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Global trends in prevalence of maternal overweight and obesity: A systematic review and meta-analysis of routinely collected data retrospective cohorts

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Abstract

Pregnant women with obesity are at greater risk of complications during pregnancy, peripartum and post-partum, compared to women with healthy BMI. Worldwide data demonstrating the changes in trends of maternal overweight and obesity prevalence informs service development to address maternal obesity, while directing resources to areas of greatest need. This systematic review and meta-analysis of population level data sought to evaluate global temporal changes in prevalence of maternal obesity and overweight/obesity, and compare trends between regions.

Pooled prevalence of obesity and overweight/obesity was estimated using random effects meta-analysis. Temporal and geographical trends in prevalence of obesity and overweight/obesity were examined using linear regression.

From 11,684 publications, 94 met inclusion criteria representing 121 study cohorts (Europe $n=71$; North America $n=23$; Australia/Oceania $n=10$; Asia $n=5$; South America $n=12$), totalling 49,009,168 pregnancies. No studies from Africa met the inclusion criteria. Eighty studies (85.1%) were evaluated as having a low risk of bias and 14 studies (14.9%) moderate. In the most recent full decade (2010–2019), global prevalence of maternal obesity was estimated as 16.3% (95% confidence interval (CI): 15.1–17.5%), or approximately one in six pregnancies. Combined overweight/obesity in pregnancy had a pooled prevalence of 43.8% (95%CI: 42.2–45.4%), approaching half of all pregnancies. In each continent, an upward trend similar to the global trend was observed. North America demonstrated the highest prevalence (obesity: 18.7% (95%CI: 15.0–23.2%)); overweight/obesity: 47.0% (95%CI: 45.7–48.3%)) and Asia demonstrated the lowest prevalence (obesity: 10.8% (95%CI: 7.0–16.5%)); overweight/obesity: 28.5% (95%CI: 18.3-41.5%)). Both maternal obesity and combined overweight/obesity prevalence increased annually by 0.34% and 0.64% ($p<0.001$), respectively. Our linear regression model estimates current global prevalence of maternal obesity as 20.9% (95%CI 18.6–23.1%) and projects that this will increase to 23.3% (95%CI 20.3–26.2%) by 2030.

Globally, maternal obesity and overweight/obesity prevalence is high and increasing, but varies greatly between regions, being highest in North America and lower in Asia. Maternity services across the globe should be adequately resourced to cope with the complexity of needs of pregnant women living with obesity. Future public health interventions should focus on reversing the high prevalence of maternal obesity observed across the globe. The availability of population-level data and research varies between regions, with more data required to understand the needs of maternal populations in the continents of Africa and Asia. Globally, there is a need for improved harmonisation and publication of data for monitoring and improvement of maternal inequalities.

Keywords

Pre-pregnancy body mass index; early pregnancy body mass index; maternal obesity; maternal overweight; BMI trends; obesity trends; overweight trends

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Introduction

Globally, rates of overweight and obesity prevalence have been increasing steadily, rising from 9.8% in 2006 to 13.2% in 2016 and are now reaching epidemic proportions worldwide [1–3]. Currently more than 50% of all adult women are overweight or obese, and this trend is reflected in women of child-bearing age [1].

There is high level of evidence that maternal obesity is associated with a range of adverse pregnancy complications and perinatal outcomes and is recognised as an important maternal risk factor by health authorities around the globe [4–8]. Outcomes of concern in pregnant women with obesity include hypertensive disorders of pregnancy (pre-eclampsia and gestational hypertension), gestational diabetes, large for gestational age fetuses, premature birth, stillbirth and infant mortality, induction of labour, emergency caesarean section, postpartum haemorrhage and shoulder dystocia [4–8].

Body mass index (BMI) is a commonly used indicator of healthy weight, calculated as an individual's weight in kilograms divided by the square of height in metres (kg/m^2) [1]. The World Health Organization (WHO) classification categorises adults (>20 years) into the following: underweight (BMI <18.5 kg/m^2), normal weight (BMI 18.5–24.9 kg/m^2), overweight (BMI 25–29.9 kg/m^2), obesity class I (BMI 30–34.9 kg/m^2), obesity class II (BMI 35–39.9 kg/m^2) and obesity class III (BMI >40 kg/m^2) [1].

There is a lack of conclusive worldwide data demonstrating the changes in trends of maternal overweight and obesity. Until recently, no study had explored the changing trends in prevalence across the globe [9]. Our review utilises population level data to provide a comprehensive update to the publication from Martínez-Hortelano *et al.* published in 2020, extending the inclusion and exclusion criteria to select cohorts that more closely reflect the populations studied [9]. Several longitudinal studies have investigated maternal obesity, however, these are not without their limitations - excluding pregnancies by gestational age cut offs [10] and including only those which resulted in live births [11–14]. Given the association between increased BMI, preterm birth and stillbirth, these studies could result in systematic bias and therefore underestimate the true prevalence of overweight and obesity.

To better understand trends in the prevalence of overweight and obesity irrespective of maternal characteristics and birth outcomes, this systematic review aims to explore population-level trends in prevalence of maternal obesity and overweight/obesity over time and across regions of the world.

Methods

Sources

Our systematic review was carried out in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Supplementary Material 1) [15]. A comprehensive search strategy was developed by two authors (LK, KAE). After discussion with specialist subject librarians, the agreed search terms were:

(1) "pregnan$" OR "matern$" OR "obstetric$" OR "mother" OR "expectant" OR "gestation$"

(2) "body mass index" OR "BMI" OR "weight" OR "overweight" OR "obesity" OR "obese"

(3) 1. AND 2.

An extensive literature search was carried out by LK in March 2020 (and updated in February 2021 and February 2023) using Ovid MEDLINE, EMBASE and CINAHL Plus searching databases from inception. Searches were restricted to full-text, human studies reported in the English language.

Study selection

Inclusion and exclusion criteria were developed to target population level studies that used administrative and routinely collected healthcare data. Studies were eligible for inclusion if (i) they presented obesity prevalence data for pregnant women; (ii) BMI was recorded pre-pregnancy (for cases of singleton or multiple births) or recorded in early pregnancy (for singleton pregnancies) [16] and (iii) the study used the WHO classification boundaries for overweight and obesity, or alternative boundaries for classification specific to race/ethnicity of the cohort studied. Studies were excluded if they had exclusion criteria relating to (i) age; (ii) race; (iii) maternal health status; (iv) birth outcome; (v) gestation at birth; or if they had (vi) reported fewer than one hundred cases; (vii) reported only livebirths; or (viii) required voluntary participation. Exclusion criteria (i) to (v) and (vii) were chosen as these characteristics are associated with BMI and have the potential to bias estimates of prevalence. The exclusion criterion of fewer than 100 cases was used as smaller studies may not reflect populations being studied. Studies that required voluntary participation were also excluded as women who are self-conscious of their BMI status may not volunteer or consent to studies which require this measurement. After removing duplicates, screening of all titles and abstracts was performed by two authors (LK & KAE March 2020 and February 2021; MMcG & LK February 2023), and full texts obtained for studies identified by all authors at this stage. Lastly, hand searching of full text papers was performed (LK) to identify any additional publications suitable for inclusion. Full text copies of the remaining articles were assessed for inclusion by three authors (LK, KAE, MMcG) with each receiving an allocation and all assessments being reviewed by the full team. Consensus decisions were made as a team on inclusion or exclusion where necessary. Additional studies were excluded if they had the same study population from the same curated data set as another included study.

Data extraction

A detailed data extraction form was developed (LK, KAE, MMcG) (Supplementary Material 2). In addition to inclusion and exclusion criteria, these forms required details of the country and region, participant characteristics, the BMI classification used, and the number and percentage of pregnant women recorded within each BMI category. Each author extracted data for a proportion of the included

studies, with 10% of papers randomly selected for independent verification by one other author. Study authors were contacted via email for clarification of inconsistencies or missing data.

Risk of bias assessment

The Hoy Risk of Bias tool was used to assess the quality and validity of measured data, and the risk of bias of included studies (LK, KAE, MMcG) (Supplementary Material 3) [17]. This validated tool for assessing the risk of bias in prevalence studies is comprised of ten questions, assessing four domains of bias. Questions 1 to 4 focus on the external validity of studies (assessing selection bias and nonresponse bias); and questions 5 to 10 consider the internal validity of studies (evaluating measurement bias and analysis-related bias). If criteria were fulfilled and the answer to the question was 'Yes' (low risk), a score of 0 was assigned. If the criteria were not met (answering 'No' or 'Unclear' to the question, meaning high risk), a score of 1 was assigned. To ensure harmonisation between authors when assessing each criterion, additional guidance was developed to reflect the context of this systematic review of population-based studies reporting prevalence of maternal overweight and obesity (Supplementary Material 3). If the overall score was 0–3, 4–6 or 7–10, the risk of bias was classified respectively as 'Low', 'Moderate' or 'High', applying the same approach as previous studies [18, 19].

Development of database

A comprehensive study database was designed (LK, MMcG) to capture study characteristics and reported prevalence of each BMI category. The data was entered by MMcG, with a random 10% sample checked for quality assurance by a second author (LK). If separate study populations were examined in one paper, each were added into the database separately, and noted as Study ID A, B, etc. to ensure there was no overlap between these study populations.

Data synthesis and analysis

All data preparation and analysis was performed using R [20]. For each included study, the midpoint date was calculated. Prevalence was calculated as the percentage of total pregnancies classed as obese (BMI $\geq$30 kg/m^2), and overweight/obese (BMI $\geq$25 kg/m^2).

Random effects meta-analysis was conducted on untransformed prevalence data using the DerSimonian and Laird [21] method to summarise estimates and 95% confidence intervals for the pooled prevalence of obesity and overweight/obesity. The percentage of total variability due to between-study heterogeneity was estimated using the I^2 statistic, however this was expected to be large due to anticipated temporal and regional differences in maternal obesity from study cohorts spanning different time periods. In the first instance this was performed for all study cohorts reflecting global prevalence over the full time-period covered by the included studies. This process was then repeated for each region of the world and each decade to describe the prevalence in different geographical regions over time. The pooled prevalence for obesity and overweight/obesity were then visualised as bar charts with 95% confidence intervals.

The relationship between prevalence and time was visualised for (i) obesity, and (ii) overweight/obesity using scatterplots of individual study cohorts. For overall global trends, a linear fitted line with 95% confidence intervals was created from all study cohorts. To visually compare trends between different geographical regions, linear fitted lines were created for maternal obesity prevalence estimates grouped by area of the world.

Linear regression was then used to model the trends in global prevalence over time, first using the full dataset containing all study cohorts. The midpoint year of the study period for each included study was used as the independent variable, and prevalence of i) obesity and ii) overweight and obesity was used as the dependent variable. As a sensitivity analysis, further linear regression models were fitted using data from i) 1980 onwards, ii) 1990 onwards, iii) 2000 onwards and iv) 2010 onwards. To compare prevalence between areas of the world, linear models were then fitted using midpoint year of study and area of the world as independent variables, and Europe, as the category with the most studies, selected as the reference. The estimated differences in prevalence and 95% confidence interval were calculated for each model and p values considered statistically significant at $\leq$0.05.

Registration

The study protocol was registered with the Research Registry (UIN: reviewregistry998) on 23$^{\mathrm{rd}}$ September 2020.

