

The Global Spread of Severe Obesity in Toddlers, Children, and Adolescents: A Systematic Review and Meta-Analysis

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Keywords

Severe obesity · Childhood · Infancy

Abstract

Introduction: Severe obesity among children and adolescents has emerged as a public health concern in multiple places around the world. **Methods:** We searched the Medline database for articles on severe obesity rates in children published between January 1960 and January 2020. For studies with available prevalence rates for an early and a more recent time period, the relative increase in prevalence was imputed. **Results:** In total, 874 publications were identified, of which 38 contained relevant epidemiological data. Rates of severe obesity varied significantly according to age, gender, geographic area, and the definition of severe obesity. The highest rates of class II and III obesity in the USA according to the Centers of Disease Control cut-off were 9.5% and 4.5%, respectively. Seventeen studies reported prevalence rates in at least two time periods. Data for 9,190,718 individuals showed a 1.71 (95% CI, 1.53–1.90) greater odds for severe obesity in 2006–2017 ($N = 5,029,584$) versus 1967–2007 ($N = 4,161,134$). In an analysis limited to studies from 1980s with a minimum follow-up of 20 years, a 9.16 (95% CI, 7.76–10.80)

greater odds for severe obesity in recent versus earlier time was found. An analysis limited to studies from 2000, with a follow-up of 5–15 years, a 1.09 (95% CI, 0.99–1.20) greater odds was noted when comparing (2011–2017; $N = 4,991,831$) versus (2000–2011; $N = 4,134,340$). **Conclusion:** Severe pediatric obesity is escalating with a marked increase from the 1980s and a slower rate from 2000.

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Introduction

The rising prevalence of severe obesity in children and adolescents was initially recognized in the USA in the mid-1970s. Severe obesity, which then accounted for less than 3% of children and adolescents, today accounts for up to 8% [1]. The recently published review of severe obesity among primary schoolchildren in 21 European countries [2] is an important resource for both clinicians and investigators. The prevalence of severe obesity varied significantly between countries, ranging from 1.0% in Swedish and Moldovan children to 5.5% in Maltese children. Nevertheless, studies have shown conflicting trends in

other parts of the world, depending on the population studied. Some studies with longitudinal follow-up report no change in the prevalence of severe obesity. Considering the extensive reporting of this phenomenon, we felt that a collation of available international data, beyond Europe and the USA, and including both preschool children and adolescents, would be helpful for examining underlying emerging patterns. Our primary objective is to describe changes in the prevalence of severe childhood obesity; the secondary objective is to study risk factors, such as sex, ethnicity, and socioeconomic position.

Methods

This review follows Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) suggestions (online suppl. material 1; see www.karger.com/doi/10.1159/000521913 for all online suppl. material). The Medline database was searched for articles on severe obesity in children and adolescents published between January 1960 and January 2020 in English. The following keywords were used alone and in combination: “severe obesity,” “morbid obesity” “extreme obesity” “children,” “adolescents,” “youth.” Published reports of studies that described obesity prevalence in children and adolescence were sought by systematically searching Medline, discussion with experts, and examination of the bibliographies of relevant articles. An experienced librarian and one of the authors (O.P.H.) conducted a comprehensive electronic search for articles using Medline, to identify studies that described prevalences of obesity, severe obesity, and morbid obesity among children and adolescents. Studies were included if they met all of the following: (1) they described severe obesity category prevalence; (2) described a cohort of children and adolescence; (3) were in English; and (4) were published between September 1960 and January 2020. These criteria were applied to all retrieved titles and abstracts of publications, to arrive at a final list of papers. Data from the retrieved studies were then abstracted and analyzed.

Data Abstraction

The following data were extracted from each study: (a) age; (b) sex; (c) date of data collection (d) obesity, definitions of severe obesity and morbid obesity; (e) rates of severe obesity category in recent and earlier time periods when available; (f) type of study; (g) ethnic group distribution according to obesity category, when available. The number of participants was 6,542,161. For each article, prevalence rates in the different time periods reported were collected. Thus, “early time period” corresponds to the prevalence rates in the first time period reported, and “recent time period” corresponds to the prevalence rates in the latest time period reported. Overlap between time periods did not preclude using the data collected for each time period.

Statistical Analysis

All the data were tabulated. In studies that provided prevalence rates in two time periods, the difference between the periods was calculated and plotted. The pooled estimates of the change in prevalence rates comparing the most recent to earlier time periods were obtained using the random effect model. Pooled estimates were

conducted for all studies that provided data for recent versus earlier time periods and separately for studies with a minimum follow-up of 20 years and studies with a follow-up ranging from 5 to 15 years. Heterogeneity was assessed using the Q and I^2 statistics. All analyses and graphics were conducted using Review Manager (RevMan) Version 5.3. Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration, 2014.

Results

A total of 874 publications were identified; 836 articles addressed bariatric surgery in severe obesity ($n = 204$), comorbidities associated with severe obesity ($n = 259$), genetic studies ($n = 120$), articles on treatment, nutrition, and psychology of severe obesity ($n = 156$) or unrelated data ($n = 83$), and were thus excluded from this review. Of the 50 full text articles assessed for eligibility, 38 contained epidemiological data on severe obesity in children and adolescents.

In all included studies weight and height were measured. The included studies defined severe obesity according to the following definitions:

- The age and gender-specific 99th percentile and above cut-offs, as proposed by the US Center of Disease Control and Prevention (CDC), according to growth curves [3]. This corresponds to body mass index (BMI) ≥ 1.2 times the 95th percentile, or the definition in adults of class II obesity, BMI ≥ 35 kg/m². The majority of the studies included this definition [1, 4–15].
- Severe obesity was further classified to class II obesity and class III obesity, as class II obesity ($\geq 120\%$ to $<140\%$ of the 95th percentile, or BMI ≥ 35 kg/m², whichever was lower), and class III obesity ($\geq 140\%$ of the 95th percentile, or BMI ≥ 40 kg/m², whichever was lower) [5, 6, 13, 14].
- WHO) median [16]. A few studies used this criterion [17–19].
- Cut-off values according to the International Obesity Task Force [20] [21–24].
- The age- and gender-specific 99th percentile and above according to the CDC cut-off [25–27] or according to the WHO [16] BMI cut-off standards.
- Cut-off values according to specific country BMI standards [28, 29].

The earliest population-based studies on severe obesity were published between 2000 and 2009 ($N = 4$) (Table 1). The remaining 34 were published between 2010 and January 2020. The studies defined morbid obesity according to different cut-off levels and described different age ranges.

