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Maternal Obesity/Pediatric Health

Maternal body mass index and risk of birth and maternal health outcomes in low- and middle-income countries: a systematic review and meta-analysis

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Summary

We conducted a systematic review and meta-analysis of population-based cohort studies of maternal body mass index (BMI) and risk of adverse birth and health outcomes in low- and middle-income countries. PubMed, Embase, CINAHL and the British Nursing Index were searched from inception to February 2014. Forty-two studies were included. Our study found that maternal underweight was significantly associated with higher risk of preterm birth (odds ratio [OR], 1.13; 95% confidence interval [CI], 1.01–1.27), low birthweight (OR, 1.66; 95% CI, 1.50–1.84) and small for gestational age (OR, 1.85; 95% CI, 1.69–2.02). Compared with mothers with normal BMI, overweight or obese mothers were at increased odds of gestational diabetes, pregnancy-induced hypertension, pre-eclampsia, caesarean delivery and post-partum haemorrhage. The population-attributable risk (PAR) indicated that if women were entirely unexposed to overweight or obesity during the pre-pregnancy or early pregnancy period, 14% to 35% fewer women would develop gestational diabetes, pre-eclampsia or pregnancy-induced hypertension in Brazil, China, India, Iran or Thailand. The highest PAR of low birthweight attributable to maternal underweight was found in Iran (20%), followed by India (18%), Thailand (10%) and China (8%). Treatment and prevention of maternal underweight, overweight or obesity may help reduce the burden on maternal and child health in developing countries.

Keywords: Low- and middle-income countries, maternal BMI, population-attributable risk, pregnancy and health outcomes.

Abbreviations: BMI, body mass index; PAR, population-attributable risk.

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Introduction

Obesity and overweight are recognized as a growing global health problem (1). Worldwide, prevalence of overweight or obesity, defined as an adult body mass index (BMI) of 25 kg m^{-2} or greater, increased by 27.5% between 1980 and 2013 (2). The proportion of overweight among adult women globally increased from 29.8% in 1980 to 38.0% in 2013, notably in developing countries (2). Patterns of overweight and obesity differ between countries, regions and by country income, with overweight or obesity more prevalent among men in developed countries and among women in developing countries (2). In developing countries, the number of deaths as a result of maternal overweight/obesity more than doubled from 336,967 deaths in 1990 to 840,427 deaths in 2010. In developed

countries, the numbers remained almost stable (739,527 deaths in 1990 to 898,040 deaths in 2010) (3). Therefore, developing countries face an increasing burden of overweight and obesity, while underweight also remains a significant health problem among women of childbearing age.

The growing epidemic of maternal overweight/obesity accounted for 1.1 million deaths and 2.3% of global disability-adjusted life years (DALYs) in 1990 and 1.7 million deaths and 4.1% of DALYs in 2010 (3,4). Several observational studies show that maternal underweight, overweight or obesity during pre-pregnancy or early pregnancy are a threat to maternal and infant health (5–14). For mothers, major adverse health outcomes are gestational diabetes, pregnancy-induced hypertension, pre-eclampsia, post-partum haemorrhage and caesarean delivery. Infants of overweight or obese mothers are at increased risk of low birthweight, preterm birth, small for gestational age and stillbirth. However, not all studies show a statistically significant relationship and there are no comprehensive assessments for each of these outcomes comparing underweight, overweight and obese mothers with normal-weight mothers using high quality cohort studies in developing countries. Maternal underweight in early pregnancy is the leading risk factor for adverse birth outcomes in developing countries, including low birthweight (8,15), preterm birth (15,16), small for gestational age (8,9,17) and stillbirths (15), but previous meta-analyses have compared these outcomes by overweight or obese versus normal-weight mothers in both developed and developing countries simultaneously (18–20). Most systematic reviews and meta-analyses are limited to the relationship between maternal BMI and specific birth and maternal health outcomes, especially gestational diabetes and caesarean delivery, and usually only in developed countries (21–23). Other maternal health problems including pregnancy-induced hypertension and post-partum haemorrhage have not been studied in relation to maternal BMI. Estimating adverse birth and maternal health risks associated with underweight, overweight or obesity may help inform decision-making in clinical settings and programme development to improve maternal and child health outcomes.

We undertook a systematic review and pooled available evidence from cohort studies conducted in developing countries with a reference group of normal BMI mothers to determine the association between maternal underweight, overweight or obesity before or during early pregnancy (first trimester or first prenatal visit) and low birthweight, preterm birth, small for gestational age and stillbirth. We assessed the risk of gestational diabetes, pregnancy-induced hypertension, pre-eclampsia, caesarean delivery and post-partum haemorrhage for underweight, overweight and obese mothers relative to normal-weight mothers. In addition, no previous study has estimated the population-attributable risk (PAR) of adverse pregnancy and maternal health outcomes for maternal BMI at pre-pregnancy or during early pregnancy. In order to assess the impact of maternal BMI, we estimated the PAR for selected adverse perinatal and maternal health outcomes by maternal BMI categories.

Methods

The review was undertaken according to the protocol (Supporting Information Text) and Meta-analysis of Observational Studies in Epidemiology (MOOSE) guidelines (Supporting Information Table S1).

Search strategy

We conducted a search for studies on pre-pregnancy and first trimester BMI and risk of perinatal and maternal health outcomes with the assistance of an information specialist. We used four electronic databases: PubMed, Embase, CINAHL and British Nursing Index. We developed search strategies consisting of a combination of free text words, words in titles/abstracts and medical subject headings for exposure, participants and study designs. The full search strategies and search results for the four databases are shown in the Supporting Information Tables S2, S2, S3 and S4. Further searches for eligible studies were conducted by reviewing references within identified papers and relevant journals. We set no language restrictions. We defined low- and middle-income countries based on the World Bank criteria of 2013 (24).

Selection of studies

In the first stage of screening, two assessors (MMR and MSR) independently screened titles and abstracts according to the inclusion and exclusion criteria. In the second stage, four assessors (MMR, SKA, SN and MK) screened the full text of selected studies to assess eligibility. Studies that were cohorts (prospective or retrospective) with pregnant women of reproductive age (15 years or over) were included as subjects. We included studies reporting BMI measures (maternal normal weight, underweight, overweight or obesity), reflecting status preceding any significant pregnancy weight gain (i.e. measured or reported pre-pregnancy and/or during the first trimester or first prenatal visit) and perinatal and maternal health outcomes. We followed the World Health Organization (WHO), Chinese Guidelines for Prevention and Control (GPC) (25) and Institute of Medicine (IOM) (26) definitions for classification of BMI. We treated BMI as our main exposure variable. Height and weight were also separately treated as exposure variables. Therefore, we ignored thresholds for defining maternal BMI in the second screening stage in order to cover studies that reported height or weight only

rather than BMI. Birth and health outcomes were preterm delivery (defined as a birth before 37 weeks of gestation), low birthweight (defined as weight <2,500 g), small for gestational age (defined as birthweight below the 10th percentile of the gestational age and sex), gestational diabetes, pre-eclampsia or pregnancy-induced hypertension, caesarean delivery, including both elective and emergency, and blood loss after delivery. Studies with high-risk populations such as people living with human immunodeficiency virus/acquired immunodeficiency syndrome, malaria, heart disease, diabetes, pre-eclampsia or pregnancy-induced hypertension at baseline were excluded.

Data extraction and management

Prior to tabulating the final data, a data extraction form was designed, trialled and modified. From full-text articles and reports using the agreed form, four review authors (MSR, SKA, SN and MK) independently extracted data on country of origin, year of study, study design, participants, exposures and their time of assessment, outcomes, confounders and measures of association based on information available from publications. We included five articles written in languages other than English (Spanish, Chinese, French and Portuguese) and consulted people proficient in these languages. We excluded two Persian studies due to lack of an appropriate translator with sufficient knowledge on the topic (27,28). We resolved discrepancies through a consensus process. We contacted authors of the original reports about further details when information on outcomes, exposures or study design was unclear.

Quality assessment in included studies

We used a specific checklist to assess the methodological quality of all included cohort studies with the Newcastle-Ottawa Scale criteria set by Wells *et al*. (29). Four authors (MSR, SKA, SN and MK) independently assessed the study quality using a predefined evaluation form for cohort studies, which assigned a score ranging from 0 to 9. Studies were defined as high quality if they scored ≥6, moderate quality if they scored 4–5 or low quality if they scored 0–3.