Results

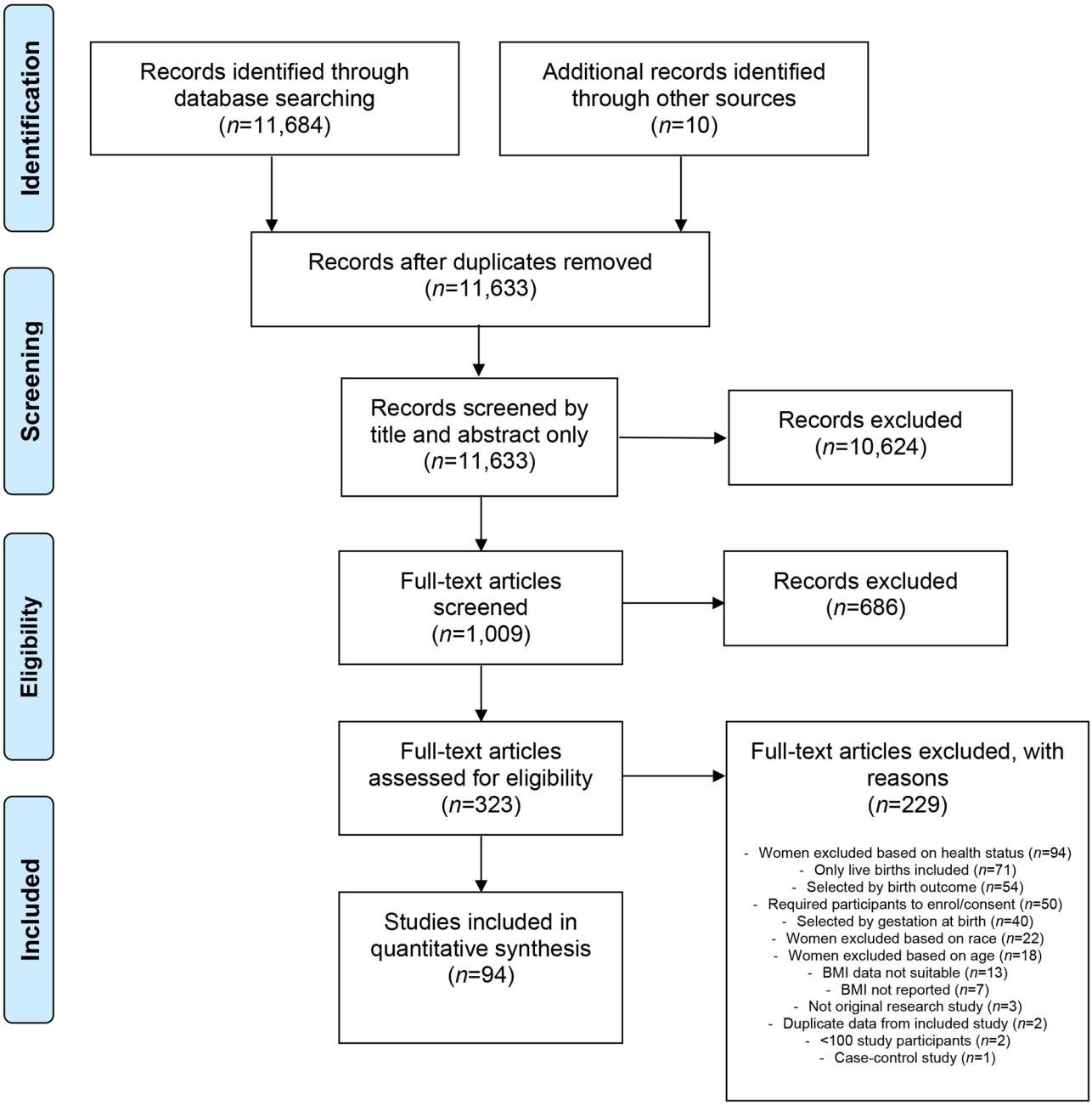
Eligibility of studies

After screening 11,635 papers, 94 studies met the inclusion criteria (PRISMA Flow Diagram, Figure 1). Nine of the included articles reported data from multiple cohorts [22–30] resulting in 121 study cohorts.

Characteristics of included studies

Overall, data from 49,009,168 pregnancies were included. Characteristics of included studies are presented in Table 1 (n = 94). Of the 121 study cohorts present in the included studies, the majority were European populations (n = 71), with 23 cohorts in North America, 12 cohorts in South America, ten from Australia and Oceania, and five from Asia. No studies were found representing populations from Africa. Included study cohorts represent the populations of 25 different countries, with all but two studies having taken place in high income countries [31, 32], according to the World Bank definition [33]. Fifty-one of the study cohorts were countrywide studies, using data from national databases, whilst 70 were regional studies which used data from databases that covered a smaller geographical region within a country, or in some cases a single hospital or group of hospitals. The years covered by the included studies span from 1959 to 2022. Midpoint dates of included studies ranged from 1962

Figure 1: PRISMA flow diagram



Reasons for full-text articles to be excluded does not sum to 229 as many studies had more than one reason for exclusion.

to 2021. Seventy-four study cohorts included only women who delivered singleton births and 36 included both singleton and multiple births, whilst eleven were unclear as to the order of the included pregnancies. Maternal BMI was measured pre-pregnancy for women in 57 study cohorts, in early pregnancy for 38 cohorts, and a combination of both pre-pregnancy and early pregnancy measurement in five study populations. Timing of BMI measurement was unclear in 21 study cohorts. BMI was categorised according to the WHO classification in the majority of study cohorts (n=95); three studies adjusted BMI classification according to ethnicity. In the remaining study cohorts that did not use the WHO BMI classification or ethnicity-specific classification, only the boundary between underweight and healthy differed, and therefore did not affect the current analysis of prevalence of overweight and obesity.

Risk of bias

Quality assessment of the 94 included studies is reported (Supplementary Material 4). Eighty studies (85.1%) were evaluated as having a low risk of bias and 14 studies (14.9%) were judged as moderate. The more common reasons for receiving a higher score were greater than 2% missing values reported or that weight or BMI was ascertained through self-report. Given that the assessed risk of bias of included studies was at highest moderate, this was not thought likely to affect the interpretation of our results.

Table 1: Characteristics of included population-level, retrospective studies

Study ID	Start date	End date	Country	Region	Countrywide or regional	Singleton or multiple births	Time of measurement	parity	cases
Asia									
Jin 2021 [34]	Jan-13	Dec-19	Japan	Fukushima	Regional	Singleton & Multiple	Pre-pregnancy	Nulli & Multi	3610
Leung 2008 [31]	Jan-95	Dec-05	China	Hong Kong	Regional	Singleton	Early pregnancy	Nulli & Multi	29303
Ma 2016 [32]	Jan-02	Dec-12	China	Zhangqiu	Regional	Singleton	Pre-pregnancy	Nulli & Multi	28256
Michlin 2000 [35]	Aug-95	Nov-95	Israel	Nahariya	Regional	Singleton & Multiple	Unclear	Nulli & Multi	887
Morikawa 2012 [36]	Jan-07	Dec-09	Japan	–	Regional	Singleton	Pre-pregnancy	Nulli & Multi	138530
Australia / Oceania									
Callaway 2006 [37]	Jan-98	Dec-02	Australia	Brisbane	Regional	Singleton	Pre-pregnancy	Nulli & Multi	14230
Cheney 2018 [38]	Jan-90	Dec-14	Australia	Sydney	Regional	Singleton	Early pregnancy	Nulliparous	42582
Cunningham 2013 [39]	Jan-05	Dec-10	Australia	North-East Victoria	Regional	Singleton	Early pregnancy	Nulli & Multi	6138
Davey 2020 [40]	Jan-09	Dec-13	Australia	Victoria	Regional	Singleton & Multiple	Unclear	Nulli & Multi	325763
Dodd 2011 [41]	Jan-08	Dec-08	Australia	South Australia	Regional	Singleton	Early pregnancy	Nulli & Multi	11233
Donald 2020 [42]	Jan-05	Dec-15	New Zealand	–	Countrywide	Singleton & Multiple	Unclear	Nulli & Multi	455010
Knight-Agarwal 2016 [43]	Jan-08	Dec-13	Australia	Australian Capital Territory	Regional	Singleton	Early pregnancy	Nulli & Multi	14857
McIntyre 2012 [44]	Jan-98	Dec-09	Australia	Brisbane	Regional	Singleton	Pre-pregnancy	Nulli & Multi	75432
San Martin Porter 2021 [45]	Jul-15	Dec-15	Australia	Queensland	Regional	Singleton	Pre-pregnancy	Nulli & Multi	27817
Watson 2013 [46]	Jan-08	Dec-08	Australia	Queensland	Regional	Singleton	Unclear	Nulli & Multi	37912
Europe									
Abayomi 2009 [47]	Jul-04	Jun-05	England	Liverpool	Regional	Unclear	Unclear	Nulli & Multi	6913
Arrowsmith 2011 [48]	Jan-04	Dec-08	England	Liverpool	Regional	Singleton	Early pregnancy	Nulli & Multi	29224
Bak 2016 [49]	Jan-08	Dec-12	Denmark	–	Countrywide	Singleton	Pre- & Early	Nulli & Multi	187486
Baker 2012 [50]	Apr-07	Mar-08	England	London	Regional	Unclear	Unclear	Nulli & Multi	4221
Bastola 2020 [51]	Jan-04	Dec-14	Finland	–	Countrywide	Singleton	Pre-pregnancy	Nulli & Multi	364678
Bhattacharya 2007 [7]	Jan-76	Dec-05	Scotland	Aberdeen	Regional	Singleton	Unclear	Nulliparous	24241
Blomberg 2010 [52]	Jan-95	Dec-07	Sweden	–	Countrywide	Unclear	Pre-pregnancy	Nulli & Multi	1049582
Blomberg 2011 [53]	Jan-97	Dec-08	Sweden	–	Countrywide	Singleton	Pre-pregnancy	Nulli & Multi	959469
Briese 2011 [54]	Jan-98	Dec-00	Germany	–	Countrywide	Singleton	Unclear	Nulliparous	243571
Cedergren 2007 [55]	Jan-94	Dec-04	Sweden	–	Countrywide	Singleton	Pre-pregnancy	Nulli & Multi	298948
Cedergren 2008a [24]	Jul-95	Dec-03	Sweden	–	Countrywide	Singleton	Pre- & Early	Nulli & Multi	636141
Cedergren 2008b [24]	Jan-92	Dec-01	Sweden	–	Countrywide	Singleton	Pre- & Early	Nulli & Multi	781725
Cnattingius 1998 [56]	Jan-92	Dec-93	Sweden	–	Countrywide	Singleton	Pre-pregnancy	Nulli & Multi	167750
Collier 2017 [57]	Jan-81	Dec-12	Scotland	–	Countrywide	Singleton & Multiple	Unclear	Nulli & Multi	47290
Denison 2014 [58]	Jan-03	Feb-10	Scotland	–	Countrywide	Singleton	Early pregnancy	Nulli & Multi	124280
Deruelle 2017 [59]	Jan-99	Dec-09	France	–	Countrywide	Singleton & Multiple	Pre-pregnancy	Nulli & Multi	346617
Erjavek 2016a [25]	Jan-10	Dec-10	Croatia	–	Countrywide	Singleton & Multiple	Pre-pregnancy	Unclear	42656
Erjavek 2016b [25	Jan-14	Dec-14	Croatia	–	Countrywide	Singleton & Multiple	Pre-pregnancy	Unclear	39092
Farah 2009 [60]	Jan-07	Dec-07	Ireland	Dublin	Regional	Singleton	Early pregnancy	Nulli & Multi	5824
Frischknecht 2009a [26]	Jan-86	Dec-86	Switzerland	Munsterlingen	Regional	Singleton	Early pregnancy	Nulli & Multi	690
Frischknecht 2009b [26]	Jan-04	Dec-04	Switzerland	Munsterlingen	Regional	Singleton	Early pregnancy	Nulli & Multi	668
Gardosi 2009 [61]	Jan-92	Dec-95	Sweden	–	Countrywide	Singleton	Early pregnancy	Nulli & Multi	354205
Hedegaard 2014 [62]	Jan-03	Dec-12	Denmark	–	Countrywide	Singleton & Multiple	Unclear	Nulli & Multi	498770
Henriksson 2020 [63]	Jan-10	Dec-18	Sweden	–	Countrywide	Singleton	Early pregnancy	Nulli & Multi	535609
Heslehurst 2007 [64]	Jan-90	Dec-04	England	Middlesbrough	Regional	Unclear	Pre- & Early	Nulli & Multi	36361
Heslehurst 2012 [65]	Jan-95	Dec-07	England	–	Countrywide	Unclear	Unclear	Nulli & Multi	502474
Huisman 2013 [66]	Aug-04	Aug-06	Netherlands	–	Countrywide	Singleton & Multiple	Unclear	Nulli & Multi	
Johansson 2017 [67]	Jul-08	Oct-14	Sweden	Stockholm-Gotland	Regional	Singleton	Early pregnancy	Nulli & Multi	160560
Kanagalingham 2005a [27]	Jan-90	Dec-90	Scotland	Glasgow	Regional	Singleton	Early pregnancy	Nulli & Multi	203
Kanagalingham 2005b [27]	Jan-02	Dec-04	Scotland	Glasgow	Regional	Singlet on	Early pregnancy	Nulli & Multi	312
Kent 2021a [28]	Jan-10	Dec-10	Northern Ireland	–	Countrywide	Singleton	Early pregnancy	Nulli & Multi	9995
Kent 2021b [28]	Jan-11	Dec-11	Northern Ireland	–	Countrywide	Singleton	Early pregnancy	Nulli & Multi	22478