Table 1. Prevalence of severe obesity in children and adolescents

Author, reference, country Years presented in the table	Age-group, years	Children with severe obesity, %	Type of study	Classification	Participant in the presented years, n
Skinner et al. [13] USA 2015–2016	2–19	Class II 6 (4.3, 7.6)	Nationally representative data	>120% of 95th percentile and >140% of 95th percentile CDC cut-off	3,340
	2–5	Class III 1.9 (1, 2.9)			
	6–8	0.2 (–0.1, 0.4)			
	9–11	1.4 (0.5, 2.3)			
	12–15	1.0 (0.4, 1.7)			
	16–19	2.2 (0.9, 3.4)			
Pan et al. [10] USA 2014	2–4	1.96	Serial cross-sectional national data	≥120% of 95th percentile, CDC cut-off	3,016,487
	2	1.13			
	3	2.10			
	4	3.12			
Marcus et al. [27] USA 2006	12	6.9	School-based screening	>99th percentile CDC cut-off	6,365
Skelton et al. [32] USA 1999–2004	2–19	3.8	Nationally representative data	>99th percentile CDC cut-off	12,384
	2–5	4.2			
	6–11	4.0			
	12–19	3.4			
Flores and Lin [26] USA 2007–2008	5.6±0.03	5.7	The National Center for Education Statistics Institute of Education Sciences (IES)	>99th percentile CDC cut-off	14,000
Robbins et al. [11] Philadelphia 2012–2013	5–18	7.3	Philadelphia public schoolchildren	≥120% of 95th percentile, CDC cutoff	88,798
Lohrmann et al. [33] Pennsylvania	Pre k–5G	12.5	National data	BMI ≥97 percentile CDC cut-off	212,055
	6G–8	14.9			
	G9–12	13.9			
Nguyen et al. [1] Philadelphia 2010	3–17	7.7 (5.8–9.9)	8 public community health centers	>120% of 95th percentile, CDC cut-off	691
	3–5	6 (3–11)			
	6–8	7 (3–13)			
	9–12	8 (5–13)			
	13–17	8 (5–13)			
Kharofa et al. [6] Cincinnati OH 2012–2014	2–18	Class II 4.7	Chart review of children	>120% of 95th percentile and 140% of 95th percentile CDC cut-off	217,037
	2–5	0.7			
	6–11	2.4			
	12–18	4.3			

Table 1 (continued)

Author, reference, country Years presented in the table	Age-group, years	Children with severe obesity, %	Type of study	Classification	Participant in the presented years, n
Day et al. [3] New York City 2010–2011	5–14 5–6 7–10 11–14	5.7 3.7 6.0 6.5	NYC public school students	>120% of 95th percentile CDC cut-off	635,257
Lo et al. [8] Northern California 2007–2010	3–5	1.6	Kaiser Permanente Northern California	>120% of 95th percentile CDC cut-off	42,559
Lo et al. [7] Northern California 2007–2010	6–17 6–11 12–17	5.6 5.3 5.8	Kaiser Permanente Northern California	>120% of 95th percentile CDC cut-off	117,618
Koebnick [47] Southern California 2007–2008	2–19 2–5 6–11 12–19	6.4 2.5 7.4 7.7	Kaiser Permanente Southern California	>120% of 95th percentile, CDC cut-off	710,949
Ball et al. [17] Edmonton Calgary Alberta, Canada 2017	4–6	2.16		BMI Z >3SD WHO cut-off	16,595
Carsley et al. [18] Toronto, Canada 2009–2015	0–6 0–2 2–5 5–6	1.0 0.5 1.3 2.1	Practice-based research network in	BMI Z >3SD WHO cut-off [≥ 99.9 th]	6,364
Carsley et al. [34] Ontario, Canada 2014–2015	<4 5–9 10–14 15–18	0.9 (0.7–1.0) 2.7 (2.3–3.1) 2.9 (2.4–3.3) 3.7 (3.1–4.3)	Electronic Medical Records Administrative data Linked Database (EMRALD)	BMI Z >3SD WHO cut-off [≥ 99.9 th]	31,272
Satkunam et al. [12] Ontario, Canada 2014–2016	1.5–2	0.3 (0.2–0.6)	The Applied Research Group for Kids (TARGET Kids) and BORN Ontario	120% of 95th percentile CDC cut-off	4,481
Jimenez Cruz et al. [35] Mexico Tijuana and Ensenada 2007	6–12	5.2	Survey	≥ 99 th percentile CDC cut-off	2,690
Shackleton et al. [38] New Zealand 2015–2016	4	2.9 (2.9, 3.0)	A national screening program	≥ 99.7 th percentile WHO cut-off	56,541
Farrant et al. [21] New Zealand 2007	13–18 <13 14 15 16 >17	2.5 (1.9–3.1) 2.6 (1.7–3.5) 2.1 (1.1–3.2) 2.6 (1.8–3.5) 2.5 (1.7–3.5) 2.7 (1.6–3.8)	Nationally representative sample	BMI >35 kg/m ² IOTF cut-off	9,107

Table 1 (continued)

Author, reference, country Years presented in the table	Age-group, years	Children with severe obesity, %	Type of study	Classification	Participant in the presented years, n
Utter et al. [22] New Zealand 2012	13–18	3.7 (2.5, 5.0)	Nationally representative sample	BMI >35 kg/m ² IOTF cut-off	8,372
Garnett et al. [5] Australia 2012	7–15	Class II 2.0 Class III 0.5	Australian cross-sectional surveys	>120% of 95th percentile and >140% of 95th percentile CDC cut-off	2,940
Xu et al. [23] Australia 2014	7–15	1.9	Cross-sectional Australian database	BMI >35 kg/m ² IOTF cut-off [\geq 99.8th]	2,079
Cho et al. [29] Korea 2007–2014	10–18	Class II 5.9 (5.2, 6.6) Class III 0.9 (0.6, 1.1)	National Health and Nutrition Examination Surveys	>120% of 95th percentile and >140% of 95th percentile Korean growth curve	7,197
Nam et al. [9] Korea 2013–2014	2–19 2–9 10–19	2.1 (1.6–2.7) 0.6 (0.3–1.3) 3.0 (2.2–4.0)	Korea Centers for Disease Control and Prevention	>120% of 95th percentile CDC cut-off	3,226
Chen et al. [36] Xiamen, China 2017	2–7	0.28	Cross-sectional survey, kindergarten	Weight-for height >50% reference population WHO cut-off	21,883
Zhang [24] China 2014	7–18 7–12 13–18	Girls 1.29 1.95 0.63 Boys 2.73 3.93 1.51	National surveys	BMI >35 kg/m ² IOTF cut-off	9,719
Eills et al. [30] United Kingdom 2012–2013	4–5 10–11	Girls 1.1 1.2 Boys 1.5 1.5	NCMP	99.9th percentile of the British 1990 (UK90) growth reference	1,076,824
Beynon and Bailey [40] Wales 2017–2018	4–5	3.1 (3.0–3.2)	CMP	99.6th percentile Royal College of Paediatrics	34,163
Bohn et al. [42] Germany 2015	<21	12.7	APR	\geq 99.5th percentile for age and sex	4,196
Segna et al. [39] Austria 2003–2004	2–16 2–4 4–7 7–10 10–1 13–16	2.1 1.8 2.4 2.5 1.3 1.2	Viennese sample of children and adolescents	BMI \geq 99.5th percentile of German national reference	24,989

