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Addressing inequalities and improving maternal and infant outcomes: the potential power of nutritional interventions across the reproductive cycle

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Maternal nutrition is essential for optimal health and well-being of women and their infants. This review aims to provide a critical overview of the evidence-base relating to maternal weight, obesity-related health inequalities and dietary interventions encompassing the reproductive cycle: preconception, pregnancy, postnatal and interpregnancy. We provide an overview of UK data showing that overweight and obesity affects half of UK pregnancies, with increased prevalence among more deprived and minoritised ethnic populations, and with significant health and cost implications. The existing intervention evidence-base primarily focuses on the pregnancy period, where extensive evidence demonstrates the power of interventions to improve maternal diet behaviours, and minimise gestational weight gain and postnatal weight retention. There is a lack of consistency in the intervention evidence-base relating to interventions improving pregnancy health outcomes, although there is evidence of the potential power of the Mediterranean and low glycaemic index diets in improving short- and long-term health of women and their infants. Postnatal interventions focus on weight loss, with some evidence of cost-effectiveness. There is an evidence gap for preconception and interpregnancy interventions. We conclude by identifying that interventions do not address cumulative maternal obesity inequalities and overly focus on individual behaviour change. There is a lack of a joined-up approach for interventions throughout the entire reproductive cycle, with a current focus on specific stages (i.e. pregnancy) in isolation. Moving forward, the potential power of nutritional interventions using a more holistic approach across the different reproductive stages is needed to maximise the benefits on health for women and children.

Health inequalities: Diet: Intervention: Maternal

Maternal weight status is defined by BMI before/early pregnancy using WHO BMI categories (Table 1). In England, maternal obesity prevalence has increased over time, from 7·6 % in 1989[1] to 21·3 % in 2015–2017[2]. Whereas maternal recommended weight has decreased over this same time period from 65·6 to 47·3 %. Recent data published in the National Maternal and Perinatal Audit (NMPA, England, Wales and Scotland)[2], and

Abbreviations: AOR, adjusted odds ratio; GDM, gestational diabetes; GI, glycaemic index; GWG, gestational weight gain; LGA, large-for-gestational-age; NAM, National Academy of Medicine; NIMATS, Northern Ireland Maternity System; NMPA, National Maternal and Perinatal Audit; QALY, quality-adjusted life years.
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Table 1. Weight status categories and GWG recommendations

Weight status categories 0·22 kg/week	BMI range, kg/m²	Total GWG*, kg	2nd and 3rd trimester mean (range) weekly GWG†, kg
Underweight	<18·5	12·5–18	0·51 (0·44–0·58)
Recommended weight	18·5–24·9	11·5–16	0·42 (0·35–0·50)
Overweight	25·0–29·9	7–11·5	0·28 (0·23–0·33)
Obese class I	30·0–34·9		
Obese class II	35·0–39·9	5–9	0·22 (0·17–0·27)
Obese class III	≥40·0		

GWG, gestational weight gain; NAM, National Academy of Medicine.
* The NAM GWG recommendations do not differentiate between WHO obesity classes[4].
† The total GWG recommendations includes a 1st trimester weight gain of 0·5–2 kg, which is not accounted for in the 2nd and 3rd trimester weekly weight gain values.

the Northern Ireland Maternity System (NIMATS)[3] highlights that overweight and obesity affects half of all pregnancies, with some UK differences in prevalence. Maternal overweight prevalence was consistent across England (28·0 %), Wales (28·5 %) and Scotland (28·4 %), and slightly higher in Northern Ireland (29·5 %). Whereas maternal obesity prevalence was highest for Wales (26·2 %), followed by Scotland (23·2 %), England (21·3 %) and Northern Ireland (20·1 %).

Gestational weight gain (GWG) is the amount of weight gained between conception and delivery, including increases in fat mass and fluids and the weight of the fetus and placenta. Although there is no international consensus on recommended GWG, the US National Academy of Medicine (NAM) recommendations[4] (Table 1) have been widely adopted, although not in the UK[5]. These guidelines require maternal weight at conception and full-term delivery to calculate total GWG[4]. However, these specific measures are not consistently applied in research[6], which can result in inaccurate interpretations. Additionally, the NAM recommendations do not account for different obesity classes. Some studies indicate that lower GWG results in better pregnancy outcomes for obesity classes II and III[7–9]. UK data[10] suggest that women with class I or II obesity gain excessive weight whereas class III have inadequate GWG below the NAM guidelines. Developing a global consensus on recommended GWG ranges, including for obesity classes I–III, and inconsistency in applying existing NAM GWG guidelines to data are areas requiring further research.

This review aims to provide a critical overview of the evidence-base relating to maternal weight, obesity-related health inequalities and dietary interventions encompassing the reproductive cycle: preconception, pregnancy, postnatal and interpregnancy. The first part of this review introduces maternal weight around the reproductive cycle with a focus on health outcomes, inequalities and costs. The second part of the review provides a critical discussion of diet interventions in the preconception, pregnancy and postnatal periods.

Maternal weight and health implications

Maternal obesity and excessive GWG can have adverse impacts on maternal and infant outcomes. These include adverse events during and immediately after pregnancy, but can also persist across the life-course and have intergenerational effects.

Pregnancy

Women entering pregnancy with obesity are at increased risk of multiple adverse outcomes, including gestational diabetes (GDM), pre-eclampsia, emergency caesarean delivery, induction of labour, antenatal depression and maternal mortality[11,12]. Infants also have increased risks, such as large-for-gestational-age (LGA) or macrosomia, neonatal hypoglycaemia and admission to neonatal intensive care units[13]. Postnatally, there is reduced breastfeeding, and increased depression[14–16] and weight retention[17]. The intrauterine environment can impact on fetal development, the results of which persist across the life course through fetal programming[18]. Children born to women with obesity and/or excessive GWG are significantly more likely to develop overweight or obesity themselves[19,20]. The associations between maternal obesity and child health persist into adulthood, particularly relating to diabetes[21]. The increased risks may be explained by the fetal overnutrition hypothesis or due to metabolic, inflammatory and neuroendocrine changes that occur from an altered fetal hormone and nutrient exposure when mothers have obesity during pregnancy[22,23].

Preconception and interpregnancy

Following pregnancy, the postnatal period is also a preconception period for women who have future pregnancies, providing an opportunity for preconception dietary and weight management interventions[24]. A recent systematic review explored associations between weight change in the prepregnancy period (including both preconception and interpregnancy) and outcomes in a subsequent pregnancy[25]. Compared with weight stability, weight gain significantly increased the odds of developing subsequent GDM, hypertensive disorders, preeclampsia, LGA, caesarean delivery, stillbirth and low Apgar score, and reduced the odds of having a vaginal birth following previous caesarean[25]. Interestingly, prepregnancy weight loss significantly reduced the odds of developing GDM compared with weight stability, but increased the odds of SGA, stillbirth and preterm delivery. There were also different patterns when analysis was carried out based on maternal BMI. For example, preterm delivery was significantly increased for women with a BMI≥25 kg/m² but not for BMI<25 kg/m². Weight loss reduced the odds of LGA for women with a BMI≥25 kg/m² but increased the odds of SGA in women with a BMI<25 kg/m². Other systematic reviews exploring the interpregnancy period have found similar results[26–28]. The associations between prepregnancy weight loss (which is the current UK guideline recommendation) and some potential for increased risks in subsequent

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pregnancies require further exploration. For example, how important is the amount of weight loss, reason for weight loss (e.g. intentional or unintentional) and time-scale for weight loss? These data would help inform evidence-based guidelines to optimise maternal and infant health.

