**Prevention of gestational diabetes: the role of dietary intake, physical activity and weight before, during and between pregnancies**

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**Abstract**

Gestational diabetes mellitus (GDM) is the most common complication of pregnancy and a significant clinical and public health problem with lifelong and intergenerational adverse health consequences for mothers and their offspring. The pre-conception, early pregnancy and inter-conception periods represent opportune windows to engage women in preventive and health promotion interventions. This review provides an overview of findings from observational and intervention studies on the role of diet, physical activity and weight (change) during these periods in the primary prevention of GDM. Current evidence suggests that supporting women to increase physical activity and achieve appropriate weight gain during early pregnancy, and enabling women to optimize their weight and health behaviors prior to and between pregnancies, have the potential to reduce rates of GDM. Translation of current evidence into practice requires further development and evaluation of co-designed interventions across community, health service and policy levels to determine how women can be reached and supported to optimize their health behaviors before, during and between pregnancies to reduce GDM risk.

**Keywords**: Prevention; Gestational diabetes; Diet; Physical activity; Weight; Review

Gestational diabetes mellitus (GDM) is a metabolic disorder defined as new onset of hyperglycemia during pregnancy which resolves after birth.1 It is the most common complication of pregnancy, and a growing health concern. There is no uniform global consensus on the screening, timing and criteria for GDM diagnosis, and the prevalence therefore varies largely between regions ranging from a median of 6.1% in Europe to 15.2% in the Middle East and North Africa.2 Regardless of diagnostic guidelines, the prevalence of GDM is increasing worldwide due to increases in maternal age, obesity, and associated risk factors.3-6

Appropriate treatment and management of hyperglycemia has been shown to reduce the risks of short-term adverse maternal and fetal outcomes, however, GDM remains independently associated with higher rates of emergency caesarean section, neonatal unit admission, and cost of care.7 Following pregnancy, women are at a nearly 10-fold increased risk of developing type 2 diabetes8 and a 2-fold higher risk of cardiovascular events9, and their offspring may be more likely to develop obesity and other cardiometabolic risk factors.10-12 The significant burden on immediate and life-long maternal and offspring health highlights the need for strategies that contribute to prevention of GDM.

In this narrative review, we summarize the current evidence on the role of diet, physical activity and weight in the primary prevention of GDM. Dietary factors evaluated include selected nutrients, food groups, dietary patterns and supplements. Diet, physical activity and weight (including weight change) are discussed as independent risk factors and stand-alone interventions, as well as combined in complex interventions. Evidence from observational and intervention studies among women before pregnancy (pre-conception), during pregnancy, and between pregnancies (inter-conception) is evaluated, and barriers and facilitators towards translation of evidence into practice are discussed. Finally, we outline areas requiring further research.

**The role of antenatal diet, physical activity and weight in the prevention of gestational diabetes**

***Epidemiological evidence***

Dietary factors

A number of antenatal dietary factors may influence GDM risk. A 2015 systematic review of observational studies identified a small number of prospective cohort studies, which showed associations with a higher risk of developing GDM for total fat (replacing 1-5% of energy from carbohydrates with fat beyond the recommended fat intake of 35% of total daily energy intake), cholesterol intake beyond the recommended intake ≥300 mg/day, and heme iron intake ≥1.1 mg/day.13 A small body of evidence on glycemic index, glycemic load and dietary fiber intake in early pregnancy in relation with GDM risk is inconsistent and most studies suggest no association.14-17 Vitamin D status has received more attention, and a meta-analysis summarizing evidence from 10 observational studies has found that low maternal concentrations of 25(OH)D during early pregnancy were associated with a higher risk of GDM (odds ratio (OR) 1.49, 95% CI 1.18-1.89).18 However, it remains unclear if higher early pregnancy vitamin D intake from foods or supplements is associated with GDM risk.