Continued

Table 1: Continued

Study ID	Start Date	End Date	Country	Region	Countrywide or Regional	Singleton or Multiple Births	Time of measurement	Parity	Cases
Kent 2021c [28]	Jan-12	Dec-12	Northern Ireland	–	Countrywide	Singleton	Early pregnancy	Nulli & Multi	22177
Kent 2021d [28]	Jan-13	Dec-13	Northern Ireland	–	Countrywide	Singleton	Early pregnancy	Nulli & Multi	22184
Kent 2021e [28]	Jan-14	Dec-14	Northern Ireland	–	Countrywide	Singleton	Early pregnancy	Nulli & Multi	22150
Kent 2021f [28]	Jan-15	Dec-15	Northern Ireland	–	Countrywide	Singleton	Early pregnancy	Nulli & Multi	22182
Kent 2021g [28]	Jan-16	Dec-16	Northern Ireland	–	Countrywide	Singleton	Early pregnancy	Nulli & Multi	21644
Kent 2021h [28]	Jan-17	Dec-17	Northern Ireland	–	Countrywide	Singleton	Early pregnancy	Nulli & Multi	10150
Khashan 2009 [68]	Jan-04	Dec-06	England	North West	Regional	Singleton	Early pregnancy	Nulli & Multi	99403
Kristensen 2005 [69]	Jan-89	Dec-96	Denmark	Aarhus	Regional	Singleton	Pre-pregnancy	Nulli & Multi	24505
Le Ray 2015a [29]	Jan-03	Dec-03	France	–	Countrywide	Singleton & Multiple	Pre-pregnancy	Nulli & Multi	13605
Le Ray 2015b [29]	Jan-10	Dec-10	France	–	Countrywide	Singleton & Multiple	Pre-pregnancy	Nulli & Multi	13644
Lindholm 2015 [70]	Jan-06	Dec-08	Sweden	–	Countrywide	Singleton	Early pregnancy	Nulliparous	71638
Lucovnik 2018 [71]	Jan-02	Dec-15	Slovenia	–	Countrywide	Singleton	Pre-pregnancy	Nulli & Multi	271913
Maier 2016 [72]	Jan-14	Dec-14	Germany	Berlin	Regional	Unclear	Pre-pregnancy	Unclear	591
Mantakas 2010 [73]	Jan-01	Nov-08	England	Sheffield	Regional	Singleton	Early pregnancy	Nulliparous	6509
McKeating 2015 [74]	Jan-09	Dec-13	Ireland	Dublin	Regional	Singleton	Early pregnancy	Nulli & Multi	41135
Melchor 2019 [75]	Jan-13	Dec-17	Spain	Vizkcaya	Regional	Singleton	Pre-pregnancy	Nulli & Multi	16609
Mogren 2018 [76]	Jan-11	Dec-16	Sweden	–	Countrywide	Singleton	Early pregnancy	Nulli & Multi	536267
Nishikawa 2017 [77]	Jan-04	Dec-12	England	London	Regional	Singleton	Early pregnancy	Nulli & Multi	42591
Nohr 2012 [78]	Jan-92	Dec-06	Sweden	–	Countrywide	Singleton	Pre-pregnancy	Nulli & Multi	1199328
Oteng-Ntim 2013 [79]	Jan-04	Dec-08	England	London	Regional	Singleton	Early pregnancy	Nulli & Multi	17910
Ovesen 2011 [80]	Jan-04	Jun-10	Denmark	–	Countrywide	Singleton	Pre-pregnancy	Nulli & Multi	369347
Penn 2014 [81]	Jan-04	May-12	England	South London	Regional	Singleton	Early pregnancy	Nulli & Multi	42678
Premru-Srsen 2019 [82]	Jan-13	Dec-17	Slovenia	–	Countrywide	Singleton	Pre-pregnancy	Nulli & Multi	98820
Raja 2012 [83]	Jan-02	Dec-07	England	London Harrow	Regional	Unclear	Early pregnancy	Nulli & Multi	24632
Ramoniene 2017 [84]	Jan-10	Dec-10	Lithuania	Kaunas	Regional	Singleton	Pre-pregnancy	Nulli & Multi	3371
Rankin 2010 [85]	Jan-03	Dec-05	England	North East	Regional	Singleton	Unclear	Unclear	30703
Rantakallio 1995a [30]	Jan-66	Dec-66	Finland	Northern	Regional	Unclear	Pre-pregnancy	Nulli & Multi	10969
Rantakallio 1995b [30]	Jul-85	Jun-86	Finland	Northern	Regional	Unclear	Pre-pregnancy	Nulli & Multi	9128
Reynolds 2019 [86]	Jan-10	Dec-17	Ireland	Dublin	Regional	Unclear	Unclear	Nulli & Multi	67349
Reynolds 2020 [87]	Jan-09	Dec-17	Ireland	Dublin	Regional	Singleton	Early pregnancy	Nulliparous	9724
Scott-Pillai 2015 [8]	Jan-04	Dec-11	Northern Ireland	Belfast	Regional	Singleton	Early pregnancy	Nulli & Multi	30298
Sebire 2001 [88]	Jan-89	Dec-97	England	London North West Thames	Regional	Singleton	Early pregnancy	Nulli & Multi	325395
Stepan 2006 [89]	Jan-01	Dec-04	Germany	Leipzig	Regional	Singleton	Pre-pregnancy	Unclear	5067
Villamor 2006 [90]	Jan-92	Dec-01	Sweden	–	Countrywide	Singleton	Pre-pregnancy	Nulliparous	151025
North America									
Abenhaim 2007 [91]	Apr-87	Mar-97	Canada	Montreal	Regional	Unclear	Pre-pregnancy	Nulli & Multi	18643
Berendzen 2013 [92]	Jan-09	Dec-09	USA	Tennessee (Knoxville)	Regional	Singleton	Pre-pregnancy	Nulli & Multi	2235
Butwick 2018 [93]	Jan-08	Dec-12	USA	California	Regional	Singleton & Multiple	Pre-pregnancy	Nulli & Multi	2176673
Chen 2004 [94]	Feb-93	Jun-01	USA	Florida (Gainsville)	Regional	Singleton	Pre-pregnancy	Nulliparous	3355
Crane 2009 [95]	Apr-01	Mar-07	Canada	Newfoundland and Labrador	Regional	Singleton	Pre-pregnancy	Nulli & Multi	5377
Declerq 2016 [96]	Jan-12	Dec-13	USA	38 States and District of Columbia	Regional	Singleton	Pre- & Early	Nulli & Multi	6178824
Doyle 2022 [97]	Mar-20	Apr-21	USA	Florida	Regional	Singleton & Multiple	Pre-pregnancy	Nulli & Multi	234492
Ehrenthal 2011 [98]	Jun-03	Dec-06	USA	Delaware (Newark)	Regional	Singleton	Pre-pregnancy	Nulli & Multi	16582
Eick 2019 [99]	Jan-05	Dec-12	Puerto Rico		Countrywide	Singleton	Pre-pregnancy	Unclear	330296
Gonzales-Rios 2022 [100]	May-08	Dec-12	USA	Pennsylvania	Regional	Singleton & Multiple	Pre-pregnancy	Nulli & Multi	8749
Kabiru 2004 [101]	Jan-99	Dec-02	USA	Atlanta, Georgia	Regional	Singleton	Early pregnancy	Nulli & Multi	5529
Leonard 2020 [102]	Jan-07	Dec-12	USA	California	Regional	Singleton & Multiple	Pre-pregnancy	Nulli & Multi	2650182
Lutsiv 2015 [103]	Apr-07	Mar-10	Canada	Ontario	Regional	Singleton	Pre-pregnancy	Nulli & Multi	
Lynch 2014 [104]	Oct-05	Oct-10	USA	Denver	Regional	Singleton	Pre-pregnancy	Nulli & Multi	11726
Magann 2011 [105]	Jan-07	Jul-08	USA	Virginia and Mississippi	Regional	Singleton	Early pregnancy	Nulli & Multi	4500

Continued

Table 1: Continued

Study ID	Start Date	End Date	Country	Region	Countrywide or Regional	Singleton or Multiple Births	Time of measurement	Parity	Cases
Miao 2021 [106]	Apr-12	Mar-18	Canada	Ontario	Regional	Singleton	Pre-pregnancy	Unclear	706017
Mills 2020 [107]	Jan-04	Dec-14	USA	–	Countrywide	Singleton & Multiple	Unclear	Nulli & Multi	9096788
Naeye 1990 [108]	Jan-59	Dec-66	USA	Several regions	Regional	Singleton & Multiple	Pre-pregnancy	Nulli & Multi	56857
Pasko 2016 [109]	Jan-06	Jun-14	USA	Alabama (Birmingham)	Regional	Singleton	Early pregnancy	Unclear	15313
Seaton 2023 [110]	Mar-20	Feb-22	USA	New York	Regional	Singleton & Multiple	Unclear	Nulli & Multi	8983
Thompson 2019 [111]	Jan-14	Dec-16	USA	–	Countrywide	Singleton	Pre-pregnancy	Nulli & Multi	10811496
Young 2016 [112]	Jan-03	Apr-14	USA	Pennsylvania (Pittsburgh)	Regional	Singleton	Pre-pregnancy	Nulliparous	28361
South America									
Carilho 2022a [22]	Jan-08	Dec-08	Brazil	–	Countrywide	Singleton & Multiple	Pre-pregnancy	Nulli & Multi	69413
Carilho 2022b [22]	Jan-09	Dec-09	Brazil	–	Countrywide	Singleton & Multiple	Pre-pregnancy	Nulli & Multi	157680
Carilho 2022c [22]	Jan-10	Dec-10	Brazil	–	Countrywide	Singleton & Multiple	Pre-pregnancy	Nulli & Multi	178033
Carilho 2022d [22]	Jan-11	Dec-11	Brazil	–	Countrywide	Singleton & Multiple	Pre-pregnancy	Nulli & Multi	232617
Carilho 2022e [22]	Jan-12	Dec-12	Brazil	–	Countrywide	Singleton & Multiple	Pre-pregnancy	Nulli & Multi	266640
Carilho 2022f [22]	Jan-13	Dec-13	Brazil	–	Countrywide	Singleton & Multiple	Pre-pregnancy	Nulli & Multi	250386
Carilho 2022g [22]	Jan-14	Dec-14	Brazil	–	Countrywide	Singleton & Multiple	Pre-pregnancy	Nulli & Multi	218177
Carilho 2022h [22]	Jan-15	Dec-15	Brazil	–	Countrywide	Singleton & Multiple	Pre-pregnancy	Nulli & Multi	230838
Carilho 2022i [22]	Jan-16	Dec-16	Brazil	–	Countrywide	Singleton & Multiple	Pre-pregnancy	Nulli & Multi	219411
Carilho 2022j [22]	Jan-17	Dec-17	Brazil	–	Countrywide	Singleton & Multiple	Pre-pregnancy	Nulli & Multi	193962
Carilho 2022k [22]	Jan-18	Dec-18	Brazil	–	Countrywide	Singleton & Multiple	Pre-pregnancy	Nulli & Multi	70614
Conde-Agudelo 2000 [113]	Jan-85	Dec-97	Uruguay	Montevideo	Regional	Singleton & Multiple	Pre-pregnancy	Nulli & Multi	878680