Healthcare costs

Healthcare services have increased costs relating to maternal obesity due to the additional care required to minimise risks and maximise healthy outcomes for women and their babies. A study in Wales identified that women with overweight and obesity in pregnancy have increased service usage and costs of 23 % and 37 %, respectively[29]. However, this was restricted to just direct costs rather than complete health costs. Other economic studies show similar results[30–32]. Additionally, a study in Canada reported that children born to mothers with overweight or obesity had more physician visits, hospital admissions and longer hospital stays with estimated costs in the first 18 years of life of $1415 (95 % CI 590, 2285), compared to $231 (95 % CI −403, 847) for maternal recommended weight[33]. The additional costs required for routine care for women with maternal overweight and obesity support the need for interventions to reduce risks from both a maternal and infant health and well-being perspective, but also from an economic perspective.

Socio-demographic inequalities

Similar to obesity trends in the general population, there are significant associations between maternal obesity, deprivation and ethnic groups.

Deprivation

UK data show a deprivation gradient with maternal weight status. Women have increased odds of their BMI being above or below the recommended range as the level of deprivation increases (Table 2). These data demonstrate wider determinants of maternal obesity than individual behaviour. There is potential for interventions that focus on individual agency and behaviour change alone to increase the inequality gap for maternal obesity. Alongside increasing levels of deprivation and poverty in the UK, food insecurity is also increasing. Women are particularly vulnerable to food insecurity due to working in low-income or part-time jobs, as well as societal expectations for them to be the main carers for children and family members, carry out unpaid housework and be the main providers of food[34–36]. When finances are scarce, women report restricting their own food intake in favour of their children and other household members[37–39]. Food insecurity is associated with a nutritionally poor diet, consumption of energy-dense food and living in an obesogenic environment, thus increasing the risk of developing obesity[40–43]. The preconception, pregnancy and postnatal periods present increased nutrient requirements, and food insecurity in pregnancy increases the risk of adverse health outcomes for both mother and child[44,45]. In the UK, food insecurity has increased since the implementation of austerity measures following the global financial crisis in 2008[46–48], further exacerbated by Covid-19[48,49], and most recently in 2022 by increases in the cost of living (largely influenced by increased costs in fuel and food)[48,50,51] (Fig. 1). The implications of continuing increases in food insecurity on maternal nutritional health and well-being, and the potential impact on fetal development, are severe.

Ethnic groups

Data for England between 1995 and 2007 showed a significantly increased prevalence of maternal obesity among Black and South Asian (compared with White) ethnic groups (adjusted odds ratio (AOR) 1·70, 95 % CI 1·62, 1·78; AOR 1·72, 95 % CI 1·66, 1·79 respectively)[52]. Within the South Asian group, Pakistani women had the highest odds of maternal obesity (AOR 2·19, 95 % CI 2·08, 2·31), followed by Indian (AOR 1·49, 95 % CI 1·39, 1·60) and Bangladeshi (AOR 1·15, 95 % CI 1·06, 1·24). This study applied the WHO Asian-specific BMI criteria for obesity (BMI≥27·5 kg/m^2) for South Asian women[53]. More recent data have been published for by the NMPA and NIMATS (Table 2). Due to the categorisation used by NIMATS (White and Other), UK-wide data can only estimate odds of BMI categories for minoritised ethnic groups compared with White. These data show a significantly increased odds of underweight, overweight and obesity class I, but significantly decreased odds of obesity classes II and III among minoritised ethnic groups (Table 2). However, data reported by the NMPA show that the pooling of heterogeneous ethnic groups masks the significantly increased odds for Black women for all obesity classes (OR ranging from 2·06; 95 % CI 1·96, 2·16 for class III, to 2·54; 95 % CI 2·48, 2·61 for class I) (Table 2). A limitation of the NMPA data is that it did not apply the WHO Asian-specific BMI criteria, which is likely to explain the difference in results compared with previously published data[52].

Intersectionality

It is important to consider the implications of multiple inequalities through an intersectionality lens: how do the different inequalities reported in this paper (i.e., deprivation, food insecurity, ethnicity, obesity) as well as others not discussed (e.g. stigma and discrimination) collide and have a cumulative impact on pregnancy health? Recent data show the cumulative increased risks for ethnic groups and deprivation. These data relate to stillbirth, preterm delivery and fetal growth restriction, where the highest risks were seen for Black and South Asian women residing in the highest deprivation quintile[54]. However, there is limited evidence relating to maternal obesity and intersectionality, which warrants further exploration.

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Table 2. Odds of maternal BMI category and area of residence deprivation

	OR (95% CI)*					
	<18·5 kg/m^2	18·5–24·9 kg/m^2	25–29·9 kg/m^2	30–34·9 kg/m^2	35–39·9 kg/m^2	≥40 kg/m^2
Deprivation measured by IMD quintile†						
2	**1·10 (1·05, 1·15)**	Reference	**1·08 (1·07, 1·10)**	**1·20 (1·17, 1·22)**	**1·31 (1·27, 1·35)**	**1·40 (1·34, 1·47)**
3	**1·24 (1·19, 1·29)**	Reference	**1·16 (1·14, 1·18)**	**1·40 (1·37, 1·43)**	**1·62 (1·57, 1·67)**	**1·86 (1·78, 1·95)**
4	**1·48 (1·43, 1·54)**	Reference	**1·27 (1·25, 1·28)**	**1·67 (1·64, 1·71)**	**1·96 (1·90, 2·02)**	**2·34 (2·24, 2·44)**
5 most deprived	**1·92 (1·85, 1·99)**	Reference	**1·38 (1·36, 1·40)**	**2·02 (1·98, 2·06)**	**2·52 (2·45, 2·60)**	**3·24 (3·11, 3·37)**
Ethnic groups: NMPA data for England, Scotland and Wales and NIMATS data for Northern Ireland						
Minoritised ethnic groups‡	**1·45 (1·42, 1·49)**	Reference	**1·43 (1·41, 1·44)**	**1·22 (1·20, 1·24)**	**0·92 (0·90, 0·94)**	**0·73 (0·70, 0·75)**
Ethnic groups: NMPA data for England, Scotland and Wales						
South Asian	**1·62 (1·57, 1·68)**	Reference	**1·24 (1·23, 1·26)**	**1·06 (1·04, 1·08)**	**0·70 (0·67, 0·72)**	**0·44 (0·41, 0·46)**
Black	1·01 (0·94, 1·09)	Reference	**1·99 (1·95, 2·04)**	**2·54 (2·48, 2·61)**	**2·23 (2·15, 2·31)**	**2·06 (1·96, 2·16)**
Mixed	**1·17 (1·08, 1·28)**	Reference	**1·08 (1·04, 1·11)**	**1·09 (1·04, 1·14)**	0·98 (0·92, 1·04)	1·00 (0·92, 1·08)
Other	**3·08 (2·91, 3·26)**	Reference	**2·22 (2·16, 2·28)**	**1·86 (1·79, 1·93)**	**1·27 (1·20, 1·34)**	**0·85 (0·77, 0·93)**

NHS, National Health Service; NIMATS, Northern Ireland Maternity System; NMPA, National Maternal and Perinatal Audit; IMD, index of multiple deprivation.
* OR calculated from data from the NMPA for births in England, Scotland and Wales NHS maternity services between 1st April 2015 and 31st March 2017, and from the NIMATS for Northern Ireland 2011–2017[2,3]. Bold data are statistically significant.
† IMD quintile 1, least deprived = deprivation reference group.
‡ Minoritised ethnic groups include the categories defined by the NMPA report as South Asian, black, mixed and other ethnic group[2]; and by the NIMATS as other (i.e. not white)[3].

