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Reference growth curves to identify weight status (underweight, overweight or obesity) in children and adolescents: systematic review

Carlos Alencar Souza Alves Junior[1]*, Priscila Custódio Martins[1], Luis Alberto Moreno Aznar[2] and Diego Augusto Santos Silva[1,3]

[1]*Federal University of Santa Catarina, Research Center in Kinanthropometry and Human Performance, Sports Center, Florianópolis, SC, Brazil*

[2]*Growth, Exercise, Nutrition and Development (GENUD) Research Group, Instituto Agroalimentario de Aragón (IA2), Universidad de Zaragoza, Instituto de Investigación Sanitaria de Aragón (IIS Aragón), Zaragoza, Centro de Investigación Biomédica em Red de Fisiopatología de la Obesidad y Nutrición (CIBEROBN), Instituto de Salud Carlos III, Madrid, Spain*

[3]*Faculty of Health Sciences, Universidad Autónoma de Chile, Providencia, Chile*

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Abstract

The identification of somatic growth, through reference curves, can be used to create strategies and public policies to reduce public health problems such as malnutrition and obesity and to identify underweight, overweight and obesity. The purpose of this systematic review was to identify studies providing reference growth curves for weight status in children and adolescents. A systematic search was conducted in eight databases and in gray literature (Google scholar). To assess the risk of bias/methodological quality of studies, the National Institutes of Health (NIH) Quality Assessment Tool for Observational Cohort and Cross-sectional Studies (NHLBI) was used. Overall, 86 studies that met the inclusion criteria were included. Through the values of reference growth curves for the identification of underweight, overweight and obesity, it was possible to verify that there is great variability among percentiles for the identification of underweight, overweight and obesity. The most prevalent percentiles for underweight were P3 and P5; for overweight, the most prevalent was P85 and the most prevalent percentiles for obesity were P95 and P97. The most prevalent anthropometric indicators were Body Mass Index (BMI), Waist Circumference (WC), Body Mass (BM) for age and height for age. Conclusion: Such data can demonstrate that the optimal growth must be reached, through the standard growth curves, but that the reference curves demonstrate a cut of the population growth, raising possible variables that can influence the optimal growth, such as an increase in the practice of physical activities and an awareness of proper nutrition.

Key words: Body composition: Reference growth curves: Growth: Child: Adolescent

Somatic monitoring in the paediatric population can be used as an indicator of health, nutritional status (underweight, overweight or obesity) and living conditions, in addition to identifying genetic, chronic diseases, infections and dietary factors that can influence rapid or slow growth[1–3]. The well-being and health of children and adolescents could reflect the both on the state of socio-economic development and quality of the health system in a given country[4–8]. In this perspective, the somatic growth of children and adolescents can be used as a weight status and health indicator[7,8].

Growth curves are used as important tools to verify the physical growth of individuals, identifying the weight status and health conditions of the population[6–8]. Growth curves can be defined in two ways: standard or reference[6]. Standard growth curves are derived from children raised in environments that minimised growth restrictions, such as inadequate nutrition and infections, involving a value judgment when describing how children 'should grow' in all countries[9], and the reference growth curves, on the other hand, are descriptive and are drawn from a population believed to be growing in the best possible state of nutrition and health in a given community, without necessarily controlling for variables such as nutrition and the presence of infections[6]. Reference curves describe children's growth at a given time and represent how children are growing, not how they should be growing[6].

Among growth curves, standard curves of the WHO[10], Centers for Disease Control and Prevention of the USA (CDC)[7] and the International Obesity Taskforce (IOTF)[8] were elaborated with the aim of classifying the weight status of

Abbreviations: BM, body mass; IOTF, International Obesity Taskforce.

* **Corresponding author:** Carlos Alencar Souza Alves Junior, email alvesjunior.cas@gmail.com

children and adolescents from the world population[7,8,10]. However, human growth and development are characterised by their intra-population and inter-population heterogeneity, being the product of continuous and complex interactions between genes and different environmental factors, linked to the living conditions of populations, such as nutrition[11], and the physical growth of populations in different parts of the world[11] can be evaluated through reference curves, being another alternative to verify the growth, because the standard growth curves take into account the optimal growth, demonstrating how the growth must occur in ideal conditions. Although optimal growth should be strongly encouraged, not all countries have ideal living conditions for the population to provide optimal growth[6,9].

Reference growth curves developed from anthropometric measurements have been used in several countries to assess the weight status and problems associated with physical growth in children and adolescents[11–14]. Body mass (BM) for age, height for age, anthropometric indexes, body perimeters and skinfolds are among the most widely evaluated indicators[11–16]. Anthropometric measurements are valuable tools to assess physical growth and weight status because they are methodologically simple and have low cost, especially for large-scale studies[17]. In this sense, listing the reference growth curves to identify weight status in the paediatric population and the use of anthropometric measurements for comparison purposes is important to understand changes associated with environmental factors or the secular trend phenomenon[17,18].

Growth patterns are heterogeneous and related to environmental factors such as geographic, meteorological, economic, social and cultural factors, which are different in different parts of the world[3,6]. Thus, the systematisation of reference growth curves to identify weight status (underweight, overweight and obesity) can contribute to the understanding of intra- and inter-population heterogeneity[17,19,20]. This review can contribute to demonstrate the comprehensiveness of the available reference growth curves, describing the variability between the different reference growth curves. In this context, the aim of this systematic review was to identify studies that proposed reference growth curves for weight status (underweight, overweight or obesity) in children and adolescents. This review presents the following research question: what are the anthropometric indicators, anthropometric indexes and percentiles used in the development of reference growth curves in relation to underweight, overweight or obesity in children and adolescents?

Method

The method used in the systematic review was developed in line with procedures of the Preferred Reporting Items for Systematic reviews and Meta-Analyses 2020 statement, an updated guideline for reporting systematic reviews[21], and Cochrane Collaboration. This review was registered on the PROSPERO International Prospective Register of Systematic Reviews platform with registration number CRD42020215063.

Systematic search strategies

The search was performed in the following databases: (1) Cumulative Index to Nursing and Allied Health Literature (CINAHL) by EBSCOhost; (2) LILACS by the Virtual Health Library; (3) PubMed by National Library of Medicine (MEDLINE); (4) ScienceDirect by Elsevier; (5) Scopus by Elsevier; (6) SPORTDiscus by EBSCOhost; (7) Scientific Electronic Library Online (SciELO) and (8) Web of Science. Manual searches were also carried out in grey literature (Google scholar) in order to find possible studies that were not retrieved by the search strategy.

