A review of maternal overweight and obesity and its impact on cardiometabolic outcomes during pregnancy and postpartum

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Abstract: The rates of maternal overweight and obesity, but also excess gestational weight gain, are increasing. Pregnancy complications, including gestational diabetes mellitus, gestational hypertension, pre-eclampsia and delivery of a preterm or growth restricted baby, are higher for both women with overweight and obesity and women who gain excess weight during their pregnancy. Other conditions such as polycystic ovary syndrome are also strongly linked to overweight and obesity and worsened pregnancy complications. All of these conditions place women at increased risk for future cardiometabolic diseases. If overweight and obesity, but also excess gestational weight gain, can be reduced in women of reproductive age, then multiple comorbidities associated with pregnancy complications may also be reduced in the years after childbirth. This narrative review highlights the association between maternal overweight and obesity and gestational weight gain, with gestational diabetes, pre-eclampsia, polycystic ovary syndrome and delivery of a preterm or growth restricted baby. This review also addresses how these adverse conditions are linked to cardiometabolic diseases after birth. We report that while the independent associations between obesity and gestational weight gain are evident across many of the adverse conditions assessed, whether body mass index or gestational weight gain is a stronger driving factor for many of these is currently unclear. Mechanisms linking gestational diabetes mellitus, gestational hypertension, pre-eclampsia, preterm delivery and polycystic ovary syndrome to heightened risk for cardiometabolic diseases are multifactorial but relate to cardiovascular and inflammatory pathways that are also found in overweight and obesity. The need for postpartum cardiovascular risk assessment and follow-up care remains overlooked. Such early detection and intervention for women with pregnancy-related complications will significantly attenuate risk for cardiovascular disease.

Keywords: cardiometabolic, cardiovascular disease, gestational weight gain, obesity, polycystic ovary syndrome, pregnancy, risk factors

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Introduction

Obesity is a significant public health concern. Globally, there is a trend of increasing body mass index (BMI) in both adults and children, with obesity rates tripling since 1975. Obesity is one of the leading risk factors for premature death related to cardiovascular disease (CVD), type 2 diabetes, cancer and poor mental health, and accounted for 4.7 million deaths globally in 2017. The World Health Organization reported that 39% of adults aged 18 years and above had overweight in 2016, and 13% had obesity. The rise in obesity prevalence has been most prominent in women of reproductive age (post-adolescent and pre-menopausal), with women tending to gain 0.5–1 kg each year from early adulthood until

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middle age. Critically, it appears that even young women are at risk of unhealthy weight gain as they approach child-bearing years. This has significant impacts on reproductive health in women as they enter pregnancy at a higher BMI.

Women with obesity take a longer time to conceive, and women with a BMI $\geq 30$ kg/m$^2$ have a near 7-fold higher risk for taking more than 12 months to conceive than those with a normal BMI. Pregnancy complications, including gestational diabetes mellitus (GDM), gestational hypertension and pre-eclampsia, are also higher for women with overweight or obesity. In addition, meta-analyses report that having overweight or obesity during pregnancy is associated with preterm birth, with different effects depending on BMI category and preterm birth subtype. Polycystic ovary syndrome (PCOS) is closely linked with obesity and cardiometabolic risk factors, and also amplifies the risk of GDM and gestational hypertension. All of these outcomes place women at heightened risk for developing type 2 diabetes and related cardiometabolic conditions. The Institute of Medicine (IOM) has developed universally endorsed recommendations in the general population for GWG based on women’s preconception BMI (Table 1). Despite Asian women having different risk profiles in pregnancy, there are no specific GWG guidelines for women from Asia. The weight gained during pregnancy is primarily due to the weight of the developing foetus and to increases in maternal body water and fat. GWG has also increased in addition to an increase in obesity, and women with obesity prior to pregnancy are more likely to have excessive GWG compared with women in the normal weight range. Using 2010–2011 data from Pregnancy Risk Assessment Monitoring System, 47.2% of women had excessive GWG, with around two-thirds of women with overweight or obesity class I (BMI $= 30–34.9$ kg/m$^2$) having the highest prevalence of excessive GWG.

### Table 1. Recommendations for gestational weight gain in singleton pregnancies.

| Preconception body mass index categories | Total gestational weight gain |
|----------------------------------------|------------------------------|
| Underweight $< 18.5$ kg/m$^2$           | 12.5–18 kg                   |
| Normal $18.5–24.9$ kg/m$^2$             | 11.5–16 kg                   |
| Overweight $25–29.9$ kg/m$^2$           | 7–11.5 kg                    |
| Obese $\geq 30$ kg/m$^2$                | 5–9 kg                       |

*Adapted from the Institute of Medicine Guidelines [2009].

Global obesity and GWG in pregnancy

Globally, the estimated number of pregnant women with overweight or obesity in 2014 was 8.9 and 14.6 million, respectively. Country-specific data indicate that 25.6% of women giving birth in Australia in 2017 had overweight and 20% had obesity, 32% of Swedish pregnant women had overweight or obesity in 2008–2010, 25% and 10% had overweight or obesity in Scotland, and in Africa, maternal obesity has ranged from as low as 6.5% up to as high as 50.7%.

The Institute of Medicine (IOM) has developed universally endorsed recommendations in the general population for GWG based on women’s preconception BMI (Table 1). Despite Asian women having different risk profiles in pregnancy, there are no specific GWG guidelines for women from Asia. The weight gained during pregnancy is primarily due to the weight of the developing foetus and to increases in maternal body water and fat. GWG has also increased in addition to an increase in obesity, and women with obesity prior to pregnancy are more likely to have excessive GWG compared with women in the normal weight range. Using 2010–2011 data from Pregnancy Risk Assessment Monitoring System, 47.2% of women had excessive GWG, with around two-thirds of women with overweight or obesity class I (BMI $= 30–34.9$ kg/m$^2$) having the highest prevalence of excessive GWG.
However, between 20% and 40% of women with a normal or underweight BMI also had excessive GWG. Furthermore, in a population cohort study among women from Sweden, those gaining the most weight in pregnancy (\(\geq 1.50\) SD, i.e. \(\geq 15.9\) kg in underweight women) were more likely to have a BMI in the underweight category. Concerningly, excessive GWG is related to post-partum weight retention and has implications for future pregnancies which are influenced by BMI in the index pregnancy. In a meta-analysis of observational studies, a BMI gain \(\geq 3\) kg/m\(^2\) between pregnancies was associated with a 2-fold higher risk for GDM, pre-eclampsia and gestational hypertension. This highlights that weight management is important for women of all BMI categories planning a pregnancy as they all may be susceptible to excess GWG.

**Risks associated with obesity and GWG in pregnancy**

The impact of obesity in pregnancy has been studied for decades, demonstrating both immediate and long-term adverse consequences for the mother and child. A meta-analysis demonstrated women with overweight or obesity had an approximate 2-fold increased risk of spontaneous miscarriage [odds ratio (OR) = 1.67, 95% confidence interval (CI) = 1.25, 2.25], and in a systematic review of reviews, there was a 2-fold increased risk of stillbirth among women in the highest BMI category [relative risk (RR) = 2.19; 95% CI = 2.03, 2.36] compared with women with a normal BMI. There is consistent evidence that overweight or obesity in pregnancy increases the risk for pre-eclampsia, GDM, gestational hypertension, GDM, caesarean delivery, preterm birth, SGA or LGA increased across pre-pregnancy BMI, which was largely independent of GWG. That is, the lowest absolute risks were found for women who had a low to normal BMI \(\leq 25\) kg/m\(^2\), with a moderate to high GWG, whereas higher absolute risks were found for women with a BMI \(\geq 30\) kg/m\(^2\) and high GWG. This meta-analysis, however, did not assess pregnancy outcomes separately, and all outcomes were treated equally; thus, the independent or combined effect of BMI and GWG cannot be established for individual outcomes.