Statistical analysis

We used BMI categories of normal, underweight, overweight and obese as defined by each study. In the meta-analysis, we used odds ratios (OR) with 95% confidence intervals (CI). If the OR was unavailable, we estimated the unadjusted OR with 95% CI from raw data and then used this estimate in the meta-analysis. A few studies did not include results for normal versus underweight or normal versus obese. In this case, we estimated pooled ORs using random-effects models among those studies reporting an OR for underweight or obese versus normal weight and then replaced this pooled estimation in those studies lacking results for underweight or obese groups. This replacement procedure increases the number of studies and may help to improve the power in meta-analysis. We checked the direction and consistency of ORs before and after imputation. The direction was the same among the studies and pooled estimation remained the same before and after replacing these values, suggesting that the replacement of exposure and outcomes did not have major effects on these findings.

We used fixed-effects (30,31) or random-effects (32) models to estimate summarized results on the basis of heterogeneity (I^2 statistic) assessments. The I^2 value refers to the percentage of variability across studies due to between-study heterogeneity (33). We estimated the I^2 statistic with *P*-values for each meta-analysis to describe the extent of heterogeneity. We used fixed-effects models if $I^2 \leq 50$ and random-effects models for outcomes with heterogeneity measured above this threshold. Values of 25%, 50% and 75% were considered as low, moderate and high heterogeneity, respectively. We used Funnel plots and Egger's regression asymmetry test to examine publication bias (34). To account for these publication biases in meta-analysis, we additionally performed trim-and-fill procedures (35).

We conducted subgroup and random-effects meta-regression analysis to assess the effects of study design (prospective or retrospective), sample size above or below the median value (≤3,715 or >3,715), maternal mean age (≤27 years or >27 years, the median of the sample), BMI measurement point (pre-pregnancy or first trimester), BMI cut-offs (WHO, GPC or IOM), confounding factors (adjusted or unadjusted), country income categories (low- and lower middle-income or upper middle-income countries) and geographic region (Southeast Asia, Middle East or Central and South America). We also performed sensitivity analyses to evaluate differences in pooled effects after dropping a small number of studies that we defined as highly influential on the basis of the variance and weight estimates from meta-analysis.

We estimated the PAR for perinatal and maternal health outcomes due to maternal underweight, overweight and obesity using the estimates obtained from our meta-analysis. The PAR estimates the fraction of adverse outcomes that would not have occurred if the maternal population was not underweight, overweight or obese during the pre-pregnancy or early pregnancy period. PAR was calculated using a modified Levin's formula for multiple exposure categories, proposed by Hanley (36,37).

The formula for the overall PAR calculation is

$$PAR\,(\%) = \frac{\sum_{k=1}^{K} p_k (OR_k - 1)}{\sum_{k=1}^{K} p_k (OR_k - 1) + 1} \times 100, k = 1, 2, \ldots, K$$

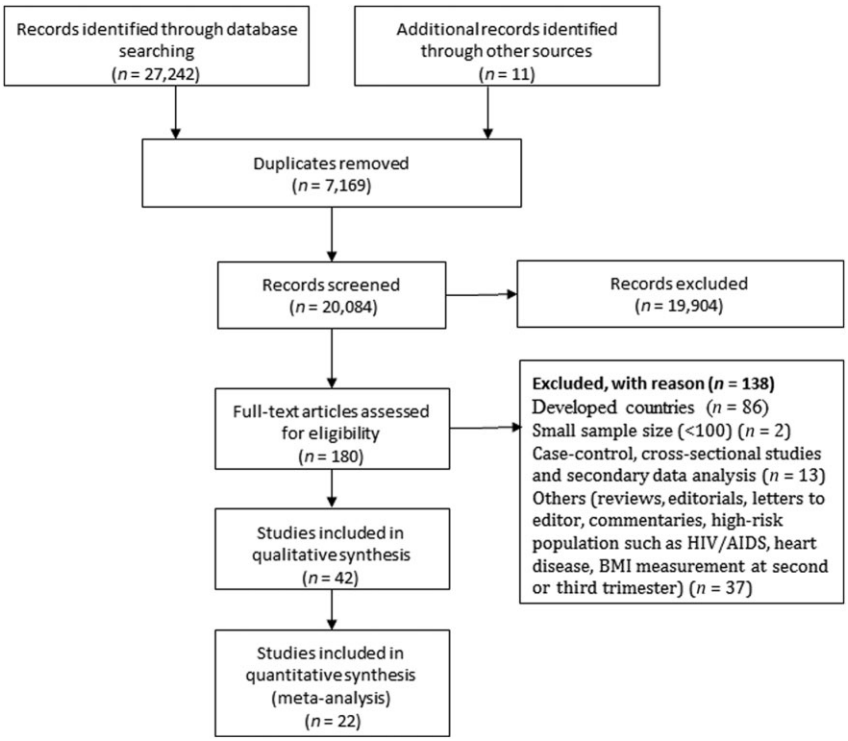

Figure 1 PRISMA flowchart for selection of studies.

while that for the exposure-specific PAR calculation is

$$PAR_K(\%) = \frac{p_k(OR_k - 1)}{\sum_{k=1}^{K} p_k(OR_k - 1) + 1} \times 100, k = 1, 2, \ldots, K$$

Where p is the proportion of exposure to the risk factor in the total population of mothers, OR is the pooled odds ratio of a risk factor for a specific birth or health outcome and K is the number of categories of the risk factor. Prevalence data were used separately for each country and maternal BMI category (underweight, overweight and obesity) to obtain PARs for each group. We used country-specific ORs for low birthweight, preterm birth, small for gestational age, stillbirths, gestational diabetes, pregnancy-induced hypertension, pre-eclampsia, caesarian delivery and post-partum haemorrhage. These were derived from the meta-analysis or from single studies where only one study could be found, while data on the proportion of BMI categories was derived from included population-based studies. We used Stata version 12.1/MP (StataCorp, College Station, TX, USA), for all analyses.

Results

Literature search

We initially identified 27,242 studies, of which 17,322 were from PubMed, 9,252 from Embase, 549 from CINAHL and 119 from the British Nursing Index (Fig. 1). After excluding duplicates, 20,073 remained for title and abstract screening. Of these, 169 full-text papers were reviewed and 138 articles were excluded due to small sample size (<100 women), study design (case-control, cross-sectional or secondary data analysis), non-research material, high-risk populations or BMI measured at second or third trimester (Fig. 1). We also included 11 studies identified through hand search and from reference lists. In total, 42 studies met the inclusion criteria for our review and 22 studies were included in the meta-analysis.

Study characteristics

The basic characteristics of the 42 studies included in our systematic review are presented in Supporting Information Table S6. The majority were conducted in Southeast Asia and in upper middle-income countries (Supporting Information Table S7). There were 34 prospective cohorts and eight retrospective cohorts. Of the 42 studies, 16 reported preterm birth (5,9,10,13–16,38–46), 18 low birthweight (7,10,11,14,15,39,41–45,47–53), seven small for gestational age (9,17,39,41,44,54,55), five stillbirth (9,15,16,44,56), 19 gestational diabetes (5,6,9,12,13,15, 17,38,40,41,43,57–64), nine pregnancy-induced hypertension (5,6,13,17,38,41,63,65,66), nine pre-eclampsia (5,9, 13,15–17,43,60,62), 10 caesarean delivery (6,9,14,15,38, 41–43,60,67), three post-partum haemorrhage (6,9,15) and two perinatal mortality (43,44). The study-specific proportion of BMI and events by perinatal and maternal