The search in the databases was performed between the months of June to August 2021. The year of publication of articles was disregarded in order to cover as many studies as possible. The search for probable articles in databases was performed using the advanced search tool ('keywords') and performed through the construction of blocks of descriptors in three languages: English, Spanish and Portuguese. Boolean operators AND was used to add at least one word from each group, OR was used to add at least one word from each block, parentheses were used to combine search terms by result categories, quotes were used to search for exact terms or expressions and asterisks were used to search for all words derived from the same prefix. Descriptors came from the Health Sciences Descriptors (DECS), Medical Subject Headings (MESH) and key words found in articles related to the subject.

The search strategy descriptor groups were divided into three blocks: (1) underweight, overweight and obesity; (2) reference growth curves and (3) population of children and adolescents: Block 1- (Overweight OR Obesity OR fats OR fatty OR 'fat body' OR 'fat mass' OR adiposity OR 'body composition' OR 'Nutritional Status' OR 'body fat' OR Thinness OR Underweight OR 'Malnutr* OR malnourish* OR Undernutr*) AND Block 2- ('Growth Curves' OR 'Growth Charts' OR 'Reference Growth Curve' OR 'Centile Curves' OR 'Distance Growth Curve') AND Block 3- (adolesc* OR teen OR teenager OR child* OR Children OR young OR 'School-age' OR Childhood OR 'young people' OR scholar OR students OR 'school children' OR 'school teenager' OR teenager OR adolescence OR student). The search was restricted to studies published in English, Portuguese or Spanish.

Manual searches were also carried out based on references of included studies in order to identify possible articles not previously included. The Zotero® bibliographic manager software, version 5.0 (Roy Rosenzweig Center for History and New Media) was used to create specific libraries, which allowed the identification and exclusion of duplicates, division and organisation of results of each database. Results were exported to the reference manager software.

Study selection criteria

In this review, the included studies showed: studies with population of children and adolescents aged 2·0–19·9 years (if the study reports mean age values, this mean should be up to 19 years old); study design (cross-sectional, longitudinal, mixed longitudinal and cohort studies), studies that developed reference growth curves in relation to underweight, overweight or obesity through anthropometric indexes such as upper arm fat area, upper arm muscle area, BMI, conicity index (Iconi), waist-to-height ratio, waist-to-hip ratio, among others; anthropometric indicators such as BM, height, body perimeters and skinfolds in children and adolescents; studies that elaborated curves through modelling methods for sex, age, race/ethnicity, sexual maturation and economic level, with the LMS method, being L (smooth curve), M (median) and S (coefficient and variance), polynomial regression or percentile regression. The use of modelling methods is important to reduce data asymmetry for the development of reference growth curves, being necessary for comparison with existing curves[8,22].

Articles were excluded according to the following criteria: duplicate articles, review articles, dissertations, abstracts, book chapters, points of view or expert opinions, monographs, theses, chapters, articles in which the population evaluated was composed only of individuals with some morbidity, except malnutrition and obesity, animal studies, study carried out with adults, elderly and athletes, articles that did not elaborate reference growth curves for underweight, overweight or obesity in children and adolescents and those that did not take into account modelling methods for the development of reference growth curves.

Risk of bias assessment

Studies included in the systematic review were analysed for methodological quality by two independent reviewers/authors (CASAJ and PCM). Disagreement between reviewers/authors regarding the evaluation of any study was resolved through a consensus meeting, and if the disagreement persisted, it was decided by a third reviewer (DASS). To assess the risk of bias/methodological quality of studies, the Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies (NHLBI) from the National Institutes of Health[23] was used. This instrument was used to assess the risk of bias, as included studies had cross-sectional, longitudinal and mixed longitudinal design, consistent with the inclusion criteria.

This methodological analysis instrument is indicated to aid the internal validity (potential risk of selection, information, measurement or confounding factors) of cross-sectional and cohort studies, covering fourteen criteria to determine the risk of bias/methodological quality, including whether the population under study was clearly specified and defined. For each criterion evaluated, the following scores were assigned: ‘no’ (N), ‘not reported’ (NR), ‘yes’ (Y) and ‘not applicable’ (NA). The ‘NR’ option was used when no information was reported in studies. The ‘NA’ option was used when it was not possible to evaluate one of the instrument’s criteria due to the type of study. At the end of the study classification, a total score was assigned to each study based on the number of positive and negative responses of the questionnaire. Responses ‘no’ and ‘NR’ had score ‘0’, while responses ‘yes’ and ‘NA’ had score ‘1’[23].

Data extraction

Data were extracted by two independent reviewers, and consensus was verified between them. The information extracted was year/author; risk of bias score; study site; population/sample; age group; study design; method to produce the growth curves; anthropometric indicators; percentiles identified in reference growth curves; stratification variables and modelling of reference growth curves; percentiles to define underweight, overweight and obesity, values identified in percentiles for underweight, overweight and obesity.

Results

Overall, 3794 studies were found and among them, 203 studies were duplicates, resulting in 3591 studies. After reading titles and abstracts, 3400 studies were excluded and then 191 studies were read in full. Of these, seventy-eight were included because they met the eligibility criteria. The references of articles included were read, and eight more studies were included in this review, ending in eighty-six studies (Fig. 1).

General characteristics of the included studies

Forty studies were carried out in the Asian continent in the following countries: four in Saudi Arabia, five in China, one in Singapore, one in the United Arab Emirates, four in India, five in Iran, three in Japan, two in Kuwait, two in Lebanon, one in Malaysia, one in Pakistan, one in Taiwan and ten in Turkey[13,14,24–61] (Table 1).

Twenty studies were conducted in the Americas, in the following countries: two in Argentina, seven in Brazil, one in Canada, one in Chile, three in Colombia, three in the USA, one in Greenland, one in Peru and one in Venezuela[2,11,17,19,20,22,62–68,68–75]. Two studies were carried out in Africa, in the countries of South Africa (one study) and Tunisia (one study)[76,77] (Table 1).

Thirty-two studies were carried out in Europe in the following countries: five in Germany, one in Bulgaria, one in Cyprus, one in Denmark, two in Spain, one in Great Britain, one in Greece, two in Italy, one in Norway, two in Poland, two in Portugal, one in the UK, one in Switzerland, ten in Turkey and one in Ukraine[1,12,13,15,16,25,29,34,35,43,48,51,52,54,78–94]. Turkey has its territory in two continents, Asia and Europe, and for this reason it was included in the accounting of both continents. Two studies were carried out in Oceania in Australia (one study) and New Zealand (one study)[95,96] (Table 1).

As for the year of publication, the oldest study was published in 1997[83]. The most recent study was published in 2020[93]. Of the eighty-six studies included, seventy-five had cross-sectional design[1,2,12,11–17,19,22,24–28,30–44,44,45,47,48,50–57,57–60,63–70,72–76,78–87,89–93,95,97]. Only eight studies had longitudinal design[29,46,49,61,71,77,88,96] and three had mixed longitudinal design[20,62,94] (Table 1).