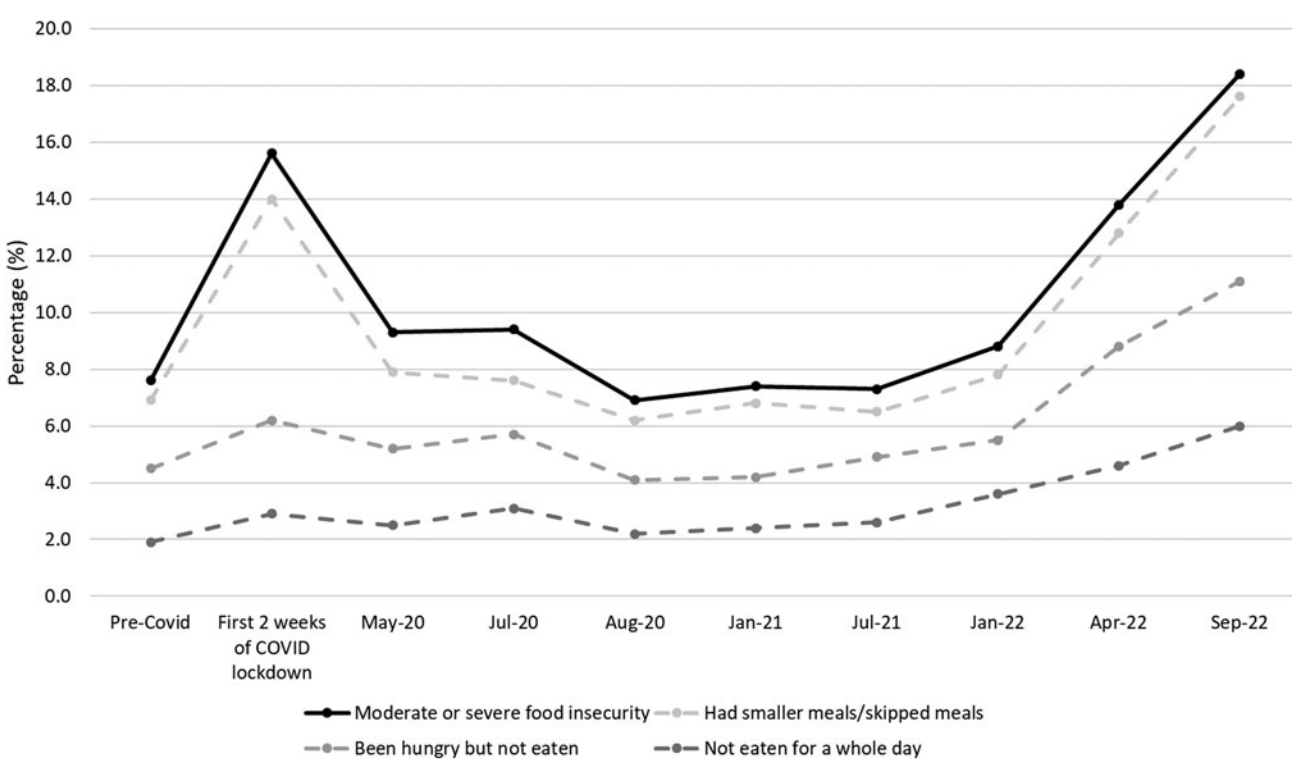

Fig. 1. Household food insecurity in the UK.*Note*: Moderate or severe food insecurity indicates answering yes to one or more of having smaller/skipping meals, been hungry but not eaten and/or not eaten for a whole day. Reproduced using data from the Food and You survey 2018[48], Food Foundation 2020, 2021, 2022[49,50,51].

Overview of the evidence-base for nutritional interventions

There is potential power for nutritional interventions, delivered during the preconception, pregnancy and post-natal/interpregnancy periods, to have substantial benefits on maternal and infant health, in the short- and long-term. There are also public health benefits from capitalising on these reproductive life course stages for prevention of adverse health outcomes and promotion of health behaviours. This section provides an overview of the existing evidence-base drawn from interventions.

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Preconception interventions

The preconception period could be the ideal opportunity for interventions to address risk factors for pregnancy prior to conception, based on the life course approach and embryo developmental programming[55,56]. However, the preconception phase is not straight-forward to define and the exact time of conceiving is often unknown as half of pregnancies in high-income countries are unplanned[57,58]. While observational evidence demonstrates strong relationships between health behaviours before pregnancy and positive pregnancy outcomes, limited intervention evidence exists[59–61]. Preconception interventions to date tend to be universal (e.g. folic acid fortification) or focus on fertility outcomes, with limited evidence specific to maternal weight[62–64]. Systematic reviews published during the past decade have attempted to identify preconception intervention evidence, but little progress has been made in relation to obesity. In 2014, a systematic review explored the effectiveness of preconception interventions on maternal, new-born and child health outcomes; however, no data for maternal obesity were reported amongst the included studies[65]. In 2015, a Cochrane review aimed to identify preconception weight loss interventions targeting overweight or obesity, but found no eligible studies for inclusion[66]. A systematic review in 2017 assessed the effect of preconception interventions on maternal and child health outcomes but again, no data on maternal obesity were reported from the included studies[67]. Preconception interventions for overweight and obesity were identified in systematic reviews published in 2017 and 2018[63,64]; however, these were specific to women seeking fertility treatment. Most recently in 2021, an integrative review identified evidence on preconception care[68]. However, the outcomes related to women's knowledge of preconception care in relation to overweight and obesity, rather than preconception nutrition or obesity interventions[68]. Across all of these reviews, the evidence for preconception interventions identified tended to be poor or moderate quality, highlighting the need for further high-quality research in the preconception period. An on-going trial, Get Ready!, uses an online digital tool to identify South Asian women with a BMI≥23 kg/m^2 or women with a BMI≥25 kg/m^2 for all other ethnicities who are planning pregnancies, and provides a personalised intervention to improve behaviours and biomarkers of metabolic health[69]. In summary, the preconception periods present theoretical promise, but there is currently a lack of high-quality interventions to inform evidence-based care.

Pregnancy interventions

There is a very different picture in relation to interventions delivered during pregnancy. Two recent systematic reviews of systematic reviews reported data for intervention effects on maternal diet and physical activity behaviours during pregnancy (*n* 16 reviews reporting data from 311 unique papers)[70], and on health-related outcomes (*n* 63 reviews reporting data from 675 unique papers)[71]. For maternal behaviour outcomes, the data showed overall consistent evidence for interventions increasing fruit and vegetable consumption and decreasing carbohydrate and fat intake, and for beneficial effects on physical activity. However, there was a lack of results from meta-analysis included in the reviews due to the heterogeneity in how studies reported behavioural outcomes[70].

For the health-related outcomes, the data showed a consistent pattern in interventions significantly reducing GWG in intervention arms (among 80 % of meta-analyses)[71]. When data were grouped according to intervention type, results were proportionately similar regardless of whether the interventions were diet only, physical activity only or combined. However, there was a noticeable difference in effect sizes with the largest reduction in GWG seen among diet-only interventions compared with physical activity-only or combined interventions (Table 3). Patterns in meta-analyses of postnatal weight retention were similar, with a majority showing a significant reduction. However, there were limited data to explore patterns according to intervention type. Results for most other health outcomes (e.g. GDM, pregnancy-induced hypertension, LGA) were mixed[71]. Overall, the meta-analyses tended to show a negative direction of effect among the intervention arms, although there was minimal or inconsistent statistical significance. An example is in Table 3 for GDM, where overall only 37 % of meta-analyses showed a significant reduction in GDM among intervention arms. However, when the meta-analyses were grouped according to intervention type, there was an increase in the proportion of statistically significant results in diet or physical activity-only interventions compared with combined interventions. Similar to GWG, the largest effect sizes were seen with diet-only interventions[71].

These data suggest that we need to understand more about why some pregnancy interventions are effective and others are not to move the evidence-base forward and identify the best strategies for improving the health of women and their babies. For example, what can we learn from the content, mode of delivery, timing and intensity of interventions that are effective compared with those that are not effective? The review data suggest that diet-only interventions may have the greatest effect, although the benefits of physical activity during pregnancy should not be dismissed. Two types of diet interventions, the Mediterranean and low glycaemic index (GI) diets, are used as examples to demonstrate the need to move our knowledge forward in this area.