Table 1 Meta-analysis summary results

Outcomes	Number of studies	Underweight		Overweight		Obese	
		OR (95% CI)	Heterogeneity (*P*-value)	OR (95% CI)	Heterogeneity (*P*-value)	OR (95% CI)	Heterogeneity (*P*-value)
Pregnancy outcomes							
Preterm birth	11	1.13 (1.01–1.27)	81.2 (<0.001)	1.05 (0.91–1.20)	74.3 (<0.001)	1.21 (0.95–1.53)	79.3 (<0.001)
Low birthweight	8	1.66 (1.50–1.84)	0.0 (0.9)	0.81 (0.73–0.9)	0.0 (0.7)	0.75 (0.65–0.86)	6.5 (0.4)
Small for gestational age	5	1.85 (1.69–2.02)	0.0 (0.4)	0.74 (0.70–0.77)	35.7 (0.2)	0.60 (0.39–0.92)	72.3 (0.01)
Stillbirth	3	0.98 (0.37–2.58)	68.1 (0.04)	1.13 (0.87–1.45)	43.2 (0.2)	1.53 (0.63–3.71)	69.4 (0.1)
Maternal health outcomes							
Gestational diabetes	13	0.47 (0.43–0.52)	0.0 (0.6)	2.18 (1.90–2.51)	54.1 (0.01)	3.74 (2.89–4.84)	78.6 (<0.001)
Pregnancy-induced hypertension	5	0.50 (0.40–0.61)	0.0 (0.5)	2.27 (2.01–2.56)	0.1 (0.4)	5.61 (4.86–6.46)	0.0 (0.5)
Pre-eclampsia	8	0.70 (0.59–0.83)	21.7 (0.2)	1.98 (1.64–2.40)	63.2 (<0.01)	3.87 (3.48–4.29)	42.8 (0.1)
Caesarean delivery	7	0.62 (0.53–0.74)	93.6 (<0.001)	1.32 (1.10–1.58)	84.8 (<0.001)	1.86 (1.36–2.54)	90.4 (<0.001)
Post-partum haemorrhage	3	0.58 (0.49–0.69)	0.0 (0.7)	3.13 (1.00–9.81)	96.9 (<0.001)	3.48 (1.62–7.47)	90.5 (<0.001)

CI, confidence interval; OR, odds ratio.

health outcomes are presented in Supporting Information Tables S8 and S9. Only three of the 42 studies were assessed as moderate in quality, all others were high quality (Supporting Information Table S10).

Pooled estimation of birth and health outcomes

Pooled ORs in the 22 studies included in the meta-analysis are presented in Table 1. Sensitivity analysis, publication bias and trim-and-fill estimates for all outcomes are in Supporting Information Tables S11 and S12. A total of 492,745 (range: 270–353,477) subjects with mean age 27.8 (mean age range: 24.3–32.3) were included in our meta-analysis. In comparison with normal weight, underweight was significantly associated with a greater risk of preterm birth (OR, 1.13; 95% CI, 1.01–1.27), low birthweight (OR, 1.66; 95% CI, 1.50–1.84) and small for gestational age (OR, 1.85; 95% CI, 1.69–2.02; Table 1). Both overweight and obesity were found to be a risk factor for gestational diabetes, pregnancy-induced hypertension, pre-eclampsia, caesarean delivery and post-partum haemorrhage (Table 1). Maternal overweight/obesity was associated with increased risk of stillbirths, but no increasing trend was observed for preterm birth with increasing BMI. Detailed country-specific pooled ORs according to perinatal and maternal health outcomes are presented in Supporting Information Tables S13 and S14. The risk of stillbirth, gestational diabetes, pregnancy-induced hypertension, pre-eclampsia, caesarean delivery and post-partum haemorrhage increased with increasing BMI. Our narrative review results indicated that the risk of delivering babies with low birthweight was significantly higher among underweight (relative risk [RR], 1.30; 95% CI, 1.09–1.54) and shorter (RR, 1.51; 95%, 1.2–1.9) women (Supporting Information Table S15) (47,50). We also found that underweight women were more likely to deliver babies with small for gestational age (Supporting Information Table S15) (5,44). Among obese mothers, incidence of gestational diabetes and caesarean section delivery was higher (Supporting Information Table S15) (38,60).

Stratified analyses

We found moderate to severe heterogeneity in some perinatal and maternal health outcomes (Table 1). Therefore, we conducted stratified analyses to examine the heterogeneity in results for preterm birth, small for gestational age, stillbirth, gestational diabetes, pre-eclampsia, caesarean delivery and post-partum haemorrhage. Stratified analyses by study design, sample size, mean maternal age, BMI measurement timing, BMI cut-offs, confounding factors, country income category and geographic region are presented in Tables 2 and 3 and Supporting Information Tables S16 and S17. Stratifying by geographic region revealed an increased risk in the Middle East among overweight mothers (OR, 1.55; 95% CI, 1.06–2.26; $P = 0.01$) for preterm birth compared with Southeast Asia and Central and South America (Table 2). Obese mothers in the Middle East were more likely to develop pre-eclampsia compared with the other regions, but the association was not statistically significant ($P = 0.20$; Table 3). In general, the BMI thresholds of individual studies were different but there was little evidence that the results varied by BMI cut-off, with preterm birth as the only outcome sensitive to the threshold definition. There was lower risk of preterm birth in the studies using WHO BMI cut-offs among overweight (OR, 0.86; 95% CI, 0.77–0.96; $P = 0.01$) and obese (OR, 0.93; 95% CI, 0.76–1.15; $P = 0.01$) mothers compared with studies that used GPC and IOM cut-offs.

Table 2 Stratified analysis of selected pregnancy outcomes by BMI

Characteristics	Preterm birth		Low birthweight	
	Pooled OR (95%CI)	*P*-value*	Pooled OR (95%CI)	*P*-value*
Underweight				
Study design				
Prospective	1.17 (0.94–1.45)	0.59	1.66 (1.46–1.88)	0.95
Retrospective	1.03 (0.80–1.33)		1.67 (1.40–1.98)	
BMI measurement				
Pre-pregnancy	1.13 (0.87–1.46)	0.12	1.61 (1.39–1.88)	0.63
First trimester	1.07 (1.02–1.13)		1.70 (1.48–1.95)	
BMI cut-off				
WHO	1.27 (0.99–1.63)	0.12	1.59 (1.41–1.79)	0.83
GPC	0.98 (0.85–1.13)		1.73 (1.35–2.22)	
IOM	0.88 (0.54–1.42)		1.67 (0.56–5.00)	
Confounding factors				
Adjusted	1.05 (0.88–1.26)	0.40	1.68 (1.37–2.06)	0.88
Unadjusted	1.18 (0.80–1.74)		1.65 (1.47–1.86)	
Country income category				
Low and lower middle-income	0.71 (0.43–1.18)	0.10	1.67(1.14–2.44)	0.98
Upper middle-income	1.16 (1.03–1.30)		1.66(1.49–1.84)	
Geographic region				
Southeast Asia	1.04 (0.82–1.32)	0.62	1.64 (1.41–1.89)	0.59
Middle East	0.88 (0.54–1.42)		2.46 (1.14–5.31)	
Central and South America	1.25 (0.95–1.65)		1.66 (1.44–1.92)	
Overweight				
Study design				
Prospective	0.83 (0.76–0.90)	0.00	0.81 (0.71–0.91)	0.99
Retrospective	1.15 (1.04–1.27)		0.76 (0.50–1.15)	
BMI measurement				
Pre-pregnancy	1.05 (0.87–1.27)	0.93	0.80 (0.67–0.96)	0.94
First trimester	1.08 (1.01–1.16)		0.80 (0.69–0.93)	
BMI cut-off				
WHO	0.86 (0.77–0.96)	0.01	0.74 (0.61–0.90)	0.46
GPC	1.13 (1.02–1.25)		0.92 (0.72–1.17)	
IOM	1.56 (1.06–2.26)		0.69 (0.22–2.20)	
Confounding factors				
Adjusted	1.09 (0.92–1.29)	0.39	0.83 (0.74–0.95)	0.30
Unadjusted	0.94 (0.74–1.20)		0.74 (0.60–0.90)	
Country income category				
Low and lower middle-income	0.81 (0.67–0.98)	0.15	0.81 (0.71–0.92)	0.91
Upper middle-income	1.09 (0.94–1.26)		0.80 (0.66–0.96)	
Geographic region				
Southeast Asia	1.07 (0.94–1.21)	0.01	0.81 (0.73–0.90)	0.89
Middle East	1.55 (1.06–2.26)		0.69 (0.22–2.20)	
Central and South America	0.83 (0.75–0.91)		0.60 (0.15–2.42)	
Obese				
Study design				
Prospective	0.93 (0.73–1.19)	0.01	0.73 (0.62–0.86)	0.63
Retrospective	1.44 (1.18–1.76)		0.69 (0.32–1.47)	
BMI measurement				
Pre-pregnancy	1.19 (0.89–1.58)	0.79	0.72 (0.52–1.00)	0.99
First trimester	1.28 (0.82–2.02)		0.74 (0.61–0.91)	
BMI cut-off				
WHO	0.93 (0.76–1.15)	0.01	0.67 (0.52–0.86)	0.22
GPC	1.57 (1.36–1.83)		0.96 (0.68–1.35)	
IOM	1.32 (0.74–2.35)		0.36 (0.08–1.65)	
Confounding factors				
Adjusted	1.31 (0.94–1.83)	0.37	0.79 (0.67–0.95)	0.22
Unadjusted	1.06 (0.89–1.26)		0.63 (0.46–0.87)	
Country income category				
Low and lower middle-income	1.10 (0.91–1.33)	0.78	0.73 (0.62–0.87)	0.88
Upper middle-income	1.23 (0.92–1.65)		0.67 (0.41–1.10)	
Geographic region				
Southeast Asia	1.35 (1.10–1.66)	0.02	0.74 (0.62–0.90)	0.53
Middle East	1.32 (0.74–2.35)		0.36 (0.08–1.65)	
Central and South America	0.80 (0.70–0.91)		1.05 (0.29–3.80)	

*Represents the test for significance of the effect modification across strata and these *P*-values come from the meta-regression.