Of the eighty-six studies, thirty-nine (45 %) presented information about the study population[1,2,12,13,15,16,19,25,31–36,41–43,50,54,56–58,63–65,68,69,71,74,77,78,85,86,88,91–93,96,97]. The sample size of the studies ranged from 279[71] to 232 140 participants[47]. Only five studies did not present sample stratified by sex[46,48,62,67,77]. One study presented sample stratified by ethnicity (African-American, European-American and Mexican-American)[67]. One study presented sample composed only of males[86], and one study presented sample composed only of

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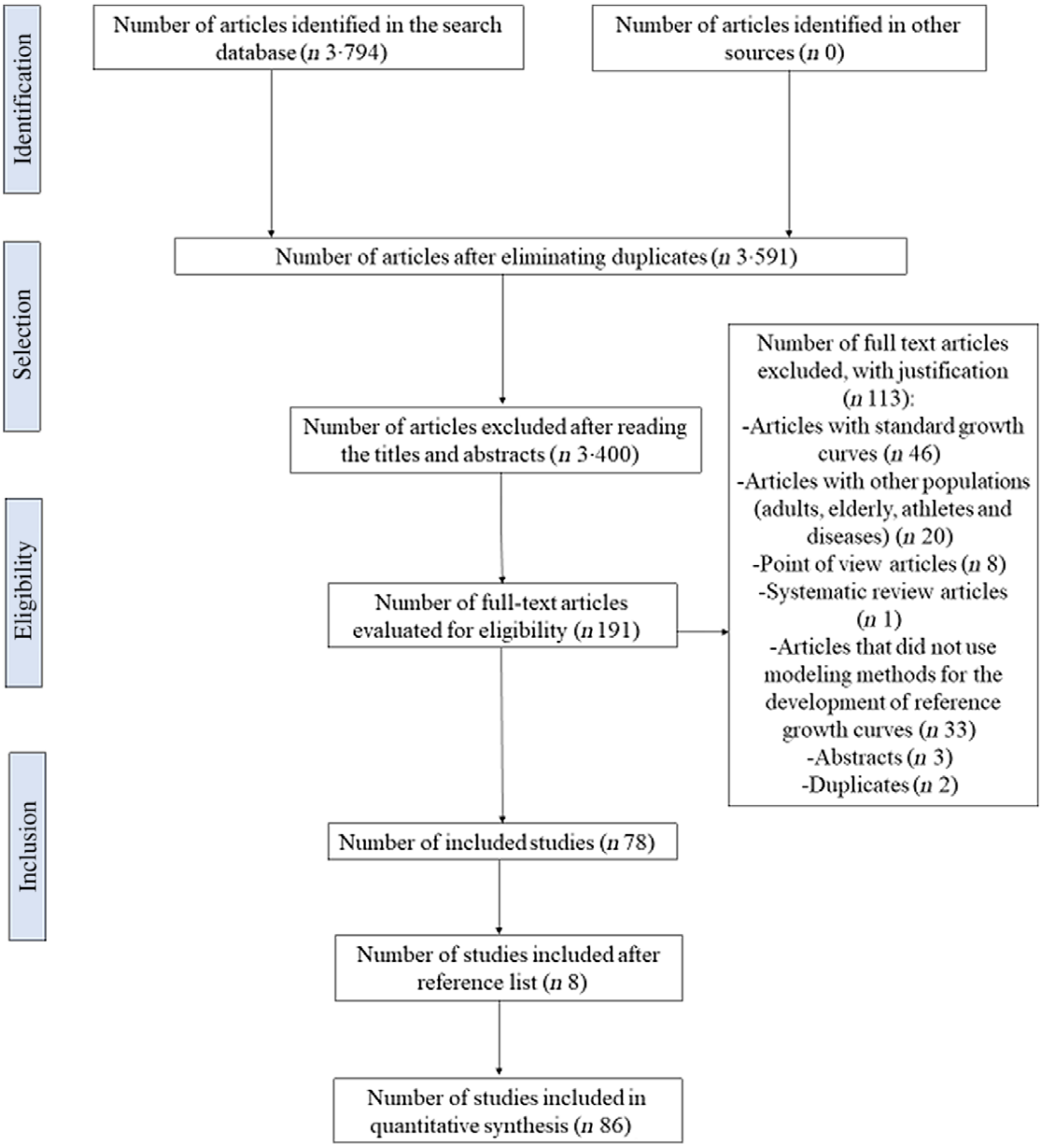

Fig. 1. Synthesis of systematic search.

females[85]. Studies were quite heterogeneous in terms of age, comprising the age group from 0 to 20 years (Table 1).

Only five studies did not use the LMS method to elaborate curves, four of them used the polynomial regression method[24,38,74,91] and one study used the percentile regression method[67] (Table 1).

Characteristics of studies in relation to anthropometric indicators used to elaborate reference growth curves in children and adolescents

Of the eighty-six studies, forty-four used BMI for age to elaborate reference growth curves for underweight, overweight and obesity, being the most prevalent anthropometric indicator[1,2,11,15,19,20,22,24,29–32,36–38,40–42,46,47,51,53,56,58,59,61,63–65,71,74,76,77,79,80,85,86,88,88–91,94,96,97] (online Supplementary File 1).

Twenty-nine studies took into account BM for age to elaborate reference growth curves for underweight, overweight and obesity in children and adolescents[1,2,11,20,25,30–33,38,42,46,51,58,63,64,68,69,71,72,77,77,79,80,85,86,88,88,91,94,96]. Twenty-five studies took into account height for age to elaborate reference growth curves for underweight, overweight and obesity in children and adolescents[1,2,2,11,20,20,30–33,38,42,51,63,64,68,69,72,77,79,80,85,86,88,91,94,96]. One study used total length for the development of reference growth curves for underweight, overweight and obesity in children and adolescents[33] (online Supplementary File 1).