Mediterranean diet during pregnancy

Mediterranean diet interventions focus on implementing a new dietary pattern rather than altering specific components. This may be beneficial as food and nutrients are consumed together rather than in isolation, which may provide a more comprehensive insight to the understanding of diet–disease relationships[72]. Within pregnancy, two key trials have highlighted the potential benefit of the Mediterranean diet: ESTEEM and St Carlos[73,74].

The ESTEEM multicentre trial in the UK recruited 1252 women with metabolic risk factors (obesity, chronic

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Table 3. Summary of meta-analysis results for interventions delivered during pregnancy

	Any intervention	Diet and PA	Diet only	PA only
GWG: *n* 36 systematic reviews reporting *n* 66 meta-analyses				
Significantly reduced	53 (80%)	26 (81%)*	8 (80%)†	19 (79%)‡
No significant difference	13 (20%)	6 (19%)	2 (20%)	5 (21%)
Significantly increased	0	0	0	0
Postnatal weight retention: *n* 7 systematic reviews reporting *n* 16 meta-analyses				
Significantly reduced	9 (56%)§	8 (53%)	0	1 (100%)
No significant difference	6 (38%)	6 (40%)	0	0 (0%)
Significantly increased	1 (6%)	1 (7%)	0	0
GDM: *n* 29 systematic reviews reporting *n* 59 meta-analyses				
Significantly reduced	22 (37%)	5 (19%)‖	6 (43%)¶	11 (58%)**
No significant difference	37 (63%)	21 (81%)	8 (57%)	8 (42%)
Significantly increased	0	0	0	0

GDM, gestational diabetes; GWG, gestational weight gain; PA, physical activity; RR, relative risk; MD, mean difference.
* Results ranged from MD −0·21 kg (95% CI −0·34, −0·08) to MD −4·65 kg (95% CI −8·14, −0·56).
† Results ranged from MD −1·56 kg (95% CI −2·94, −0·99) to MD −5·77 kg (95% CI −9·34, −2·21).
‡ Results ranged from MD −0·36 kg (95% CI −0·64, −0·09) to MD −2·22 kg (95% CI −3·13, −1·30).
§ Results ranged from MD −0·68 kg (95% CI −1·28, −0·09) at 12 months to MD −1·90 kg (95% CI −1·69, −1·12) at 6 months.
‖ Results ranged from RR 0·61 (95% CI 0·41, 0·90) to RR 0·83 (95% CI 0·69, 1·00).
¶ Results ranged from OR 0·33 (95% CI 0·14, 0·76) to RR 0·56 (95% CI 0·36, 0·87).
** Results ranged from RR 0·51 (95% CI 0·31, 0·82) to RR 0·74 (95% CI 0·57, 0·97).
Data from: Hayes *et al*.[71].

hypertension or hypertriglyceridemia) and aimed to address inequalities by targeting inner-city women[73]: 60 % of participants were Black or Asian and 69 % had obesity. The intervention consisted of a Mediterranean-style diet where women were encouraged to have a high intake of nuts, extra virgin olive oil, fruits, vegetables, non-refined grains and legumes; moderate to high consumption of fish; low intake of poultry, dairy products, red and processed meats; and avoidance of sugary drinks, fast food and food rich in animal fat. The results suggested that women in the intervention group had a 35 % reduction in odds of GDM (AOR 0·65, 95 % CI 0·47, 0·91), with a greater reduction among women with obesity (AOR 0·58, 95 % CI 0·40, 0·86). Women receiving the dietary intervention also gained less weight throughout pregnancy (mean difference [MD] −1·2 kg, 95 % CI −2·2, −0·2 kg), and improved dietary behaviours. These included a significantly increased consumption of olive oil, nuts, fish, pulses and preferential consumption of chicken and turkey, and significantly reduced consumption of red/processed meat and butter/margarine. However, there was no significant difference between intervention and control arms for additional health outcomes such as pre-eclampsia, SGA or stillbirth. The St Carlos trial was based in Spain and recruited 874 women[74]. The population was different to the ESTEEM trial: two-thirds of women were White, with a mean BMI of 22·9 kg/m^2 (SD 3·6) in the intervention arm and 23·3 kg/m^2 (SD 4·0) in the control. However, the results relating to GDM were almost identical to ESTEEM (AOR 0·67, 95 % CI 0·53, 0·84). Additionally, this study identified improved glucose tolerance among all women, and a significant reduction in some pregnancy outcomes including reduced LGA, SGA, caesarean delivery and preterm birth.

Taken together, these two trials suggest that the Mediterranean diet may be an effective strategy for the prevention of GDM. The similar effect sizes demonstrate that the interventions are effective in very different populations and may go some way to addressing inequalities. Both trials also reported high adherence, suggesting that the Mediterranean diet is an acceptable intervention for pregnant women. The potential mechanisms for beneficial effect include the increased intake of polyphenol-rich foods, which act to improve glycaemic control through a variety of biological pathways[75]. The increased intake of MUFA and *n*-3 PUFA may exert an anti-inflammatory response, particularly in adipose tissue, and counteract the effect of SFA which decrease insulin sensitivity[76]. The increased intake of fruits, vegetables and wholegrains reduces GI and increases fibre, which both act to promote euglycaemia[77]. As the Mediterranean diet changes the whole dietary pattern, the beneficial effect from different aspects may compound towards a positive effect. Further research could focus on applying this dietary strategy in the context of the preconception and postnatal/interpregnancy periods.

Low GI diet during pregnancy

The UPBEAT multicentre randomised-controlled trial in the UK encouraged switching from high GI foods to low/moderate GI foods[78]. The intervention targeted women with obesity and maternity services in deprived areas with high prevalence of Black and South Asian populations. Results showed no intervention effect on GDM or LGA; however, there was a significant reduction in GWG (MD −0·55 kg, 95 % CI −1·08, −0·02) and there were improvements in diet and physical activity. There was a significantly reduced dietary glycaemic load (MD −21, 95 % CI −26, −21), energy intake/day (MD −0·70 MJ/day, 95 % CI −0·96, −0·45), carbohydrate intake (MD −1·4 %, 95 % CI −2·2, −0·58), total fat (MD −0·88 %, 95 % CI −1·49, −0·26) and saturated

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fat intake (MD 0·85 %, 95 % CI −1·2, −0·51), and significantly increased median physical activity at 28 weeks' gestation (intervention 1836 metabolic equivalents [METS]/per week (interquartile range [IQR] 792–4158); control 1386 METS/week (IQR 639–3363), $P = 0·001$). There was also a significant difference in maternal sum of skinfolds at 36 weeks' gestation (control 125 mm (SD 27); intervention 122 mm (SD 26), $P = 0·008$) suggesting reduced adiposity among women receiving the intervention.

Despite not observing a significant intervention effect for the primary outcome, the women and children were followed up. Analysis of these data investigated the effect of maternal dysglycaemia on the infant epigenome[79]. A sub-set of 557 women were included in the analysis of the relationship between maternal GDM and genome-wide DNA methylation in the infant. Results from the analysis of cord blood samples indicated that maternal GDM, fasting plasma glucose and 1 and 2 h plasma glucose levels were associated with significant changes to the cord blood methylome in sites associated with cell signalling and transcriptional regulation. Women who had received the intervention appeared to display an attenuation of epigenetic changes associated with GDM, 1 and 2 h plasma glucose-associated methylation. These results suggest that low GI diet may have had an effect at epigenetic level, therefore, having a life course impact beyond pregnancy. Further analysis of 514 mothers and infants at 3 years also indicated sustained benefits of the low GI intervention. Infants born from mothers in the intervention arm had a significantly lower pulse rate (−5 bpm, 95 % CI −8·41, −1·07), which may imply a reduced CVD risk, although odds of childhood overweight or obesity were not significant at this time point (OR 0·73, 95 % CI 0·50, 1·08)[80]. There was evidence that the positive intervention effect on maternal diet persisted 3 years postnatal with lower glycaemic load, total energy and SFA intake, and increased protein intake. These data highlight the importance of long-term follow-up to fully understand the potential for wider benefits of interventions beyond pregnancy for both maternal and child health.