BMI, body mass index; CI, confidence interval; GPC, Guidelines for Prevention and Control for Chinese; IOM, Institute of Medicine; OR, odds ratio; WHO, World Health Organization.

Table 3 Stratified analysis of selected maternal health outcomes by BMI

Characteristics	Gestational diabetes		Pre-eclampsia		Caesarean delivery	
	Pooled OR (95%CI)	*P*-value*	Pooled OR (95%CI)	*P*-value*	Pooled OR (95%CI)	*P*-value*
Underweight						
Study design						
Prospective	0.46 (0.40–0.54)	0.36	0.75 (0.54–1.03)	0.19	0.70 (0.67–0.73)	0.24
Retrospective	0.44 (0.32–0.61)		0.57 (0.40–0.79)		0.55 (0.33–0.92)	
BMI measurement						
Pre-pregnancy	0.48 (0.38–0.59)	0.43	0.66 (0.46–0.96)	0.83	0.70 (0.47–1.03)	0.33
First trimester	0.46 (0.39–0.55)		0.67 (0.52–0.86)		0.58 (0.46–0.72)	
BMI cut-off						
WHO	0.46 (0.37–0.55)	0.18	0.73 (0.55–0.97)	0.43	0.66 (059–0.74)	0.73
GPC	0.54 (0.45–0.64)		0.52 (0.30–0.91)		0.58 (0.28–1.18)	
IOM	0.22 (0.05–0.94)		0.68 (0.36–1.28)		0.41 (0.14–1.26)	
Confounding factors						
Adjusted	0.51 (0.42–0.62)	0.30	0.74 (0.58–0.95)	0.44	0.58 (0.28–1.18)	0.64
Unadjusted	0.46 (0.39–0.54)		0.41 (0.16–1.03)		0.66 (0.59–0.74)	
Country income category						
Low and lower middle-income	0.46 (0.33–0.66)	0.78	NA		0.70 (0.66–0.74)	0.28
Upper middle-income	0.49 (0.43–0.55)		0.68 (0.54–0.85)		0.58 (0.44–0.75)	
Geographic region						
Southeast Asia	0.49 (0.40–0.61)	0.59	0.48 (0.30–0.77)	0.17	0.62 (0.48–0.79)	0.74
Middle East	0.45 (0.36–0.58)		0.68 (0.36–1.28)		0.41 (0.14–1.26)	
Central and South America	0.46 (0.36–0.58)		0.76 (0.63–0.93)		0.70 (0.66–0.74)	
Overweight						
Study design						
Prospective	2.04 (1.68–2.48)	0.33	1.67 (1.41–1.97)	<0.01	1.13 (0.87–1.48)	0.00
Retrospective	2.40 (1.89–3.04)		2.61 (2.13–3.18)		1.55 (1.42–1.68)	
BMI measurement						
Pre-pregnancy	2.18 (1.89–2.51)	0.82	1.84 (1.56–2.17)	0.06	1.30 (0.94–1.80)	0.92
First trimester	2.17 (1.48–3.18)		2.55 (1.43–4.57)		1.38 (1.13–1.68)	
BMI cut-off						
WHO	2.48 (1.87–3.28)	0.37	1.58 (1.32–1.90)	0.17	1.18 (0.93–1.51)	0.18
GPC	1.98 (1.72–2.28)		2.32 (1.68–3.20)		1.60 (1.50–1.69)	
IOM	2.32 (1.35–3.98)		2.38 (1.53–3.70)		1.30 (0.65–2.60)	
Confounding factors						
Adjusted	1.99 (1.82–2.19)	0.44	1.98 (1.46–2.68)	0.92	1.47 (1.24–1.74)	0.30
Unadjusted	2.46 (1.75–3.44)		1.91 (1.69–2.16)		1.25 (0.97–1.61)	
Country income category						
Low and lower middle-income	3.10 (2.11–4.55)	0.13	NA		1.20 (0.77–1.88)	0.15
Upper middle-income	2.11 (1.85–2.41)		1.98 (1.64–2.40)		1.45 (1.28–1.65)	
Geographic region						
Southeast Asia	2.28 (1.88–2.77)	0.75	2.30 (1.78–2.97)	0.04	1.38 (1.14–1.67)	0.44
Middle East	2.22 (1.52–3.25)		2.38 (1.53–3.70)		1.30 (0.66–2.6)	
Central and South America	1.97 (1.59–2.45)		1.51 (1.28–1.78)		0.93 (0.61–1.41)	
Obese						
Study design						
Prospective	3.23 (2.13–4.89)	0.30	3.59 (3.14–4.10)	<0.01	1.49 (0.96–2.32)	0.02
Retrospective	4.37 (2.94–6.49)		5.37 (4.20–6.88)		2.45 (2.21–2.72)	
BMI measurement						
Pre-pregnancy	3.54 (2.65–4.73)	0.63	3.79 (3.24–4.44)	0.04	1.87 (1.14–3.06)	0.97
First trimester	4.16 (2.22–7.79)		5.58 (4.00–7.77)		1.84 (1.11–3.04)	
BMI cut-off						
WHO	3.85 (2.33–6.37)	0.57	3.83 (2.84–5.16)	0.72	1.61 (1.05–2.47)	0.40
GPC	3.26 (2.45–4.32)		4.49 (3.40–5.93)		2.49 (2.24–2.78)	
IOM	6.21(3.21–12.01)		4.70 (2.50–8.83)		1.61 (0.81–3.22)	
Confounding factors						
Adjusted	3.33 (2.46–4.50)	0.31	4.19 (3.21–5.48)	0.88	1.90 (1.24–2.90)	0.92
Unadjusted	4.59 (2.72–7.73)		4.28 (3.05–6.00)		1.84 (1.20–2.81)	
Country income category						
Low and lower middle-income	8.23 (5.26–12.87)	0.03	NA		1.82 (0.82–4.03)	0.82
Upper middle-income	3.42 (2.72–4.30)		4.12 (3.46–4.90)		1.93 (1.44–2.59)	
Geographic region						
Southeast Asia	4.10 (2.92–5.77)	0.53	4.64 (3.63–5.93)	0.20	2.12 (1.52–2.97)	0.19
Middle East	4.04 (1.53–10.67)		4.70 (2.50–8.83)		1.61 (0.81–3.22)	
Central and South America	2.75 (1.94–3.91)		3.25 (2.71–3.89)		0.94 (0.62–1.43)	

*Represents the test for significance of the effect modification across strata and these *P*-values come from the meta-regression.

BMI, body mass index; CI, confidence interval; GPC, Guidelines for Prevention and Control for Chinese; IOM, Institute of Medicine; NA, not applicable; OR, odds ratio; WHO, World Health Organization.