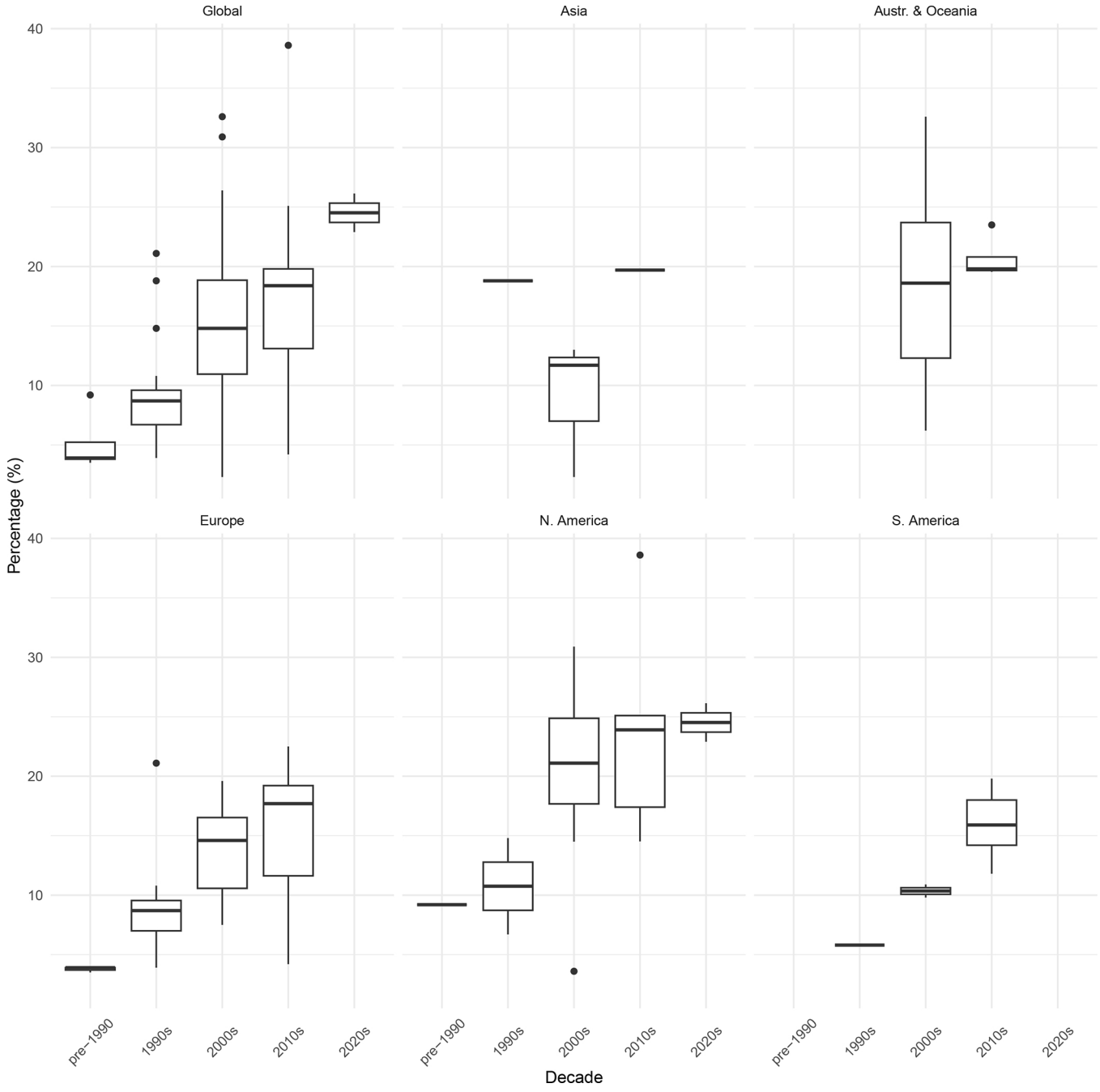
Synthesis of results (Tables 2 and 3, Figures 2 and 3)

The prevalence for each BMI category is presented separately for all included study cohorts in Table 2 and visualised via box plots in Figures 2, 3. Pooled prevalence, synthesised by area of the world and decade, is presented in Table 3 and visualised in Supplementary Materials 5, 6. Globally, prevalence of obesity (BMI $\geq$30 kg/m^2) in pregnancy has more than tripled from 4.7% (95% CI 2.6–8.6) pre-1990 to 16.3% (95% CI: 15.1–17.5), or one in approximately six pregnancies, in the decade 2010 to 2019 (Figures 2 and Supplementary Material 5). Only two studies reported prevalence of obesity since 2020, both from North America, but these appear to show a continuation of the upward trend, with a pooled prevalence of obesity estimated as 24.5% (95% CI: 21.4–27.8), or one in every four pregnancies. Prevalence of combined overweight & obesity (BMI $\geq$25 kg/m^2) in pregnancy has also increased globally, more than doubling from 20.6% (95% CI: 16.4-25.6) pre-1990 to 43.8% (95% CI: 42.2-45.4) in the decade 2010 to 2019 (Figures 3 and Supplementary Material 6). Asia did not have sufficient study cohorts to allow for a pooled estimate of prevalence to be estimated for each decade. Across the remaining areas, only North America and Europe had sufficient results to stratify by at least three decades (1990s, 2000s, 2010s). Pooled prevalence was possible for 2000s and 2010s for Australia & Oceania and South America. Across each area of the world, an upward trend similar to the global trend was observed, with North America demonstrating the highest prevalence in obesity and overweight/obesity in each decade. Percentage of total variability due to between-study heterogeneity, as measured by the I^2 statistic, was large in all meta-analyses, ranging from 98.0 to 100%.

Temporal trends in prevalence of maternal overweight and obesity (Table 4, Figure 4)

Figure 4 further demonstrates the upward trend of prevalence of both obesity, and overweight/obesity in pregnancy. This trend is apparent globally (Figure 4a,b) and for each area of the world (Figure 4c,d). North America demonstrates some of the highest prevalence rates for obesity and overweight/obesity, with Australia and Oceania appearing to increase at a greater rate and reaching similar rates as North America by 2010.

Figure 2: Prevalence of obesity (BMI $\geq$30 kg/m^2) in pregnancy



Linear regression performed on all studies reporting (i) obesity prevalence ($n = 120$ study cohorts) and (ii) combined overweight and obesity prevalence ($n = 110$ study cohorts), both demonstrated a statistically significant increase over time ($p < 0.001$), with prevalence increasing by (i) 0.34% (95% CI: 0.23–0.45) and (ii) 0.64% (95% CI: 0.44–0.84), respectively, with each year.

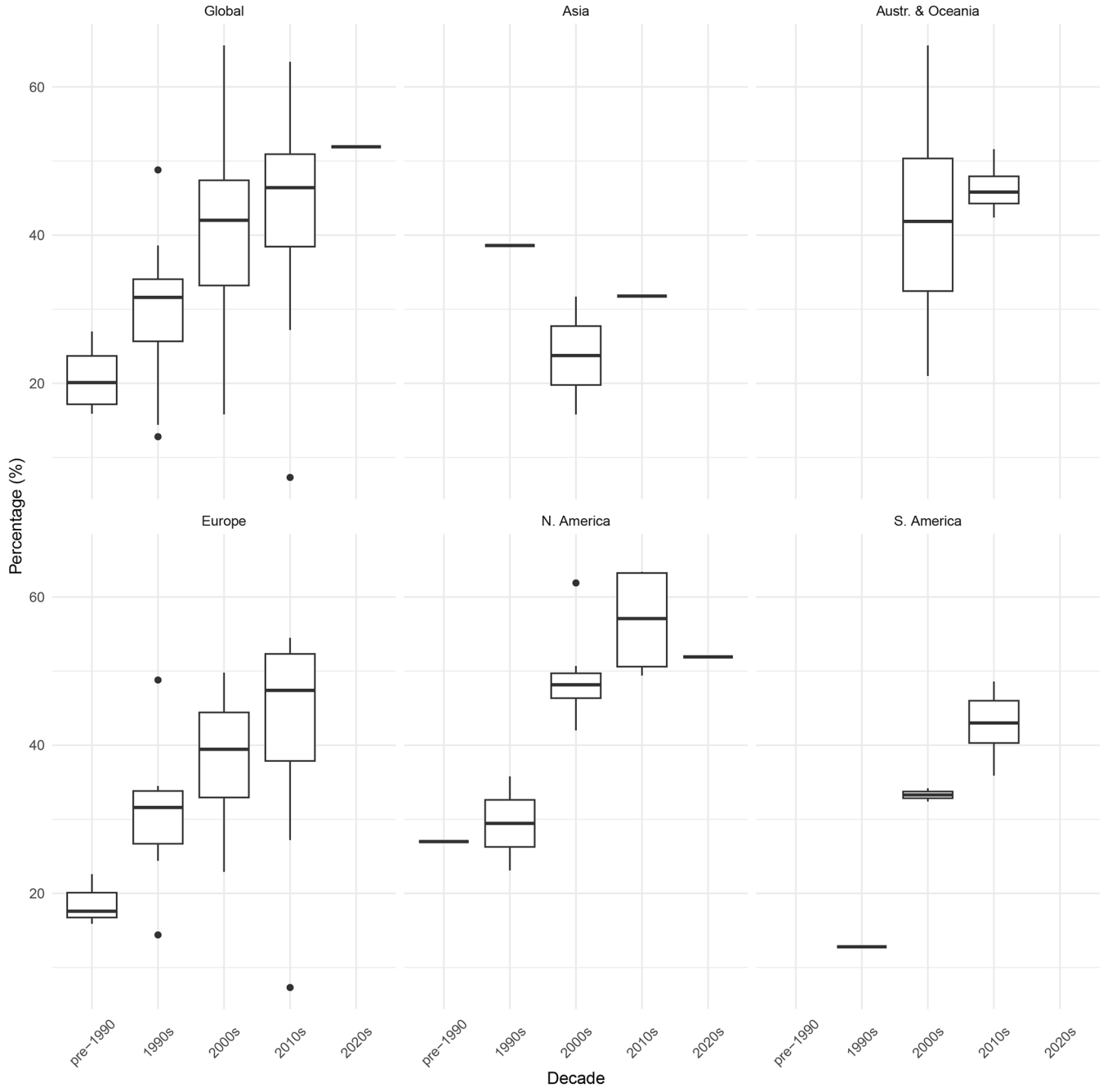
Sensitivity analysis

Additional analysis was carried out on all studies from 1980, 1990, 2000 and 2010 onwards. The range in estimated yearly increase in prevalence of maternal obesity was 0.32–0.63% (each model $p < 0.05$), and 0.60–0.82% for overweight/obesity (each model $p < 0.05$) (Table 4).

Comparison of prevalence of maternal overweight and obesity between areas of the world (Table 5)

Using Europe as a reference and adjusting for midpoint year of study, obesity prevalence was compared across areas of the world. A significantly higher prevalence was observed for study cohorts from North America (6.90%, $p < 0.001$) and Australia & Oceania (5.59%, $p = 0.002$). Analysis of combined overweight and obesity rates demonstrated a significantly greater prevalence in North America (9.83%, $p < 0.001$).