Table 1 (continued)

Author, reference, country Years presented in the table	Age-group, years	Children with severe obesity, %	Type of study	Classification	Participant in the presented years, <i>n</i>
Cadenas-Sanchez et al. [41] Spain 2014–2015	4.6±0.9	Class II 1.2	PREFIT project	>120% of 95th percentile and >140% of 95th percentile WHO cut-off	3,178
van Dommelen et al. [15] Holland 1980–2009	2–18 2–5 6–11 12–18	Girls 1.00 0.63 0.17	National Dutch Growth Studies	>120% of 95th percentile WHO cut-off	10,894
Twig et al. [14] Israel 2015	17	Boys Class II 1.9 Class III 0.5	National data	>120% of 95th percentile and >140% of 95th percentile CDC cut-off	63,652
El Mouzan et al. [19] Saudi Arabia 2005	5–18 5–12 13–18	2 1.5 2.4	Cross-sectional sample from a stratified listing based on the population census	BMI >3 SDS WHO cut-off	19,317
AlBlooshi et al. [25] Ras Al-Khaimah United Arab Emirates 2014–2015	3–6 7–10 11–14 15–18	3.3 3.8 5.7 8.8	Population-based study	BMI ≥99th percentile CDC cut-off	44,942
Total, <i>N</i>					6,542,161

The CDC cut-off of >120% of the 95th percentile and WHO cut-off of zBMI >3, applied to the age and sex standardized. zBMI scores from WHO growth reference charts were used to estimate prevalence of severe obesity. IOTF, International Obesity Task Force; NCMP, National Child Measurement Programme; CMP, Childhood Measurement Programme; APV, Adiposity Patients Registry; BORN, Better Outcomes Registry and Network.

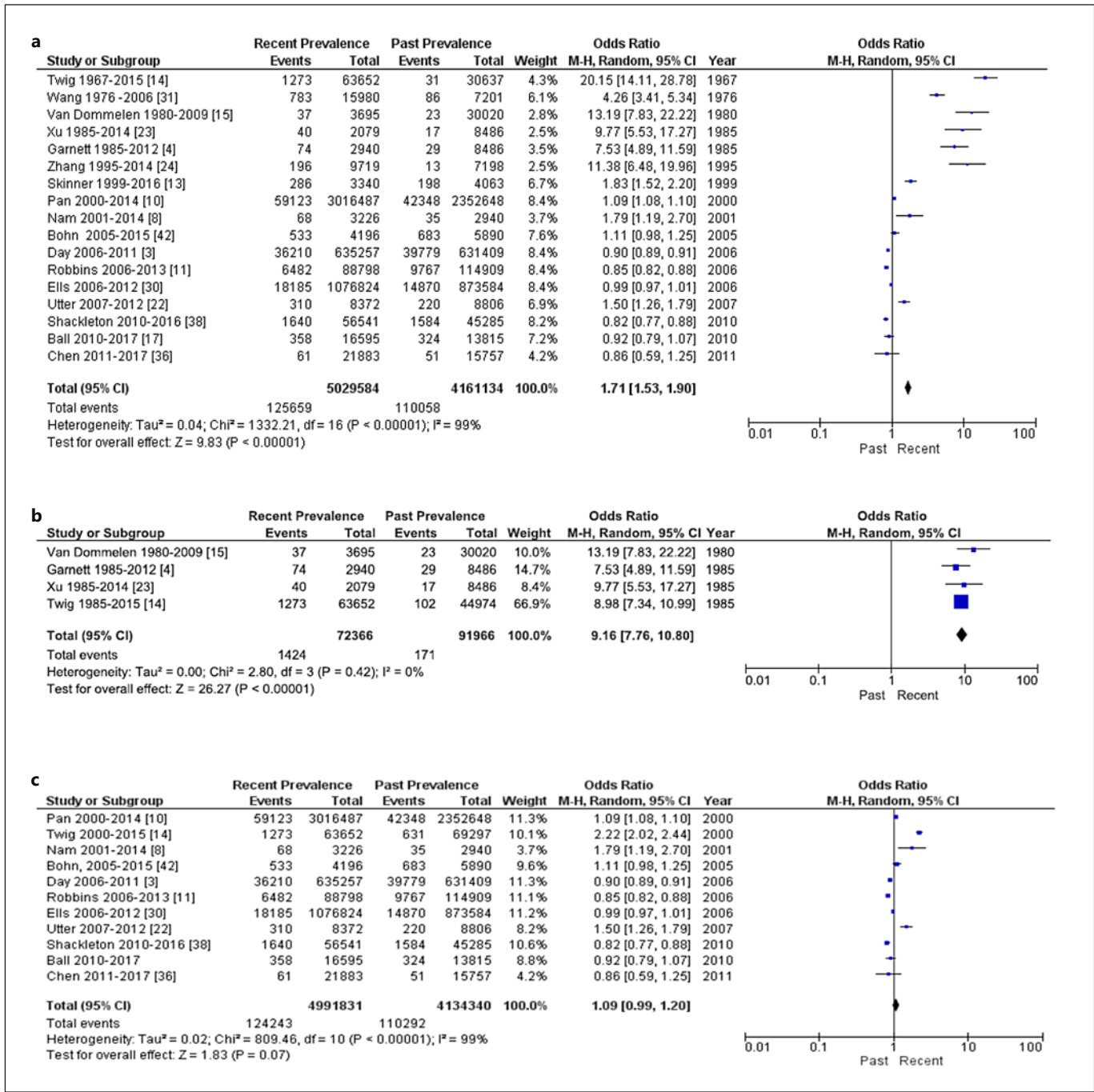


Fig. 1. a Trends of severe obesity in childhood – all studies 1967–2017 ($n = 17$). **b** Trends of severe obesity in childhood – studies from 1980 with follow-up of more than 20 years ($n = 4$). **c** Trends of severe obesity in childhood – studies from 2000 with follow-up of 5–15 years ($n = 11$).