Table 4 Pregnancy and health outcomes attributed maternal body mass index (BMI)

Country	Prevalence, %	Population-attributable risk, %						
		Preterm birth	Low birthweight	Gestational diabetes	Pre-eclampsia	Pregnancy-induced hypertension	Caesarean delivery	Post-partum haemorrhage
Argentina								
Underweight	5.9	2.7			–0.4			
Overweight	19.3	–3.4			8.3			
Obese	8.2	–1.7			13.5			
Total BMI		–2.3			21.5			
Brazil								
Underweight	5.61			–2.0	–1.1	–0.7		
Overweight	25.13			16.5	4.2	15.8		
Obese	17.38			20.0	32.6	41.9		
Total BMI				44.9	35.7	57.0		
China								
Underweight	11.5	0.4	7.9	–4.3	–3.9	–4.6	–2.8	–1.6
Overweight	18.3	1.7	–1.4	13.9	14.1	14.4	9.3	17.1
Obese	6.8	3.7	–0.3	9.9	15.7	19.9	8.6	13.1
Total BMI		5.9	6.2	19.6	25.9	29.7	15.1	28.6
India								
Underweight	20.9		17.5	–5.6		–6.8	–5.2	–2.7
Overweight	20.9		–3.6	22.0		16.0	9.3	55.2
Obese	9.3		–2.1	33.5		25.4	13.7	17.0
Total BMI			11.9	49.9		34.6	17.7	69.6
Iran								
Underweight	15.8	–1.9	19.8	–7.5	–4.0	–7.9	–9.6	
Overweight	13.2	6.8	–3.5	13.5	14.4	18.6	4.1	
Obese	3.6	1.1	–2.0	8.3	10.5	15.3	2.3	
Total BMI		6.1	14.4	14.3	20.9	26.0	–3.2	
Thailand								
Underweight	17.7	11.1	9.7	–10.6	–9.9		–9.0	–7.7
Overweight	13.0	0.6	–4.5	26.9	13.5		4.8	5.3
Obese	4.3	0.0	–2.4	14.9	16.2		4.8	3.0
Total BMI		11.7	2.7	31.2	19.8		0.6	0.6
Turkey								
Underweight	1.8			–0.4				
Overweight	50.0			28.5				
Obese	13.6			34.7				
Total BMI				62.9				

Burden of maternal body mass index

The PARs of selected adverse perinatal and maternal health outcomes attributable to maternal BMI are presented by country in Table 4. The PAR for maternal BMI ranged from 14% in Iran to 63% in Turkey for gestational diabetes, 26% in Iran to 57% in Brazil for pregnancy-induced hypertension, 20% in Thailand to 36% in Brazil for pre-eclampsia and 0.6% in Thailand to 70% in India for post-partum haemorrhage. The highest PAR of gestational diabetes for maternal obesity was found in Turkey (35%), followed by India (34%), Brazil (20%) and Thailand (15%). The PAR for maternal underweight also varied across countries, ranging from 8% in China to 20% in Iran for low birthweight. In India, maternal obesity before or during early pregnancy contributed to 25% of pre-eclampsia, 14% of caesarean delivery and 17% of post-partum haemorrhage; whereas maternal underweight contributed to 18% of low-birthweight deliveries.

Discussion

In this systematic review and meta-analysis, we investigated the effect of maternal BMI (underweight, overweight or obese), before or during early pregnancy, on perinatal and maternal health outcomes in low- and middle-income countries. This is the first attempt to assess the proportion of selected adverse perinatal and maternal health outcomes attributable to maternal BMI. Most included cohort studies were high quality. In women who were overweight or obese during pre-pregnancy or early pregnancy, the meta-analysis demonstrated a significantly higher risk of adverse health

outcomes, including gestational diabetes, pregnancy-induced hypertension, pre-eclampsia, caesarean delivery and post-partum haemorrhage. Underweight mothers were found to be at higher risk of delivering preterm, low-birthweight and small-for-gestational-age babies than normal-weight mothers. Sensitivity analyses confirmed a similar association after dropping a small number of highly influential studies. Higher maternal BMI contributed 10% to 35% of adverse maternal health outcomes and underweight contributed 8% to 20% of adverse perinatal outcomes, especially low birth-weight in developing countries.

The most recent Global Burden of Disease data shows that globally almost 38% of adult women aged 20 years or older fell into overweight categories with a BMI between 25 and 30 kg/m^2 in 2013 (2). In developing countries, overweight or obesity is more prevalent among women than men (2); while underweight remains a significant health problem among women (6,9,13,54). Our review data showed that underweight is more prevalent among women pre-pregnancy or during early pregnancy in India (21%) (6), Thailand (18%) (15), Iran (16%) (13) and China (11%) (9). High maternal BMI is common in Turkey (50% of women are overweight and 14% obese) (40) and Brazil (25% of women are overweight and 17% obese) (54). However, some countries, including India (6), China (9), Iran (13) and Thailand (15), are facing problems due to low and high maternal BMI simultaneously. Our study found a greater burden of poor maternal health attributable to obesity in Brazil (20% of gestational diabetes, 33% of pre-eclampsia and 42% of pregnancy-induced hypertension) and India (34% of gestational diabetes, 25% of pregnancy-induced hypertension, 14% of caesarean delivery and 17% of post-partum haemorrhage). Underweight accounted for a major proportion of low birthweight in Iran (20%), India (18%), China (10%) and Thailand (10%). Our study showed that overall the highest contribution of maternal BMI to the burden of gestational diabetes is in Turkey (63%), followed by India (50%), Brazil (45%), Thailand (31%), China (20%) and Iran (14%). Pregnancy-induced hypertension due to maternal BMI is also more prevalent in Brazil (57%) and India (35%) than China (30%) and Iran (26%). Developing countries are facing a double burden of adverse perinatal and maternal health outcomes attributable to maternal BMI.

According to our results, overweight and obesity are associated with significantly higher risk of gestational diabetes, pregnancy-induced hypertension, pre-eclampsia, caesarean delivery and post-partum haemorrhage relative to normal BMI mothers. Previous meta-analyses found a similar association regarding gestational diabetes (68,69) and caesarean delivery (21). However, these previous papers were mainly limited to developed countries and maternal pre-pregnancy BMI. The effect of overweight and obesity on gestational diabetes, pre-eclampsia and caesarean delivery was consistent by maternal age (aged ≤27 years vs. >27 years) and confounding adjustment (adjusted vs. unadjusted) across studies. We did not find greater risk of adverse maternal health outcomes among underweight women, suggesting that the main contribution to greater adverse maternal health outcomes is from overweight and obese mothers.

Our systematic review and meta-analysis indicated that underweight mothers have a higher risk of delivering low-birthweight and small-for-gestational-age babies. This finding is consistent with one meta-analysis (23), but we cannot compare with other meta-analyses due to different categorization of BMI. For instance, previous studies present the results of low birthweight (20) and preterm birth (18,19) among overweight and/or obese women compared with normal-weight women. Although several epidemiological studies indicated that maternal underweight is still a significant problem in developing countries and the leading risk factor for low birthweight (8,15), preterm birth (15,16) and small for gestational age (8,17), none of these previous meta-analyses considered underweight in their analysis. We considered all four BMI categories in our meta-analysis to investigate perinatal and maternal health outcomes in connection with maternal BMI. Our study demonstrated that the risk of stillbirth is relatively higher among overweight and obese mothers but the association was not statistically significant. Two previous meta-analyses found a significantly higher risk of stillbirth among all higher categories of maternal BMI (18,22). The small discrepancy regarding significant association might be due to the lack of more detailed analysis or the limited number of studies reporting stillbirth as an outcome. To date, there are very few epidemiological studies that reported stillbirth in relation to maternal BMI, especially in developing countries, and the extent of the association is still unclear in low-income countries. Assessment of stillbirth outcomes is lacking in many epidemiological studies of perinatal outcomes and is a neglected issue. Even Millennium Development Goal 4 excludes stillbirth as an outcome of progress in perinatal health.

Consistent with previous studies (70–74), maternal height was inversely associated with risk of low birthweight. Ozaltin *et al*. found that maternal height is negatively associated with risk of child mortality, stunting, undernutrition and wasting (72). Although it is not completely understood how maternal height might be associated with adverse birth and health outcomes, several biomechanical, biological or environmental factors may be involved (75–77). Small uterus size and lower blood flow, found in short-statured women, directly imposes physical limitations on the growth of the uterus, placenta and fetus (70,73,74,78–80). This may lead to membrane stretching, vaginal difficulties during labour and increased risk of preterm birth, low birthweight and caesarean delivery.

Chronic maternal energy and micronutrient deficiency during early life are also an important component limiting growth, resulting in retardation and short stature as well as subsequent restricted fetal growth, duration of gestation or other adverse health outcomes especially in developing countries (74,77,78,81–83). Generally, shorter women are more likely to pass a genetic predisposition for small growth on to their fetus (78).