Postnatal and interpregnancy interventions

As previously described, the postnatal period can be a preconception or interpregnancy period for diet interventions, and women have shown motivation for weight loss during this time[81]. Additionally, approximately half of women have excessive GWG with associated postnatal weight retention[82]. Interventions in this period could support longer-term weight management as well as preconception weight management for women who have subsequent pregnancies. A systematic review[83] highlighted that commencement of postnatal interventions varies, with some beginning in pregnancy while others commence at varying postnatal time points. There have been several systematic reviews and meta-analyses exploring postnatal interventions to date, which overwhelmingly related to postnatal weight loss[83–86] with a lack of data on other maternal health outcomes or subsequent pregnancies.

Meta-analyses demonstrate that interventions appear to be effective at reducing weight in the postnatal period[83–86]. In contrast to the evidence-base for pregnancy interventions, postnatal intervention data suggest that combined diet and physical activity interventions result in greater effect, and more consistent statistical significance, than either behaviours on their own. For example, Dodd *et al.*[85] reported greater postnatal weight loss for combined interventions (MD −2·49 kg, 95 % CI −3·34, −1·63) than for diet (MD −1·82 kg, 95 % CI −2·19, −1·44) or physical activity (MD −1·45 kg, 95 % CI −2·41, −0·50). Similarly, meta-analyses from Lim *et al.*[84,86] reported significantly greater weight loss from combined interventions (MD −3·15 kg, 95 % CI −4·34, −1·96 and −3·15 kg, 95 % −4·34, −1·96) than physical activity (MD −1·63 kg, 95 % −2·16, −1·10 and −0·78 kg, 95 % CI −1·73, 0·16) or diet-only interventions (MD −2·30 kg, 95 %CI −5·27, 0·67). When reported, postnatal weight loss was also significantly greater in interventions which targeted women with overweight or obesity compared to those targeting all women (MD −3·17 kg, 95 % CI −4·45, −1·89 and −1·04 kg, 95 % CI −1·74, −0·34 respectively)[86]. Unlike pregnancy, the potential duration of the postnatal period is highly variable, and this is reflected in the duration of postnatal interventions. One review suggested that short/medium duration (≤6 months) interventions tended to show greater weight loss than longer durations (>12 months)[83]. Whereas, a meta-analysis showed similar results regardless of whether weight was measured at the end of the intervention with variable durations (MD −2·49 kg, 95 % CI −3·34, −1·63) or at 12 months postnatal (MD −2·41 kg, 95 % CI −3·89, −0·93)[85]. Thus, future interventions should further explore the optimal duration of the intervention for weight reduction.

Evidence from general populations suggests greater intervention intensity results in greater weight loss[87,88], whereas a systematic review[86] of postnatal interventions to date shows greater weight loss with low intensity and flexible interventions. Further research exploring postnatal intervention intensity and duration is required to inform the best approach for this population. Of note, we identified few postnatal weight management interventions that focused solely on women with obesity within the existing literature. As women with obesity are at greater risk of postnatal weight retention (>5 kg) and are more likely to gain two or more interpregnancy BMI units compared to women with recommended weight[89], there is a need for effective strategies targeting women with obesity.

Cost-effectiveness evidence for interventions

The cost-effectiveness evidence for interventions across the reproductive cycle is limited, and focused on the pregnancy and post-partum periods. An economic evaluation of diet and/or physical activity interventions in pregnancy using individual participant data from thirty trials (*n* 17 727 women) found no evidence that interventions

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were cost-effective compared to usual care[90]. This result remained when secondary analysis was performed based on maternal BMI. The heterogeneity between studies due to different intervention types and intensities may have reduced the accuracy of the costs imputed into the model. As discussed in the pregnancy intervention section of this paper, there appears to be differences in effect size of interventions for some outcomes depending on whether they are combined, or diet or physical activity only. Further work extending the economic evaluation to look at specific intervention components and modes of delivery, as well as expanding data on costs to allow for calculation of quality-adjusted life years (QALY), would allow for a full cost-utility analysis. A further limitation with current intervention cost-effectiveness analyses is that they tend to focus only on outcomes that have been significantly different in intervention and control arms. For example, a cost-effectiveness analysis of the LIMIT trial (an intervention targeting women with a BMI≥25 kg/m^2 in pregnancy) focused on respiratory distress syndrome and infant macrosomia, even though data were collected on a range of maternal and infant outcomes[91,92].

A cost-utility analysis was conducted for a postnatal weight loss intervention that was delivered to sixty-eight Swedish women for 12 weeks[93]. The intervention targeted women with a BMI>25 kg/m^2 and focused on energy intake reduction. The cost-utility analysis suggested the intervention was effective; the intervention group had a cost per QALY of 8643–9758 USD and the willingness to pay per QALY was set at 50 000 USD. Another Swedish postnatal dietary intervention in 110 women found similar results[94]. The 12-week intervention with 2-year follow-up showed a significant improvement in quality of life compared to standard care ($P < 0{\cdot}050$). The cost per QALY gained was 1704–7889 USD, and the likelihood of cost-effectiveness was 0·77–1·00 based upon a willingness to pay of 50 000 USD per QALY. These two studies suggest a beneficial effect of interventions in the postnatal period on quality of life, as well as being cost-effective. Given the small sample sizes of these trials, cost-effectiveness data from larger studies with a more diverse demographic would provide a better understanding of cost-effectiveness. A gap in the existing evidence-base is for economic evaluations to also incorporate longer-term outcomes that may be improved by interventions, such as those reported by the UPBEAT trial, and outcomes more closely aligned with public health, such as improvements in maternal behaviours. Future research could also incorporate patient and public involvement to help guide the design of economic evaluations with a focus on more holistic patient benefit beyond clinical outcomes.

Interventions and inequalities

Given the significant associations between maternal weight and inequalities, particularly deprivation, food insecurity and ethnicity, we must take a critical look at the potential for interventions to reduce the inequality gap, or to widen it. There are some existing interventions, such as ESTEEM and UPBEAT, which have specifically targeted inequalities in their study design and could have potential for addressing these inequalities. However, on the whole, the evidence-base to date does not address inequalities through targeting. The focus of interventions to date is also on individual responsibility (albeit supported) for women to improve diet, physical activity, minimise GWG, prevent adverse pregnancy outcomes and lose weight postnatally. This focus on individuals has the potential to increase the inequality gap given that individual responsibility places resource demands (e.g. financial and time) on the individuals, and can also limit potential for scale-up and implementation[95,96]. Evidence suggests that the transition from pregnancy to postnatal may be associated with a poorer diet, and it can be challenging to identify ways to increase physical activity, restrict intakes of food and drink and cope with child rearing at the same time, especially amongst low-income women[97,98]. As women are disproportionately affected by food insecurity, particularly those living in poverty, access to healthy food and individual agency for healthy diets is more difficult[36]. Interventions which use technology-based strategies have shown potential impact on postnatal weight management, but the effectiveness of those interventions in disadvantaged groups of women is limited[99–101]. Thus, interventions also need to consider ways to reduce health inequalities more holistically, considering the wider determinants of health, and any focus on individual responsibility needs to include access to the resources required for women to make behaviour changes. Further research is required to identify how to optimise diet interventions across reproductive stages in a way that is equally accessible to all women in order to tackle inequalities. More involvement of patients and public, who have lived experience of these inequalities, in the design of interventions, possibly using co-production methods, may be one way to move this agenda forward.