Regarding anthropometric indexes, nine studies used waist-to-hip ratio to elaborate reference growth curves for underweight, overweight and obesity[14,16,19,45,50,60,73,78,90]. Four studies used waist-to-height ratio to elaborate reference growth curves for underweight, overweight and obesity mainly the central[16,41,50,53]. Two studies used BM for height (BM/height) to

Table 1. Characteristics of reference growth curve studies for thinness, overweight and obesity

Year/Author	Quality score	Study location	Population/Sample		Age group	Outline	Curves method
Abdulrazzaq *et al.*, (2011)[97]	12	United Arab Emirates	104·1982/ 20·494	♂: 8·335; ♀:12·159	2–18 years old	Cross-sectional	LMS
Addo *et al.*, (2010)[62]	13	USA	NR /32·718		2–19 years old	Mixed longitudinal	LMS
Aeberli *et al.*, (2011)[78]	12	Switzerland	NR/ 2·303 (♂: 1·128; ♀: 1·175)		6–13 years old	Cross-sectional	LMS
Al-Isa *et al.*, (2016)[24]	12	Kuwait	124·918/ 113·013	♂: 55·053; ♀: 57·960	3–9 years old	Cross-sectional	Polynomial Regression
Altunay *et al.*, (2011)[25]	12	Turkey	3·094/ 2·963	♂:1·472; ♀:1·491	24–84 months	Cross-sectional	LMS
Anzo et al, (2015)[26]	12	Japan	NR/ 19·233 (♂: 9·668; ♀: 9·565)		6–17 years old	Cross-sectional	LMS
Ayatollahi *et al.*, (2010)[27]	12	Iran	NR /2·397 (♂: 1·268; ♀: 1·129)		6 years old and 5 months and 11 years old and 5 months	Cross-sectional	LMS
Ayatollahi *et al.*, (2008)[28]	12	Iran	NR/ 2·237 (♂:1163; ♀: 1074)		6–12 years old	Cross-sectional	LMS
Barbosa Filho *et al.*, (2014)(19)	12	Brazil	27·000/ 2·035	♂:1·016; ♀: 1019	6 and11 years old	Cross-sectional	LMS
Bonilla *et al.*, (2018)(11)	10	Colombia	NR/2·241 (♂: 1·159; ♀: 1082)		6–17 years old and 9 months	Cross-sectional	LMS
Brannsether *et al.*, (2013)(12)	12	Norway	8·299/ 4·606	♂: 2·325; ♀: 2·281	4–16 years old	Cross-sectional	LMS
Bundak *et al.*, (2006)[29]	11	Turkey	NR/ 2·209 (♂: 1·100; ♀: 1·019)		6–18 years old	Longitudinal	LMS
Bustamante *et al.*, (2015)[63]	12	Peru	72·000/ 8·753	♂: 4·130; ♀: 4·623	4–17 years old	Cross-sectional	LMS
Cacciari *et al.*, (2002)[79]	12	Italy	NR/ 54·795 (♂:27·374, ♀: 27·421)		6–19 years old	Cross-sectional	LMS
Campos *et al.*, (2014)[64]	10	Brazil	26·725/ 6·531	♂: 3·315; ♀: 3·216	6–17 years old and 9 months	Cross-sectional	LMS
Chacar; Salameh (2007)[30]	12	Lebanon	NR/ 2·547 (♂: 1·131; ♀: 1·416)		11–18 years old	Cross-sectional	LMS
Chacar; Salameh (2011)[31]	12	Lebanon	NR/ 12·299 (♂:5·529 ; ♀: 6·770)		10–18 years old	Cross-sectional	LMS
Chaves *et al.*, (2015)[80]	12	Portugal	NR/ 3·094 (♂: 1·537; ♀: 1·557)		7–17 years old	Cross-sectional	LMS
Cicek *et al.*, (2014)[13]	12	Turkey	1·200 000/ 4·285	♂: 1·914; ♀: 2·371	6–17 years old	Cross-sectional	LMS
Conde; Monteiro (2006)[22]	12	Brazil	NR/ 26·102 (♂: 13·279; ♀: 12·823)		24–240 months	Cross-sectional	LMS
De Plata *et al.*, (2011)[65]	12	Colombia	318·916/ 1·773	♂: 865; ♀: 908	10–16 years old	Cross-sectional	LMS
Eisemann., (2005)[95]	12	Australia	NR/ 8·500 (♂:4·277 ♀: 4·162)		7–15 years old	Cross-sectional	LMS
EL MOUZAN *et al.*, (2007)[32]	12	Saudi Arabia	42·000/ 35·279	♂: 17·880 ♀: 17·399	2–19 years old	Cross-sectional	LMS
EL MOUZAN *et al.*, (2016)[33]	12	Saudi Arabia	42·000/ 19·299	♂: 9·827; ♀: 9·472	5–18 years old	Cross-sectional	LMS
FRAINER *et al.*, (2013)[66]	12	Brazil	NR/ 2·936 (♂: 1·498 ♀: 1·438)		7–10 years old and 6months	Cross-sectional	LMS
FERNANDEZ *et al.*, (2004)[67]	12	USA	NR/ 9·713 (3·414 African American; 2·746 European-American e 3·553 Mexican - American)		2–18 years old	Cross-sectional	Percentile Regression
GALCHEVA *et al.*, (2009)[81]	12	Bulgaria	NR/ 3·827 (♂: 2·052 ♀: 1·775)		6–18 years old	Cross-sectional	LMS
Guedes *et al.*, (2009)[68]	12	Brazil	61·000/ 6·084	♂: 2·949; ♀: 3·135	7–18 years old	Cross-sectional	LMS
Guedes *et al.*, (2010)[69]	12	Brazil	175·826/ 5·100	♂: 2·730; ♀: 2·730	6–18 years old	Cross-sectional	LMS
Ghouili *et al.*, (2018)[76]	12	Tunisia	NR/ 4·358 (♂: 2·176; ♀: 2·182)		2–18 years old	Cross-sectional	LMS
Gomez-Campos *et al.*, (2019)[2]	12	Chile	31·696/ 9·232	♂: 4·851; ♀: 4·381	6–18 years old and 9 months	Cross-sectional	LMS
Hatipoglu *et al.*, (2007)[34]	12	Turkey	1·000·000/4·770	♂: 2·337; ♀: 2·433	7–17 years old	Cross-sectional	LMS
Hatipoglu *et al.*, (2013)[35]	12	Turkey	1 200 000/2·947	♂: 1·471; ♀: 1·476	24–84 months	Cross-sectional	LMS
Herbish *et al.*, (2009)[36]	12	Saudi Arabia	42·000/ 35·279	♂: 17·880 ♀: 17·399	2–19 years old	Cross-sectional	LMS
Hosseini *et al.*, (2013)[37]	12	Iran	NR/ 2·107 (♂: 1·152; ♀: 955)		2–6 years old	Cross-sectional	Polynomial Regression
Hosseini *et al.*, (2016)[38]	11	Iran	NR/ 14·865 (♂: 7·635; ♀: 7·230)		7–18 years old	Cross-sectional	LMS
Inokuchi *et al.*, (2015)[14]	12	Japan	NR/ 29·679 (♂: 15·466; ♀: 14·213)		6–18 years old	Cross-sectional	LMS
Jackson *et al.*, (2011)[39]	12	Kuwait	NR/ 9·593 (♂: 4·843; ♀: 4·750)		5–18 years old	Cross-sectional	LMS
Jaworski *et al.*, (2012)[82]	11	Poland	NR/ 17·416 (♂: 8·321; ♀: 9·095)		6–18 years old and 5 months	Cross-sectional	LMS
Jiang *et al.*, (2006)[40]	10	China	NR/ 96·104 (♂: 48·790; ♀: 47·314)		2–18 years old	Cross-sectional	LMS
Katzmarzyk, (2004)[70]	12	Canada	NR/ 3·064 (♂: 1·540; ♀: 1·524)		11–18 years old	Cross-sectional	LMS
Kelishadi *et al.*, (2007)[41]	12	Iran	16·000·000/ 21·111	♂: 10·253; ♀: 10·858	6–18 years old	Cross-sectional	LMS
Klaldikar *et al.*, (2009)[42]	12	India	19·834/ 18·666	♂: 10·496; ♀: 8·170	5–18 years old	Cross-sectional	LMS