Time Trends in the Prevalence of Severe Obesity

Seventeen studies reported trends of severe obesity over a period of time. Data for 9,190,718 individuals showed a 1.71 (95% CI, 1.53–1.90) greater odds for severe

obesity in the recent time period 2006–2017 ($N = 5,029,584$) than during the earlier time period, 1967–2007 ($N = 4,161,134$) (Fig. 1a). There was significant heterogeneity between the studies (p for heterogeneity 0.00001, I^2

Table 2. Prevalence of severe obesity in children according to ethnic groups

Author		White	Black	Hispanic	Asian/PI	Other	Age
Skinner et al. [13] USA 2015–2016	Class II	3.9 (2.8, 5.0)	9.0 (6.0, 12.1)	6.1 (6.7, 11.6)	1.4 (−0.3, 3.1)	7.6 (0.0, 15.3)	12–19
	Class III	1.1 (0.2, 2.0)	3.8 (1.8, 5.9)	3.3 (2.0, 11.6)	0	0.7 (−0.3, 1.6)	
Pan et al. [10] USA 2014	Class II	1.41	1.41	2.58	1.31	American Indian Alaska Native 2.35	2–4
Marcus et al. [27] USA 2006	>99th percentile	4.9	8	7.3			12
	Girls	4.1	8.7	6.4		5.7	
	Boys	5.8	7.1	8.2		8.0	
Skelton et al. [32] USA 1999–2004	>99th percentile	3.1	5.8	5.2		3.7	12–19
Robbins et al. [11] Philadelphia 2012–2013	Class II	5.8	8.3	7.7	1.8	5.3	5–18
Nguyen [1] Philadelphia 2010	Class II	4 (0–20)	9 (6–12)	6 (3–12)	9 (3–19)	6 (2–13)	
Kharofa et al. [6] Cincinnati OH 2012–2014	Class II	4.3	5.6	6.5		3	2–18
	Class III	2.4	3.9	2.8		2	
Day et al. [4] New York City 2010–2011	Class II	3.7	6.5	7.2	2.3		5–14
Lo et al. [8] Northern California 2007–2010	Class II						3–5
	Girls	1	1.7	2.2	1.0	1.1	
	Boys	0.8	1.3	3.3	1.6	1.8	
Lo et al. [7] Northern California 2007–2010	Class II	3.8	8.3	8.5	3.5	5.3	
Koebnic [47] Southern California 2007–2008	Class II	3.8	8.2	7.9	3.4	6.8	2–19
Farrant et al. [21] New Zealand 2007	Class II	1 (0.7, 1.3)			Asian 0.9 (0.2, 1.6) PI 9 (6.7–11.2) Maori 4.6 (3.4–5.9)		13–18
Utter et al. [22] New Zealand 2012		1.4 (1.1, 1.7)			Asian 0.8 (0.2, 1.4) PI 14.0 (10.7, 17.3) Maori 4.6 (3.3, 5.9)		
Shackleton et al. [38] New Zealand 2015–2016	≥99.7th percentile	2 (2.0–2.1)			Asian 1.8 (1.7, 1.8) PI 7.9 (7.7, 8.0) Maori 4.2 (4.1, 4.3)		4
Ells et al. [30] UK 2006–2013	99.6th percentile	1.83	4.46		3.41	3.16	4–5
		3.12	6.39		4.38	5.00	10–11
van Dommelen et al. [15] Holland 2009	2–18		Girls	Boys			
	Dutch		0.53	0.59			
	Turkish		1.71	2.53			
	Moroccan		1.65	1.07			

PI, Pacific Islanders.

= 99%). In an analysis limited to data from four studies with a minimum follow-up of 20 years, a 9.16 (95% CI, 7.76–10.80) greater odds for severe obesity in recent versus earlier time period was found, studies were homogeneous (p for heterogeneity 0.42, I^2 0%) (Fig. 1b). In an analysis limited to eleven studies with a follow-up in the range of 5–15 years, a 1.09 (0.99 [95% CI, 0.99–1.20]) greater odds for severe obesity was noted when comparing a more recent time period (2011–2017; $N = 4,991,831$) versus an earlier time period (2000–2011; $N = 4,134,340$) (Fig. 1c).

Ethnicity

Table 2 presents the distribution of severe obesity according to ethnic groups for the studies for which this was presented. Substantial racial-ethnic differences were demonstrated. In the USA, the highest rates of severe obesity were observed in Hispanic and non-Hispanic blacks across nearly all classes of obesity and all years between 1999 and 2016; prevalences of class II obesity reached 11.9% and 8.6%, respectively, in 2015–2016 [13]. Notably, for Asian Americans prevalences of obesity in all age and sex categories were relatively low [13]. In New Zealand, the prevalence of severe obesity was higher for Pacific students (9%) and Maori students (5%). Of the Pacific islanders, those of Tongan and Samoan ethnicity had a higher prevalence. In England, the highest prevalence levels were documented in 10 to 11-year-old black Caribbean children [30]. In Holland, the prevalence of morbid obesity in children of Turkish and Moroccan ethnicity was 2 to 3-fold higher than in Dutch children [15]. In general, severe obesity was associated with lower socioeconomic status.

Sex

Most studies showed higher rates of severe obesity among boys (Table 3). Three out of the 38 studies exceptions to such were observed. One is the study from Philadelphia, of randomly selected children aged 3–17 years, in which the rates in girls and boys were 9 and 6%, respectively [1]; the other exceptions are studies conducted in the United Arab Emirates, among children aged 3–10 years [25], and among 13–18-year-old adolescents from New Zealand [22].

Age

In most of the reports from the USA, the prevalence of severe obesity increased with increasing age. Similar trends were observed in Canada, Korea [9], the United Arab Emirates [25], and Saudi Arabia [19]. In contrast,

decreases in the prevalence of severe obesity with age were observed in China, Holland [15], and Austria.