Conclusions

This review paper has provided an overview of the importance of addressing maternal weight before, during and after pregnancy. It includes evidence of the increasing prevalence, inequalities and costs of maternal obesity, as well as reviewing observational evidence relating to GWG, preconception and interpregnancy weight change and health outcomes. There is a critical discussion of the existing intervention evidence-base, primarily drawn from systematic reviews. This has highlighted an abundance of pregnancy interventions demonstrating effectiveness at improving maternal behaviour and weight, the need to understand more about the mechanisms relating to health outcomes and potential benefits of Mediterranean and Low GI diets. However, there is a paucity of evidence for preconception interventions and a limited focus of postnatal interventions on weight loss without capitalising on the interpregnancy period for future pregnancies or considering other maternal health outcomes. We have also highlighted the limited evidence

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to date from economic evaluations of interventions and provided a critical discussion of how interventions to date might impact on inequalities.

The review has identified some key areas for future research relating to the topics discussed in this paper, such as more focus on preconception and interpregnancy periods for future interventions, and advancing our understanding of how pregnancy interventions might work in order to maximise effectiveness. We should also consider potential unintended consequences of interventions, both positively and negatively. For example, do interventions targeting women have a 'ripple effect' to their wider family or households? Do they have a negative impact by widening the existing inequalities observed for maternal obesity? There is a clear need for interventions to address the multiple inequalities associated with maternal obesity, and using an intersectionality approach is one opportunity to explore how these compound and impact on maternal and infant health.

The existing evidence-base demonstrates the importance of diet around the reproductive cycle in the context of maternal obesity and GWG, and the potential power of dietary interventions in the pregnancy period to have life-long benefits for women and their children. However, there is a lack of a joined-up approach for interventions throughout the entire reproductive cycle, with a current focus on specific stages (i.e. pregnancy) in isolation. Moving forward, we should consider the potential power of diet interventions using a more holistic approach across the different reproductive stages to maximise the benefits on health for women and their children.

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Conflict of Interest

None.

Authorship

The authors had sole responsibility for all aspects of preparation of this paper.

References

1. Heslehurst N, Rankin J, Wilkinson JR *et al.* (2010) A nationally representative study of maternal obesity in England, UK: trends in incidence and demographic inequalities in 619 323 births, 1989–2007. *Int J Obes* **34**, 420–428.
2. Relph S, Coe M, Carroll F *et al.* (2021) *NHS Maternity Care for Women with a Body Mass Index of 30 kg/m² or Above: Births between 1 April 2015 and 31 March 2017 in England, Wales and Scotland*. London: RCOG.
3. Kent L, Cardwell C, Young I *et al.* (2021) Trends in maternal body mass index in Northern Ireland: a cross-sectional and longitudinal study. *Fam Med Community Health* **9**, e001310.
4. Institute of Medicine & National Research Council Committee (2009) *Weight Gain during Pregnancy: Reexamining the Guidelines*. Washington, DC: National Academies Press (USA).
5. National Institute for Health and Social Care (NICE) (2010) Weight management before, during and after pregnancy [PH27]. https://www.nice.org.uk/guidance/ph27 (Accessed 15 February 2023).
6. Gilmore LA & Redman LM (2015) Weight gain in pregnancy and application of the 2009 IOM guidelines: toward a uniform approach. *Obesity* **23**, 507–511.
7. Faucher MA & Barger MK (2015) Gestational weight gain in obese women by class of obesity and select maternal/newborn outcomes: a systematic review. *Women Birth* **28**, e70–e79.
8. Devlieger R, Ameye L, Nuyts T *et al.* (2020) Reappraisal of gestational weight gain recommendations in obese pregnant women: a population-based study of 337,590 births. *Obes Facts* **13**, 333–348.
9. LifeCycle Project-Maternal Obesity and Childhood Outcomes Study Group, Voerman E & Santos S (2019) Association of gestational weight gain with adverse maternal and infant outcomes. *JAMA* **321**, 1702.
10. Heslehurst N, Flynn AC, Ngongalah L *et al.* (2021) Diet, physical activity and gestational weight gain patterns among pregnant women living with obesity in the north east of England: the GLOWING pilot trial. *Nutrients* **13**, 1981.
11. Fakhraei R, Denize K, Simon A *et al.* (2022) Predictors of adverse pregnancy outcomes in pregnant women living with obesity: a systematic review. *Int J Environ Res Public Health* **19**, 2063.
12. Ellis JA, Brown CM, Barger B *et al.* (2019) Influence of maternal obesity on labor induction: a systematic review and meta-analysis. *J Midwifery Womens Health* **64**, 55–67.
13. Marchi J, Berg M, Dencker A *et al.* (2015) Risks associated with obesity in pregnancy, for the mother and baby: a systematic review of reviews. *Obes Rev* **16**, 621–638.
14. Achike M & Akpinar-Elci M (2021) The role of maternal prepregnancy body mass index in breastfeeding outcomes: a systematic review. *Breastfeed Med* **16**, 678–686.
15. Lyons S, Currie S & Smith DM (2019) Learning from women with a body mass Index (BMI) ≥ 30 kg/m² who have breastfed and/or are breastfeeding: a qualitative interview study. *Matern Child Health J* **23**, 648–656.
16. Dachew BA, Ayano G, Betts K *et al.* (2021) The impact of pre-pregnancy BMI on maternal depressive and anxiety symptoms during pregnancy and the postpartum period: a systematic review and meta-analysis. *J Affect Disord* **281**, 321–330.