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Table 1. (*Continued*)

Year/Author	Quality score	Study location	Population/Sample		Age group	Outline	Curves method
Klovgaard *et al.*, (2018)[71]	13	Greenland	383/ 279	♂: 147; ♀: 132	2–8 years old	Longitudinal	LMS
Kondolot *et al.*, (2017)[43]	12	Turkey	2·000/ 1·766	♂: 874; ♀: 892	24–83 months	Cross-sectional	LMS
Kromeyer-Hauschild *et al.*, (2012)[44]	12	Germany	NR/ 2·132 (♂: 1·114; ♀: 1·018)		6–14 years old and five months	Cross-sectional	LMS
Kuriyan *et al.*, (2011)[45]	12	India	NR/ 9·060 (♂: 5·172; ♀: 3·888)		3–16 years old	Cross-sectional	LMS
Li *et al.*, (2015)[46]	13	Taiwan	24·200/ 18·466		0–5 years old	Longitudinal	LMS
Luciano *et al.*, (1997)[83]	10	Italy	NR/ 41·869 (♂: 20·796; ♀: 21·073)		3–19 years old	Cross-sectional	LMS
Ma *et al.*, (2010)[47]	12	China	NR/ 232·140 (♂: 116·676; ♀: 115·464)		7–18 years old	Cross-sectional	LMS
Mazicioglu *et al.*, (2010)[48]	10	Turkey	1·200·000/ 5·481		6–18 years old	Cross-sectional	LMS
Mccarthy *et al.*, (2001)[84]	11	Great Britain	NR/ 8·355 (♂: 3585; ♀: 4770)		5–16 years old	Cross-sectional	LMS
Moreno *et al.*, (2006)[15]	12	Spain	213·624/ 2·160	♂: 1·109; ♀: 1·051	13–18 years old	Cross-sectional	LMS
Moreno *et al.*, (2007)[16]	12	Spain	213·624/ 2·160	♂: 1·109; ♀: 1·051	13 years old and 5 months 17 years old and 5 months	Cross-sectional	LMS
Mukherjee *et al.*, (2016)[49]	12	Singapore	NR/ 3·029 (♂: 1·506; ♀: 1·523)		6–17 years old	Longitudinal	LMS
Mumm *et al.*, (2014)[85]	12	Germany	17·000/ 3·776♀		10–17 years old	Cross-sectional	LMS
Mumm *et al.*, (2016)[86]	12	Germany	17·000/ 3·956♂		10–17 years old	Cross-sectional	LMS
Mushtaq *et al.*, (2011)[50]	12	Pakistan	2·500·000/ 1·860	♂: 997; ♀: 883	512 years old	Cross-sectional	LMS
Nawarycz *et al.*, (2009)[87]	12	Poland	NR/ 5·663 (♂: 2·779; ♀: 2·884)		7–18 years old	Cross-sectional	LMS
Nielsen *et al.*, (2009)[88]	13	Denmark	5·998/ 4·105	♂: 2·779; ♀: 2·884	2–5 years old	Longitudinal	LMS
Nyankovskyy *et al.*, (2018)[1]	12	Ukraine	25·000/ 13·712	♂: 6·582; ♀: 7·130	7–18 years old	Cross-sectional	LMS
Nyati *et al.*, (2019)[77]	13	South Africa	5·460/ 3·273		2–19 years old	Longitudinal	LMS
Ohyenart *et al.*, (2014)[72]	12	Argentina	NR/ 18·698 (♂: 8·672; ♀: 10·026)		3–13 years old	Cross-sectional	LMS
Ohyenart *et al.*, (2019)[17]	12	Argentina	NR/ 22·736 (♂: 11·397; ♀: 11·339)		4–14 years old	Cross-sectional	LMS
Ozer, (2007)[51]	12	Turkey	NR/ 1·427 (♂: 709; ♀: 718)		6–17 years old	Cross-sectional	LMS
Ozturk *et al.*, (2009)[52]	12	Turkey	NR/ 5·553 (♂: 2·710 ♀: 2·843)		6–17 years old	Cross-sectional	LMS
Pandey *et al.*, (2009)[53]	12	India	NR/ 1·225 (♂: 684; ♀: 541)		14–18 years old	Cross-sectional	LMS
Pirincci *et al.*, (2012)[54]	12	Turkey	31·219/ 3·342	♂: 1·708; ♀: 1·634	6–11 years old	Cross-sectional	LMS
Poh *et al.*, (2011)[55]	12	Malaysia	NR/ 16·203 (♂: 8·093; ♀: 8·110).		6–16 years old	Cross-sectional	LMS
Qiu *et al.*, (2013)[56]		China	19·006·000/ 81·055 (♂: 40·078; ♀: 40·110).		6–18 years old	Cross-sectional	LMS
Ramirez-Velez *et al.*, (2017)[73]	12	Colombia	NR/ 7·954 (♂: 3·460; ♀: 4·494)		9–17 years old and 9 months	Cross-sectional	LMS
Rosario *et al.*, (2010)[89]	12	Germany	NR/ 17·641 (♂: 8·645; ♀: 8·378)		2–17 years old	Cross-sectional	LMS
Rosner *et al.*, (1998)[74]	12	USA	101·298/ 66·772	♂:34·031; ♀: 32·741	5–17 years old	Cross-sectional	Polynomial Regression
Rush *et al.*, (2013)[96]	13	New Zealand	3·080/ 1·225	♂: 643; ♀: 582	2–10 years old	Longitudinal	LMS
Sakomoto *et al.*, (2008)[57]	12	Japan	1·338·220/ 358·706	♂:179·328; ♀: 179·353	5–17 years old	Cross-sectional	LMS
Santos *et al.*, (2011)[90]	12	Portugal	NR/ 1·500 (♂: 698; ♀:892)		15–18 years old	Cross-sectional	LMS
Savva *et al.*, (2001)[91]	12	Cyprus	128·700/ 2·472	♂: 1·214; ♀:1·258	6–17 years old	Cross-sectional	Polynomial Regression
Schwandt *et al.*, (2008)[92]	12	Germany	5·377/ 3·531	♂: 1·788 ♀:1·743	3–11 years old	Cross-sectional	LMS
Shah *et al.*, (2020)[92]	12	UK	2·682/ 1·562	♂: 652 ♀: 910	4–13 years old	Cross-sectional	LMS
Shaik *et al.*, (2016)[58]	12	Saudi Arabia	42·000/ 15·601	♂: 7·896; ♀: 7·705	24–60 months	Cross-sectional	LMS
Shang *et al.*, (2003)[59]	12	China	NR/ 27·200 (♂: 13·600; ♀: 13·600)		2–18 years old	Cross-sectional	LMS
Silva *et al.*, (2012)[20]	13	Brazil	NR/ 6·591 (♂: 3·280; ♀: 3·311)		7–17 years old	Mixed longitudinal	LMS
Smpokos *et al.*, (2018)[94]	11	Greece	NR/ 12·619 (♂: 7·034; ♀: 5·585)		24–78 months	Mixed longitudinal	LMS
Sung *et al.*, (2008)[60]	12	China	NR/ 14·842 (♂: 7·432; ♀: 7·370)		6–18 years old	Cross-sectional	LMS
Virani, (2010)[61]	12	India	NR/ 7·401 (♀: 3·814; ♀: 3·587)		2–18 years old	Longitudinal	LMS
Vargas *et al.*, (2011)[75]	11	Venezuela	NR/ 1·787 (♀: 884; ♀: 903)		2–18 years old	Cross-sectional	LMS