Figure 3: Prevalence of overweight/obesity (BMI $\geq$25 kg/m^2) in pregnancy



Discussion

Main findings

The scale of this systematic review, along with the strict inclusion and exclusion criteria applied, provides a comprehensive insight into the current state of global and continental maternal overweight and obesity prevalence. Our findings demonstrate a significant increase in maternal obesity and overweight/obesity prevalence over time, with our linear regression analysis estimating a 0.34% and 0.64% increase in obesity prevalence and combined overweight and obesity prevalence, respectively, with every passing year. Pooled analysis from the most recent studies (post 2010) indicates that globally, one in six pregnancies are now complicated by obesity. In North America, since 2020, one in four pregnancies are complicated by obesity.

Comparisons with existing literature

In comparison to a previous review of pre-pregnancy BMI from Martínez-Hortelano *et al*, global obesity prevalence found in our study was slightly lower for the full time period (13.6% v. 16.3%) [9]. This may be due to inclusion of earlier studies, with lower prevalence, in our study. However, when results were stratified by continent, our pooled prevalence of maternal obesity was higher, and particularly striking when the analysis was limited to the decade 2010–2019: North America (23.1% vs. 17.6%), Europe (14.6% vs. 9.1%), Australia and Oceania (20.6% vs. 11.3%). Our

Table 2: Prevalence of Maternal Overweight and Obesity: Individual Study Cohort Results

Study ID	Overweight (%)	Obese I (%)	Obese II (%)	Obese III (%)	Obese all (%)	Overweight & obese (%)
Asia						
Jin 2021	12.1	.	.	.	19.7	31.8
Leung 2008	13.5	.	.	.	2.3	15.8
Ma 2016	18.7	8.6	.	.	13.0	31.7
Michlin 2000	19.7	.	.	.	18.8	38.6
Morikawa 2012	.	.	.	.	.	11.7
Australia/ Oceania						
Callaway 2006	20.3	.	.	1.7	13.5	33.8
Cheney 2018	14.8	4.2	1.3	0.7	6.2	21.0
Cunningham 2013	33.0	18.6	8.3	5.7	32.6	65.6
Davey 2020	26.8	.	.	.	19.9	46.7
Dodd 2011	26.2	13.6	6.1	4.0	23.7	49.9
Donald 2020	28.1	.	.	.	23.5	51.6
Knight-Agarwal 2016	25.2	10.8	5.0	4.0	19.7	44.9
McIntyre 2012	20.1	7.6	2.8	1.5	11.9	32.0
San Martin Porter 2021	22.8	.	.	.	19.6	42.4
Watson 2013	26.8	14.0	6.1	3.6	23.7	50.5
Europe						
Abayomi 2009	26.7	.	.	.	17.2	43.9
Arrowsmith 2011	27.3	11.3	4.3	2.1	17.7	45.0
Bak 2016	21.8	8.1	2.9	1.3	12.2	34.0
Baker 2012	19.0	.	.	.	11.0	30.0
Bastola 2020	22.6	.	.	.	13.0	35.7
Bhattacharya 2007	21.9	7.7	.	.	8.3	30.2
Blomberg 2010	24.4	7.3	2.1	0.7	10.2	34.5
Blomberg 2011	24.7	7.6	2.3	0.8	10.7	35.3
Briese 2011	19.0	.	.	.	7.9	26.9
Carillo-Aguirre 2020 A	33.9	13.6	4.0	1.4	19.0	52.9
Carillo-Aguirre 2020 B	33.4	13.6	4.0	1.4	19.0	52.4
Carillo-Aguirre 2020 C	33.3	13.8	4.1	1.4	19.2	52.6
Carillo-Aguirre 2020 D	33.0	14.5	4.2	1.5	20.3	53.3
Carillo-Aguirre 2020 D	33.6	14.9	4.6	1.5	21.0	54.5
Cedergren 2007	23.7	.	.	.	9.4	33.1
Cedergren 2008 A	24.2	.	.	.	9.6	33.8
Cedergren 2008 B	22.5	.	.	.	8.1	30.7
Cnattingius 1998	19.9	.	.	.	6.2	26.1
Collier 2017	27.6	.	.	.	21.1	48.8
Denison 2014	28.2	.	.	2.2	19.6	47.8
Deruelle 2017	16.2	.	.	0.8	8.3	24.5
Erjavek 2016 A	.	5.2	1.4	0.4	7.0	.
Erjavek 2016 B	.	5.8	1.5	0.5	7.8	.
Farah 2009	28.2	.	.	1.6	15.0	43.2
Frischknecht 2009 A	12.5	.	.	.	3.5	15.9
Frischknecht 2009 B	21.1	.	.	.	9.0	30.1
Gardosi 2009	.	.	.	.	6.7	.
Hedegaard 2014	33.1	12.0	.	.	16.1	49.2
Henriksson 2020	25.0	.	.	.	12.8	37.8
Heslehurst 2007	23.7	.	.	.	10.8	34.5
Heslehurst 2012	25.9	.	.	.	14.8	40.7
Johansson 2017	21.4	6.4	1.7	0.5	8.6	30.0
Kanagalingham 2005 A	.	.	.	.	9.4	.
Kanagalingham 2005 B	.	.	.	.	18.9	.
Kent 2021 A	28.6	11.9	4.2	2.3	18.4	47.0
Kent 2021 B	29.1	12.1	4.6	2	18.7	47.8
Kent 2021 C	29.3	12	4.8	2.3	19.1	48.4

Continued

Table 2: Continued

Study ID	Overweight (%)	Obese I (%)	Obese II (%)	Obese III (%)	Obese all (%)	Overweight & obese (%)
Kent 2021 D	29.5	12.1	4.9	2.2	19.2	48.7
Kent 2021 E	29.1	12.5	5.3	2.5	20.3	49.4
Kent 2021 F	30.2	12.6	5.3	2.5	20.4	50.7
Kent 2021 G	30.0	13.5	5.9	2.9	22.3	52.3
Kent 2021 H	29.9	13.3	6.4	2.8	22.5	52.4
Khashan 2009	28.4	.	.	1.8	17.9	46.4
Kristensen 2015	10.5	.	.	.	3.9	14.4
Le Ray 2015 A	15.4	.	.	.	7.5	22.9
Le Ray 2015 B	17.3	.	.	.	9.9	27.2
Lindholm 2015	22.4	.	.	2.9	9.8	32.1
Lucovnik 2018	17.8	.	.	.	8.2	26.1
Maier 2016	17.9	.	.	.	11.7	29.6
Mantakas 2010	26.5	.	.	.	14.5	41.0
McKeating 2015	29.3	11.3	3.8	1.5	16.6	45.9
Melchor 2019	25.1	9.0	3.2	1.1	13.3	38.4
Mogren 2018	25.4	9.2	2.9	1.0	13.1	38.6
Nishikawa 2017	24.6	9.8	3.5	1.5	14.7	39.4
Nohr 2012	23.3	6.7	.	.	9.1	32.5
Oteng-Ntim 2013	24.3	9.2	3.3	1.5	13.9	38.2
Ovesen 2011	20.9	7.7	.	.	11.7	32.6
Penn 2014	24.6	.	.	.	14.9	39.5
Premru-Srsen 2019	19.2	.	.	.	9.8	29.0
Raja 2012	29.8	.	.	1.1	15.8	45.6
Ramoniene 2017	3.1	2.8	.	.	4.2	7.3
Rankin 2010	26.3	.	.	.	16.4	42.7
Rantakallio 1995 A	18.7	3.4	.	.	3.9	22.6
Rantakallio 1995 B	13.7	3.1	.	.	3.9	17.6
Reynolds 2019	29.1	11.2	4.1	1.7	17.0	46.1
Reynolds 2020	26.3	8.1	2.7	0.8	11.6	37.9
Scott-Pillai 2015	27.8	11.0	3.9	1.9	16.9	44.6
Sebire 2001	24.3	.	.	.	9.6	33.9
Stepan 2006	31.0	13.3	3.9	1.6	18.8	49.8
Villamor 2006	19.0	.	.	.	5.4	24.4
North America						
Abenhaim 2007	16.5	.	.	0.6	6.7	23.1
Berendzen 2013	22.6	.	.	5.8	26.4	48.9
Butwick 2018	25.9	12.7	5.2	3.1	21.0	47.0
Chen 2004	21.0	.	.	2.0	14.8	35.8
Crane 2009	26.4	.	.	4.3	24.4	50.7
Declerq 2016	25.5	13.4	6.3	4.3	23.9	49.4
Ehrenthal 2011	24.9	11.8	5.8	3.6	21.2	46.1
Eick 2019	24.7	.	.	.	17.8	42.5
Gonzales-Rios 2022	48.7				14.5	63.2
Kabiru 2004	31.0	17.0	8.0	5.9	30.9	61.9
Leonard 2020	25.8	12.6	5.2	3.0	20.8	46.6
Lisonkova 2017	25.8	13.0	6.2	4.2	23.5	49.3
Lutsiv 2015	.	.	.	.	.	48.2
Lynch 2014	24.7	10.7	4.0	2.7	17.3	42.0
Magann 2011	23.8	.	.	.	26.3	50.1
Miao 2021	.	.	.	.	17.4	.
Mills 2020	.	.	.	.	3.6	.
Naeye 1990	17.9	.	.	.	9.2	27.0
Pasko 2016	24.8	18.0	10.3	10.3	38.6	63.4
Seaton 2023	.	.	.	.	22.9	.
Thompson 2019	25.9	13.9	6.7	4.6	25.1	51.0
Young 2016	.	.	.	.	14.5	.

Continued

Table 2: Continued

Study ID	Overweight (%)	Obese I (%)	Obese II (%)	Obese III (%)	Obese all (%)	Overweight & obese (%)
South America						
Carrilho 2022 A	22.6	.	.	.	9.8	32.4
Carrilho 2022 B	23.3	.	.	.	10.9	34.2
Carrilho 2022 C	24.1	.	.	.	11.8	35.9
Carrilho 2022 D	25.2	.	.	.	13.1	38.3
Carrilho 2022 E	26.1	.	.	.	14.2	40.3
Carrilho 2022 F	26.4	.	.	.	14.5	40.9
Carrilho 2022 G	27.1	.	.	.	15.9	43
Carrilho 2022 H	27.6	.	.	.	17	44.6
Carrilho 2022 I	28	.	.	.	18	46
Carrilho 2022 J	28.6	.	.	.	19	47.6
Carrilho 2022 K	28.8	.	.	.	19.8	48.6
Conde-Agudelo 2000	7.0	.	.	.	5.8	12.8