Severe Childhood Obesity according to Region US – NHANES Reports

The first data on the increasing prevalences of childhood severe obesity are from the mid-1970s and reported initially in 2011 [31]. According to National Health and Nutrition Examination Surveys (NHANES) data, the prevalence in 1976–1980 of severe obesity in US children and adolescents aged 2–19 years was 1.2%. This prevalence increased incrementally to 2.9% and 3.1% in the years 1988 and 1994, respectively, and were 5.1% and 4.7% in 1999 and 2006, respectively (p value for the trend <0.001) [31, 32]. Among 6,358 children aged 12 years in 2006, 6.9% were with severe obesity [27]. Data for the sexes combined showed a prevalence of class II obesity of 5.8% (4.6–7.15) in 2009–2010, 6.2% (5.2–7) in 2013–2014; and 6.0% (4.3–7.6) in 2015–2016 [13]. Prevalences of class III obesity in the respective years were 1.6%, 2.3%, and 1.9%. The prevalence of severe obesity was shown to increase with age. In 2015–2016, 9.5% and 4.5% of 16- to 19-year-old adolescents had class II and class III obesity. Prevalence was higher in African Americans and Hispanics (Table 2) and in boys (Table 3). Of note, the prevalence of severe obesity among infants aged 2–4 years in 2014 was 2.0% [10].

Despite the gradual increase in severe pediatric obesity reported by NHANES, in various regions of the USA, a decrease in the prevalence of severe obesity has been recorded. Other reports from the USA since the year 2000. Three studies reported the prevalence of severe obesity in Philadelphia, Pennsylvania [1, 11, 33]. Using the criteria of a BMI percentile of 120% or higher, the prevalence of severe obesity decreased significantly for all children from 8.5% in 2006–2007 to 7.3% in 2012–2013, a relative decline of 13.9% [11]. Decreased prevalence was observed in all racial/ethnic groups, except for Hispanics. Using the definition of BMI ≥ 97 th percentile, high rates of severe obesity were reported, reaching up to 16% of students in grades 6–12 in 2007. However, between 2007 and 2011, declines were observed of 6.3% among girls and 8.1% among boys [33]. In Cincinnati, Ohio a decrease in class III obesity in 6- to 11-year-old girls (2.7% to 2.3) was observed over 3 years, between 2012 and 2014 [6]. Similarly, an overall reduction in severe obesity was observed in New York City public schoolchildren aged 5–14 years, over a 5-year period, from 6.3 in 2006 to 5.7% in 2011, representing a 9.5% decrease [4]. Overall, prevalence rates of severe obesity categories were higher in older children (12–18 years of age), Hispanic children, and children on Medicaid [6–8].

Table 3. Prevalence of severe obesity in children and adolescents according to gender

Author Country	Years	Age-group, years	Children with severe obesity, %		
			females	males	
Skinner et al. [13] USA	2015–2016	2–19			>120% of 95th percentile and >140% of 95th percentile CDC cut-off
		Class II	5.2 (3.3, 7.1)	6.7 (4.4, 8.9)	
		Class III	1.8 (0.8, 2.8)	2.0 (0.9, 3.2)	
Pan et al. [10] USA	2000	2–4	1.85	1.75	≥120% of 95th percentile, CDC cut-off
	2014		2.06	1.85	
Marcus et al. [27] USA	2006	12	6.4	7.5	>99th percentile CDC cut-off
Skelton et al. [32] USA	1999–2004	2–19	2.9	4.6	>99th percentile CDC cut-off
Robbins et al. [11] Philadelphia, USA	2006	5–18	8.1	8.9	≥120% of 95th percentile, CDC cut-off
	2013		7.2	7.5	
Nguyen et al. [1] Philadelphia, USA	2010	3–17	9 (6–12)	6 (4–10)	>120% of 95th percentile, CDC cut-off
Kharofa et al. [6] Cincinnati, OH, USA	2012–2014	2–18			>120% of 95th percentile and 140% of 95th percentile CDC cut-off
		Class II	4.9	4.5	
		Class III	3.1	2.5	
Day et al. [4] New York City, USA	2006	5–14	5.5	7.2	>120% of 95th percentile CDC cut-off
	2011		4.9	6.4	
Lo et al. [8] Northern California, USA	2007–2010	3	1.0	1.1	>120% of 95th percentile CDC cut-off
		4	1.1	1.6	
		5	2.1	3.0	
Lo et al. [7] Northern California, USA	2007–2010	6–17	5.3	5.8	>120% of 95th percentile CDC cut-off
		6–11	4.2	6.3	
		12–17	4.7	6.9	
Koebnick [47] Southern California, USA	2007–2008	2–19	5.5	7.3	>120% of 95th percentile, CDC cut-off
		2–5	2.3	2.7	
		6–11	6.0	8.8	
		12–19	6.8	8.7	
Carsley et al. [18] Toronto, Canada	2009–2015	0–2	0.4	0.6	BMI Z >3SD WHO cut-off [≥99.9th]
		2–5	0.8	1.7	
		5–6	1.7	2.4	
Carsley et al. [34] Ontario, Canada	2004–2015	≤4	0.6 (0.4, 0.8)	1.2 (0.9, 1.4)	BMI Z >3SD WHO cut-off
		5–9	1.7 (1.3, 2.2)	3.5 (2.9, 4.2)	
		10–14	2.4 (2.0, 3.0)	3.3 (2.7, 4.0)	
		15–18	3.8 (3.0, 4.8)	3.5 (2.7, 4.0)	
Cruz et al. [35] Tijuana and Ensenada, Mexico	2007	6–12	4.1	6.3	≥99th percentile CDC cut-off
Shackleton et al. [38] New Zealand	2010–2011	4	2.9 (2.8, 3.0)	4.0 (3.9, 4.1)	≥99.7th percentile WHO cut-off
	2015–2016		2.5 (2.5, 2.6)	3.2 (3.2, 3.3)	
Farrant et al. [21] New Zealand	2007	13–18	2.3 (1.4, 3.2)	2.6 (2.0, 3.3)	BMI >35 kg/m ² IOTF cut-off
Utter et al. [22] New Zealand	2007	13–18	2.4 (1.5, 3.2)	2.6 (2.0, 3.3)	BMI >35 kg/m ² IOTF cut-off
	2012		4.2 (2.5, 6.0)	3.2 (2.1, 4.3)	
2007–2012					

Table 3 (continued)