♂, male; ♀, female; NR, not reported.

elaborate reference growth curves for underweight, overweight and obesity[27,33]. One study used BM/total length (BM/length) to elaborate reference growth curves for underweight, overweight and obesity[33]. Two studies took into account total length/height to elaborate reference growth curves for underweight, overweight and obesity[58,71]. Two studies used arm fat area and arm muscle area to elaborate reference curves to identify underweight, overweight and obesity[17,52] (online Supplementary File 1).

With regard to skinfolds, eight studies used triceps skinfold for the development of reference growth curves for underweight, overweight and obesity in children and adolescents[12,13,16,44,52,62,66,82]. Eight studies used subscapular skinfold for the construction of reference growth curves for underweight, overweight and obesity[12,13,16,44,53,62,66,82]. Two studies used suprailiac skinfold to elaborate reference growth curves for underweight, overweight and obesity[13,66]. One study used biceps skinfold to develop reference growth curves for underweight, overweight and obesity[13]. One study took into account calf skinfold for the construction of reference growth curves for underweight, overweight and obesity in children and adolescents[66]. One study took into account the abdominal skinfold for the construction of reference growth curves for underweight, overweight and obesity[82] (online Supplementary File 1).

Regarding body perimeters, thirty-three studies used waist circumference to elaborate reference growth curves for underweight, overweight and obesity mainly abdominal, in children and adolescents[2,16,19,26,34,35,39,41,45,49,50,53–55,60,61,63,65,67,70,73,75,77,78,80,81,84,87,90–93,95]. Three studies used head perimeter[16,41,77] and two studies used arm perimeter[17,28]. Three studies used head perimeter[33,58,94], and two studies used neck perimeter[43,48] (online Supplementary File 1).

Characteristics of studies in relation to percentiles (P) used to elaborate reference growth curves in children and adolescents and percentiles used to identify underweight, overweight and obesity in children and adolescents

The percentiles identified in studies on reference growth curves for underweight, overweight and obesity varied, and percentiles are presented in online Supplementary File 2. Thirty-six studies presented percentiles used in reference growth curves to identify underweight children and adolescents ranging from P1 to P10[1,2,11,13,15,16,22,25,27,28,34,35,37,40,44,52,56,58,59,63,63–65,71,72,76–81,83,85,86,88,95,97]. Thirty-nine studies presented percentiles used in reference growth curves to identify overweight in children and adolescents ranging from P75 to P90[1,2,11–14,22,24,24,26–29,32,34,35,40,42,51–53,58,61–64,66,71,73,74,76,78,80,81,88,89,91,94,94,95,97] (online Supplementary File 1).

Sixty-seven studies presented percentiles used in reference growth curves to identify obesity in children and adolescents ranging from P75 to P99·6 (online Supplementary File 1).

Nineteen studies did not report percentiles used in reference growth curves to define underweight, overweight and obesity[17,20,30–33,36,41,46,47,56,57,60,68,69,82,83,90,96] (online Supplementary File 1).

Characteristics of studies in relation to variables used for stratification and modelling of reference growth curves in children and adolescents

All studies considered sex and age group for stratification and modelling of reference growth curves for children and adolescents (*n* 86). In addition, one study took into account regions of the country for stratification and modelling of curves[79], two studies considered ethnicity[67,74] and one study considered menarche[86]. One study took into account the maturational stage for stratification and modelling of reference growth curves for children and adolescents[85], one study considered skin colour[85] and two studies considered area of residence[56,59] (online Supplementary File 1).

Risk of bias assessment

Regarding the methodological quality, when considering the overall score of included studies (*n* 86), it was found that the highest score obtained was 13[20,46,62,71,77,96], and the lowest score of studies was 10[11,40,48,64,83] (Table 2).

Discussion

This systematic review identified eighty-six studies that took into account growth curves for underweight, overweight and obesity, with forty studies carried out in the Asian continent, thirty-two studies carried out in Europe, twenty studies carried out in the Americas, two studies carried out in Africa and two studies carried out in Oceania. Reference growth curves are used all over the world, both to estimate height–BM changes over time and to estimate the growth of these parameters and population weight status[12,19,22,33,78,97]. Although there are institutions such as the CDC, WHO and IOTF that have developed standard growth curves to estimate the weight status of the world population, several countries, from all continents, develop their own reference growth curves[6,11,35,37,38,63,67]. Since prescriptive growth patterns define how a population of children should grow, following ideal nutrition and ideal health, on the other hand, reference growth curves emerged, which are descriptive and elaborated from a population that believes to be growing up in the best possible state of nutrition and health in a given community, describing the growth of children at a specific time[3,6]. Although the standard curve is the growth objective to be achieved, the elaboration of reference growth curves by countries is necessary to verify the phenomenon of the secular trend of thinness, overweight and obesity. In addition, the growth curves are useful for demonstrating genetic and geographic differences between populations and generations, as well as exploring possible economic and cultural differences between countries[3,6–8,11,35,37,38,63,67].