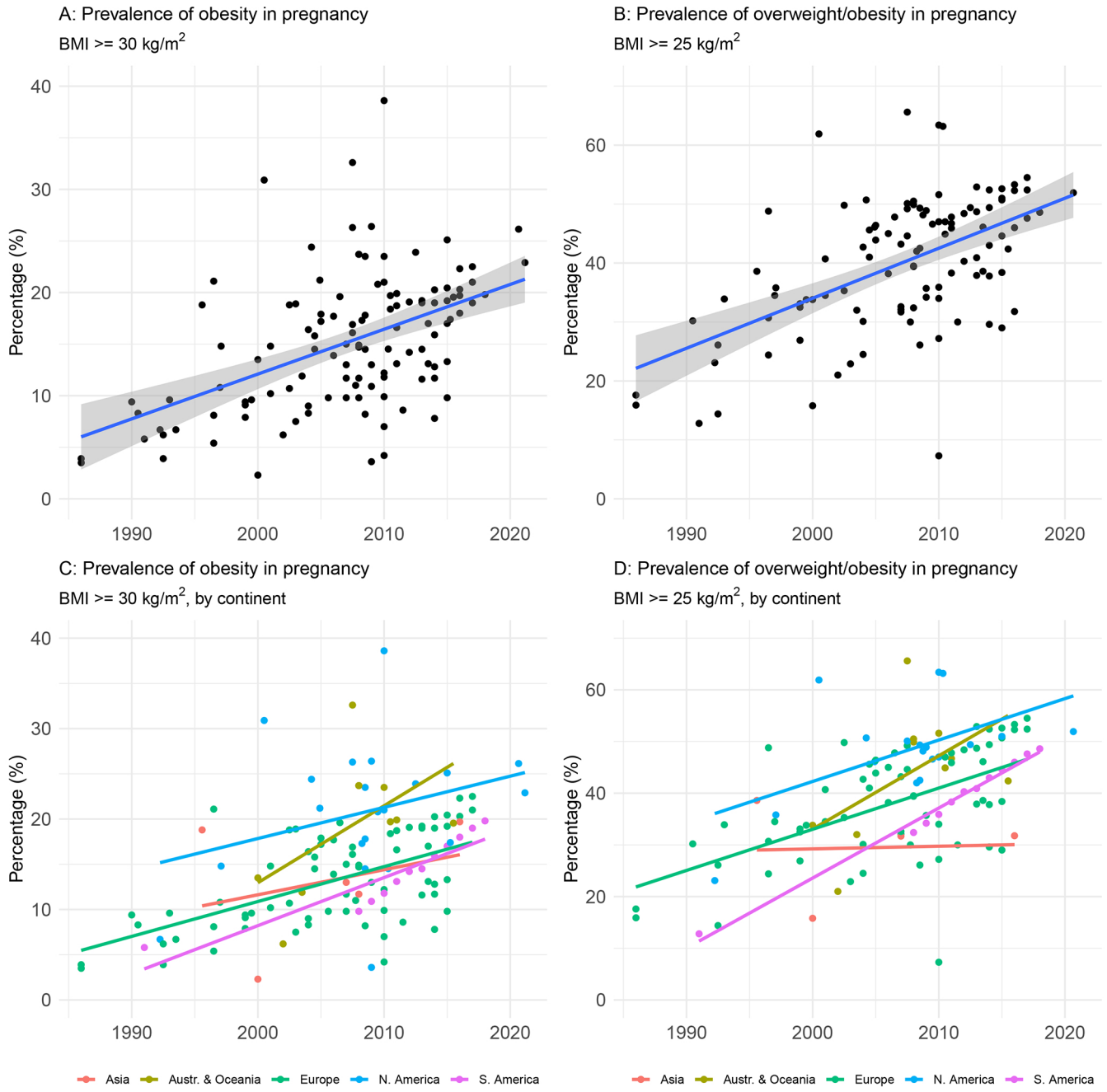
Table 3: Pooled prevalence of obesity and overweight/obesity in pregnancy

	Obesity			Overweight/Obesity		
	Cohorts (n)	Total individuals (n)	Estimated prevalence [95% CI]	Cohorts (n)	Total individuals (n)	Estimated prevalence [95% CI]
Global	120	48,935,440	13.6 [12.4, 15.0]	110	38,235,147	38.9 [37.2, 40.6]
Asia	5	200,586	10.8 [7.0, 16.5]	4	62,056	28.5 [18.3, 41.5]
Austr. & Oceania	10	1,010,974	18.2 [15.3, 21.5]	10	1,010,974	43.4 [37.8, 49.1]
Europe	71	11,642,821	12.1 [11.2, 12.9]	65	10,847,479	36.9 [35.3, 38.5]
N. America	22	33,114,608	18.7 [15.0, 23.2]	19	23,348,187	47.0 [45.7, 48.3]
S. America	12	2,966,451	13.6 [10.8, 16.9]	12	2,966,451	37.9 [29.9, 46.6]
Stratified by decade						
Global						
Pre-1990	4	77,644	4.7 [2.6, 8.6]	4	77,644	20.6 [16.4, 25.6]
1990–1999	18	5,192,253	8.7 [7.8, 9.8]	16	4,837,845	29.1 [25.1, 33.5]
2000–2009	51	21,148,274	14.3 [11.9, 17.1]	47	11,599,137	39.8 [37.7, 42.0]
2010–2019	45	22,273,794	16.3 [15.1, 17.5]	42	21,486,029	43.8 [42.2, 45.4]
2020+	2	243,475	24.5 [21.5, 27.8] [a]	1	234,492	–
Austr. & Oceania						
1990–1999	–	–	–	–	–	–
2000–2009	6	187,527	16.7 [10.7, 25.3]	6	187,527	41.4 [30.3, 53.4]
2010–2019	4	823,447	20.6 [18.4, 23.1]	4	823,447	46.4 [42.8, 50.1]
Europe						
1990–1999	14	4,290,688	8.4 [7.4, 9.4]	12	3,936,280	30.2 [28.1, 32.3]
2000–2009	28	5,465,686	13.3 [12.1, 14.6]	26	5,106,500	38.0 [35.3, 40.7]
2010–2019	26	1,865,660	14.6 [13.1, 16.3]	24	1,783,912	42.0 [39.0, 45.1]
N. America						
1990–1999	2	21,998	10 [4.4, 21.0]	2	21998	29.0 [18.3, 42.8]
2000–2009	12	15,071,879	19.1 [11.9, 29.2]	11	6020458	48.3 [47.2, 49.4]
2010–2019	5	17,720,399	23.1 [21.2, 25.1]	4	17014382	56.5 [55.1, 57.8]
2020+	2	243,475	24.6 [21.4, 27.7] [a]	1	234,492	–
S. America						
1990–1999	–	–	–	–	–	–
2000–2009	2	227,093	10.3 [9.3, 11.5]	2	227,093	33.3 [31.6, 35.1]
2010–2019	9	1,860,678	15.7 [14.2, 17.4]	9	1,860,678	42.7 [40.2, 45.3]

[a]Both studies conducted in N. America, therefore not reflective of global prevalence.

findings likely reflect the more recent studies included in our review, and our strict inclusion/exclusion criteria which ensured that results were reflective of population-based prevalence and not biased by including studies that may

Figure 4: Temporal trends in prevalence of obesity (BMI ≥30 kg/m^2) and overweight/obesity (BMI ≥25 kg/m^2) in pregnancy



have unintentionally excluded pregnant women with higher BMI's.

The estimated global trend of increasing overweight and obesity prevalence in pregnant women mirrors that seen in the general female population [114]. It is estimated that mean BMI has increased by 0.59 kg/m^2 per decade from 1975 to 2014 [114], and 0.5 kg/m^2 per decade from 1980 to 2008 [115]. In 2014, obesity prevalence in the general female population was estimated to be 14.9% [114], reflected by WHO estimates in 2016 (15%) [2]. However, a much higher prevalence has been estimated for the general female population in high income countries; 25.3% in 2014, and 26.2% in 2016 [2]. Our linear regression analysis suggests that global obesity prevalence in the pregnant population was 17.8% in 2014, and 18.4% in 2016. Using our model, the current global prevalence of maternal obesity is 20.9% (95% CI 18.6 to 23.1%), and is projected to reach 23.3% (95% CI 20.3 to 26.2%) by 2030.

The highest prevalence of maternal obesity is found in North America and Australia/Oceania, who also demonstrate the highest prevalence of combined overweight/obesity. These findings are also recognised in the general female population; with national bodies including, the National Academy of Medicine (USA) [116], Health Canada [117], the National Health and Medical Research Council (Australia) [118] and the National Institute for Health and Care Excellence (UK) [6], recognising the urgent need for strategies to support weight management, including pre-conception care [119]. A steeper increase in obesity and overweight/obesity prevalence was seen in studies carried out in Australia/Oceania. Our findings are similar to those reported by Finucane et al., who noted

Table 4: Rate* of increase per year in prevalence of maternal overweight and obesity

Obesity		
Model	**Estimated increase in prevalence (%) per year**	
	% [95%CI]	**p**
Full time period	0.34 [0.23, 0.45]	<0.001
1980+	0.42 [0.28, 0.56]	<0.001
1990+	0.41 [0.26, 0.56]	<0.001
2000+	0.32 [0.07, 0.57]	0.0141
2010+	0.63 [0.03, 1.23]	0.0435
Overweight and Obesity		
Model	**Estimated increase in prevalence (%) per year**	
	% [95%CI]	**p**
Full time period	0.64 [0.44, 0.84]	<0.001
1980+	0.82 [0.57, 1.07]	<0.001
1990+	0.77 [0.50, 1.04]	<0.001
2000+	0.60 [0.17, 1.03]	0.0073
2010+	0.82 [−0.36, 2.00]	0.1845

*Estimated from linear regression of prevalence versus midpoint year of study.

Table 5: Differences* in prevalence of maternal overweight and obesity across continents

Obesity		
Model	**Estimated difference in prevalence (%) between continents**	
	% [95%CI]	**p**
Europe	Reference	–
N. America	6.90 [4.45, 9.35]	<0.001
Austr. & Oceania	5.59 [2.20, 8.98]	0.002
Asia	0.02 [−4.62, 4.65]	0.995
S. America	−0.97 [−4.16, 2.22]	0.552
Overweight and Obesity		
Model	**Estimated increase in prevalence (%) between continents**	
	% [95%CI]	**p**
Europe	Reference	–
N. America	9.83 [5.30, 14.36]	<0.001
Austr. & Oceania	4.68 [−1.23, 10.60]	0.124
Asia	−7.74 [−16.69, 1.22]	0.093
S. America	−2.98 [−8.54, 2.59]	0.297

*Estimated from linear regression of prevalence versus continent adjusted for midpoint year of study.

greatest increase in BMI in the general population of females in Australia/Oceania (1980–2008) [115].

Challenges in conducting world-wide meta-analyses of prevalence of maternal obesity

Comparing prevalence of maternal overweight and obesity between areas of the world is challenging. Studies included in this review ranged significantly in the type of data used (e.g. routinely collected healthcare data versus vital statistics) and scale of the population covered (e.g. hospital database versus region or countrywide datasets), making it difficult to assess comparable studies. In Nordic countries, reporting of all births to national organisations is required [120]. As a result, the number of population wide studies included in our review from Sweden ($n = 12$) was higher than other countries, which may have skewed the results for Europe. Many studies carried out in USA were excluded as much of the published data currently relies on information obtained from birth certificates, meaning stillbirths are often excluded. As a result, North America contributed only three countrywide studies [99, 107, 111]. A further challenge was the ability to reliably compare trends on a global scale, as the number of studies per geographical region varied greatly. As previously stated, no studies undertaken in Africa met the inclusion criteria, mainly due to the lack of routinely collected data from retrospective studies. The lack of data available for analysis may reflect local constraints in collecting healthcare

information, including lack of digitised healthcare records, late or non-presentation of women for antenatal care, and lower levels of tertiary education resulting in poor self-reporting of pre-pregnancy weight [121]. Of the five Asian studies that were included, only two used the WHO recommended BMI classification specific to the Asian population [34, 36] (BMI of 23–24.9 kg/m^2 considered overweight and $\geq$25 kg/m^2 obese) [122]. This may have resulted in possible misclassification of at-risk overweight and obese Asian women. Furthermore, pre-pregnancy BMI may be influenced by country income [114]; only two studies included in this review took place outside a high-income country [31, 32], due to limited publication of routinely collected data from low- and middle-income countries. Again, this publication bias may reflect the paucity of standardised national databases and digitised clinical records [123]. Maternal BMI is also linked to ethnicity [124, 125] and parity [126] however included studies had insufficient data to enable us to explore this association further.

There is also a paucity of guidance in the field of evidence synthesis of prevalence, which has been previously recognised [127]. This has led to variability in approaches to the methods, risk of bias assessment, data synthesis and reporting of such reviews. We echo the Prevalence Estimates Review-Systematic Review Methodology Group (PERSyst) call to action to develop guidance and reporting standards for these types of review [127].

Strengths and limitations

The use of strict inclusion and exclusion criteria ensured high quality studies of population level data representative of all births were included. In addition, use of an appropriate risk of bias tool for studies investigating prevalence [17] supports the interpretation and generalisation of results in this review. No studies were judged to have a high risk of bias, ensuring that our results were not unduly influenced by selection bias, sampling bias, non-response bias or data-collection bias, and that they were suitably representative of population-level data.