Similar adverse outcomes to obesity also occur with excess, and even inadequate, GWG. In a meta-analysis of more than 1 million women, GWG below guidelines was associated with a higher risk of small for gestational age (SGA) [USA/Europe (OR=1.51; 95% CI=1.39, 1.63), Asia (OR=1.63; 95% CI=1.45, 1.82)] and preterm birth [USA/Europe (OR=1.35; 95% CI=1.17, 1.56), Asia (OR=1.06; 95% CI=0.78, 1.44)], and GWG above guidelines was associated with a higher risk of large for gestational age (LGA) [USA/Europe (OR=1.93; 1.81–2.06), Asia (OR=1.68; 95% CI=1.51, 1.87)] and macrosomia [USA/Europe (OR=1.87; 95% CI=1.70, 2.06), Asia (OR=2.18; 95% CI=1.91, 2.49)].

Key to this review is the comparison of Asian studies applying regional BMI categories compared with the World Health Organization (WHO) BMI categories. The analysis showed that across all pre-pregnancy BMI categories and in different ethnicities, insufficient GWG was associated with increased risk of SGA and preterm birth, whereas excess GWG was associated with increased risk of LGA, macrosomia and caesarean section. In a meta-analysis of 13 studies, women who had GWG above the IOM were more likely to have hypertensive disorders of pregnancy (HDP; OR=1.82; 95% CI=1.53, 2.17), pre-eclampsia (OR=1.92; 95% CI=1.36, 2.72) or gestational hypertension (OR=1.67; 95% CI=1.43, 1.95).

**The independent or combined effect of BMI and GWG on pregnancy outcome**

The impact of overweight and obesity and excess GWG on maternal and neonatal outcomes can be difficult to disentangle when risks for various outcomes are comparable. Using data from 196,670 participants within 25 cohort studies, the absolute risk for any adverse outcome, that is, the presence of 1 or more of pre-eclampsia, gestational hypertension, GDM, caesarean delivery, preterm birth, SGA or LGA increased across pre-pregnancy BMI, which was largely independent of GWG. That is, the lowest absolute risks were found for women who had a low to normal BMI \(\leq 25\) kg/m\(^2\), with a moderate to high GWG, whereas higher absolute risks were found for women with a BMI \(\geq 30\) kg/m\(^2\) and high GWG. This meta-analysis, however, did not assess pregnancy outcomes separately, and all outcomes were treated equally; thus, the independent or combined effect of BMI and GWG cannot be established for individual outcomes.

In a meta-analysis of 8 studies (n = 13,748 participants) which authors generally reported as medium quality, the effect of GWG on GDM did not differ depending on maternal pre-pregnancy BMI category. In a meta-analysis of individual participant data, diet and lifestyle interventions to reduce GWG demonstrated a reduction in GDM...
of 24% (OR = 0.76; 95% CI = 0.65, 0.89) and caesarean section by 9%. Moreover, the effect was observed irrespective of maternal BMI. Consistent evidence for an independent effect of GWG is apparent for HDP. In a meta-analysis of 21 studies, the increased odds of HDP were greatest among women with overweight and obesity pre-pregnancy, and gained weight in excess of the IOM guidelines (OR = 2.17; 95% CI = 1.56, 3.02). The effect of pre-pregnancy BMI and GWG on preterm birth is unclear, and risk may be different depending on the population studied and type of preterm birth. In a multicentre study in Brazil (n = 3273 preterm birth, n = 920 term births), insufficient GWG, regardless of the initial BMI, increased risk for spontaneous preterm birth by 76% (OR = 1.76; 95% CI = 1.34, 2.31) and also excess GWG increased risk for preterm birth in women with overweight (OR = 1.43; 95% CI = 1.16, 1.77) and obesity (OR = 1.76; 95% CI = 1.37, 2.26). In a retrospective cohort study in Peru (n = 8964), there was an independent association between GWG and preterm birth, with a protective effect seen for underweight women (OR = 0.91; 95% CI = 0.82, 1.00).

Despite both BMI and GWG being independent risk factors for a range of pregnancy outcomes, further high-quality research is needed on their independent and additive effects.

**Management of overweight and obesity in pregnancy**

Standard guidelines for lifestyle management as a component of antenatal care involve advice relating to eating the recommended number of daily serves of the five food groups, drinking plenty of water, and advice that low- to moderate-intensity physical activity during pregnancy is associated with a range of health benefits and is not associated with adverse outcomes. In addition to this, health professionals should also offer appropriate advice relating to folic acid supplementation, food hygiene, including how to reduce the risk of a food-acquired infection and advice relating to smoking cessation, and the implications of recreational drug use and alcohol consumption in pregnancy. Guidelines also highlight offering women the opportunity to be weighed and to give women advice about appropriate weight gain during pregnancy in relation to either their pre-pregnancy BMI if recorded or their BMI at the first antenatal visit. At every antenatal visit, health professionals should encourage self-monitoring of weight gain and discuss weight gain, diet and level of physical activity with all women.

During pregnancy, women with overweight or obesity may require additional monitoring of foetal growth, GDM, HDP, neural tube defects and potential complications during birth, including anaesthetic risk. They may also need a referral to an accredited dietitian. Women are recommended to gain less weight over the course of their pregnancy, specifically 7–11.5 kg for women with overweight and 5–9 kg for women with obesity (Table 1). Antenatal lifestyle (diet and physical activity) interventions are recommended to achieve this and resulted in significantly less GWG compared with control (−0.70 kg; 95% CI = −0.92, −0.48) and reduced the odds of caesarean section (0.91 kg; 95% CI = 0.83, 0.99). To achieve this in clinical practice, interventions also need to move beyond monitoring and provision of advice. These should practically support women in achieving lifestyle changes and include health professional training and embedding in the workforce with further implementation research warranted in this field. With regard to specific physical activity advice, women should be informed that moderate physical activity during pregnancy has a range of health benefits, particularly for women with overweight or obesity. With regard to specific dietary recommendations, women should be advised limiting additional serves and avoiding energy-dense foods to limit excessive weight gain. Folic acid supplementation is also recommended to be increased from 500 µg/day to 5 mg/day for women with a BMI >30 kg/m². The International Federation of Gynecology and Obstetrics’ (FIGO) Pregnancy and Non-Communicable Diseases (PNCD) Committee has also recently emphasised that management of obesity in pregnancy should be considered in the context of a life course approach, linking with preconception and post-partum and interconception services to prevent excess weight gain before and during pregnancy. Advice on GWG, particularly for women with an obese BMI is also highlighted in the FIGO guideline for the management of pre-pregnancy, pregnancy and post-partum obesity.

It must also be acknowledged that there are a wide variety of individual and environmental factors affecting food and physical activity choices. Current guidelines for optimising lifestyle...
recognise this complex relationship which can be understood through models such as the Social-Ecological Model encompassing social and cultural norms and values, sectors (systems, organisation, and business and industries), settings and individual factors. They highlight that support and active engagement from a range of sectors of society are required to both optimise individual diet and physical activity and achieve improvements in population health.

**Adverse conditions during pregnancy and their relationship to cardiometabolic diseases**

**Polycystic ovary syndrome**

PCOS is a common endocrinopathy, affecting 13% of reproductive-aged women. It is characterised by irregular menstrual cycles, clinical/biochemical hyperandrogenism and polycystic ovaries on ultrasound. PCOS is associated with increased risk of metabolic (including type 2 diabetes, hypertension, dyslipidaemia and thrombosis), reproductive (including anovulatory infertility and pregnancy complications) and psychological (including anxiety, depression and poor quality of life) disorders. Overweight or obesity is present in up to 88% of women with PCOS, with insulin resistance as a key pathophysiological factor influencing clinical outcomes in PCOS. Women with PCOS and overweight and obesity usually present with a more severe phenotype of the condition.