The most prevalent anthropometric indicators for the construction of a reference growth curve for underweight, overweight and obesity were BMI for age (forty-six studies), waist circumference (thirty-three studies), BM for age (twenty-nine studies) and height for age (twenty-five studies). The justification for the greater use of these anthropometric indicators is related to the simplicity of measurement, with less possibility of technical

Table 2. Bias risk assessment of studies included in the systematic review

Author(s), (year)	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Final Escore
Abdulrazzaq *et al.*, (2011)[97]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Addo *et al.*, (2010)[62]	1	1	1	1	1	1	1	1	1	1	1	0	1	1	13
Aeberli *et al.*, (2011)[78]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Al-Isa *et al.*, (2016)[24]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Altunay *et al.*, (2011)[25]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Anzo *et al.*, (2015)[26]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Ayatollahi *et al.*, (2010)[27]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Ayatollahi *et al.*, (2008)[28]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Barbosa Filho *et al.*, (2014)[19]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Bonilla *et al.*, (2018)[11]	1	1	0	1	0	0	0	1	1	NA	1	NA	NA	1	10
Brannsether *et al.*, (2013)[12]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Bundak *et al.*, (2006)[29]	1	1	NR	1	0	1	1	1	1	1	1	0	1	1	11
Bustamante *et al.*, (2015)[63]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Cacciari *et al.*, (2002)[79]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Campos *et al.*, (2014)[64]	1	1	0	1	1	0	0	1	1	NA	1	NA	NA	1	10
Chacar; Salameh (2007)[30]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Chacar; Salameh (2011)[31]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Chaves *et al.*, (2015)[80]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Cicek *et al.*, (2014)[13]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Conde; Monteiro (2006)[22]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
De Plata *et al.*, (2011)[65]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Eisemann., (2005)[95]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
El Mouzan *et al.*, (2007)[32]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
El Mouzan *et al.*, (2016)[33]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Frainer *et al.*, (2013)[66]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Fernandez *et al.*, (2004)[67]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Galcheva *et al.*, (2009)[81]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Guedes *et al.*, (2009)[68]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Guedes *et al.*, (2010)[69]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Ghouili *et al.*, (2018)[76]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Gomez-Campos *et al.*, (2019)[2]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Hatipoglu *et al.*, (2007)[34]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Hatipoglu *et al.*, (2013)[35]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Herbish *et al.*, (2009)[36]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Hosseini *et al.*, (2013)[37]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Hosseini *et al.*, (2016)[38]	1	1	1	1	0	0	0	1	1	NA	1	NA	NA	1	11
Inokuchi *et al.*, (2015)[14]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Jackson *et al.*, (2011)[39]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Jaworski *et al.*, (2012)[82]	1	1	1	1	0	0	0	1	1	NA	1	NA	NA	1	11
Jiang *et al.*, (2006)[40]	1	1	0	1	0	0	0	1	1	NA	1	NA	NA	1	10
Katzmarzyk, (2004)[70]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Kelishadi *et al.*, (2007)[41]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Klaldikar *et al.*, (2009)[42]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Klovgaard *et al.*, (2018)[71]	1	1	1	1	1	1	1	1	1	1	1	0	1	1	13
Kondolot *et al.*, (2017)[43]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Kromeyer-Hauschild *et al.*, (2012)[44]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Kuriyan *et al.*, (2011)[45]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Li *et al.*, (2015)[46]	1	1	1	1	1	1	1	1	1	1	1	0	1	1	13
Luciano *et al.*, (1997)[83]	1	1	0	1	0	0	0	1	1	NA	1	NA	NA	1	10
Ma *et al.*, (2010)[47]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Mazicioglu *et al.*, (2010)[48]	1	1	0	1	0	0	0	1	1	NA	1	NA	NA	1	10
Mccarthy *et al.*, (2001)[84]	1	1	1	0	1	0	0	1	1	NA	1	NA	NA	1	11
Moreno *et al.*, (2006)[15]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Moreno *et al.*, (2007)[16]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Mukherjee *et al.*, (2016)[49]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Mumm *et al.*, (2014)[85]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Mumm *et al.*, (2016)[86]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Mushtaq *et al.*, (2011)[50]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Nawarycz *et al.*, (2009)[87]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Nielsen *et al.*, (2009)[88]	1	1	1	1	1	1	1	1	1	1	1	0	1	1	13
Nyankovskyy *et al.*, (2018)[1]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Nyati *et al.*, (2019)[77]	1	1	1	1	1	1	1	1	1	1	1	0	1	1	13
Ohyenart *et al.*, (2014)[72]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Ohyenart *et al.*, (2019)[17]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Ozer, (2007)[51]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Ozturk *et al.*, (2009)[52]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Pandey *et al.*, (2009)[53]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Pirincci *et al.*, (2012)[54]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12

Table 2. (*Continued*)

Author(s), (year)	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Final Escore
Poh *et al.*, (2011)[55]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Qiu *et al.*, (2013)[56]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Ramirez-Velez *et al.*, (2017)[73]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Rosario *et al.*, (2010)[89]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Rosner *et al.*, (1998)[74]	1	1	1	1	1	1	1	1	1	NA	1	0	NR	1	12
Rush *et al.*, (2013)[96]	1	1	1	1	1	1	1	1	1	1	1	0	1	1	13
Sakomoto *et al.*, (2008)[57]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Santos *et al.*, (2011)[90]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Savva *et al.*, (2001)[91]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Schwandt *et al.*, (2008)[92]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Shah *et al.*, (2020)[93]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Shaik *et al.*, (2016)[58]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Shang *et al.*, (2003)[59]	1	1	1	1	1	0	0	1	1	NA	1	NA	NA	1	12
Silva *et al.*, (2012)[20]	1	1	1	1	1	1	1	1	1	1	1	0	1	1	13
Smpokos *et al.*, (2018)[94]	1	1	1	1	1	0	1	1	1	0	1	0	1	1	11
Sung *et al.*, (2008)[60]	1	1	1	1	1	0	1	1	1	NA	1	NA	NA	1	12
Virani, (2010)[61]	1	1	1	1	1	1	1	1	1	1	1	0	0	1	12
Vargas *et al.*, (2011)[75]	1	1	1	0	1	0	0	1	1	NA	1	NA	NA	1	11

