIB, Gonzalez MC, *et al.* Assessment of body composition in pediatric overweight and obesity: a systematic review of the reliability and validity of common techniques. Obes Rev 2020; 21:1–18.
This systematic review summarizes the reliability and validity of field and laboratory body composition techniques used in pediatric obesity studies, to facilitate the selection of techniques for research and in clinical practice.
14. Shypailo RJ, Wong WW. Fat and fat-free mass index references in children and young adults: assessments along racial and ethnic lines. Am J Clin Nutr 2020; 112:566–575.
15. Sun J, Yang R, Zhao M, *et al.* Tri-ponderal mass index as a screening tool for identifying body fat and cardiovascular risk factors in children and adolescents: a systematic review. Front Endocrinol (Lausanne) 2021; 12:1–16.

16. Bakhtiani P, Geffner ME. Early anthropometric indicators of type 2 diabetes mellitus. Curr Opin Endocrinol Diabetes Obes 2022; 29:52–56.
17. Leite NN, Cota BC, Gotine AREM, *et al.* Visceral adiposity index is positively associated with blood pressure: a systematic review. Obes Res Clin Pract 2021; 15:546–556.
18. Caprio S, Santoro N, Weiss R. Childhood obesity and the associated rise in cardiometabolic complications. Nat Metab 2020; 2:223–232.
19. Bojanic D, Ljubojevic M, Krivokapic D, Gontarev S. Waist circumference, waist-to-hip ratio, and waist-to-height ratio reference percentiles for abdominal obesity among Macedonian adolescents. Nutr Hosp 2020.
20. Iñarritu-Pérez MdelC, Kaufer-Horwitz M, Yamamoto-Kimura L, *et al.* Neck circumference cut-offs for overweight and obesity in a group of Mexican adolescents. Eur J Clin Nutr [Internet] 2021; 75:1654–1660.
21. Ezzatvar Y, Izquierdo M, Ramírez-Vélez R, *et al.* Accuracy of different cutoffs of the waist-to-height ratio as a screening tool for cardiometabolic risk in children and adolescents: a systematic review and meta-analysis of diagnostic test accuracy studies. Obes Rev 2022; 23:1–10.
22. Chen R, Ji L, Chen Y, Meng L. Weight-to-height ratio and body roundness index are superior indicators to assess cardio-metabolic risks in Chinese children and adolescents: compared with body mass index and a body shape index. Transl Pediatr 2022; 11:318–329.
23. Larqué E, Labayen I, Flodmark CE, *et al.* From conception to infancy — early risk factors for childhood obesity. Nat Rev Endocrinol 2019; 15:456–478.
24. Heslehurst N, Vieira R, Akhter Z, *et al.* The association between maternal body mass index and child obesity: a systematic review and meta-analysis. PLoS Med 2019; 16:1–20.
25. Eshriqui I, Valente AMM, Di Folchetti L, *et al.* Prepregnancy BMI is associated with offspring body composition in adulthood before adiposity-related disorders: a retrospective cohort. Public Health Nutr 2021; 24:1296–1303.
26. Sharp GC, Lawlor DA. Paternal impact on the life course development of obesity and type 2 diabetes in the offspring. Diabetologia 2019; 62:1802–1810.
27. ▪ Rodgers A, Sferruzzi-Perri AN. Developmental programming of offspring adipose tissue biology and obesity risk. Int J Obes 2021; 45:1170–1192.
This review summarizes the evidence for a role of early environmental factors, such as maternal malnutrition, maternal obesity, and other factors during gestation in the programming of adipose tissue and obesity in the offspring.
28. Champion ML, Harper LM. Gestational weight gain: update on outcomes and interventions. Curr Diab Rep 2020; 20:11.
29. Lau EY, Liu J, Archer E, *et al.* Maternal weight gain in pregnancy and risk of obesity among offspring: a systematic review. J Obes 2014; 2014:524939.
30. Nehab SRG, Villela LD, Abranches AD, *et al.* Influence of gestational and perinatal factors on body composition of full-term newborns. J Pediatr (Rio J) 2020; 96:771–777.
31. Knudsen GTM, Dharmage S, Janson C, *et al.* Parents' smoking onset before conception as related to body mass index and fat mass in adult offspring: findings from the RHINESSA generation study. PLoS One 2020; 15:1–20.
32. Nakano Y. Adult-onset diseases in low birth weight infants: association with adipose tissue maldevelopment. J Atheroscler Thromb 2020; 27:397–405.
33. Resende CB, Luft VC, Duncan B, *et al.* Birth weight and body fat mass in adults assessed by bioimpedance in the ELSA-Brasil study. Cad Saude Publica 2021; 37:e00061619.
34. Zou Z, Yang Z, Yang Z, *et al.* Association of high birth weight with overweight and obesity in Chinese students aged 6-18 years: a national, cross-sectional study in China. BMJ Open 2019; 9:1–8.
35. Hong YH, Lee JE. Large for gestational age and obesity-related comorbidities. J Obes Metab Syndr 2021; 30:124–131.
36. Flores-Barrantes P, Iglesia I, Miguel-Berges ML, *et al.* Rapid infant weight gain is associated with excess adiposity at 7-years of age in children from Aragon, Spain. Child Adolesc Obes 2021; 4:60–77.
37. Rotevatn TA, Overgaard C, Melendez-Torres GJ, *et al.* Infancy weight gain, parental socioeconomic position, and childhood overweight and obesity: a Danish register-based cohort study. BMC Public Health 2019; 19:1–13.
38. Shin YL. The timing of rapid infant weight gain in relation to childhood obesity. J Obes Metab Syndr 2019; 28:213–215.
39. Grote V, Jaeger V, Escribano J, *et al.* Effect of milk protein content in Toddler formula on later BMI and obesity risk: protocol of the multicentre randomised controlled Toddler Milk Intervention (ToMI) trial. BMJ Open 2021; 11: e048290.
40. Jochum F, Abdellatif M, Adel A, *et al.* Burden of early life obesity and its relationship with protein intake in infancy: the Middle East Expert Consensus. Pediatr Gastroenterol Hepatol Nutr 2022; 25:93.
41. Ooi PH, Thompson-Hodgetts S, Pritchard-Wiart L, *et al.* Pediatric sarcopenia: a paradigm in the overall definition of malnutrition in children? J Parenter Enter Nutr 2020; 44:407–418.
42. Gilligan LA, Towbin AJ, Dillman JR, *et al.* Quantification of skeletal muscle mass: sarcopenia as a marker of overall health in children and adults. Pediatr Radiol 2020; 50:455–464.
43. Guss CE, McAllister A, Gordon CM. DXA in children and adolescents. J Clin Densitom 2021; 24:28–35.
44. Simoni P, Guglielmi R, Gómez MPA. Imaging of body composition in children. Quant Imaging Med Surg 2020; 10:1661–1671.
45. Perteet-Jackson AD, Earthman CP, Larson-Nath CM. Body composition post pediatric liver transplant: implications and assessment. Nutr Clin Pract 2021; 36:1173–1184.