The higher BMI commonly observed in women with PCOS extends into their pregnancies with women with PCOS having a higher BMI around conception [standard mean difference (SMD) = 0.63 kg/m²; 95% CI = 0.42, 0.84] and a higher GWG (SMD = 0.26 kg/m²; 95% CI = 0.03, 0.50), compared with women without PCOS. It is not clear if this higher GWG in PCOS is clinically significant. Furthermore, ongoing pregnancies in PCOS are more likely to be complicated with GDM, gestational hypertension and pre-eclampsia. The adverse maternal outcomes are worsened by, but occur independent of, obesity in PCOS, evidenced by the risks in women with and without PCOS when comparing the outcomes in women with a BMI >30 kg/m² around conception. With regard to infant complications, infants born to women with PCOS are up to 2 times more likely to be born premature, LGA, and require intensive neonatal care at birth. The main risk factors for adverse infant outcomes in PCOS are not known. However, these could be secondary to the higher rate of maternal pregnancy complications, particularly as the higher preterm and LGA births in PCOS are probably explained by maternal BMI at conception with similar risk for infant outcomes observed in women with and without PCOS with obesity. The driving factor could potentially be insulin resistance, which fades away in those with obesity. There is relatively limited research assessing GWG in PCOS and the impact of GWG on adverse pregnancy outcomes in PCOS is still unclear. However, it may contribute to higher BMI and longitudinal weight gain, higher type 2 diabetes and cardiovascular risk factors, post-pregnancy, in women with PCOS.

**Lifestyle and management.** The first-line treatment in women with PCOS is lifestyle management. A 5–10% weight loss in PCOS can improve presentations, including infertility. Given that infertility is an independent risk factor for pregnancy complications, where women with PCOS lose weight preconception they may have a higher likelihood of spontaneous conception and a lower BMI at conception which would offer further benefits for reducing the risk of pregnancy complications. Lifestyle and weight management in PCOS should be as per the recommendations for the general population for a healthy balanced diet and optimal levels of physical activity and sedentary time. This should involve a multidisciplinary support with inclusion of allied health professionals such as dietitians, exercise physiologists and psychologists where required. Given the higher risk profile for pregnancy complications in PCOS, additional risk factors for pregnancy complications including smoking, alcohol consumption and high caffeine intake should be particularly focused on preconception and during pregnancy. After conception, women with PCOS should be advised to monitor their GWG and aim for a healthy GWG. Given that there is no GWG guidelines specific to PCOS, women with PCOS should follow the IOM guidelines and follow the recommendations for the general population with a healthy balanced diet, and exercise and physical activity.

**PCOS and future cardiometabolic diseases.** Women with PCOS have a 2- to 3-fold elevated prevalence of type 2 diabetes and...
risk factors for CVD including hypertension, thromboembolism and dyslipidaemia compared with women without PCOS. Despite this, there is inconclusive evidence as to whether PCOS independently increases the risk of clinical CVD events. Insulin resistance is a characteristic feature of PCOS presenting in 75% of lean and 95% of women with overweight or obesity, which worsens the reproductive, metabolic and psychological presentations. Excess weight further exacerbates insulin resistance and the features of PCOS, including cardiometabolic risk. Women with PCOS also have higher longitudinal weight gain and prevalence of overweight/obesity. Given the consistent associations with cardiovascular risk factors in women with PCOS, and potential links to future cardiometabolic diseases, it highlights the need for interventions for improving risk factors in PCOS.

**Gestational diabetes mellitus**

GDM is defined as ‘any degree of glucose intolerance with onset or first recognition during pregnancy’. It is one of the most common metabolic complications in pregnancy, affecting 5–25% of all pregnant women worldwide, depending on screening approaches (universal or targeted) and diagnostic criteria. The intergenerational cycle of diabetes and obesity, that is, the association between maternal diabetes, GDM and maternal obesity with increased risk of diabetes and obesity in the offspring, has been neatly articulated in a review by Ma and Popkin. Both obesity and GWG have also demonstrated independent effects on babies born large for gestational age. In a retrospective analyses of 9,835 women, in those without GDM, 21.6% of infants born LGA were attributable to maternal overweight and obesity; with the combination of having overweight or obesity and having GDM, accounting for a similar 23.3%, of infants born LGA. Similarly, in a cohort of 9,270 Spanish women with or without obesity and in women with and without GDM, had significantly higher odds of having an infant born LGA than those of normal weight. In a recent Australian study, almost one-quarter of all macrosomia was attributable to overweight and obesity. Encouragingly, it was estimated that 15.9% of macrosomia could be prevented if women with overweight or obesity were to move down one BMI category over a 4-year period. While diet and physical activity interventions aimed at reducing GWG can reduce the incidence of GDM compared with standard care, the effects vary by BMI. This highlights the importance of future studies addressing BMI and GWG to reduce GDM and potential offspring outcomes.

The relationship between obesity, GDM and related adverse pregnancy outcomes is complex and is modified by ethnicity. In a population-based, cross-sectional study among 5,562 women, compared with non-Hispanic white women, Asian women had a 2-fold higher likelihood for GDM (OR=2.44; 95% CI=1.81, 3.29). Ethnic minority origin was also an independent predictor for GDM in South Asians [OR=2.24 (95% CI=1.26, 3.97)] and Middle Eastern women [OR=2.13 (95% CI=1.12, 4.08)], after adjusting for age, pre-pregnancy BMI and parity. Ethnicity may be a blunt but implementable surrogate marker for specific physiologic glucometabolic profiles accounting for different clinical phenotypes. Although important, ethnicity cannot be considered in isolation because translation into a system-based approach should recognise the important independent effects of cultural and linguistic identity especially where lifestyle-based interventions are predominant.

**Lifestyle and management.** Treatment of GDM is directed at reducing blood glucose levels to near normal levels. Target blood glucose levels vary based on how institutional and/or national clinical practice guidelines have operationalised evidence from two interventional trials, where a combination of lifestyle measures and insulin treatment reduced adverse pregnancy outcomes in women with mild hyperglycaemia consistent with contemporary diagnostic criteria. Lifestyle-based interventions are the foundation of treatment and are effective at adequately controlling blood glucose levels during pregnancy for the majority of women. Where blood glucose levels are inadequately controlled with lifestyle measures alone, pharmacologic therapy is instituted. Pharmacologic therapy most commonly consists of metformin and/or insulin, with preference varying internationally. It is evident that lifestyle management for GDM rarely focuses on healthy GWG which may prove a useful strategy in future intervention studies.
Gestational diabetes and future cardiometabolic diseases. GDM is associated with a number of longer term health complications to mother and offspring beyond the immediate risks to pregnancy. In women with a history of GDM, the risk of recurrent GDM is about 30–84%.92 This is not surprising as GDM and type 2 diabetes both sit on the same continuous spectrum of glucose abnormality, albeit the former a milder state of impairment which is unmasked by a surge in placental hormones required to support glucose transfer to the foetus and promote insulin resistance. Therefore, at completion of pregnancy with the rapid dissipation of placental hormones, GDM rapidly resolves. In a prospective cohort study with up to 18 years of follow-up, baseline BMI (i.e. within 2 years of GDM diagnosis), most recent BMI and weight gain after GDM were significantly and positively associated with risk of progression from GDM to type 2 diabetes, suggesting the need for managing weight at onset of GDM and post-partum, to reduce risk for type 2 diabetes.

In the longer term, GDM is a well-established risk factor for future cardiovascular events mediated by an increased risk of type 2 diabetes, metabolic syndrome, hyperlipidaemia, atherosclerosis and obesity.93–95 Impaired glucose tolerance or upper normal glycaemic level in the normoglycaemic obstetric population, termed ‘maternal dysglycaemia’, is an increasingly recognised risk factor for future cardiovascular risk, with an estimated 13% increase in risk for every 1 mmol/L increment in blood glucose.96 This highlights the importance of antenatal glucose screening and interval monitoring with early identification of future cardiovascular risk.