In terms of food intake, higher consumption of red and processed meat, and consumption of seven or more eggs per week, were associated with higher risk of developing GDM based on a limited number of prospective cohort and case-control studies.13, 19 Findings on relationships between dietary patterns and GDM are inconsistent. Some prospective cohort studies show no associations between *a priori* defined dietary patterns20 or *a posteriori* or data-driven identified dietary patterns16 and GDM risk. In contrast, a cross-sectional study among 253 US pregnant women found dietary patterns reflecting high consumption of refined grains, fat, added sugars and low intake of fruits and vegetables were associated with higher odds of GDM21 and another prospective study among 1,076 pregnant women from 10 Mediterranean countries found an inverse association between higher adherence to the Mediterranean Diet Index and lower risk of GDM.22

Collectively, evidence on associations of nutrient and food intake and dietary patterns with GDM risk is limited, and based on a small number of high quality studies conducted among predominantly Caucasian pregnant populations. Therefore, no specific conclusions can be drawn on the role of early pregnancy dietary factors in the prevention of GDM.2, 23

Physical activity

Physical activity has consistently been found to be associated with lower GDM risk.17, 24 A 2011 meta-analysis among >4,000 pregnant women demonstrated that total recreational physical activity in early pregnancy was associated with a 24% lower odds of developing GDM (OR 0.76, 95% CI 0.70-0.83; 5 studies).24 Evidence on associations for types of activities is less clear. Early pregnancy longer walking duration or distance (OR 0.77, 95% CI 0.51-1.16; 2 studies) and participation in vigorous activity (OR 0.55, 95% CI 0.21-1.43; 2 studies) may lower GDM risk. These findings were confirmed in a more recent meta-analysis, including studies published up to 2017.17 Compared to women who did not engage in any physical activity during early pregnancy, women who engaged in any type of physical activity (OR 0.79, 95% CI 0.64-0.97; 8 studies) or in any leisure time physical activity (OR 0.69, 95% CI 0.50-0.96; 5 studies) were consistently found to be less likely to develop GDM.17 Meta-analyses of studies examining duration, intensity, frequency and type of physical activity were not possible, however, evidence from both meta-analyses demonstrates that higher levels of physical activity may lower GDM risk and that any compared with no physical activity may be beneficial.17, 24

Gestational weight gain

Excessive gestational weight gain (GWG) is a known risk factor for GDM.25-28 Current guidelines for GWG include weekly GWG goals according to pre-pregnancy BMI, and were informed by evidence of associations between GWG and key maternal and infant outcomes including GDM.29 Over the past decade, adherence to GWG guidelines has been extensively studied with findings demonstrating that weight gain above the recommendations is associated with higher GDM risk30, in particular early weight gain in the first trimester.27, 28

Studies have also explored the possible benefits of weight loss during pregnancy among women with overweight (BMI 25-29.9 kg/m2) or obesity (BMI ≥30 kg/m2). A 2015 meta-analysis showed that weight loss during pregnancy for women with obesity was associated with lower risks of large-for-gestational-age infants, macrosomia and caesarean birth, but also with a higher risk of small-for-gestational-age infants and low birth weight.31 Weight loss among women with obesity was not associated with GDM.31 While weight loss in pregnancy is not currently recommended given the increased risks for the infant, many clinicians aim for weight stability in women with obesity to improve pregnancy outcomes including GDM.2, 32

***Antenatal diet and physical activity interventions***

Based on the established relationship with GDM for excessive GWG, and some evidence for dietary factors and physical activity independent of GWG, antenatal randomized controlled trials (RCTs) have tested the effects of interventions using various diets, increased physical activity and behavior change techniques on improving maternal and perinatal outcomes. There have been at least 12 meta-analyses published in the past five years summarizing results from these RCTs which compare an antenatal lifestyle intervention with standard antenatal care (**Table 1**). Findings point towards a beneficial effect, but have not consistently shown reductions in GDM risk (**Figure 1**). This may, in part, be explained by the diversity of RCTs in terms of i) populations included (women with or without a combination of pre-existing risk factors), ii) intervention approaches used (different behavior change techniques, online and/or in-person intervention delivery, and targeting different dietary factors and/or physical activity goals), and iii) timing of the intervention during early, mid or late pregnancy. For better comparison of RCTs, stratified analysis that group interventions based on specific characteristics (such as pre-pregnancy BMI, ethnicity and maternal age) have been conducted, however, there is no evidence that effects differ across subgroups of women.33 When RCTs are grouped according to timing of the intervention, meta-analysis suggests lifestyle modification (diet and/or physical activity) initiated ≤15 weeks’ gestation may reduce GDM risk (relative risk (RR) 0.78, 95% CI 0.64-0.96; 20 RCTs), whereas interventions commencing after 15 weeks’ gestation may not (RR 0.97, 95% CI 0.82-1.13; 8 RCTs).34 Initiation time of the intervention was also found to be a significant predictor of intervention effect based on meta-regression results of 47 RCTs.35