Author Country	Years	Age-group, years	Children with severe obesity, %		
			females	males	
Nam et al. [9] Korea 2001–2014	2014	2–9	0.8 (0.4, 1.9)	0.5 (0.1, 1.7)	>120% of 95th percentile CDC cut-off
		10–19	1.0 (0.5, 2.0)	4.7 (3.4, 6.5)	
Chen et al. [36] Xiamen, China 2011–2017	2017	2–7	0.17	0.39	Weight-for height >50% reference population WHO cut-off
		2	0.08	0.24	
		3	0.14	0.17	
		4	0.09	0.28	
		5	0	0.34	
6	0.55	0.86			
Zhang [24] China 1995–2014	1995	7–18	0.11	0.25	BMI >35 kg/m ² IOTF cut-off
	2014	7–12	1.29	2.73	
	2014	13–18	1.95	3.93	
				0.63	
Ells et al. [30] United Kingdom	2006–2013	4–5	1.9	2.3	99.9th percentile of the British 1990 (UK90) growth reference
		10–11	2.9	3.9	
Beynon and Bailey [40] Wales, United Kingdom 2017–2018	2017–2018	4–5	3.0 (2.7–3.2)	3.6 (3.4–3.9)	99.6th percentile Royal College of Paediatrics
Bohn et al. [42] Germany 2005–2015	2005	<21	11.2	12.2	≥99.5th percentile for age and sex
	2015		11.2	13.8	
Segna et al. [39] Vienna, Austria	2003–2004	2–16	1.9	2.3	BMI ≥99.5th percentile of German national reference
Cadenas-Sanchez et al. [41] Spain	2014–2015	4.6±0.9	1.2	1.3	>120% of 95th percentile and >140% of 95th percentile WHO cut-off
van Dommelen et al. [15] Holland	1980–2009	2–5	1.00	0.53	>120% of 95th percentile WHO cut-off
		6–11	0.63	0.62	
		12–18	0.17	0.60	
Twig et al. [14] Israel 1967–2015	1967–2015	17			>120% of 95th percentile and >140% of 95th percentile CDC cut-off
		Class II	1.2	1.9	
		Class III	0.4	0.5	
El Mouzan et al. [19] Saudi Arabia	2005	5–12	1.0	2.0	BMI >3 SDS WHO cut-off
		12–18	2.1	2.6	
AlBlooshi et al. [25] United Arab Emirates	2013–2015	3–6	3.4	2.5	BMI ≥99th percentile CDC cut-off
		7–10	4.4	3.9	
		11–14	5.6	7.1	
		15–18	7.2	9.6	

IOTF, International Obesity Task Force.

Canada

Four studies have been published from various regions of Canada. They are particularly important in their reporting the prevalence of severe obesity among infants and toddlers.

Edmonton and Calgary, Alberta

During an 8-year period, 2010–2017, the prevalence of severe obesity remained steady, at 2.2–2.4%, among children aged 4–6 years [17]. A greater proportion of boys than girls were classified as having severe obesity.

Toronto

A longitudinal study was conducted through The Applied Research Group for Kids! (TARGET Kids!), a practice-based research network [18]. Among 5,738 children aged <5 years, 0.8% had a BMI-Z >3. Among 626 children aged 5–6 years, 2.1% had a BMI-Z >3.

Ontario

A cross-sectional study was conducted among toddlers aged 17–24 months ($n = 768$) [12]. In total, 1.1% (95% CI, 0.8–1.4) of them met the adapted WHO definition of severe obesity compared to 0.3% (95% CI, 0.2–0.6) using the CDC definition. Low neighborhood household income and maternal prepregnancy obesity were associated with severe obesity.

In a repeated cross-sectional study that included 55,233 children aged 18 years or less, a plateauing of estimates and a small decrease in BMI-Z over time were observed, from 2.6% in 2004 to 1.8% in 2015 [34]. Overall, the prevalence of severe obesity increased with increasing age (Table 1) and was 2-fold higher in boys than in girls [18].

Central America

Mexico

A survey was conducted among 2,690 boys and girls aged 6–12 years in Tijuana and Ensenada [35]. An overall prevalence of severe obesity (the 99th percentile of BMI) was 5.2%: 6.3% among boys and 4.1% among girls.

Asia-Pacific Region

Shandong Province, China

A total of 41,500 students of Han nationality, aged 7–18 years old, were assessed [24]. For children aged 7–12 years, the prevalence of severe obesity increased from 0.39% in boys and 0.11% in girls in 1995 to 3.93% in boys and 1.95% in girls in 2014. For adolescents aged 13–18 years, the increases were from 0.11% in boys and 0.11% in girls in 1995 to 1.51% and 0.63%, respectively, in 2014. Thus, the incremental increases were greater in younger children than in adolescents. In more recent years, there has been a halt to the rise in severe obesity incidents. Xiamen, China. The prevalence of severe obesity decreased from 0.32% in 2011 to 0.28% in 2017 in preschool children aged 2–7 years ($n = 567,338$) in urban areas [36].

Korea

Data from 19,593 youth (10,271 boys) aged 2–19 were obtained from the Korean National Health and Nutrition Examination Surveys (2001–2014) [9]. The data were as-

essed according to two sets of criteria for severe obesity, based on BMI calculations. Severe obesity was defined as a BMI $\geq 120\%$ of the 95th percentile according to the US CDC criteria; and as BMI ≥ 99 th percentile according to the Korean CDC criteria (Table 1). According to CDC criteria, the overall prevalence of severe obesity increased from 1.2–1.8% in 2001 to 2.1–2.4% in 2013–2014 (p for trend 0.01). The increasing trend was statistically significant in boys, especially those aged 10–19 years (2.5% [95% CI: 1.5–3.9%] in 2001 to 4.7% [95% CI: 3.4–6.5%] in 2014, p for the trend 0.049) with no significant change among girls of any of the age-groups investigated.

Thailand, Bangkok

A cross-sectional survey was conducted among 462 schoolchildren aged 6 and 14 years old in northeastern Thailand between 2013 and 2014 [37]. According to a definition of severe obesity as weight for age >3 SD, 1.73% were classified as severely obese.

New Zealand

Trends in the prevalence of severe obesity among New Zealand 4 year olds across 5 years (2010–2015) were examined across quintiles of socioeconomic deprivation and by ethnicity [38]. Overall, 2.9% of the children were with severe obesity in 2016, a downtrend prevalence of 0.6% from 2010. The highest prevalence was observed among Pacific Islander children, specifically Tongans, 9.3%.

Similarly, in a national survey of the health and well-being of secondary school students in New Zealand, conducted in 2007 [21], the prevalence of severe obesity among Pacific students was 9.0%, Maori students 4.6%, and those from European origin 1.0%. Severe obesity was more common among students living in deprived (5.7%) than affluent (0.8%) areas and among students living in urban (3%) than rural areas (1%). In a survey that assessed the trend of severe obesity during 2007–2012, the prevalence for the general population did not change, while the prevalence for students aged 13–17 years from Pacific ethnicity increased from 9% to 14% [22].