Hypertensive disorders of pregnancy
HDP are classified into two main groups: first, hypertension known prior to pregnancy or presenting during the first 20 weeks, which includes chronic hypertension, white coat hypertension and masked hypertension; and second, hypertension arising at or after 20 weeks, which includes transient gestational hypertension, gestational hypertension and pre-eclampsia.97 Chronic hypertension is the most prevalent HDP, with 14% of women experiencing during pregnancy; a further 2–5% of pregnancies are affected by gestational hypertension or pre-eclampsia.97 The prevalence of HDP has increased rapidly over the past 10 years, potentially due to corresponding increases in overweight, obesity, diabetes and advanced maternal age.97

Overweight and obesity are identified as strong clinical risk factors for pre-eclampsia. A pre-pregnancy BMI of >25 and >30 kg/m² has been demonstrated in meta-analysis to be associated with an increased risk of pre-eclampsia (overweight RR = 2.1, 95% CI = 2.0, 2.2; obesity RR = 2.8, 95% CI = 2.6, 3.1).98 Guidelines from the International Society for the Study of Hypertension in Pregnancy (ISSHP) indicate that while there is no test available during the first or second trimester of pregnancy to accurately predict pre-eclampsia, all women should be screened during the first trimester for risk factors known to be strongly associated with pre-eclampsia.97 Risk factors include maternal BMI >30 kg/m², history of pre-eclampsia, chronic hypertension, pre-gestational diabetes, antiphospholipid syndrome and assisted reproduction pregnancies.97 Women identified as having clinical risk factors for pre-eclampsia, including obesity, are recommended to be treated with aspirin (75–165 mg/day) before 16 weeks’ gestation as an intervention to prevent pre-eclampsia.97

Lifestyle and management. A 2019 systematic review of 23 randomised controlled trials explored the efficacy of diet and/or exercise interventions among pregnant women with overweight or obesity, as a strategy to prevent pre-eclampsia.99 The review identified that despite achieving significantly lower weight gain in the intervention groups, there was no significant difference in the risk of pre-eclampsia between groups (diet and/or exercise versus usual/expectant care). These results are consistent with other systematic reviews of antenatal weight management interventions, which also found no impact on pre-eclampsia incidence.100 Therefore, further research is required to explore the role of weight management pre-pregnancy, inter-pregnancy and during pregnancy on the occurrence of HDP, particularly among women with a previous hypertensive pregnancy.

HDP and future cardiometabolic diseases. A diagnosis of HDP has a significant impact on maternal CVD risk, with an 8-fold risk of developing cardiovascular risk factors and up to 5-fold risk of
premature CVD. Although the exact mechanisms remain unclear, an interplay between pre-pregnancy predisposition and the cardiometabolic effects of HDP has been proposed. The occurrence of endothelial dysfunction leading to accelerated atherogenesis is a common theory. The prevalence and onset of cardiovascular risk factors among women appear to correlate with both the severity of HDP and the presence of other pregnancy-related complications such as SGA births and preterm delivery. Following recurrent pre-eclampsia (i.e. women with a history of pre-eclampsia in a previous pregnancy), risk for ischaemic heart disease (RR = 2.40; 95% CI = 2.15, 2.68) and cerebrovascular disease (RR = 1.69; 95% CI = 1.21, 2.35) is higher compared with women with an uncomplicated pregnancy.

There is emerging evidence of the contribution of overweight and obesity post-pregnancy to the higher risk of cardiovascular risk factors among women following HDP. Analysis of the Nurses’ Health Study II cohort study (n = 54,588) and the 45 and Up cohort study (n = 71,819) both found that a history of HDP and a higher BMI following pregnancy were associated with the greatest risk of chronic hypertension. However, research in this area is in its infancy, and further research is needed to examine the contribution of overweight and obesity, and associated risk factors (e.g. poor diet, physical inactivity) on the cardiovascular health of women following HDP.

**Preterm birth**

Preterm birth is a heterogeneous condition with multiple attributable factors such as systemic inflammation, infection or vascular diseases. While maternal BMI and increased GWG has been associated with delivery of a preterm baby, other studies have also reported a protective effect of obesity.

Women with previous preterm deliveries have a higher burden of atherogenesis, atherogenic lipid accumulation and carotid intima-media thickness detected in later life. Thus, dysregulation in cardiometabolic factors may be a common pathway partly explaining the potential relationship between preterm birth and future CVD. This may be driven, in part, by a higher incidence of postpartum hypertension, hypercholesterolaemia, type 2 diabetes mellitus and elevated BMI in women with preterm delivery.

Over the last 20 years, increasing evidence highlights that preterm delivery poses an increased risk of future maternal cardiovascular health. Most notably, a recent meta-analysis included 21 studies with over 5.8 million women, with more than 338,000 women with previous preterm deliveries. Preterm birth was associated with an increased risk of a range of CVD outcomes by up to 2-fold, including maternal future CVD (RR = 1.43; 95% CI = 1.18, 1.72), death from CVD (RR = 1.78; 95% CI = 1.42, 2.21), coronary heart disease (RR = 1.49, 95% CI = 1.38, 1.60), death from coronary heart disease (RR = 1.87, 2.36) and stroke (RR = 1.65; 95% CI = 1.51, 1.79). This highlights clear and consistent associations between preterm delivery and increased risk for future maternal adverse cardiovascular outcomes. Although the authors discussed that follow-up guidelines recommend the consideration of preterm delivery in CVD prevention, it was also recommended that a detailed evaluation of a screening programme for CVD in women with a history of preterm birth should be conducted.

**Lifestyle and management.** Lifestyle factors have important implications for both women’s reproductive health and cardiovascular outcomes. The adverse cardiovascular effects of smoking, alcohol, recreational substance use, sedentary lifestyle and obesity also increase the risk of low birthweight and preterm birth. Conversely, moderate exercise has been associated with reduced preterm birth and more favourable pregnancy and cardiovascular outcomes, particularly in women with raised BMI.

**Foetal growth restriction**

Foetal growth restriction occurs when a foetus does not grow according to its genetic growth potential. Most commonly, SGA is defined as a birthweight below the 10th percentile for gestational age on the normative population growth curve and intrauterine growth restriction with birthweight less than 5th percentile. Maternal obesity is associated with SGA and intrauterine growth restriction (IUGR), and both maternal obesity and growth restriction are associated with placental insufficiency. This occurs when the placenta cannot deliver an adequate
supply of nutrients and oxygen to the foetus which can lead to foetuses with structural and functional cardiovascular changes which can persist through infancy, childhood and adolescence. An infant born growth restricted has increased blood pressure, arterial stiffness and aortic intima-media thickness, a marker of preclinical atherosclerosis. Women who gave birth to a moderate or very SGA infant (i.e. less than 1–2 standard deviations below the mean based on Swedish reference curves) and who was also born at less than 31 weeks’ gestation had up to 4-fold increased risk for CVD. One major causal factor behind preterm birth and growth restriction is maternal pre-eclampsia. As highlighted earlier, women who had pre-eclampsia are at higher risk for future CVD. Pre-eclampsia and related HDP may be a driving factor in the relationship between foetal growth restriction and CVD. Further studies assessing these relationships are warranted, along with mechanisms linking maternal risk for future CVD following delivery of a growth restricted baby.

Lifestyle and management. Maternal energy and protein deficiency are associated with foetal growth restriction; however, dietary intervention studies have been inconsistent in terms of increasing birthweight. While other lifestyle factors such as smoking and maternal BMI also increase the risk for growth restriction, there are currently no specific diet and lifestyle guidelines aimed at preventing foetal growth restriction. Given the links between maternal obesity, pre-eclampsia and growth restriction, similar management strategies may also support appropriate foetal growth.