A key limitation is that our review mainly included studies from countries categorised as high income at the time of review, this may have been in part due to the exclusion of reports not written in English. Translation of non-English language reports was not within the scope of this review due to funding constraints. A further limitation is that the income status of countries where specific studies took place was not assessed at the time of their study period but instead when the review was undertaken, as a result some income status' may have differed. Additionally, several study populations were included that had overlapping data, for example, studies using national data from the Swedish Medical Birth Registry. Instead of withdrawing studies and risking exclusion of valid data for certain years, we attempted to ameliorate these effects by calculating and reporting midpoint year of studies. Further MeSH terms, such as "antenatal" or "perinatal$" may have yielded additional studies. The review did not evaluate underweight or undernutrition, which we acknowledge can also be linked to adverse pregnancy outcomes [128, 129].

Future implications

Our findings provide key epidemiological and clinical insights. This review demonstrates an increasing trend in overweight and obesity prevalence in pregnant women across the world, with particularly high prevalence in high income countries, notably in North America, Australia/Oceania and Europe.

To improve accurate surveillance of maternal BMI, key public health stakeholders must focus their efforts on provision of better data informatics to assist in cohesive collection of healthcare data, particularly in low- and middle- income countries. A robust evidence base is required to allow comparable analysis, with this review pointing to the need for further research to be focused in Asia, South America, Africa and in low- and middle-income countries worldwide, using ethnically appropriate BMI classification boundaries. While BMI is a useful tool for population level surveillance, it has limitations at an individual level [130, 131], and there is a need for development of useful tools to aid clinical assessment of personal risk [132]. One example is the Edmonton Obesity Staging System [130, 131]. Novel tools such as this must also be evaluated for use at both an individual and population level in women of child-bearing age.

The increasing trend towards maternal obesity in pregnancy demonstrated by this review is set to provide further challenges to provision of obstetric care. Interpregnancy weight gain, independent of parity and baseline BMI, increases adverse obstetric and neonatal outcomes, including gestational diabetes, hypertensive disorders of pregnancy, increased need for operative delivery, fetal macrosomia and stillbirth [43, 133, 134]. Women with increased BMI in pregnancy are also more likely to have pre-existing multimorbidity (two or more long-term physical or mental health conditions) which is likely to further complicate their pregnancy and postpartum course [135].

Effective strategies to support optimisation of weight before conception are essential to reduce maternal, fetal and neonatal risks and to help women establish a healthy weight trajectory beyond pregnancy.

Conclusion

Our study shows high global prevalence of maternal overweight and obesity which is increasing over time. Overweight and obesity prevalence varies greatly between areas of the world, being highest in North America and lower in Asia. Maternity services across the globe should be adequately resourced to cope with the complexity of needs of pregnant women living with obesity. Future public health interventions should focus on a life-course approach to addressing the trajectory of obesity; with particular focus on the preconception and inter-pregnancy periods. At present, our research demonstrates a less apparent trend to high obesity prevalence in Asia. This may represent an opportunity for early intervention, and to reverse trends in maternal obesity at a population-level.

The availability of population-level maternity BMI data and research varies between regions, with more data required to understand the needs of maternal populations in the continents of Africa and Asia. Globally, there is a need for improved harmonisation and publication of data to enable

better monitoring of obesity trends, and the opportunity to address maternal inequalities in relation to obesity.

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Contributorship statement

LK and MMcG contributed equally to this paper and are joint first authors.

LK contributed to the Conceptualisation, Data Curation, Formal Analysis, Methodology, Visualisation, Resources, Writing - Review and Editing, Supervision and Project Administration of this systematic review.

MMcG contributed to the Data Curation, Formal Analysis, Writing - Original Draft and Visualisation of this systematic review.

LK & KAE is corresponding author and is responsible for the overall content as guarantor.

KAE contributed to the Conceptualisation, Methodology, Writing - Review and Editing, Supervision, Project Administration and Funding Acquisition of this systematic review.

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Competing interests

The authors declare no competing interests.

Ethics approval

Ethics approval was not required as this study synthesised data from published studies.

Availability of data, code and other materials

All data relevant to the study are included in the article or uploaded as Supplementary Information. Code used for the data synthesis and analysis is available at https://github.com/lisa-kent/systematic-review-maternal-obesity. Other materials (data extraction form template, risk of bias assessment questions) are available as Supplementary Information.

Registration information

Review Registry UIN: reviewregistry998
Protocol can be accessed: https://www.researchregistry.com/browse-the-registry#registryofsystematicreviewsmeta-analyses/registryofsystematicreviewsmeta-analysesdetails/5f6b0b90d0a6c20018b0a0c4/
Changes to protocol since registration:

Initial Registered Protocol Details	Changes
Inclusion criteria included control groups from interventional studies or case control studies, providing that there were no restrictions imposed regarding age, race, or health conditions.	Control groups of interventional studies requiring informed consent were excluded due to the possibility of bias through participant self-selection
BMI must be measured during pregnancy	BMI measurement was accepted if measured pre-pregnancy or early pregnancy
Mean and standard error or standard deviation, or median and 95% confidence interval should be reported.	Prevalence (%) within each BMI category was collected
Risk of bias will be assessed using the Newcastle-Ottawa scale (http://www.ohri.ca/programs/clinical_epidemiology/oxford.asp) or the NHLBI Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies (https://www.nhlbi.nih.gov/health-topics/study-quality-assessment-tools) as appropriate depending on study design.	Risk of Bias was assessed using the Hoy Risk of Bias Tool
Descriptive data analysis will be performed. Results will be presented in tables and figures and a narrative review of all studies will be included.	A more robust statistical approach was employed, namely random effects meta-analysis and linear regression

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Supporting Information

Supplementary Material 1: PRISMA Checklist

PRISMA 2020 Checklist

Section and Topic	Item #	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	Line 3
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	Line 26
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	Line 78
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	Line 88
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	Line 109
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	Line 104
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	Line 99
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	Line 118
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	Line 126
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	S2
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	S2
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	Line 131
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	Line 149
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	Line 149
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	Line 156
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	Line 172
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	Line 160
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	Line 167
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	Line 181
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	N/A
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	Line 161

PRISMA 2020 Checklist

Section and Topic	Item #	Checklist item	Location where item is reported
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	Fig 1
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	Fig 1
Study characteristics	17	Cite each included study and present its characteristics.	Table 1
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	S4
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	Table 2
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	Line 227
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	Line 232 Table 3 Figs 2&3
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	Table 4
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	Table 4
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	N/A
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	Tables 3-5
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	Line 302
	23b	Discuss any limitations of the evidence included in the review.	Line 372
	23c	Discuss any limitations of the review processes used.	Line 372
	23d	Discuss implications of the results for practice, policy, and future research.	Line 393
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	Line 466
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	Line 471
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	Line 476
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	Line 451
Competing interests	26	Declare any competing interests of review authors.	Line 455
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	Line 461

From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi:

Supplementary Material 2: Data Extraction Form

Paper Details	
Title of Study	
Study ID (First Author + Year)	
Reference Details	
ID's of other reports for this study (i.e. duplicates or follow-up studies)	
Notes	

General Information	
Date form completed	
Initials of person extracting data	
Publication type	
Funding sources	
Potential conflicts of interest	
Notes	

Study Eligibility					
Study characteristics	Eligibility criteria	Yes	No	Unclear	Location in text
Inclusion Criteria (must answer yes)	Pregnant women (any gestation at time of birth)				
	BMI measured pre-pregnancy or during pregnancy				
	If BMI measured during pregnancy, was it singleton pregnancy? (NB not applicable if BMI measured pre-pregnancy)				Not applicable ☐
Exclusion Criteria (must answer no)	Selected by age?				
	Selected by race?				
	Selected by health status?				
	Selected by birth outcome?				
	Selected by gestation at birth?*				
	n≤100				
	Only live births				
	Required participants to volunteer or provide consent?				
INCLUDE: ☐		EXCLUDE: ☐			
Reason for exclusion					
Notes: *Please note if database or if study excludes based on gestation at birth					

***** DO NOT PROCEED IF STUDY EXCLUDED FROM REVIEW *****

Population and Setting		
	Description	Location in text
Country (+Region)		
Population + Setting		
Inclusion criteria		
Exclusion criteria		
Method(s) of data collection		
Name of database		
Notes:		

Methods			
	Description		Location in text
Aim of study			
Study Design			
Month / Year of BMI Measurement	Start:		
	End:		
	Other detail:		
Ethical approval needed/ obtained			
Notes:			

Participant Characteristics			
	Description		Location in text
No. cases in sampling frame			
No. cases in reported data			
Gestation at Measurement	Pre-pregnancy:		
	Early pregnancy:		
	Pre- & Early:		
Race/ ethnicity			
Parity	Nulliparous		
	Multiparous		
	Nulli and Multi		
Notes:			

Results related to primary aim of review				
	Description			Location in text
BMI Classification WHO: <18.5 = underweight 18.5-24.99 = normal 25-29.99 = overweight 30-34.99 = obese(I) 35-39.99 = obese(II) ≥40 = obese(III)	Was WHO classification used? (if not, report boundaries)			
BMI	Mean:			
	Median			
	SD:			
	95%CI:			
	Other:			
BMI Class	Underweight	n		
		%		
	Normal	n		
		%		
	Overweight	n		
		%		
	Obese (all classes)	n		
		%		
	Obese I	n		
		%		
	Obese II	n		
		%		
	Obese III	n		
		%		
Notes:				

Supplementary Material 3: Hoy Risk of Bias Tool

Item #	Question	Criteria with bespoke study specific guidance
Q1	Was the study's target population a close representation of the national population in relation to relevant variables (e.g. age, sex, occupation)	Yes (Low Risk) e.g. National database No (High Risk) e.g. Urban hospital database
Q2	Was the sampling frame a true or close representation of the target population?	Yes (Low Risk) No (High Risk) e.g. only public patients (not private or vice versa)
Q3	Was some form of random selection used to select the sample, OR, was a census undertaken?	Yes (Low Risk) No (High Risk)
Q4	Was the likelihood of non-response bias minimal?*(NB- interpret as missing pregnancies from dataset or pregnancies with missing information on BMI)*	Yes (Low Risk) i.e. <2% excluded due to missing values No (High Risk) i.e. 2% and above
Q5	Were data collected directly from the subjects (as opposed to a proxy)?	Yes (Low Risk) i.e. either self-reported or measured No (High Risk)
Q6	Was an acceptable case definition used in the study?	Yes (Low Risk) No (High Risk)
Q7	Was the study instrument that measured the parameter of interest shown to have reliability and validity?	Yes (Low Risk) i.e. BMI measured No (High Risk) i.e. BMI self-reported or mix of self-reported/measured
Q8	Was the same mode of data collection used for all subjects?	Yes (Low Risk) e.g. all data collected at booking appointment by midwife No (High Risk)
Q9	Was the length of the shortest prevalence period for the parameter of interest appropriate?	Yes (Low Risk) e.g. woman asked about BMI prior to pregnancy/ BMI measured at booking No (High Risk) e.g. any period longer than pre-preg to booking
Q10	Were the numerator(s) and denominator(s) for the parameter of interest appropriate?	Yes (Low Risk) No (High Risk) e.g. if numbers within BMI groups do not add up to the reported total included
Q11	Summary item on the overall risk of study bias	LOW RISK OF BIAS: Further research is very unlikely to change our confidence in the estimate. MODERATE RISK OF BIAS: Further research is likely to have an important impact on our confidence in the estimate and may change the estimate. HIGH RISK OF BIAS: Further research is very likely to have an important impact on our confidence in the estimate and is likely to change the estimate.