Our study found that high BMI was associated with a larger increase in risk of gestational diabetes, hypertension and caesarian delivery. The exact biological mechanisms by which obesity affects the mode of delivery or development of gestational diabetes are not well understood. Obesity may increase adipocytes or pelvic soft issue even in the absence of disease (84–86). Abundance of adipocytes in obese women has been suggested as a cause of excessive inflammatory responses and pelvic soft tissue could narrow the diameter of the birth canal, influencing both the development of gestational diabetes and caesarean delivery, respectively (84–86). Thus, policymakers in developing nations need to be aware of both maternal height as well as the growing epidemic of overweight and obesity in populations of young women and the tide of increased maternal risks that this epidemic will bring.

This study focused on high quality cohort studies with large sample sizes, including both published and gray literature, and covered foreign language papers. This enabled us to include a large number of high-quality studies, which allowed us to draw strong conclusions. Additionally, we used a comprehensive search strategy, performed extensive quality assessment, followed the checklist of the MOOSE group (87) and examined heterogeneity with stratified analysis in order to investigate the effect of maternal BMI before or in early pregnancy on birth and health outcomes. However, several limitations should be considered. First, although the WHO developed the standard cut-off points for BMI categorization (underweight, <18.50 kg m^{-2}; normal, 18.50–24.99 kg m^{-2}; overweight, ≥25–<30 kg m^{-2} and obese, ≥30 kg m^{-2}), not all studies used this categorization. Different definitions and categorization can lead to variations in ORs even within a single data set. However, in our systematic review, almost all studies used WHO thresholds except studies in China and Iran. Chinese studies mainly used GPC thresholds for overweight (24 kg m^{-2}–<28 kg m^{-2}) and obesity (≥28 kg m^{-2}) in Chinese adults (25) and Iranian studies followed the categorization of BMI from the IOM, American Academy of Pediatrics and American College of Obstetricians and Gynecologists (underweight, <19.8 kg m^{-2}; normal, 19.8–<26 kg m^{-2}; overweight, 26–29 kg m^{-2} and obese, >29 kg m^{-2}) (26). Consistent with other meta-analyses, we summarized the data according to the original studies' definitions and classification of BMI (20,88). This minimizes the variation of BMI cut-off points across studies and allows the definition of specific populations for each country. Additionally, we performed sensitivity analyses for different BMI thresholds for each BMI category and found little evidence that the summary results varied by definition of BMI. Second, our study addressed only findings related to pre-pregnancy or first trimester BMI and excluded studies analysing data related to second or third trimester BMI, gestational weight gain, visceral fat or fat distribution. However, epidemiological studies suggest that maternal pre-pregnancy or early pregnancy BMI is a strong predictor of pregnancy and maternal health outcomes (6,8,9,16). Third, not all studies presented adjusted ORs and adjustment factors varied across studies. We used both crude and adjusted ORs in the same meta-analysis, so the pooled risk estimates may be biased. However, we conducted meta-regression and subgroup analysis by presence or absence of confounder adjustment and did not find any significant differences in pooled ORs. Fourth, out of 22 studies in the meta-analysis, most of the studies were from upper middle-income countries (18 studies) and only four studies were from low- and lower middle-income countries. Therefore, the results may not be generalizable to low-income settings. This uneven distribution of studies suggests a strong need to improve research on maternal health outcomes and risk factors in the poorest countries, particularly using well-designed prospective studies.

In conclusion, maternal overweight and obesity were associated with a significantly higher risk of gestational diabetes, pregnancy-induced hypertension, pre-eclampsia, caesarean delivery and post-partum haemorrhage. Being short or underweight was associated with a significantly higher risk of low birthweight and small for gestational age. Although overweight and obesity were found to be slightly protective against low-birthweight deliveries, small for gestational age and preterm babies in low-income countries, greater adverse maternal health outcomes were found in these groups. Clinicians and policymakers should counsel women pre-pregnancy or in early pregnancy on the adverse threats of height, underweight, overweight and obesity on their own and their infant's health in order to encourage informed women to optimize their BMI before conception. Clinicians need to be aware of the importance of management of weight in pregnancy and the proper identification and management of BMI-related risks during antenatal care. To prevent height-related pregnancy burden, long-term interventions are necessary in order to improve the height of young women before they become pregnant. Public and private organizations in low- and middle-income countries should jointly work together to introduce long-term interventions including adequate calorie/protein or micronutrient supplementation during the pre-pubescent or adolescent period and prevent child marriage. By acting to prevent this epidemic and to minimize the associated risks, policymakers in low- and middle-

income countries can reduce the consequences of the epidemiological transition for pregnant mothers and infants and can ensure that gains in maternal and child health are not reduced during this complex phase of health system transition.

Conflict of interest statement

No conflict of interest was declared.

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MMR in collaboration with KS and EO developed the research protocol. MK, SN, SKA, MSR and MMR extracted the data and assessed studies for quality. MMR performed the analysis and MSR compiled the tables. MMR and SKA wrote the primary draft. MK wrote the methods. VB checked the consistency of the PAR analysis. KS, EO and SG contributed to the intellectual content of the paper and contributed to writing and editing the paper. This study was supported in part by grants from the Japan Ministry of Health, Labour and Welfare (H25-chikyukibo-ippan-007, MOH 26260101) and by the World Health Organization (grant number HQHWA1208014). The funder had no role in the study protocol design, literature search, data extraction, data analysis, interpretation or write up. We are grateful to Miwako Segawa for her help with the electronic search strategies and retrieval of articles. Thank you also to our colleagues for assistance with the interpretation of the foreign language papers: Ralf Moreno (Spanish/Portuguese), Yi Liao (Chinese) and Shiori Otsuki (French). We appreciate Dr. Naoki Kondo for giving us the time to consult with him regarding handling of the missing data.

Supporting information

Additional Supporting Information may be found in the online version of this article, http://dx.doi.org/10.1111/obr.12293

Table S1. Reporting Checklist for Meta-analysis Of Observational Studies in Epidemiology (MOOSE).
Table S2. PubMed for nutritional disorders and pregnancy outcomes (accessed on 2014/02/13).
Table S3. Embase for nutritional disorders and pregnancy outcomes (accessed on 2014/02/13).
Table S4. CINAHL Plus with full text via EBSCO for nutritional disorders and pregnancy outcomes (accessed 2014/02/13; excluding MEDLINE records).
Table S5. British Nursing Index via Proquest for nutritional disorders and pregnancy outcomes (accessed on 2014/02/13).
Table S6. Background information of the included study in systematic review and meta-analysis.
Table S7. Region and country income profiles.
Table S8. Event and prevalence according to body mass index.
Table S9. Event and odds ratio (95% confidence interval) by body mass index categories and outcomes.
Table S10. Newcastle-Ottawa scale assessment of study quality.
Table S11. Sensitivity analysis after dropping highly influential studies.
Table S12. Publication bias and 'Trim and Fill' estimates.
Table S13. Country-specific summary odds ratios of pregnancy outcomes by maternal body mass index categories.
Table S14. Country-specific summary odds ratios of maternal health outcomes by maternal body mass index categories.
Table S15. Overview of cohort studies included in the narrative review.
Table S16. Stratified analysis of pregnancy outcomes by maternal body mass index.
Table S17. Stratified analysis of health outcomes by maternal body mass index.

References

1. Global Burden of Metabolic Risk Factors for Chronic Diseases Collaboration (BMI Mediated Effects), Lu Y, Hajifathalian K *et al*. Metabolic mediators of the effects of body-mass index, overweight, and obesity on coronary heart disease and stroke: a pooled analysis of 97 prospective cohorts with 1.8 million participants. *Lancet* 2014; **383**: 970–983.
2. Ng M, Fleming T, Robinson M *et al*. Global, regional, and national prevalence of overweight and obesity in children and adults during 1980–2013: a systematic analysis for the Global Burden of Disease Study 2013. *Lancet* 2014; **384**: 766–781.
3. Institute for Health Metrics and Evaluation HDN, The World Bank. *The Global Burden of Disease: Generating Evidence, Guiding Policy– South Asia Regional Edition*. IHME: Seattle, WA, 2013.
4. Lim SS, Vos T, Flaxman AD *et al*. A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. *Lancet* 2012; **380**: 2224–2260.
5. Chen Z, Du J, Shao L *et al*. Prepregnancy body mass index, gestational weight gain, and pregnancy outcomes in China. *Int J Gynaecol Obstet* 2010; **109**: 41–44.
6. Joshi S, Unni J, Vijay S, Khanijo V, Gupte N, Divate U. Obesity and pregnancy outcome in a private tertiary hospital in India. *Int J Gynaecol Obstet* 2011; **114**: 82–83.
7. Kumar A, Chaudhary K, Prasad S. Maternal indicators and obstetric outcome in the north Indian population: a hospital-based study. *J Postgrad Med* 2010; **56**: 192–195.
8. Xu X, Ding X, Zhang X *et al*. Genetic and environmental influences on blood pressure variability: a study in twins. *J Hypertens* 2013; **31**: 690–697.
9. Liu X, Du J, Wang G, Chen Z, Wang W, Xi Q. Effect of pre-pregnancy body mass index on adverse pregnancy outcome in north of China. *Arch Gynecol Obstet* 2011; **283**: 65–70.
10. Liabsuetrakul T. Is international or Asian criteria-based body mass index associated with maternal anaemia, low birthweight,