Post-partum follow-up care
Clinically, post-partum follow-up care for GDM is based around managing the risks of recurrent GDM and progression to cardiometabolic disease, that is, type 2 diabetes and CVD, predominantly through lifestyle measures. These include dietary interventions focused around caloric restriction, physical activity, sleep optimisation, stress management and the tackling contributory factors such as low mood and identification and treatment of a range of medical causes of obesity. Numerous recommendations suggest a follow-up of glycaemic status after pregnancy, using WHO criteria for the diagnosis of diabetes 6 weeks to 3 months post-partum, with additional follow-up every 1–3 years. Adherence to a follow-up programme after GDM is typically low. For HDP, many clinical guidelines recognise HDP as a primary risk factor specifically for CVD, to be considered as part of follow-up care. A recent review of clinical guidelines, however, acknowledged there is currently no international consensus for post-partum follow-up care after its diagnosis. This includes consensus for the role of different health professionals, along with the timing, duration or focus of care. One of the more detailed guidelines is that of the Society of Obstetric Medicine of Australia and New Zealand (SOMANZ). The SOMANZ guidelines recommend counselling women with a history of HDP regarding lifestyle risk factors (i.e. excess body weight, physical inactivity, poor diet and smoking), along with monitoring blood pressure annually, and serum lipids and blood glucose at least every 5 years as a CVD preventive strategy. The SOMANZ guidelines also acknowledge the need to provide advice to women following HDP (>6 weeks post-partum) about optimising risk factors, such as obesity, prior to subsequent pregnancies.

There is evidence to suggest, however, that follow-up care consistent with clinical guidelines is not routinely being provided. For example, a survey of 127 Australian women, aged ≥18 years with recent (<2 years) pre-eclampsia, found 34% were unaware of their increased risk of CVD, and while 95% reported monitoring of their blood pressure, less than half (41%) reported monitoring of their cholesterol and/or glucose, and <25% had received advice/counselling on lifestyle risk factors. Notably, a 2019 systematic review of post-partum interventions to reduce long-term CVD risk in women after HDP located only two published randomized controlled trials evaluating such interventions. They acknowledged the paucity of intervention trials and concluded research is urgently required to determine the best method of CVD risk reduction following HDP. Additional trials are currently underway that may provide further guidance on the efficacy and implementation of post-partum follow-up care for CVD prevention.
There is no literature assessing lifestyle or post-partum follow-up care for women with preterm birth or growth restriction. Further work in this area is needed to identify and initiate risk-reduction strategies for future cardiovascular risk.

**Conclusion**

Obesity is a clear contributor to a range of pregnancy complications, including GDM, HDP and delivery of a preterm or growth restricted baby, but also to PCOS as an adverse condition, which is itself associated with worsened pregnancy outcomes. GWG also contributes to a range of pregnancy complications; however, further studies investigating which is a stronger driving factor will help tailor lifestyle interventions. Nevertheless, all of these conditions discussed pose significant increased risk for future cardiometabolic-related diseases. If overweight and obesity, but also excess GWG and post-partum weight retention, can be reduced through lifestyle interventions, then multiple comorbidities associated with pregnancy complications may also be reduced in the years after childbirth. The need for post-partum cardiovascular risk assessment and follow-up remains under-recognised, and further research in this area is warranted.

**Author contributions**

L.J.M. designed the review and J.A.G. contributed to the concept of this work. All authors contributed to interpretation of data, drafted the article and revised it critically for important intellectual content, approved the version to be published and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

**Conflict of interest statement**

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**References**

1. National Academies Press. Global trends in obesity. Current status and response to the global obesity pandemic: Proceedings of a workshop (ed. EA Callahan). Washington, DC: National Academies of Sciences, Engineering, and Medicine; Health and Medicine Division; Food and Nutrition Board; Roundtable on Obesity Solutions, 2019.

2. GBD 2017 Risk Factor Collaborators. Global, regional, and national comparative risk assessment of 84 behavioural, environmental and occupational, and metabolic risks or clusters of risks for 195 countries and territories, 1990-2017: a systematic analysis for the Global Burden of Disease Study 2017. Lancet 2018; 392: 1923–1994.

3. World Health Organization. Obesity and overweight (Key facts), 2016, https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight

4. 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.

5. Gomersall SR, Dobson AJ and Brown WJ. Weight gain, overweight, and obesity: determinants and health outcomes from the Australian Longitudinal Study on Women’s Health. Curr Obes Rep 2014; 3: 46–53.

6. Davis D, Brown WJ, Foureur M, et al. Long-term weight gain and risk of overweight in parous and nulliparous women. Obesity (Silver Spring) 2018; 26: 1072–1077.

7. Gesink Law DC, Maclehose RF and Longnecker MP. Obesity and time to pregnancy. Hum Reprod 2007; 22: 414–420.
8. Hassan MA and Killick SR. Negative lifestyle is associated with a significant reduction in fecundity. *Fertil Steril* 2004; 81: 384–392.

9. Fuchs F, Senat MV, Rey E, et al. Impact of maternal obesity on the incidence of pregnancy complications in France and Canada. *Sci Rep* 2017; 7: 10859.

10. Schummers L, Hutcheon JA, Bodnar LM, et al. Risk of adverse pregnancy outcomes by prepregnancy body mass index: a population-based study to inform prepregnancy weight loss counseling. *Obstet Gynecol* 2015; 125: 133–143.

11. Torloni MR, Betran AP, Daher S, et al. Impact of maternal obesity on the incidence of pregnancy complications in France and Canada. *Sci Rep* 2017; 7: 10859.

12. Schummers L, Hutcheon JA, Bodnar LM, et al. Risk of adverse pregnancy outcomes by prepregnancy body mass index: a population-based study to inform prepregnancy weight loss counseling. *Obstet Gynecol* 2015; 125: 133–143.

13. Sam S. Obesity and polycystic ovary syndrome. *Obes Manag* 2007; 3: 69–73.

14. McKenzie-Sampson S, Paradis G, Healy-Proftos J, et al. Gestational diabetes and risk of cardiovascular disease up to 25 years after pregnancy: a retrospective cohort study. *Acta Diabetol* 2018; 55: 315–322.

15. Berks D, Hoedjes M, Raat H, et al. Risk of cardiovascular disease after pre-eclampsia and the effect of lifestyle interventions: a literature-based study. *BJOG* 2013; 120: 924–931.

16. Cooney LG and Dokras A. Beyond fertility: polycystic ovary syndrome and long-term health. *Fertil Steril* 2018; 110: 794–809.

17. Godfrey KM, Gluckman PD and Hanson MA. Developmental origins of metabolic disease: life course and intergenerational perspectives. *Trends Endocrinol Metab* 2010; 21: 199–205.

18. Fleming TP, Watkins AJ, Velazquez MA, et al. Origins of lifetime health around the time of conception: causes and consequences. *Lancet* 2018; 391: 1842–1852.

19. Krishnaveni GV and Yajnik CS. Developmental origins of diabetes-an Indian perspective. *Eur J Clin Nutr* 2017; 71: 865–869.

20. Rasmussen KM, Catalano PM and Yaktine AL. New guidelines for weight gain during pregnancy: what obstetrician/gynecologists should know. *Curr Opin Obstet Gynecol* 2009; 21: 521–526.

21. Goldstein RF, Abell SK, Ranasinha S, et al. Association of gestational weight gain with maternal and infant outcomes: a systematic review and meta-analysis. *JAMA* 2017; 317: 2207–2225.

22. Chen C, Xu X and Yan Y. Estimated global overweight and obesity burden in pregnant women based on panel data model. *PloS One* 2018; 13: e0202183.

23. Australian Institute of Health and Welfare (AIHW). *Australia's mothers and babies*. Australian Government, 2017, https://www.aihw.gov.au/getmedia/2a0c22a2-ba27-4ba0-ad47-ebbe51854cd6/aihw-per-100-in-brief.pdf.aspx?inline=true

24. Bjermo H, Lind S and Rasmussen F. The educational gradient of obesity increases among Swedish pregnant women: a register-based study. *BMC Public Health* 2015; 15: 315.

25. Lahti-Pulkkinen M, Bhattacharya S, Wild SH, et al. Consequences of being overweight or obese during pregnancy on diabetes in the offspring: a record linkage study in Aberdeen, Scotland. *Diabetologia* 2019; 62: 1412–1419.