Findings on the effectiveness of diet-based compared with physical activity-based interventions are mixed. While two recent meta-analyses suggest physical activity-based interventions may be most effective,33, 36 other meta-analyses have not confirmed this.35, 37 Meta-analyses by Davenport et al and Guo et al have estimated that a 25% reduction in the odds of developing GDM can be achieved by accumulating at least 140 minutes and 100-120 minutes/week of moderate-intensity exercise (such as brisk walking, water aerobics, stationary cycling or resistance training), respectively.35, 36 Findings from an individual participant data (IPD) meta-analysis, which included published and unpublished results, showed an overall beneficial effect of diet and physical activity-based interventions on GDM risk (OR 0.76, 95% CI 0.65-0.89; 59 studies)33. When separating types of interventions, physical activity-based but not diet-based or combined diet and physical activity interventions were effective in reducing GDM risk33 (Figure 1).

**The role of diet, physical activity and weight before and between pregnancies in the prevention of gestational diabetes**

The recognition that modifying diet, physical activity and weight after women enter into antenatal care is challenging and may lead to only modest reductions in GDM risk has identified the need for a new approach. The periods before and between pregnancies and the first weeks of pregnancy before a woman knows she is pregnant are critical for optimizing gamete function, early placentation and embryonic development,38 and an opportunity to optimize health behaviors and weight to ensure women enter pregnancy as healthy as possible.

***Epidemiological evidence***

Pre-conception dietary intake

Large prospective cohort studies following women from before to during pregnancy have identified various dietary factors associated with GDM risk. Potentially harmful factors include higher consumption of heme iron,19, 39, 40 animal fat,41 animal protein,42 sugar sweetened beverages,43 red and processed meat,19, 42, 44 and fast food.45, 46 Moreover, a Western style dietary pattern (high in red and processed meat, refined grains, and sweet and savory snacks), a diet relatively low in carbohydrates and high in (animal) fat and protein,47, 48 and a diet characterized by poor micronutrient adequacy49 are associated with higher risk of GDM.44, 50, 51 Dietary factors that have been associated with lower risk of GDM include higher consumption of dietary fiber,47, 52 nuts,42 higher adherence to the Alternate Healthy Eating Index (AHEI-2010),53, 54 and a Mediterranean-style dietary pattern.22, 50, 53

These associations have been observed independent of pre-pregnancy BMI. Among over 3,000 Australian women, the relationship between a pre-conception Mediterranean-style dietary pattern and GDM was only partly mediated by pre-pregnancy BMI, suggesting pre-conception diet quality is important in addition to BMI.55

Pre-conception physical activity

Higher levels of physical activity before pregnancy were associated with lower GDM risk based on two meta-analyses.17, 24 Women in the highest quantiles for total recreational physical activity compared with those in the lowest had a 55% lower risk of developing GDM (OR 0.45, 95% CI 0.28-0.75; 7 studies).24 There was also an inverse association between participation in vigorous activity compared with no vigorous activity before pregnancy (OR 0.47, 95% CI 0.19-0.75).24 Similarly, in a more recent meta-analysis, lower GDM risk was observed for women engaging in any type of physical activity compared to none (OR 0.70, 95% CI 0.57-0.85; 11 studies) and for taking part in any leisure time physical activity compared to none before pregnancy (OR 0.65, 95% CI 0.43-1.00; 10 studies).17 These associations for pre-conception physical activity were stronger than associations for physical activity in early pregnancy described previously.17, 24