and preterm Births among Thai population?–an observational study. *J Health Popul Nutr* 2011; **29**: 218–228.
11. Safavi Ardabili N, Kamali Z, Kariman NS. The association between maternal body mass index during first trimester of pregnancy with low birth weight. *Obes Rev* 2011; **12**: 118.
12. Soheilykhah S, Mogibian M, Rahimi-Saghand S, Rashidi M, Piroz M. Incidence of gestational diabetes mellitus in pregnant women. *Iran J Reprod Med* 2010; **8**: 24–28.
13. Tabatabaei M. Gestational weight gain, prepregnancy body mass index related to pregnancy outcomes in Kazerun, Fars, Iran. *J Prenat Med* 2011; **5**: 35–40.
14. Yekta Z, Ayatollahi H, Porali R, Farzin A. The effect of pre-pregnancy body mass index and gestational weight gain on pregnancy outcomes in urban care settings in Urmia-Iran. *BMC Pregnancy Childbirth* 2006; **20**: 15.
15. Saereepomcharenkul K. Correlation of BMI to pregnancy outcomes in Thai women delivered in Rajavithi Hospital. *J Med Assoc Thai* 2011; **94**: S52–S58.
16. Hauger MS, Gibbons L, Vik T, Belizan JM. Prepregnancy weight status and the risk of adverse pregnancy outcome. *Acta Obstet Gynecol Scand* 2008; **87**: 953–959.
17. Nucci LB, Schmidt MI, Duncan BB, Fuchs SC, Fleck ET, Britto MMS. Nutritional status of pregnant women: prevalence and associated pregnancy outcomes. *Rev Saude Publica* 2001; **35**: 502–507.
18. Chu SY, Kim SY, Lau J *et al*. Maternal obesity and risk of stillbirth: a metaanalysis. *Am J Obstet Gynecol* 2007; **197**: 223–228.
19. Kanadys WM, Leszczynska-Gorzelak B, Jedrych M, Oleszczuk J. Maternal pre-pregnancy obesity and the risk of preterm birth: a systematic overview of cohort studies with meta-analysis. *Ginekol Pol* 2012; **83**: 270–279.
20. McDonald SD, Han Z, Mulla S, Beyene J, Knowledge Synthesis Group. Overweight and obesity in mothers and risk of preterm birth and low birth weight infants: systematic review and meta-analyses. *BMJ* 2010; **341**: c3428.
21. Chu SY, Kim SY, Schmid CH *et al*. Maternal obesity and risk of cesarean delivery: a meta-analysis. *Obes Rev* 2007; **8**: 385–394.
22. Aune D, Saugstad OD, Henriksen T, Tonstad S. Maternal body mass index and the risk of fetal death, stillbirth, and infant death: a systematic review and meta-analysis. *JAMA* 2014; **311**: 1536–1546.
23. Yu Z, Han S, Zhu J, Sun X, Ji C, Guo X. Pre-pregnancy body mass index in relation to infant birth weight and offspring overweight/obesity: a systematic review and meta-analysis. *PLoS ONE* 2013; **8**: e61627.
24. World Bank. World Bank list of economies (February 2014). 2014. URL http://data.worldbank.org/about/country-classifications/country-and-lending-groups (accessed February 2014).
25. Chen C, Lu FC; Department of Disease Control Ministry of Health, PR China. The guidelines for prevention and control of overweight and obesity in Chinese adults. *Biomed Environ Sci* 2004; **17**: 1–36.
26. Suitor CW. Perspectives on nutrition during pregnancy: Part I, Weight gain; Part II, Nutrient supplements. *J Am Diet Assoc* 1991; **91**: 96–98.
27. Sharifzadeh F, Kashanian M, Jouhari S. Study of the relationship between body mass index and birth weight, spontaneous preterm labor and maternal anemia in Shahid Akbarabadi Hospital, Tehran, 2008. *Iran J Obstet Gynecol Infert* 2012; **15**: 1–6.
28. Moghadami N, Aminikhah B. The effect of maternal body mass index on spontaneous versus induced preterm birth: a prospective study. *Tehran Univ Med J* 2009; **67**: 221–225.
29. Wells G, Shea B, O'Connell D *et al*. The Newcastle-Ottawa Scale (NOS) for assessing the quality of nonrandomised studies in meta-analyses. 2014. URL http://www.ohri.ca/programs/clinical_epidemiology/nos_manual.pdf (accessed February 2014).
30. Greenland S, Robins JM. Estimation of a common effect parameter from sparse follow-up data. *Biometrics* 1985; **41**: 55–68.
31. Mantel N, Haenszel W. Statistical aspects of the analysis of data from retrospective studies of disease. *J Natl Cancer Inst* 1959; **22**: 719–748.
32. DerSimonian R, Laird N. Meta-analysis in clinical trials. *Control Clin Trials* 1986; **7**: 177–188.
33. Higgins J, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analyses. *BMJ* 2003; **327**: 557–560.
34. Egger M, Smith GD, Schneider M, Minder C. Bias in meta-analysis detected by a simple, graphical test. *BMJ* 1997; **315**: 629–634.
35. Duval S, Tweedie R. Trim and fill: a simple funnel-plot–based method of testing and adjusting for publication bias in meta-analysis. *Biometrics* 2000; **56**: 455–463.
36. Hanley JA. A heuristic approach to the formulas for population attributable fraction. *J Epidemiol Community Health* 2001; **55**: 508–514.
37. Levin ML. The occurrence of lung cancer in man. *Acta Unio Int Contra Cancrum* 1953; **9**: 531–541.
38. Adnan S, Ismail H, Mohd Rus R, Nusee Z. The effects of maternal body mass index (BMI) on the pregnancy outcome among primigravida who delivered at Hospital Tengku Ampuan Afzan (HTAA), Kuantan, Pahang. *Int J Gynaecol Obstet* 2012; **119**: 37.
39. Chen P-C, Doyle P, Ho C-K, Chang P-J, Wang J-D. Influence of maternal risk factors on low birthweight, preterm delivery, and small for gestational age – a prospective cohort study of pregnancy. *Chin J Publ Health* 2000; **19**: 192–202.
40. Karcaaltincaba D, Buyukkaragoz B, Kandemir O, Yalvac S, Kıykac-Altınbaş S, Haberal A. Gestational diabetes and gestational impaired glucose tolerance in 1653 teenage pregnancies: prevalence, risk factors and pregnancy outcomes. *J Pediatr Adolesc Gynecol* 2011; **24**: 62–65.
41. Li N, Liu E, Guo J *et al*. Maternal prepregnancy body mass index and gestational weight gain on pregnancy outcomes. *PLoS ONE* 2013; **8**: e82310.
42. Munim S, Maheen H. Association of gestational weight gain and pre-pregnancy body mass index with adverse pregnancy outcome. *J Coll Physicians Surg Pak* 2012; **22**: 694–698.
43. Ortiz FM. Maternal body mass index and its association with mode of delivery and perinatal outcomes. *Salud(i)Ciencia* 2013; **19**: 607–612.
44. Osman NB, Challis K, Cotiro M, Nordahl G, Berström S. Perinatal outcome in an obstetric cohort of Mozambican women. *J Trop Pediatr* 2001; **47**: 30–38.
45. Ronnenberg AG, Wang X, Xing H *et al*. Low preconception body mass index is associated with birth outcome in a prospective cohort of Chinese women. *J Nutr* 2003; **133**: 3449–3455.
46. Wang T, Zhang J, Lu X, Xi W, Li Z. Maternal early pregnancy body mass index and risk of preterm birth. *Arch Gynecol Obstet* 2011; **28**: 813–819.
47. Dawodu A, Laditan A. Low birthweight in an urban community in Nigeria. *Ann Trop Paediatr* 1985; **5**: 61–66.
48. Fourn L, Ducic S, Séguin L. Risk factors associated with low birth weight: a multivariate analysis. *Sante* 1999; **9**: 7–11.
49. Grandi CA. Relationship between maternal anthropometry and weight gain with birth weight, and risks of low birth weight, small for gestational age and prematurity at an urban population