26. Onubi OJ, Marais D, Aucott L, et al. Maternal obesity in Africa: a systematic review and meta-analysis. *J Public Health (Oxf)* 2016; 38: e218–e231.

27. Cheng HR, Walker LO, Brown A, et al. Gestational weight gain and perinatal outcomes of subgroups of Asian-American women, Texas, 2009. *Women's Health Issues* 2015; 25: 303–311.

28. Institute of Medicine. *Committee to reexamine IOM pregnancy weight guidelines*. Institute of Medicine (US) and National Research Council (US), 2009, https://www.ncbi.nlm.nih.gov/books/NBK32810/

29. Deputy NP, Sharma AJ, Kim SY, et al. Prevalence and characteristics associated with gestational weight gain adequacy. *Obstet Gynecol* 2015; 125: 773–781.

30. Xu H, Arkema EV, Cnattingius S, et al. Gestational weight gain and delivery outcomes: a population-based cohort study. *Paediatr Perinat Epidemiol*. Epub ahead of print 29 July 2020. DOI: 10.1111/ppe.12709.

31. Timmermans YEG, van de Kant KDG, Oosterman EO, et al. The impact of interpregnancy weight change on perinatal outcomes in women and their children: a systematic review and meta-analysis. *Obes Rev* 2020; 21: e12974.
32. Poston L, Caleyachetty R, Cnaatningius S, et al. Preconceptional and maternal obesity: epidemiology and health consequences. *Lancet Diabetes Endocrinol* 2016; 4: 1025–1036.

33. Metwally M, Ong KJ, Ledger WL, et al. Does high body mass index increase the risk of miscarriage after spontaneous and assisted conception? A meta-analysis of the evidence. *Fertil Steril* 2008; 90: 714–726.

34. Marchi J, Berg M, Dencker A, et al. Risks associated with obesity in pregnancy, for the mother and baby: a systematic review of reviews. *Obes Rev* 2015; 16: 508–521.

35. McDonald SD, Han Z, Mulla S, et al. Maternal adiposity as an independent risk factor for pre-eclampsia: a meta-analysis of prospective cohort studies. *Obes Rev* 2013; 14: 508–521.

36. Santos S, Voerman E, Amiano P, et al. Impact of maternal body mass index and gestational weight gain on pregnancy complications: an individual participant data meta-analysis of European, North American and Australian cohorts. *Br J Obstet Gynaecol* 2019; 126: 984–995.

37. Gaillard R, Welten M, Oddy WH, et al. Associations of maternal prepregnancy body mass index and gestational weight gain with cardio-metabolic risk factors in adolescent offspring: a prospective cohort study. *Br J Obstet Gynaecol* 2016; 123: 207–216.

38. McDonald SD, Han Z, Mulla S, et al. Maternal obesity and risk of preterm birth and low birth weight infants: systematic review and meta-analyses. *BMJ* 2010; 341: c3428.

39. Yu Z, Han S, Zhu J, et al. 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.

40. Goldstein RF, Abell SK, Ranasinha S, et al. Gestational weight gain across continents and ethnicity: systematic review and meta-analysis of maternal and infant outcomes in more than one million women. *BMC Med* 2018; 16: 153.

41. Ren M, Li H, Cai W, et al. Excessive gestational weight gain in accordance with the IOM criteria and the risk of hypertensive disorders of pregnancy: a meta-analysis. *BMC Pregnancy Childbirth* 2018; 18: 281.

42. Voerman E, Santos S, Inskip H, et al. Association of gestational weight gain with adverse maternal and infant outcomes. *JAMA* 2019; 321: 1702–1715.

43. Brunner S, Stecher L, Ziebarth S, et al. Excessive gestational weight gain prior to glucose screening and the risk of gestational diabetes: a meta-analysis. *Diabetologia* 2015; 58: 2229–2237.

44. International Weight Management in Pregnancy Collaborative Group. Effect of diet and physical activity based interventions in pregnancy on gestational weight gain and pregnancy outcomes: meta-analysis of individual participant data from randomised trials. *BMJ* 2017; 358: j3119.

45. Silva FP, Souza RT, Cecatti JG, et al. Role of Body Mass Index and gestational weight gain on preterm birth and adverse perinatal outcomes. *Sci Rep* 2019; 9: 13093.

46. Carnero AM, Mejia CR and Garcia PJ. Rate of gestational weight gain, pre-pregnancy body mass index and preterm birth subtypes: a retrospective cohort study from Peru. *Br J Obstet Gynaecol* 2012; 119: 924–935.

47. National Health and Medical Research Council (NHMRC). Alcohol guidelines: reducing the health risks. Australian Government and the National Health and Medical Research Council, 2009, https://www.nhmrc.gov.au/health-topics/alcohol-guidelines

48. National Health and Medical Research Council (NHMRC). *Australian clinical practice guidelines: pregnancy care*. Australian Government, 2018, https://www.clinicalguidelines.gov.au/portal/2589/clinical-practice-guidelines-pregnancy-care-2018-edition

49. National Institute for Health and Care Excellence (NICE). *Antenatal care for uncomplicated pregnancies*, 2008, https://www.nice.org.uk/guidance/cg62

50. National Institute for Health and Care Excellence (NICE). *Weight management before, during and after pregnancy*, 2010, https://www.nice.org.uk/guidance/ph27

51. RANZCOG. The Royal Australian and New Zealand College of Obstetricians and Gynaecologists. Management of Obesity in Pregnancy, 2017, https://ranz cog.edu.au/RANZCOG_SITE/media/RANZCOG-MEDIA/Women%27s%20Health/Statement%20and%20guidelines/Clinical-Obstetrics/Management-of-obesity-(C-Obs-49)-Review-March-2017.pdf?ext=.pdf

52. Hanson M, Jacob CM, Hod M, et al. The FIGO pregnancy obesity and nutrition initiative (PONI). *Int J Gynaecol Obstet* 2019; 147: 131–133.

53. McAuliffe FM, Killeen SL, Jacob CM, et al. Management of prepregnancy, pregnancy,
and postpartum obesity from the FIGO
Pregnancy and Non-Communicable Diseases
Committee: a FIGO (International Federation
of Gynecology and Obstetrics) guideline. Int J
Gynaecol Obstet 2020; 151(Suppl. 1): 16–36.

54. U.S. Department of Health and Human
Services and U.S. Department of Agriculture
(USDA). 2015–2020 dietary guidelines for
Americans (8th ed.), 2015, http://health.gov/
dietaryguidelines/2015/guidelines/

55. Story M, Kaphingst KM, Robinson-O’Brien
R, et al. Creating healthy food and eating
environments: policy and environmental
approaches. Annu Rev Public Health 2008; 29:
253–272.

56. Bozdag G, Mumusoglu S, Zengin D, et al. The
prevalence and phenotypic features of polycystic
ovary syndrome: a systematic review and meta-
analysis. Hum Reprod 2016; 31: 2841–2855.

57. Rotterdam ESHRE/ASRM-Sponsored PCOS
Consensus Workshop Group. Revised 2003
consensus on diagnostic criteria and long-
term health risks related to polycystic ovary
syndrome. Fertil Steril 2004; 81: 19–25.

58. Joham AE, Palomba S and Hart R. Polycystic
ovary syndrome, obesity, and pregnancy. Semin
Reprod Med 2016; 34: 93–101.

59. Stepto NK, Cassar S, Joham AE, et al. Women with
polycystic ovary syndrome have intrinsic insulin
resistance on euglycaemic-hyperinsulaemic
clamp. Hum Reprod 2013; 28: 777–784.

60. Barber TM, Hanson P, Weickert MO, et al.
Obesity and polycystic ovary syndrome:
implications for pathogenesis and novel
management strategies. Clin Med Insights Reprod
Health 2019; 13: 1179558119874042.

61. Bahri Khomami M, Boyle JA, Tay CT, et al.
Polycystic ovary syndrome and adverse pregnancy outcomes: current state of
knowledge, challenges and potential
implications for practice. Clin Endocrinol (Oxf)
2018; 88: 761–769.