Australia

Between 1985 and 2012, the prevalence of class II severe obesity increased from 0.3% to 2.0%, and of class III obesity from 0.1% to 0.5% [5]. In 2014, 28% of children with obesity were classified as having severe obesity [23].

Europe

A review [2] on severe obesity among children aged 6–9 years old in 21 countries in Europe was recently pub-

lished (Albania, Belgium, Bulgaria, Czech Republic, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Malta, Norway, Portugal, Slovenia, Spain, Republic of Macedonia, Republic of Moldova, Romania, San Marino, Sweden, Turkey). We report here data from countries that were not included in that report, more recent data, and data of age ranges that were not reported.

Austria

A total of 24,989 Viennese children, which represents 8% of the children and adolescents in Vienna, were recruited between 2003 and 2004 [39]. More boys (2.3%) than girls had severe obesity. Severe obesity was more prevalent in children from Turkish families and among those presumably of Serbo-Croatian origin than among children of native German origin. The respective prevalences of severe obesity among these groups were 2.7%, 3.4%, and 1.8% for boys; and 2.4%, 2.4%, and 1.6%, for girls. The highest prevalence was identified among children aged 7–10 years (2.5%), followed by 4–7 years (2.4%), 2–4 years (1.8%), 10–13 years (1.3%), and 13–16 years (1.2%).

Holland

Cross-sectional height and weight data of children of Dutch, Turkish, and Moroccan origin, aged 2–18 years, were selected from three national Dutch Growth Studies performed in 1980, 1997, and 2009 ($n = 54,814$) [15]. A significant upward trend occurred, and in 2009, the prevalence of severe obesity in children of Dutch origin was 0.59% in boys and 0.53% in girls. The prevalence was 3 to 4-fold higher in Turkish than in Dutch children (2.53% of the Turkish boys and 1.71% of the girls). Similarly, the prevalence of severe obesity in Moroccan children was 2- to 3-fold higher than in Dutch children. The highest prevalence rates of severe obesity were observed among children whose parents had low education.

England

Trend of severe obesity was assessed for the years 2006–2007 and 2012–2013 [30]. Severe obesity was classified in 1.9% of girls and 2.3% of boys aged 4–5 years. The odds of being severely obese slightly decreased for this age-group. For the 10- to 11-year age-group, the prevalence of severe obesity in 2012–2013 was 2.9% for girls and 3.9% for boys. The odds of being severely obese increased for the older girls and boys by 1.02 times for each additional year of measurement. Significant variations in prevalences of severe obesity were documented between ethnic groups, with the highest levels in 10-year-old to

11-year-old black Caribbean children. Among 10- to 11-year-old girls, the odds of being severely obese were 4.35 times greater for those in the most-deprived index of the multiple deprivation deciles than for those in the least-deprived reference category.

Wales

Data were assessed of 162,208 children mean age 5.06 ± 0.35 years, during 2013–14 and 2017–18 [40]. The overall prevalence of severe obesity was 3.1% (95% CI 3.0–3.2%). This ranged from 1.9% (95% CI 1.7–2.1%) in the least deprived areas to 3.9% (95% CI 3.7–4.0%) in the most deprived areas and was higher among boys than girls: 3.6% (95% CI 3.4–3.9%) versus 3.0% (95% CI 2.7–3.2%). Prevalence has increased over time, but the trend is not statistically significant.

Spain

Prevalences of class II and class III obesity among 3,178 preschool children, mean age 4.6 ± 0.9 , were 1.2% and 1.3%, respectively [41].

Germany

Data were provided by the Adiposity Patients Registry [42], used by 182 centers in Germany that specialize in pediatric obesity care; thus, the data do not reflect the prevalence in the general population. Severe obesity was defined as a BMI ≥ 99.5 th percentile for age and sex. Overall, among children with overweight and obesity, the prevalence of severe obesity increased from 11.6% in 2005 to 12.7% in 2015. This trend was present in both sexes. Severe obesity became more frequent both among younger (< 11 years: from 22.6% to 23.7% $p < 0.0001$) and older individuals (≥ 11 years: from 10.0% to 12.8%; $p < 0.0001$). The highest prevalence of severe obesity was found among Turkish native-speaking children and adolescents.

East/Middle

East Israel

A total of 2,785,227 Israeli adolescents (aged 17.2 ± 0.5 years) between 1967 and 2015 were included in a national study [14]. In 2015, 1.6% of the adolescents were with class II obesity and 0.44% with class III obesity. The rate of class II obesity was higher among boys, 1.9%, than among girls, 1.2%. Class III obesity was present in 0.5% of boys and 0.4% of girls. From 1967 through 1998, the prevalence of class II obesity increased from 0.12% to 0.80% in boys and from 0.01% to 0.50% in girls. The prevalence subsequently increased markedly, to approximately 2.0% in boys and 1.2% in girls during 2010–2015. The

prevalence of class III obesity remained low, at less than 0.05% until the late 1990s. From then, it increased dramatically, reaching 0.55% and 0.45% in boys and girls, respectively, by 2015.

Saudi Arabia

A total of 19,317 healthy children and adolescents aged 5–18 years were screened using WHO criteria for diagnosis [19]. The reported prevalence of severe obesity in 2005 was 2%. The prevalence was significantly higher among boys than girls (2.3% vs. 1.6%; $p < 0.001$).

United Arab Emirates

A population-based study comprised of 15,532 children (aged 4–12 years) in 2013–2014, and 29,410 children (aged 3–18 years) in 2014–2015 [25]. The rate of severe obesity was 9.6-fold higher in boys than girls (0.58% vs. 0.06%). For ages 15–18 years, 10.3% of boys and 3.0% of girls were severely obese.

Discussion

This review confirms the rise in global reporting of severe obesity in children and adolescents. Data recording during 1967–2017, including 9 million children and adolescents demonstrated a 1.7 increase in the prevalence of severe obesity when comparing recent to earlier time periods (2006–2017 and 1967–2007, respectively). When the analysis was limited to studies with a minimum of 20 years of follow-up, including data from the 1980s a 9.16-fold increase in the prevalence of severe obesity was demonstrated compared to a 1.09-fold increase in more recent studies with a 5- to 15-year follow-up. The varying definitions of severe obesity, age-groups, time periods, and study designs render the data hard to compare directly over time and across countries. Nonetheless, the relative homogenous results obtained in an analysis of data obtained from the studies with the longer follow-up period support the hypothesis that from 1980 to 2015 there was a substantial increase in severe obesity rates in children, with a slower rate of increase from 2000.