17. Rong K, Yu K, Han X *et al.* (2015) Pre-pregnancy BMI, gestational weight gain and postpartum weight retention: a meta-analysis of observational studies. *Public Health Nutr* **18**, 2172–2182.
18. Strain J, Spaans F, Serhan M *et al.* (2022) Programming of weight and obesity across the lifecourse by the maternal metabolic exposome: a systematic review. *Mol Aspects Med* **87**, 100986.
19. Heslehurst N, Vieira R, Akhter Z *et al.* (2019) The association between maternal body mass index and child obesity: a systematic review and meta-analysis. *PLoS Med* **16**, e1002817.
20. Voerman E, Santos S, Patro Golab B *et al.* (2019) Maternal body mass index, gestational weight gain, and the risk of overweight and obesity across childhood: an individual participant data meta-analysis. *PLoS Med* **16**, e1002744.
21. Lahti-Pulkkinen M, Bhattacharya S, Wild SH *et al.* (2019) Consequences of being overweight or obese during pregnancy on diabetes in the offspring: a record linkage study in Aberdeen, Scotland. *Diabetologia* **62**, 1412–1419.
22. Taylor PD & Poston L (2007) Developmental programming of obesity in mammals. *Exp Physiol* **92**, 287–298.
23. Forbes S, Barr SM, Reynolds RM *et al.* (2015) Convergence in insulin resistance between very severely obese and lean women at the end of pregnancy. *Diabetologia* **58**, 2615–2626.
24. Barker M, Dombrowski SU, Colbourn T *et al.* (2018) Intervention strategies to improve nutrition and health behaviours before conception. *Lancet* **391**, 1853–1864.
25. Nagpal TS, Souza SC, Moffat M *et al.* (2022) Does prepregnancy weight change have an effect on subsequent pregnancy health outcomes? A systematic review and meta-analysis. *Obes Rev* **23**, e13324.
26. Oteng-Ntim E, Mononen S, Sawicki O *et al.* (2018) Interpregnancy weight change and adverse pregnancy outcomes: a systematic review and meta-analysis. *BMJ Open* **8**, e018778.
27. Teulings NEWD, Masconi KL, Ozanne SE *et al.* (2019) Effect of interpregnancy weight change on perinatal outcomes: systematic review and meta-analysis. *BMC Pregnancy Childbirth* **19**, 386.
28. Timmermans YEG, van de Kant KDG, Oosterman EO *et al.* (2020) The impact of interpregnancy weight change on perinatal outcomes in women and their children: a systematic review and meta-analysis. *Obes Rev* **21**, e12974.
29. Morgan KL, Rahman MA, Hill RA *et al.* (2015) Obesity in pregnancy: infant health service utilisation and costs on the NHS. *BMJ open* **5**, e008357.
30. Watson M, Howell S, Johnston T *et al.* (2013) Pre-pregnancy BMI: costs associated with maternal underweight and obesity in Queensland. *Aust NZ J Obstet Gynaecol* **53**, 243–249.
31. Denison FC, Norrie G, Graham B *et al.* (2009) Increased maternal BMI is associated with an increased risk of minor complications during pregnancy with consequent cost implications. *Bjog* **116**, 1467–1472.
32. Lenoir-Wijnkoop I, Van der Beek EM, Garssen J *et al.* (2015) Health economic modeling to assess short-term costs of maternal overweight, gestational diabetes, and related macrosomia–a pilot evaluation. *Front Pharmacol* **6**, 103.
33. Kuhle S, Muir A, Woolcott CG *et al.* (2019) Maternal pre-pregnancy obesity and health care utilization and costs in the offspring. *Int J Obes* **43**, 735–743.
34. Dolin CD, Compher CC, Oh JK *et al.* (2021) Pregnant and hungry: addressing food insecurity in pregnant women during the COVID-19 pandemic in the United States. *Am J Obstet Gynecol MFM* **3**, 100378.
35. Cukrowska-Torzewska E & Matysiak A (2020) The motherhood wage penalty: a meta-analysis. *Soc Sci Res* **88–89**, 102416.
36. Ivers LC & Cullen KA (2011) Food insecurity: special considerations for women. *Am J Clin Nutr* **94**, 1740s–1744s.
37. McIntyre L, Glanville NT, Raine KD *et al.* (2003) Do low-income lone mothers compromise their nutrition to feed their children? *Cmaj* **168**, 686–691.
38. Shinwell J & Defeyter MA (2021) Food insecurity: a constant factor in the lives of low-income families in Scotland and England. *Front Public Health* **9**, 588254.
39. Armstrong B, Hepworth AD & Black MM (2020) Hunger in the household: food insecurity and associations with maternal eating and toddler feeding. *Pediatr Obes* **15**, e12637.
40. Watson M, Booth S, Velardo S *et al.* (2022) The orthodox and unorthodox food acquisition practices and coping strategies used by food insecure adults: a scoping review. *J Hunger Environ Nutr*, 1–16. doi: 10.1080/19320248.2021.2021121
41. Tarasuk V (2001) Discussion paper on household and individual food insecurity. Health Canada, Ottawa, Canada.
42. Anderson SA (1990) Core indicators of nutritional state for difficult-to-sample populations. *J Nutr* **120**, 1555–1600.
43. Nettle D, Andrews C, Bateson M (2017) Food insecurity as a driver of obesity in humans: the insurance hypothesis. *Behav Brain Sci* **40**, e105.
44. Augusto ALP, de Abreu Rodrigues AV, Domingos TB *et al.* (2020) Household food insecurity associated with gestational and neonatal outcomes: a systematic review. *BMC Pregnancy Childbirth* **20**, 229.
45. Kazemi F, Masoumi SZ, Shayan A *et al.* (2020) Prevalence of food insecurity in pregnant women and its association with gestational weight gain pattern, neonatal birth weight, and pregnancy complications in Hamadan County, Iran, in 2018. *Agric Food Secur* **9**, 12.
46. Dowler EA, Kneafsey M, Lambie H *et al.* (2011) Thinking about 'food security': engaging with UK consumers. *Crit Public Health* **21**, 403–416.
47. Dowler E (2014) Food banks and food justice in 'Austerity Britain'. In *First World Hunger Revisited: Food Charity or the Right to Food?*, pp. 160–175 [G Riches and T Silvasti, editors]. London: Palgrave Macmillan UK.
48. Fuller E, Bankiewicz U, Davies B *et al.* (2019) The food and you survey, wave 5: combined report for England, Wales and Northern Ireland. [FS Agency, editor]. London.
49. Loopstra R (2020) *Vulnerability to Food Insecurity Since the COVID-19 Lockdown*. London: The Food Foundation.
50. The Food Foundation (2022) *Millions of adults missing meals as cost of living crisis bites*. https://foodfoundation.org.uk/press-release/millions-adults-missing-meals-cost-living-crisis-bites (Accessed 15 February 2023).
51. Food Standards Agency (2022) *Household food insecurity: annex B to the FSA 22-06-09*. https://www.food.gov.uk/about-us/fsa-22-06-09-household-food-insecurity-annex-b (Accessed 15 February 2023).
52. Heslehurst N, Sattar N, Rajasingam D *et al.* (2012) Existing maternal obesity guidelines may increase inequalities between ethnic groups: a national epidemiological study of 502,474 births in England. *BMC Pregnancy Childbirth* **12**, 156.

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https://doi.org/10.1017/S002966512300006X Published online by Cambridge University Press