62. Bahri Khomami M and Moran LJ. Polycystic
ovary syndrome and gestational weight gain.
Carr Opin Endocrin Metabol Res 2020; 12: 20–25.

63. Kjerulf LE, Sanchez-Ramos L and Duffy D.
Pregnancy outcomes in women with polycystic
ovary syndrome: a meta-analysis. Am J Obstet
Gynecol 2011; 204: 558.e1–558.e6.

64. Boomsma CM, Eijkemans MJ, Hughes EG, et al. A meta-analysis of pregnancy outcomes in
women with polycystic ovary syndrome. Hum
Reprod Update 2006; 12: 673–683.

65. Qin JZ, Pang LH, Li MJ, et al. Obstetric
complications in women with polycystic ovary
syndrome: a systematic review and meta-
analysis. Reprod Biol Endocrinol 2013; 11: 56.

66. Yu HF, Chen HS, Rao DP, et al. Association
between polycystic ovary syndrome and the
risk of pregnancy complications: a PRISMA-
compliant systematic review and meta-analysis.
Medicine (Baltimore) 2016; 95: e4863.

67. Bahri Khomami M, Joham AE, Boyle JA, et al.
The role of maternal obesity in infant outcomes
in polycystic ovary syndrome—A systematic
review, meta-analysis, and meta-regression.
Obes Rev 2019; 20: 842–858.

68. Musa OAH, Islam N, Thalib L, et al. The
impact of obesity on the gestational diabetes
differential between pregnant women with and
without polycystic ovary syndrome. Obes Rev
2019; 20: 1665–1666.

69. Al Mamun A, Mannan M, O’Callaghan MJ,
et al. Association between gestational weight
gain and postpartum diabetes: evidence from
a community based large cohort study. PLoS
ONE 2013; 8: e75679.

70. Fraser A, Tilling K, Macdonald-Wallis C, et al.
Associations of gestational weight gain with
maternal body mass index, waist circumference,
and blood pressure measured 16 y after
pregnancy: the Avon Longitudinal Study of
Parents and Children (ALSPAC). Am J Clin
Nutr 2011; 93: 1285–1292.

71. Teede HJ, Joham AE, Paul E, et al.
Longitudinal weight gain in women identified
with polycystic ovary syndrome: results of an
observational study in young women. Obesity
(Silver Spring) 2013; 21: 1526–1532.

72. Teede HJ, Misso ML, Costello MF, et al.
Recommendations from the international
evidence-based guideline for the assessment and
management of polycystic ovary syndrome. Clin
Endocrinol 2018; 89: 251–268.

73. Huijgen NA, Louwers YV, Willemsen SP, et al.
Dietary patterns and the phenotype of
polycystic ovary syndrome: the chance of
ongoing pregnancy. Reprod Biomed Online 2017;
34: 668–676.

74. Legro RS, Dodson WC, Kunselman AR, et al. Benefit of delayed fertility therapy with
preconception weight loss over immediate
therapy in obese women with PCOS. J Clin Endocrinol Metab 2016; 101: 2658–2666.

75. National Health and Medical Research Council. Australian dietary guidelines. Canberra, ACT, Australia: National Health and Medical Research Council, 2013.

76. Pathirathna ML, Sekijima K, Sadakata M, et al. Effects of physical activity during pregnancy on neonatal birth weight. Scientific Reports 2019; 9: 6000.

77. Osibogun O, Ogunmoroti O and Michos ED. Polycystic ovary syndrome and cardiometabolic risk: opportunities for cardiovascular disease prevention. Trends Cardiovasc Med 2019; 30: 399–404.

78. Lim S, Norman R, Davies M, et al. The effect of obesity on polycystic ovary syndrome: a systematic review and meta-analysis. Obes Rev 2013; 14: 95–109.

79. National Diabetes Data Group. Classification and diagnosis of diabetes mellitus and other categories of glucose intolerance. Diabetes 1979; 28: 1039–1057.

80. International Diabetes Federation. IDF diabetes atlas (9th ed.). Brussels, 2019, https://www.diabetesatlas.org/

81. Ma RCW and Popkin BM. Intergenerational diabetes and obesity-A cycle to break. PLoS Med 2017; 14: e1002415.

82. Black MH, Sacks DA, Xiang AH, et al. The relative contribution of prepregnancy overweight and obesity, gestational weight gain, and IADPSG-defined gestational diabetes mellitus to fetal overgrowth. Diabetes Care 2013; 36: 56–62.

83. Ricart W, López J, Mozas J, et al. Body mass index has a greater impact on pregnancy outcomes than gestational hyperglycaemia. Diabetologia 2005; 48: 1736–1742.

84. Cheney K, Farber R, Barratt AL, et al. Population attributable fractions of perinatal outcomes for nulliparous women associated with overweight and obesity, 1990-2014. Med J Aust 2018; 208: 119–125.

85. Bennett CJ, Walker RE, Blumfield ML, et al. Interventions designed to reduce excessive gestational weight gain can reduce the incidence of gestational diabetes mellitus: a systematic review and meta-analysis of randomised controlled trials. Diabetes Res Clin Pract 2018; 141: 69–79.

86. Chen L, Shi L, Zhang D, et al. Influence of acculturation on risk for gestational diabetes among Asian women. Prev Chronic Dis 2019; 16: E158.

87. Jenum AK, Mørkrid K, Sletten L, et al. Impact of ethnicity on gestational diabetes identified with the WHO and the modified International Association of Diabetes and Pregnancy Study Groups criteria: a population-based cohort study. Eur J Endocrinol 2012; 166: 317–324.

88. Crowther CA, Hiller JE, Moss JR, et al. Effect of treatment of gestational diabetes mellitus on pregnancy outcomes. N Engl J Med 2005; 352: 2477–2486.

89. Landon MB, Spong CY, Thom E, et al. A multicenter, randomized trial of treatment for mild gestational diabetes. N Engl J Med 2009; 361: 1339–1348.

90. National Institute for Health and Care Excellence. Diabetes in pregnancy: management from preconception to the postnatal period (NICE guideline [NG3]). London: NICE, 2015.

91. American Diabetes Association. 14. Management of diabetes in pregnancy: standards of medical care in diabetes—2020. Diabetes Care 2020; 43(Suppl. 1): S183–S192.

92. Kim C, Berger DK and Chamany S. Recurrence of gestational diabetes mellitus: a systematic review. Diabetes Care 2007; 30: 1314–1319.

93. Grandi SM, Filion KB, Yoon S, et al. Cardiovascular disease-related morbidity and mortality in women with a history of pregnancy complications. Circulation 2019; 139: 1069–1079.

94. Sullivan SD, Umans JG and Ratner R. Gestational diabetes: implications for cardiovascular health. Curr Diab Rep 2012; 12: 43–52.

95. Mosca L, Benjamin EJ, Berra K, et al. Effectiveness-based guidelines for the prevention of cardiovascular disease in women—2011 update: a guideline from the American Heart Association. J Am Coll Cardiol 2011; 57: 1404–1423.

96. Retnakaran R and Shah BR. Glucose screening in pregnancy and future risk of cardiovascular disease in women: a retrospective, population-based cohort study. Lancet Diabetes Endocrinol 2019; 7: 378–384.

97. Brown MA, Magee LA, Kenny LC, et al. Hypertensive disorders of pregnancy: ISSHP classification, diagnosis, and management
recommendations for international practice. *Hypertension* 2018; 72: 24–43.

98. Bartsch E, Medcalf KE, Park AL, et al. Clinical risk factors for pre-eclampsia determined in early pregnancy: systematic review and meta-analysis of large cohort studies. *BMJ* 2016; 353: i1753.

99. Syngelaki A, Sequeira Campos M, Roberge S, et al. Diet and exercise for preeclampsia prevention in overweight and obese pregnant women: systematic review and meta-analysis. *J Matern Fetal Neonatal Med* 2019; 32: 3495–3501.