Pre-conception weight and weight change

Maternal obesity is the most significant risk factor for GDM. Compared with women with a normal weight (BMI 18.5-24.9 kg/m2), women with obesity have a 4-9 times higher GDM risk, and the risk of GDM increases with increasing BMI.56 A study among over 66,500 pregnancies in Canada showed that more than half (57%) of GDM cases could be prevented if all women with overweight or obesity had a normal weight.57 Moreover, 33% and 15% of GDM cases could be prevented if women with overweight or obesity would shift down one BMI class or lose 10% of body weight, respectively.57

 Several observational studies have shown that pre-conception weight change may influence the risk of GDM. Two prospective cohort studies found that weight gain between adolescence and adulthood,58 and in the years leading up to pregnancy,59 were associated with higher GDM risk. Importantly, this increased risk was observed among women with overweight or obesity but also among women who gained weight within the normal weight range.59 Weight loss was observed among only a small number of women and was not associated with GDM risk.58, 59 In a larger population-based cohort study in Canada (n = 226,958), a 10% lower pre-pregnancy BMI was associated with a meaningful lower GDM risk of at least 10%.60 Moreover, women with obesity who had undergone bariatric surgery had a significantly lower risk of GDM based on a meta-analysis of nine studies (OR 0.31, 95% CI 0.15-0.65), however, these women also had a higher odds of small-for-gestational-age infants.61 Although bariatric surgery may be effective for weight loss, after surgery women are often diagnosed with nutrient deficiencies, and further research is needed to determine if this is an appropriate preventive strategy for GDM.62

In addition to weight loss prior to a first pregnancy, the inter-conception period may be an opportunity to promote weight loss when women are in relatively intensive contact with health and care professionals with their first child. Meta-analyses have shown that weight gain between pregnancies is associated with a higher GDM risk in a subsequent pregnancy, and that inter-conception weight loss of >1 BMI unit may lower the risk of GDM by 20-25% although pooled results did not reach statistical significance.63-65 A recent study among 2,763 women with GDM in their first pregnancy has also shown that inter-conception weight loss of >1 BMI unit may reduce the risk of GDM recurrence among women with overweight or obesity.66

Poor health behaviors often co-occur, and findings from the Nurses’ Health Study II have demonstrated that if women are able to optimize multiple health behaviors, including consuming a healthy diet (top two quintiles of the AHEI-2010 score), exercising for ≥30 minutes/day, not smoking and maintaining a BMI <25 kg/m2, more than 45% of GDM cases could be prevented.67

***Pre- and inter-conception interventions***

Despite the compelling evidence from epidemiological studies that pre-conception weight change, better diet quality and higher physical activity levels are associated with a lower risk of developing GDM, evidence from intervention studies is currently limited. Pre-conception health interventions among couples contemplating pregnancy, including face-to-face, online and combined approaches, have shown that women and men had higher fruit and vegetable intake, women were more likely to take a folic acid supplement and less likely to consume alcohol and use tobacco by the end of the intervention of at least 6 months.68, 69 Moreover, RCTs have shown potential to improve women’s pre-conception health knowledge, motivations and intentions,70, 71 however, the clinical relevance of these findings remain unclear, and further follow-up is needed to determine effects on maternal and offspring outcomes in pregnancy and beyond.72 Several high-quality pre- and inter-conception trials are currently underway with primary aims to optimize GWG73, maintain healthy maternal glucose metabolism,74 and reduce risk of GDM (as part of a composite outcome).75 Findings from these studies will reveal if interventions result in uptake of pre-conception care, adherence to health behaviors, and effects on clinically relevant outcomes.