These findings are consistent with previous reports. Accordingly, Spinelli et al. [2] reported that during 2007–2013, among 636,933 primary schoolchildren in 21 countries in Europe, the prevalence of severe obesity varied greatly among countries, ranging from 1.0% in Swedish and Moldovan children to 5.5% in Maltese children. In many countries, 1 in 4 children with obesity had severe obesity. The consistent findings of increases over time in

rates of severe obesity, across heterogenous studies, demonstrate that the phenomenon is not limited to particular regions, but has become nearly universal.

Interestingly, an analysis of data from 2000 onward, showed no significant changes in the prevalence of severe obesity. Decreased prevalence of severe obesity in New Zealand was speculated to be secondary to improved diet and increased activity levels [38]. Decreased prevalence of severe obesity in New York [10] was speculated to be secondary to a number of federal programs promoting healthy food choices, increased support for families and communities, and the implementation of comprehensive public health strategies aimed to prevent and manage childhood obesity. The latter include school-based nutrition education, greater access to free or reduced-price meals, shifts toward healthier food items [11, 38], and outreach to parents by means of mobile health technology [38]. Alternatively, 6 years may be too short to detect changes at a national level.”

Among adults, greater prevalences of severe obesity have been reported among certain ethnic minority groups, such as African-Americans and Hispanic Americans. Similarly, prevalences of severe obesity are particularly high among adolescents from minority groups in the USA (African-Americans, Hispanic-Americans), Canada (First Nations people), Australia (Aboriginal), and New Zealand (Maori). In addition, data from Holland, the United Kingdom, and Austria indicate significantly higher prevalences among children and adolescents from immigrant groups (Moroccan, Turkey, Pakistan). While analyses of social trends suggest that adoption of a Western lifestyle is strongly associated with severe obesity in these populations, the low socioeconomic position should be considered. Indeed, data from England [30] and Wales, in particular [40] revealed significantly higher levels of severe obesity in regions of socioeconomic deprivation. Moreover, in the USA, severe obesity was more prevalent among children who were on Medicaid [6].

Severe obesity was generally more prevalent among boys than girls. This is consistent with the comprehensive review from Europe [2]. In contrast, data collected from adults during 1975–2014 estimated severe obesity in 58 million men compared to 126 million women [43]. Similarly in the USA, women were more likely to have severe obesity than men: 9.7% versus 5.6% [44]. Physical activity, cultural values (obesity is more culturally acceptable among women because excess weight gain is associated with maternity and nurturing), biological factors (e.g., menopause), and urbanization were the most commonly discussed explanations for sex disparities [45]. However,

rarely did studies elaborate beyond general terms. We hypothesize that in children and adolescents, cultural factors that place increasing pressure on girls not to be obese are attributed to the gender disparities. Furthermore, in regions such as China and Arab countries, the societal preference has traditionally been for sons. This could result in boys enjoying more of a family's resources [46]. In addition, in Arab countries, a perception still prevails among parents and their children that being overweight is a sign of high social class, beauty, fertility, and prosperity.

Severe obesity in children is higher in regions with a high incidence of severe obesity in adults. Population-based data have been pooled to estimate trends of severe obesity among adults from 1975 to 2014. Severe obesity was found to be highest in the high-income English-speaking countries (27.1%; 50 million), followed by the Middle East and Northern Africa (13.9%; 26 million) [43]. Thus, we suggest that attention to the epidemiology of general obesity in children and severe obesity in adult populations may be helpful in predicting the emergence of severe obesity in children. These data may have implications for screening programs in countries where severe obesity was not yet studied in children.

The association between age and severe obesity was not consistent. In some studies, the prevalence increased with age [47], while in others it did not. Severe obesity may be expected to develop during childhood, and thus be more prevalent in adolescents. On the other hand, body image is of great concern to adolescents, so they may strive harder to prevent severe obesity. The most worrying fact is the prevalence of severe obesity in infancy and early childhood. Data from Canada in infants aged 1.5–2 years show that 1.1% already have severe obesity, and at the age of 4–6 years the prevalence reaches 2.4%. Similar prevalence rates have been documented in Austria, among toddlers aged 2–4 years the prevalence is 1.8%, and in England, at 4–5 years it reaches 2.3%. In New Zealand, the prevalence in children aged 4–5 years was 2.9% years but reaches a prevalence of 9.3% among Pacific Islander toddlers. The significance of obesity so severe already at an early age on the associated morbidity associated should be investigated in long-term epidemiological studies.

This review has several limitations. First, it was limited to published data. Therefore, information was not available from regions where systemic data have not yet been collected. In addition, the exclusion of reports not in the English language limits generalizing globally. Moreover, the inclusion of varying definitions of severe obesity, age-groups, time periods, and study designs render the data hard to compare directly, over time and across countries.

Despite these limitations, the studies reviewed here confirm that severe obesity is being recognized as a health problem of international scope in children and adolescents, following much the same pattern as in adults. Our findings suggest that particular attention should be given to anthropometric parameters of infants, children, and adolescents living in areas characterized by a rise in severe obesity in adults. Since the lifelong occurrence of obesity-associated complications can also be expected to be higher in the pediatric age-group due to the long disease duration, the implementation of appropriate screening measures is particularly important. Based on these data, it would be helpful in the future if researchers would adopt a standard age breakdown and limit samples to individuals up to age 20 years. Second, the classification of severe obesity is inconsistent. The adoption of a unified cutoff level will enable better comparison and understanding of the implications of increasing pediatric obesity for international public health.

Statement of Ethics

An ethics statement is not applicable because this study is based exclusively on published literature.

Conflict of Interest Statement

The authors of this manuscript have no conflicts of interest to declare.

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Author Contributions

Orit Pinhas-Hamiel and Uri Hamiel performed the systematic search, did data extraction, interpreted the data, did the graphs and tables, and drafted and revised the review. Cole D. Bendor and Aya Bardugo contributed to the discussion and critically revised the manuscript. Gilad Twig and Tali Cukierman-Yaffe supervised the review, interpreted the data, and drafted and revised the manuscript. All authors read and approved the final manuscript.

Data Availability Statement

All data generated or analyzed during this study are included in these article material files. Further enquiries can be directed to the corresponding author.

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