100. Ho LC, Saunders KA, Owen DJ, et al. Are antenatal weight management interventions effective in preventing pre-eclampsia? Systematic review of randomised control trials. *Pregnancy Hypertens* 2012; 2: 341–349.

101. Arnott C, Nelson M, Alfaro Ramirez M, et al. Maternal cardiovascular risk after hypertensive disorder of pregnancy. *Heart* 2020; 106: 1927–1933.

102. Benschop L, Duvekot JJ, and Roeters van Lennep JE. Future risk of cardiovascular disease risk factors and events in women after a hypertensive disorder of pregnancy. *Heart* 2019; 105: 1273–1278.

103. Brown MC, Best KE, Pearce MS, et al. Cardiovascular disease risk in women with pre-eclampsia: systematic review and meta-analysis. *Eur J Epidemiol* 2013; 28: 1–19.

104. Osl G and Bernstein I. Preeclampsia and maternal cardiovascular disease: consequence or predisposition? *J Vasc Res* 2014; 51: 290–304.

105. Wenger N. Tailoring cardiovascular risk assessment and prevention for women: one size does not fit all. *Glob Cardiol Sci Pract* 2017; 2017: c201701.

106. Brouwers L, van derMeiden-van Roest AJ, Savelkoul C, et al. Recurrence of preeclampsia and the risk of future hypertension and cardiovascular disease: a systematic review and meta-analysis. *BJOG* 2018; 125: 1642–1654.

107. Timpka S, Stuart JJ, Tanz LJ, et al. Lifestyle in progression from hypertensive disorders of pregnancy to chronic hypertension in Nurses’ Health Study II: observational cohort study. *BMJ* 2017; 358: j3024.

108. Tooher J, Chiu CL, Yeung K, et al. High blood pressure during pregnancy is associated with future cardiovascular disease: an observational cohort study. *BMJ Open* 2013; 3e002964.

109. Romero R, Espinoza J, Kusanovic JP, et al. The preterm parturition syndrome. *BJOG* 2006; 113(Suppl. 3): 17–42.

110. Siddiqui N and Hladunewich M. Understanding the link between the placenta and future cardiovascular disease. *Trends Cardiovasc Med* 2011; 21: 188–193.

111. Ehrenberg HM, Iams JD, Goldenberg RL, et al. Maternal obesity, uterine activity, and the risk of spontaneous preterm birth. *Obstet Gynecol* 2009; 113: 48–52.

112. Catov JM, Muldoon MF, Reis SE, et al. Preterm birth with placental evidence of malperfusion is associated with cardiovascular risk factors after pregnancy: a prospective cohort study. *BJOG* 2018; 125: 1009–1017.

113. Tanz LJ, Stuart JJ, Williams PL, et al. Preterm delivery and maternal cardiovascular disease in young and middle-aged adult women. *Circulation* 2017; 135: 578–589.

114. Wu P, Gulati M, Kwok CS, et al. Preterm delivery and future risk of maternal cardiovascular disease: a systematic review and meta-analysis. *J Am Heart Assoc* 2018; 7e007809.

115. Gupta PC and Sreevidya S. Smokeless tobacco use, birth weight, and gestational age: population based, prospective cohort study of 1217 women in Mumbai, India. *BMJ* 2004; 328: 1538.

116. Kumar S, Sharma S and Thaker R. Occupational, environmental, and lifestyle factors and their contribution to preterm birth—an overview. *Indian J Occup Environ Med* 2017; 21: 9–17.

117. Guendelman S, Pearl M, Kosa JL, et al. Association between preterm delivery and pre-pregnancy body mass (BMI), exercise and sleep during pregnancy among working women in Southern California. *Matern Child Health J* 2013; 17: 723–731.

118. Juhl M, Andersen PK, Olsen J, et al. Physical exercise during pregnancy and the risk of preterm birth: a study within the Danish National Birth Cohort. *Am J Epidemiol* 2008; 167: 859–866.

119. Grieger JA and Clifton VL. A review of the impact of dietary intakes in human pregnancy on infant birthweight. *Nutrients* 2015; 7: 153–178.

120. Howell KR and Powell TL. Effects of maternal obesity on placental function and fetal development. *Reproduction* 2017; 153: R97–R108.
121. Crispi F, Bijnens B, Figueras F, et al. Fetal growth restriction results in remodeled and less efficient hearts in children. *Circulation* 2010; 121: 2427–2436.

122. Crispi F, Miranda J and Gratacós E. Long-term cardiovascular consequences of fetal growth restriction: biology, clinical implications, and opportunities for prevention of adult disease. *Am J Obstet Gynecol* 2018; 218: S869–S879.

123. Bonamy AK, Parikh NI, Cnattingius S, et al. Birth characteristics and subsequent risks of maternal cardiovascular disease: effects of gestational age and fetal growth. *Circulation* 2011; 124: 2839–2846.

124. Smith GC, Pell JP and Walsh D. Pregnancy complications and maternal risk of ischaemic heart disease: a retrospective cohort study of 129,290 births. *Lancet* 2001; 357: 2002–2006.

125. Kvalvik LG, Wilcox AJ, Skjaerven R, et al. Term complications and subsequent risk of preterm birth: registry based study. *BMJ* 2020; 369: m1007.

126. Kramer MS. Balanced protein/energy supplementation in pregnancy. *Cochrane Database Syst Rev* 2000: CD000032.

127. Kharkova OA, Grjibovski AM, Krettek A, et al. Effect of smoking behavior before and during pregnancy on selected birth outcomes among singleton full-term pregnancy: a Murmansk County Birth Registry study. *Int J Environ Res Public Health* 2017; 14: 867.

128. Prabhu N, Smith N, Campbell D, et al. First trimester maternal tobacco smoking habits and fetal growth. *Thorax* 2010; 65: 235–240.

129. Nankervis A, Price S and Conn J. Gestational diabetes mellitus: a pragmatic approach to diagnosis and management. * Aust J Gen Pract* 2018; 47: 445–449.

130. NICE. Diabetes in pregnancy: management from preconception to the postnatal period: NICE guidelines, https://www.nice.org.uk/guidance/ng3

131. Russell MA, Phipps MG, Olson CL, et al. Rates of postpartum glucose testing after gestational diabetes mellitus. *Obstet Gynecol* 2006; 108: 1456–1462.

132. Lawrence JM, Black MH, Hsu JW, et al. Prevalence and timing of postpartum glucose testing and sustained glucose dysregulation after gestational diabetes mellitus. *Diabetes Care* 2010; 33: 569–576.

133. Dalfrà MG, Burlina S, Del Vescovo GG, et al. Adherence to a follow-up program after gestational diabetes. *Acta Diabetol* 2020; 57: 1473–1480.

134. Gamble DT, Brikins B, Myint PK, et al. Hypertensive disorders of pregnancy and subsequent cardiovascular disease: current national and international guidelines and the need for future research. *Front Cardiovasc Med* 2019; 6: 55.

135. Lowe SA, Bowyer L, Lust K, et al. The SOMANZ guidelines for the management of hypertensive disorders of pregnancy 2014. *Aust N Z J Obstet Gynaecol* 2015; 55: 11–16.

136. Hutchesson M, Shrewsbury V, Park F, et al. Are women with a recent diagnosis of pre-eclampsia aware of their cardiovascular disease risk? A cross-sectional survey. *Aust N Z J Obstet Gynaecol* 2018; 58: E27–E28.

137. Lui NA, Jeyaram G and Henry A. Postpartum interventions to reduce long-term cardiovascular disease risk in women after hypertensive disorders of pregnancy: a systematic review. *Front Cardiovasc Med* 2019; 6: 160.

138. Henry A, Arnott C, Makris A, et al. Blood pressure postpartum (BP2) RCT protocol: follow-up and lifestyle behaviour change strategies in the first 12 months after hypertensive pregnancy. *Pregnancy Hypertens* 2020; 22: 1–6.