Supplementary Material 4: Risk of bias of included studies (assessed using Hoy Risk of Bias Tool)

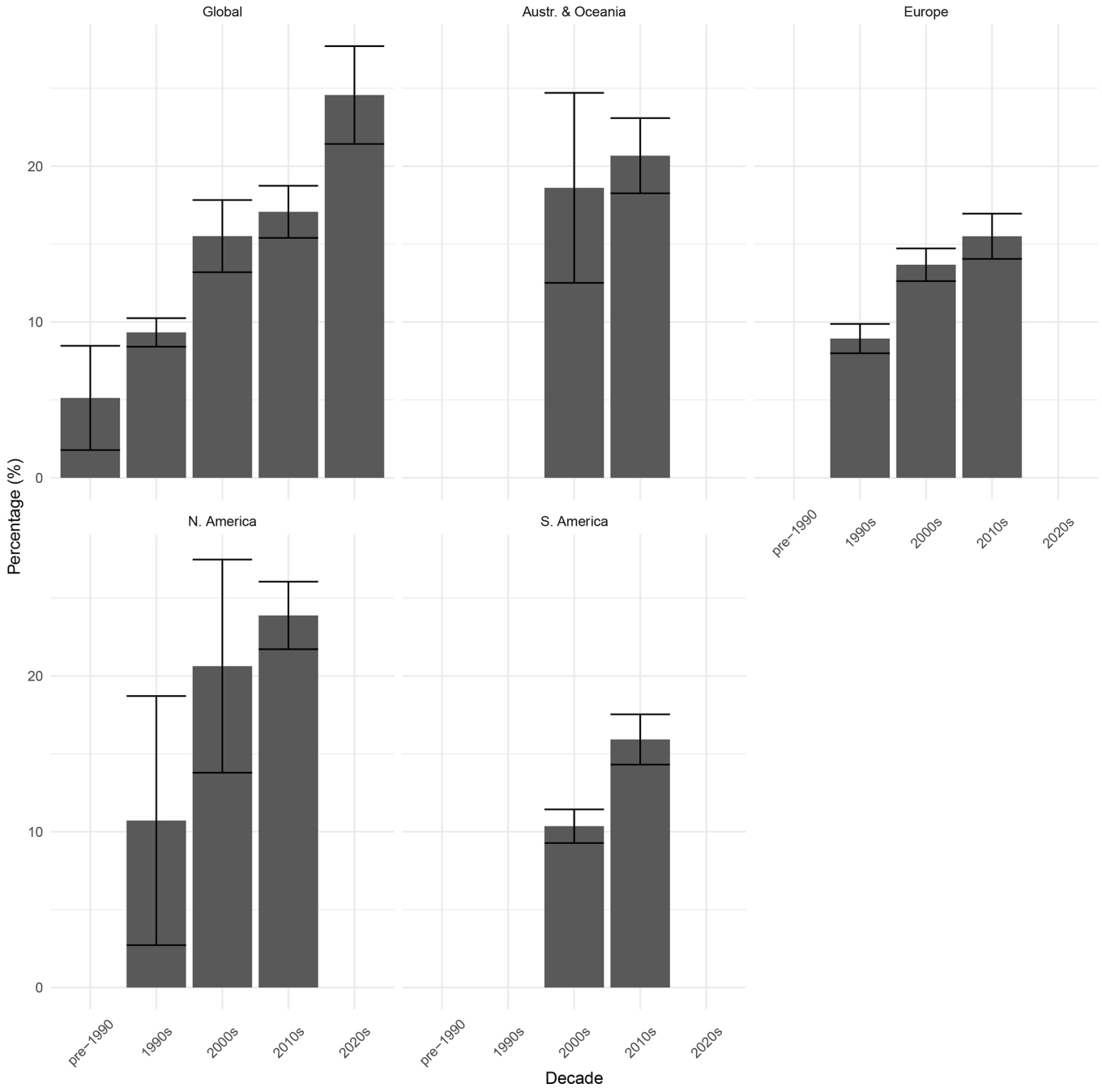
Study ID	1	2	3	4	5	6	7	8	9	10	Total score	Risk of bias
Asia												
Jin 2021	-	-	-	+	-	-	+	-	-	-	2	Low
Leung 2008	+	+	-	-	-	-	-	-	-	-	2	Low
Ma 2016	+	-	-	-	-	-	+	-	-	-	2	Low
Michlin 2000	+	-	-	+	+	-	+	+	-	-	5	Moderate
Morikawa 2012	-	-	-	+	-	-	-	-	-	-	1	Low
Australia/ Oceania												
Callaway 2006	+	-	-	+	-	-	+	-	-	-	3	Low
Cheney 2018	+	-	-	+	-	-	-	-	-	-	2	Low
Cunningham 2013	+	-	-	+	-	-	-	-	-	-	2	Low
Davey 2020	-	-	-	+	-	-	+	+	-	+	4	Moderate
Dodd 2011	-	-	-	+	-	-	-	-	-	-	1	Low
Donald 2020	-	-	-	+	-	-	+	+	+	-	4	Moderate
Knight-Agarwal 2016	-	-	-	+	-	-	-	-	-	-	1	Low
McIntyre 2012	+	-	-	+	-	-	+	-	-	-	3	Low
San Martin Porter 2021	-	-	-	+	-	-	+	-	-	-	2	Low
Watson 2013	+	+	-	+	-	-	+	+	-	-	5	Moderate
Europe												
Abayomi 2009	+	-	-	+	-	-	-	-	-	-	2	Low
Arrowsmith 2011	+	-	-	+	-	-	-	-	-	-	2	Low
Bak 2016	-	-	-	-	-	-	-	-	-	-	0	Low
Baker 2012	+	-	-	+	-	+	-	-	-	+	4	Moderate
Bastola 2020	-	-	-	+	-	-	+	+	-	-	3	Low
Bhattacharya 2007	+	-	-	+	+	-	+	+	-	-	5	Moderate
Blomberg 2010	-	-	-	+	-	-	+	-	-	-	2	Low
Blomberg 2011	-	-	-	+	-	-	-	-	-	-	1	Low
Briese 2011	-	-	-	+	+	-	+	+	-	-	4	Moderate
Carillo-Aguirre 2020	-	+	-	+	-	-	+	+	-	-	4	Moderate
Cedergren 2007	-	-	-	+	-	-	-	-	-	+	2	Low
Cedergren 2008	-	-	-	+	-	-	+	+	-	-	3	Low
Cnattingius 1998	-	-	-	+	-	-	+	-	-	-	2	Low
Collier 2017	-	-	-	+	-	-	-	-	-	-	1	Low
Denison 2014	-	-	-	+	-	-	+	-	-	-	2	Low
Deruelle 2017	-	-	-	+	-	-	+	-	-	-	2	Low
Erjavec 2016	-	-	-	-	-	-	+	+	-	-	2	Low
Farah 2009	+	-	-	+	-	-	-	-	-	-	2	Low
Frischknecht 2009	+	-	-	+	-	-	-	-	-	+	3	Low
Gardosi 2009	-	-	-	+	-	-	-	-	-	-	1	Low
Hedegaard 2014	-	-	-	+	-	-	+	+	-	-	3	Low
Henriksson 2020	-	-	-	-	-	-	-	-	-	-	0	Low
Heslehurst 2007	+	-	-	+	-	-	-	-	-	+	3	Low
Heslehurst 2012	-	-	-	+	-	-	+	-	-	-	2	Low
Huisman 2013	-	-	-	-	-	-	-	+	-	-	1	Low
Johansson 2017	-	-	-	-	-	-	-	-	-	-	0	Low
Kanagalingam 2005	+	-	-	-	-	-	-	-	-	+	2	Low
Kent 2021	-	-	-	+	-	-	-	-	-	-	1	Low
Khashan 2009	-	-	-	+	-	-	-	-	-	-	1	Low
Kristensen 2005	-	-	-	+	-	-	+	+	-	-	3	Low
Le Ray 2005	-	-	-	+	-	-	-	-	-	-	1	Low
Lindholm 2015	-	-	-	+	-	-	+	-	-	-	2	Low
Lucovnik 2008	-	-	-	-	-	-	-	-	-	-	0	Low
Maier 2016	+	-	-	-	-	-	+	-	-	-	2	Low
Mantakas 2010	+	-	-	+	-	-	+	-	-	-	3	Low
McKeating 2015	+	-	-	+	-	-	-	-	-	-	2	Low
Melchor 2019	+	-	-	-	-	-	-	-	-	+	2	Low
Mogren 2018	-	-	-	-	-	-	-	-	-	-	0	Low

Continued

Supplementary Material 4: Continued

Study ID	1	2	3	4	5	6	7	8	9	10	Total Score	Risk of Bias
Nishikawa 2017	+	+	-	-	-	-	-	-	-	-	2	Low
Nohr 2012	-	-	-	+	-	-	+	+	-	-	3	Low
Oteny-Ntim 2013	+	-	-	+	-	-	+	-	-	-	3	Low
Ovesen 2011	-	-	-	+	-	-	+	-	-	-	2	Low
Penn 2014	+	-	-	+	-	-	-	-	-	-	2	Low
Premru-Srsen 2019	-	-	-	-	-	-	+	-	-	-	1	Low
Raja 2012	+	-	-	+	-	-	-	-	-	-	2	Low
Ramoniene 2017	+	-	-	+	-	-	+	+	-	-	4	Moderate
Rankin 2010	+	-	-	+	-	-	+	+	-	-	4	Moderate
Rantakallio 1995	+	-	-	+	-	-	+	-	-	-	3	Low
Reynolds 2019	+	-	-	-	-	-	-	-	-	-	1	Low
Reynolds 2020	+	-	-	-	-	-	-	-	-	-	1	Low
Scott-Pillai 2015	+	-	-	+	-	-	-	-	-	-	2	Low
Sebire 2001	+	-	-	+	-	-	-	-	-	-	2	Low
Stepan 2006	+	-	-	-	-	-	+	-	-	-	2	Low
Villamor 2006	-	+	-	+	-	-	+	-	-	-	3	Low
North America												
Abenhaim 2007	+	-	-	+	-	-	+	+	+	+	6	Moderate
Berendzen 2013	+	-	-	+	-	-	+	-	-	-	3	Low
Butwick 2018	-	-	-	+	-	-	+	-	-	-	2	Low
Chen 2004	+	+	-	+	-	-	-	-	-	-	3	Low
Crane 2009	-	-	-	+	-	-	+	-	-	-	2	Low
Declerq 2016	-	-	-	+	-	-	+	-	-	-	2	Low
Doyle 2022	-	-	-	+	-	-	+	-	-	-	2	Low
Ehrenthal 2011	+	-	-	+	-	-	+	-	-	-	3	Low
Eick 2019	-	-	-	-	-	-	+	+	-	-	2	Low
Gonzalez-Rios 2022	+	-	-	-	-	-	+	-	-	+	3	Low
Kabiru 2004	+	-	-	+	-	-	-	-	-	-	2	Low
Leonard 2020	-	-	-	+	-	-	+	+	-	-	3	Low
Lisonkova 2017	-	-	-	+	-	-	+	-	-	-	2	Low
Lutsiv 2015a	-	-	-	+	-	-	+	-	-	-	2	Low
Lynch 2014	+	-	-	-	-	-	+	+	-	-	3	Low
Magann 2011	+	-	-	-	-	-	-	-	-	-	1	Low
Miao 2021	-	-	-	+	+	-	+	+	-	-	4	Moderate
Mills 2020	-	-	-	-	+	-	+	+	+	-	4	Moderate
Naeye 1990	+	-	-	+	-	-	+	-	-	-	3	Low
Pasko 2016	+	-	-	+	-	-	-	-	-	-	2	Low
Seaton 2023	+	-	-	-	+	-	+	-	+	-	4	Moderate
Thompson 2019	-	-	-	+	-	-	+	-	-	-	2	Low
Young 2016	+	-	-	+	-	-	+	-	-	-	3	Low
aSouth America												
Carrilho 2022	-	+	-	+	-	-	+	-	-	-	3	Low
Conde-Agudelo 2000	-	-	-	+	-	-	+	-	-	-	2	Low

Supplementary Material 5: Maternal Obesity Pooled Prevalence



Supplementary Material 6: Maternal Overweight and Obesity Prevalence