of Buenos Aires, Argentina. *Arch Latinoam Nutr* 2003; **53**: 369–375.
50. Hirve SS, Ganatra BR. Determinants of low birth weight: a community based prospective cohort study. *Indian Pediatr* 1994; **31**: 1221–1225.
51. Lawoyin T. Maternal weight and weight gain in Africans. Its relationship to birth weight. *J Trop Pediatr* 1991; **37**: 166–171.
52. Mohanty C, Prasad R, Reddy AS, Ghosh JK, Singh T, Das B. Maternal anthropometry as predictors of low birth weight. *J Trop Pediatr* 2006; **52**: 24–29.
53. Panahandeh Z. Gestational weight gain and fetal birth weight in rural regions of Rasht/Iran. *Iran J Pediatr* 2009; **19**: 18–24.
54. Nomura RM, Paiva LV, Costa VN, Liao AW, Zugaib M. Influence of maternal nutritional status, weight gain and energy intake on fetal growth in high-risk pregnancies. *Rev Bras Ginecol Obstet* 2012; **34**: 107–112.
55. Ota E, Haruna M, Suzuki M *et al*. Maternal body mass index and gestational weight gain and their association with perinatal outcomes in Viet Nam. *Bull World Health Organ* 2011; **89**: 127–136.
56. Stringer EM, Vwalika B, Killam WP *et al*. Determinants of stillbirth in Zambia. *Obstet Gynecol* 2011; **117**: 1151–1159.
57. Baci Y, Üstüner I, Keskin HL, Ersoy R, Avsar AF. Effect of maternal obesity and weight gain on gestational diabetes mellitus. *Gynecol Endocrinol* 2013; **29**: 133–136.
58. Dode M, Santos I. Risk factors for gestational diabetes mellitus in the birth cohort in Pelotas, Rio Grande do Sul State, Brazil, 2004. *Cad Saúde Pública* 2009; **25**: 1141–1152.
59. Far M, Ziaei S, Kazemnejad A. The impact of maternal age, pre-pregnancy body mass index, weight gain and parity on glucose challenge test (GCT). *Int J Fertil Steril* 2012; **5**: 207–210.
60. Idris N, Nyan K. The association of maternal obesity and gestational weight gain with obstetric and neonatal outcomes among parturients in Seremban, Malaysia. *Int J Gynaecol Obstet* 2012; **2012**: 75. Wiley-Blackwell 111 River St, Hoboken 07030-5774, NJ, USA.
61. Keshavarz M, Cheung NW, Babaee GR, Moghadam HK, Ajami ME, Shariati M. Gestational diabetes in Iran: incidence, risk factors and pregnancy outcomes. *Diabetes Res Clin Pract* 2005; **69**: 279–286.
62. Teng Y, Yan L, Dong W, Lai J. Effects of pre-pregnancy BMI on blood glucose, blood pressure and weight in pregnancy. *Wei Sheng Yan Jiu* 2010; **39**: 570–572.
63. Unni J, Tapadia A. The Effect of Gestational Weight Gain on Maternal and Perinatal Outcome in Western India. RCOG World Congress 2013. Liverpool: BJOG, 2013. URL http://www.epostersonline.com/rcog2013/?q=node/514 (accessed February 2014).
64. Yang H, Wei Y, Gao X *et al*. Risk factors for gestational diabetes mellitus in Chinese women – a prospective study of 16 286 pregnant women in China. *Diabet Med* 2009; **26**: 1099–1104.
65. Khan GAN, Ishrat N, Sabzposh NA. Blood Pressure pattern in pregnant women of different body mass index in three trimesters of pregnancy. *Indian Journal of Public Health Research & Development* 2013; **4**: 98–102.
66. Rebelo F, Dayana Rodrigues F, Roberta Mendes H, Claudio Jose S, Gilberto K. Blood pressure changes during pregnancy according to pre-pregnancy body mass index: a prospective cohort from Rio de Janeiro, Brazil. *Ann Nutr Metab* 2013; **2013**: 427. Karger Allschwilerstrasse 10, Ch-4009 Basel, Switzerland.
67. Rodrigues PL, Costa de Oliveira L, Santos Brito AD, Kac G. Determinant factors of insufficient and excessive gestational weight gain and maternal–child adverse outcomes. *Nutrition* 2010; **26**: 617–623.
68. Chu SY, Callaghan WM, Kim SY *et al*. Maternal obesity and risk of gestational diabetes mellitus. *Diabetes Care* 2007; **30**: 2070–2076.
69. Torloni MR, Betran AP, Horta BL *et al*. Prepregnancy BMI and the risk of gestational diabetes: a systematic review of the literature with meta-analysis. *Obes Rev* 2009; **10**: 194–203.
70. Han Z, Lutsiv O, Mulla S, McDonald SD. Maternal height and the risk of preterm birth and low birth weight: a systematic review and meta-analyses. *J Obstet Gynaecol Can* 2012; **34**: 721–746.
71. Kamathi SA. Maternal short stature: a risk factor for low birth weight in neonates. *J Med Allied Sci* 2012; **2**: 62–65.
72. Ozaltin E, Hill K, Subramanian SV. Association of maternal stature with offspring mortality, underweight, and stunting in low- to middle-income countries. *JAMA* 2010; **303**: 1507–1516.
73. Nkwabong E, Nounemi NK, Sando Z, Mbu RE, Mbede J. Risk factors and placental histopathological findings of term born low birth weight neonates. *Placenta* 2015; **36**: 138–141.
74. Christian P. Maternal height and risk of child mortality and undernutrition. *JAMA* 2010; **303**: 1539–1540.
75. Rush D. Nutrition and maternal mortality in the developing world. *Am J Clin Nutr* 2000; **72**: 212S–40S.
76. van Roosmalen J, Brand R. Maternal height and the outcome of labor in rural Tanzania. *Int J Gynaecol Obstet* 1992; **37**: 169–177.
77. Hart N. Famine, maternal nutrition and infant mortality: a re-examination of the Dutch hunger winter. *Popul Stud (Camb)* 1993; **47**: 27–46.
78. Camilleri AP. The obstetric significance of short stature. *Eur J Obstet Gynecol Reprod Biol* 1981; **12**: 347–356.
79. Maternal anthropometry and pregnancy outcomes. A WHO Collaborative Study: Introduction. *Bull World Health Organ* 1995; **73**: 1–98.
80. Subramanian S, Ackerson LK, Smith GD, John NA. Association of maternal height with child mortality, anthropometric failure, and anemia in India. *JAMA* 2009; **301**: 1691–1701.
81. Martorell R. Body size, adaptation and function. *Hum Organ* 1989; **48**: 15–20.
82. Martin RM, Smith GD, Frankel S, Gunnell D. Parents' growth in childhood and the birth weight of their offspring. *Epidemiology* 2004; **15**: 308–316.
83. Hisham TJ, Moawed SA. The relation of low birth weight to psychosocial stress and maternal anthropometric measurements. *Saudi Med J* 2000; **21**: 649–654.
84. Kriketos AD, Greenfield JR, Peake PW *et al*. Inflammation, insulin resistance, and adiposity: a study of first-degree relatives of type 2 diabetic subjects. *Diabetes Care* 2004; **27**: 2033–2040.
85. Kaiser PS, Kirby RS. Obesity as a risk factor for cesarean in a low-risk population. *Obstet Gynecol* 2001; **97**: 39–43.
86. Young TK, Woodmansee B. Factors that are associated with cesarean delivery in a large private practice: the importance of prepregnancy body mass index and weight gain. *Am J Obstet Gynecol* 2002; **187**: 312–320.
87. Stroup DF, Berlin JA, Morton SC *et al*. Meta-analysis of observational studies in epidemiology: a proposal for reporting. Meta-analysis Of Observational Studies in Epidemiology (MOOSE) group. *JAMA* 2000; **283**: 2008–2012.
88. Stothard KJ, Tennant PW, Bell R, Rankin J. Maternal overweight and obesity and the risk of congenital anomalies: a systematic review and meta-analysis. *JAMA* 2009; **301**: 636–650.