53. Consultation WE (2004) Appropriate body-mass index for Asian populations and its implications for policy and intervention strategies. *Lancet* **363**, 157–163.
54. Jardine J, Walker K, Gurol-Urganci I *et al.* (2021) Adverse pregnancy outcomes attributable to socioeconomic and ethnic inequalities in England: a national cohort study. *Lancet* **398**, 1905–1912.
55. Stephenson J, Heslehurst N, Hall J *et al.* (2018) Before the beginning: nutrition and lifestyle in the preconception period and its importance for future health. *Lancet* **391**, 1830–1841.
56. Hanson M, Barker M, Dodd JM *et al.* (2017) Interventions to prevent maternal obesity before conception, during pregnancy, and post partum. *Lancet Diabetes Endocrinol* **5**, 65–76.
57. Public Health England (2018) *Health matters: reproductive health and pregnancy planning*. https://www.gov.uk/government/publications/health-matters-reproductive-health-and-pregnancy-planning (Accessed 15 February 2023).
58. Bearak J, Popinchalk A, Ganatra B *et al.* (2020) Unintended pregnancy and abortion by income, region, and the legal status of abortion: estimates from a comprehensive model for 1990–2019. *Lancet Global Health* **8**, e1152–e1161.
59. Schummers L, Hutcheon JA, Bodnar LM *et al.* (2015) Risk of adverse pregnancy outcomes by prepregnancy body mass index: a population-based study to inform prepregnancy weight loss counseling. *Obstet Gynecol* **125**, 133–143.
60. Tobias DK, Zhang C, van Dam RM *et al.* (2011) Physical activity before and during pregnancy and risk of gestational diabetes mellitus: a meta-analysis. *Diabetes Care* **34**, 223–229.
61. Aune D, Saugstad OD, Henriksen T *et al.* (2014) Physical activity and the risk of preeclampsia: a systematic review and meta-analysis. *Epidemiology* **25**, 331–343.
62. Toivonen KI, Lacroix E, Flynn M *et al.* (2018) Folic acid supplementation during the preconception period: a systematic review and meta-analysis. *Prev Med* **114**, 1–17.
63. Lan L, Harrison CL, Misso M *et al.* (2017) Systematic review and meta-analysis of the impact of preconception lifestyle interventions on fertility, obstetric, fetal, anthropometric and metabolic outcomes in men and women. *Hum Reprod* **32**, 1925–1940.
64. Price SA, Sumithran P, Nankervis A *et al.* (2019) Preconception management of women with obesity: a systematic review. *Obes Rev* **20**, 510–526.
65. Dean SV, Lassi ZS, Imam AM *et al.* (2014) Preconception care: closing the gap in the continuum of care to accelerate improvements in maternal, newborn and child health. *Reprod Health* **11**, S1.
66. Opray N, Grivell RM, Deussen AR *et al.* (2015) Directed preconception health programs and interventions for improving pregnancy outcomes for women who are overweight or obese. *Cochrane Database Syst Rev*, Article no. CD010932. doi: 10.1002/14651858.CD010932.pub2
67. Brown HK, Mueller M, Edwards S *et al.* (2017) Preconception health interventions delivered in public health and community settings: a systematic review. *Can J Public Health* **108**, e388–e397.
68. Cha E, Smart MJ, Braxter BJ *et al.* (2021) Preconception care to reduce the risks of overweight and obesity in women of reproductive age: an integrative review. *Int J Environ Res Public Health* **18**, 4582.
69. Flynn AC, Pryke E, Wadhera M *et al.* (2021) A preconception intervention targeted at women with modifiable risk factors before pregnancy to improve outcomes; protocol for the Get Ready! feasibility trial. *Pilot and Feasibility Studies* **7**, 86.
70. Heslehurst N, Hayes L, Jones D *et al.* (2020) The effectiveness of smoking cessation, alcohol reduction, diet and physical activity interventions in changing behaviours during pregnancy: a systematic review of systematic reviews. *PLoS ONE* **15**, e0232774.
71. Hayes L, McParlin C, Azevedo LB *et al.* (2021) The effectiveness of smoking cessation, alcohol reduction, diet and physical activity interventions in improving maternal and infant health outcomes: a systematic review of meta-analyses. *Nutrients* **13**, 1036.
72. Hu FB (2002) Dietary pattern analysis: a new direction in nutritional epidemiology. *Curr Opin Lipidol* **13**, 3–9.
73. Wattar HA, Dodds J, Placzek A *et al.* (2019) Mediterranean-style diet in pregnant women with metabolic risk factors (ESTEEM): a pragmatic multicentre randomised trial. *PLoS Med* **16**, e1002857.
74. Assaf-Balut C, García de la Torre N, Durán A *et al.* (2017) A Mediterranean diet with additional extra virgin olive oil and pistachios reduces the incidence of gestational diabetes mellitus (GDM): a randomized controlled trial: the St. Carlos GDM prevention study. *PLoS ONE* **12**, e0185873.
75. Kim Y, Keogh JB & Clifton PM (2016) Polyphenols and glycemic control. *Nutrients* **8**, 17.
76. Martín-Peláez S, Fito M & Castaner O (2020) Mediterranean diet effects on type 2 diabetes prevention, disease progression, and related mechanisms. A review. *Nutrients* **12**, 2236.
77. Riccardi G, Rivellese AA & Giacco R (2008) Role of glycemic index and glycemic load in the healthy state, in prediabetes, and in diabetes. *Am J Clin Nutr* **87**, 269S–274S.
78. Poston L, Bell R, Croker H *et al.* (2015) Effect of a behavioural intervention in obese pregnant women (the UPBEAT study): a multicentre, randomised controlled trial. *Lancet Diabetes Endocrinol* **3**, 767–777.
79. Antoun E, Kitaba NT, Titcombe P *et al.* (2020) Maternal dysglycaemia, changes in the infant's epigenome modified with a diet and physical activity intervention in pregnancy: secondary analysis of a randomised control trial. *PLoS Med* **17**, e1003229.
80. Dalrymple KV, Tydeman FAS, Taylor PD *et al.* (2021) Adiposity and cardiovascular outcomes in three-year-old children of participants in UPBEAT, an RCT of a complex intervention in pregnant women with obesity. *Pediatr Obes* **16**, e12725.
81. Phelan S (2010) Pregnancy: a 'teachable moment' for weight control and obesity prevention. *Am J Obstet Gynecol* **202**, e131–e135. e138.
82. Deputy NP, Sharma AJ, Kim SY *et al.* (2015) Prevalence and characteristics associated with gestational weight gain adequacy. *Obstet Gynecol* **125**, 773–781.
83. Dalrymple KV, Flynn AC, Relph SA *et al.* (2018) Lifestyle interventions in overweight and obese pregnant or postpartum women for postpartum weight management: a systematic review of the literature. *Nutrients* **10**, 1074.
84. Lim S, O'Reilly S, Behrens H *et al.* (2015) Effective strategies for weight loss in post-partum women: a systematic review and meta-analysis. *Obes Rev* **16**, 972–987.
85. Dodd JM, Deussen AR, O'Brien CM *et al.* (2018) Targeting the postpartum period to promote weight loss: a systematic review and meta-analysis. *Nutr Rev* **76**, 639–654.
86. Lim S, Liang X, Hill B *et al.* (2019) A systematic review and meta-analysis of intervention characteristics in postpartum weight management using the TIDieR framework: a summary of evidence to inform implementation. *Obes Rev* **20**, 1045–1056.

https://doi.org/10.1017/S002966512300006X Published online by Cambridge University Press

87. Perri MG, Nezu AM, Patti ET *et al.* (1989) Effect of length of treatment on weight loss. *J Consult Clin Psychol* **57**, 450–452.
88. American College of Cardiology/American Heart Association Task Force on Practice Guidelines OEP, 2013 (2014) Executive summary: guidelines (2013) for the management of overweight and obesity in adults: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines and the Obesity Society published by the Obesity Society and American College of Cardiology/American Heart Association Task Force on Practice Guidelines. Based on a systematic review from the The obesity expert panel, 2013. *Obesity* **22**(Suppl. 2), S5–39.
89. Sha T, Cheng G, Li C *et al.* (2019) Patterns of women's postpartum weight retention and Its associations with maternal obesity-related factors and parity. *Int J Environ Res Public Health* **16**, 4510.
90. Rogozinska E, Marlin N, Jackson L *et al.* (2017) Effects of antenatal diet and physical activity on maternal and fetal outcomes: individual patient data meta-analysis and health economic evaluation. *Health Technol Assess* **21**, 1–158.
91. Dodd JM, Turnbull D, McPhee AJ *et al.* (2014) Antenatal lifestyle advice for women who are overweight or obese: LIMIT randomised trial. *BMJ* **348**, g1285.
92. Dodd JM, Ahmed S, Karnon J *et al.* (2015) The cost-effectiveness of providing antenatal lifestyle advice for women who are overweight or obese: the LIMIT randomised trial. *BMC Obesity* **2**, 14.
93. Hagberg LA, Brekke HK, Bertz F *et al.* (2014) Cost-utility analysis of a randomized controlled weight loss trial among lactating overweight/obese women. *BMC Public Health* **14**, 38.
94. Hagberg L, Winkvist A, Brekke HK *et al.* (2019) Cost-effectiveness and quality of life of a diet intervention postpartum: 2-year results from a randomized controlled trial. *BMC Public Health* **19**, 38.
95. Cobiac L, Vos T & Veerman L (2010) Cost-effectiveness of weight watchers and the lighten up to a healthy lifestyle program. *Aust N Z J Public Health* **34**, 240–247.
96. White M, Adams J & Heywood P (2009) How and why do interventions that increase health overall widen inequalities within populations. *Soc Inequality Public Health* **65**, 82.
97. Craigie AM, Macleod M, Barton KL *et al.* (2011) Supporting postpartum weight loss in women living in deprived communities: design implications for a randomised control trial. *Eur J Clin Nutr* **65**, 952–958.
98. George GC, Hanss-Nuss H, Milani TJ *et al.* (2005) Food choices of low-income women during pregnancy and postpartum. *J Am Diet Assoc* **105**, 899–907.
99. Evans WD, Harrington C, Patchen L *et al.* (2019) Design of a novel digital intervention to promote healthy weight management among postpartum African American women. *Contemp Clin Trials Commun* **16**, 100460.
100. McGirr C, Rooney C, Gallagher D *et al.* (2020) Text messaging to help women with overweight or obesity lose weight after childbirth: the intervention adaptation and SMS feasibility RCT: NIHR Journals Library, Southampton (UK).
101. Colleran HL & Lovelady CA (2012) Use of MyPyramid menu planner for moms in a weight-loss intervention during lactation. *J Acad Nutr Diet* **112**, 553–558.