1, yes; 2, no; NA, not applicable; NR, not reported. Q1: Was the research question or objective in this study clearly stated?; Q2: Was the study population clearly specified and defined?; Q3: Was the participation rate of eligible persons at least 50 %?; Q4: Were all the subjects selected or recruited from the same or similar populations (including the same time period)? Were inclusion and exclusion criteria for being in the study pre-specified and applied uniformly to all participants?; Q5: Was a sample size justification, power description or variance and effect estimates provided?; Q6: For the analyses in this study, were the exposures of interest measured prior to the outcome(s) being measured?; Q7: Was the time frame sufficient so that one could reasonably expect to see an association between exposure and outcome if it existed?; Q8: For exposures that can vary in amount or level, did the study examine different levels of the exposure as related to the outcome (e.g. categories of exposure or exposure measured as a continuous variable)?; Q9: Were the exposure measures (independent variables) clearly defined, valid, reliable and implemented consistently across all study participants?; Q10: Were the exposures assessed more than once over time?; Q11: Were the outcome measures (dependent variables) clearly defined, valid, reliable and implemented consistently across all study participants?; Q12: Were the outcome assessors blinded to the exposure status of participants?; Q13: Was loss to follow-up after baseline 20 % or less?; Q14: Were key potential confounding variables measured and adjusted statistically for their impact on the relationship between exposures and outcomes?

errors and low operational cost[46,71,73,85,93]. Thus, BMI is the anthropometric indicator most frequently used to identify the reference physical growth and weight status in clinical and epidemiological practice, as it is a simple and low-cost indicator and strong discriminator of child and adolescent health and for presenting highly significant correlation with BM and height[19,32,80,98]. Limitations of BMI must be considered, as BMI assesses not only fat mass but also fat-free mass[13,32,36,37,80,98]. It is a good index to identify those children with 'adequate' adiposity, but among those with high BMI, there is an important proportion of children with normal adiposity[13,32,36,37,56,80,98]. BM for age and height for age are also widely used to identify malnutrition, overweight and obesity in children and adolescents, taking into account the simplicity of measurements and its use to calculate BMI[14,38,58,76,77,94]. Waist circumference is widely used in population surveys, as it is a highly sensitive and specific measure of central body fat in childhood and adolescence to identify overweight and obesity and discriminate risk for metabolic complications[26,49,63,73,77,80]. The percentiles used to define underweight in the reference growth curves in children and adolescents ranged from P1 to P10. The most prevalent underweight percentiles found in studies were P3 and P5, which is in line with percentiles suggested by WHO, IOTF and CDC[7,8,10]. However, the values present in studies included in this review differ from those presented by WHO, IOTF and CDC. Thus, the development of growth curves to identify underweight is necessary, as different locations in the world have different subsistence conditions, which can directly interfere with nutritional conditions[3].

The percentiles used to define overweight in reference growth curves for children and adolescents ranged from P75 to P90. The most prevalent percentile found in studies to identify overweight was P85, which is in line with values recommended by WHO, IOTF and CDC. However, values of this percentile in studies were either below or above those recommended by the aforementioned agencies, demonstrating that the variability of physical growth and human development is characterised by intra- and inter-population heterogeneity, resulting from the continuous and complex interaction between genes and mesogenic conditions[3,11]. Thus, percentile values related to overweight are different in different locations around the world, requiring understanding the characteristics of the population under study.

The percentiles used to identify obesity in the reference growth curves of children and adolescents ranged from P75 to P99·6. The most prevalent percentiles used to identify obesity found in studies were P95 and P97. However, both P75, P85 and P90, which were also used to identify overweight in studies, were also used to identify obesity, demonstrating once again that percentiles vary depending on the country and population under study[11]. The aetiology of obesity is complex, with a multifactorial character that involves historical, ecological, political, socioeconomic, psychosocial, cultural, biological factors, in addition to the possible imbalance between inadequate nutrition and insufficient physical activity practices[4,11,99]. Due to this multifactorial character of obesity, studies show greater variability of percentiles to identify it.

All studies considered sex and age group for stratification and modelling of reference growth curves for children and

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adolescents. Sex and age group are important variables to be considered when modelling reference growth curves, especially in the age groups in which the process of sexual maturation and release of the testosterone hormone in boys begins, which provides an increase in the fat-free mass and the estradiol hormone in girls, which causes an increase in fat mass[100].

Regarding the methodological quality, when considering the overall score of studies (*n* 86), it was found that the highest score obtained was 13, and the lowest score was 10. Since most studies have cross-sectional design (seventy-five studies), it was not possible to verify the trend of underweight, overweight and obesity in children and adolescents, as there was no more than one assessment over time. Longitudinal, cohort or cross-sectional studies could more concretely address the secular trend regarding weight status, contributing to greater elucidation of underweight, overweight and obesity in the different locations specified in this systematic review.

The method used in studies for modelling reference growth curves for underweight, overweight and obesity was the LMS method (eighty-one studies). The L parameter represents the Box–Cox coefficient used for the mathematical transformation of values of anthropometric indicators with the aim of obtaining normal distribution in each stratum. The value selected for the L coefficient is the one whose transformation produces the smallest sum of squares of the variable's deviations. The M parameter expresses the median value of the index observed within each stratum; the S parameter represents the CV of each stratum[8]. LMS is the method mostly used in the elaboration of growth curves, because the main assumption of this method is that for independent data with positive values, the Box–Cox transformation, at each age, can be used to normalise data that present asymmetry in their distribution[8].

The main limitations of this systematic review are the heterogeneity of included studies, such as age group, sample size and the variability of percentiles used to identify underweight, overweight and obesity, which does not allow the recommendation of a specific percentile for the definition of underweight, overweight and obesity, but the presentation of the most prevalent percentiles. In addition, some studies did not indicate the specific percentiles for underweight, overweight and obesity, only demonstrating the sample percentiles. It should be added that the study was limited to English, Spanish and Portuguese. The systematic search carried out in nine different databases and manual searches in grey literature (Google scholar) in order to find possible studies that were not retrieved by the search strategy are among the strengths of this study. In addition, studies were rigorously peer-reviewed, being submitted to the methodological quality analysis tool, which allows verifying aspects of internal and external validity of studies and there was the synthesis of data from eighty-six studies carried out in six continents, presenting percentile variability in identifying public health problems such as underweight, overweight and obesity.

Conclusion

We identified that there is great variability among percentiles for the identification of underweight, overweight and obesity in the paediatric population. The most prevalent percentiles for underweight were P3 and P5; for overweight, the most prevalent was P85 and the most prevalent percentiles for obesity were P95 and P97. The most prevalent anthropometric indicators used for growth curves were BMI, waist circumference, BM for age and height for age. Such data can be used to create strategies and public policies to reduce public health problems such as malnutrition and obesity and to identify underweight, overweight and obesity, taking into account the variability of physical growth and human development characterised by intra- and inter-population heterogeneity. Such data can demonstrate that the optimal growth must be reached, through the standard growth curves, but that the reference curves demonstrate a cut of the population growth, raising possible variables that can influence the optimal growth, such as an increase in the practice of physical activities and an awareness of proper nutrition.

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Supplementary material

For supplementary materials referred to in this article, please visit https://doi.org/10.1017/S0007114522003786

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