Despite the current lack of high-quality evidence from RCTs on the effects of pre- and inter-conception care on pregnancy outcomes, supporting women to optimize their health behaviors will improve their health status irrespective of a future pregnancy. Health care providers in regular contact with young women – such as general practitioners – are ideally placed to identify women planning pregnancy, identify poor health behaviors, and advice and support women to optimize their dietary intake, physical activity and weight. Moreover, during the postpartum or inter-conception period, healthcare providers – including pediatricians, maternal and child health nurses and health visitors – could play a role in supporting healthy behaviors and prevention of weight retention, and thereby contribute to providing continuum of care before, during and between pregnancies. Resources, such as the FIGO Nutrition Checklist, are available to healthcare practitioners to identify and address nutrition and weight issues before and during pregnancy.76, 77 A pre-conception risk assessment by health care professionals may identify women with pre-existing diabetes, and also identify women at risk of GDM.78 Risk assessment tools have shown nulliparous women at risk of GDM may be accurately identified before pregnancy based on a set of easily obtainable lifestyle and health-related characteristics,79, 80 however further research is needed to determine if pre-conception risk identification is acceptable and if model implementation followed by targeted pre-conception care reduces rates of GDM. Moreover, risk assessment among women intending to become pregnant only reaches a proportion of all women who become pregnant with approximately half of all pregnancies being unplanned.81, 82 In addition to provision of pre-conception care among women planning pregnancy, a universal approach of discussing dietary habits, risks of obesity, and potential benefits of weight loss prior to pregnancy at every contact with a healthcare practitioner is recommended.77

**Emerging and novel interventions and approaches for GDM prevention**

***Modulating the gut microbiota***

Changes to the gut microbiome may contribute to the physiological changes seen in pregnancy, including GDM.83 The ability to modulate the gut microbiota with probiotics to prevent GDM is equivocal, potentially due to protocol variations that relate to participant characteristics (e.g. history of atopy, pre-pregnancy BMI, GDM diagnostic criteria, probiotic species) and intervention delivery (with or without dietary and lifestyle counselling and modification, week of commencement).84-88 Finnish and New Zealand studies have demonstrated probiotic supplementation may reduce the risk of elevated maternal glucose concentrations (OR diet/probiotics vs control group 0.31, 95% CI 0.12-0.78; N =256)86 and the incidence of GDM (OR 0.59, 95% CI 0.32-1.08; N=212; OR 0.27, 95% CI 0.11-0.62; N=256).84, 85 However, a recent Australian study, that lacked intensive lifestyle change support, failed to reduce GDM incidence.88

***Diet approaches targeting inflammation and glycemic pathways***

Emerging research is investigating the anti-inflammatory potential for specific dietary patterns, foods and nutrients to mitigate inflammatory pathways, potentially modulating glucose tolerance vital to the pathogenesis of GDM.89 A small number of studies involving anti-inflammatory dietary patterns show promise in influencing both inflammation, and the development of GDM, including the Dietary Approaches to Stop Hypertension (DASH) diet,90 the Mediterranean diet,22 and a low dietary inflammatory index diet.91 Research into the anti-inflammatory and glucose sensitizing effects of probiotics,92, 93 polyphenols (bioactive plant compounds),94, 95 and vitamins and minerals including selenium and zinc,96, 97 is limited by the lack of scaled, high-quality clinical trials to validate their use in GDM prevention.

***Types of physical activity***

Yoga, high-intensity interval training (HIIT) and aquatic exercise are novel physical activity approaches that provide wide-ranging health benefits during pregnancy. Preliminary evidence suggests these therapies can improve maternal glucose metabolism98-101 and GWG,102 and reduce the incidence of GDM.100, 103 While further high-quality evidence from RCTs is needed, these types of physical activity, in conjunction with traditional physical activity modes (i.e. resistance and aerobic training), can improve the overall health and wellbeing of pregnant women.

***Digitally delivered interventions***

The ubiquity of digital technology, with more than 5 billion people globally possessing mobile devices, offers an important means of sustaining and promoting health.104 Digitally delivered and linked health technology (smartphones, websites, text messaging, wearables, sensors) is becoming an increasingly important mode to deliver information and support self-management of health by linking geographically dispersed communities of peers and professionals.105 Opportunities exist for GDM prevention to use the pervasive and scalable nature of technology.106 The fragmentation of health systems and lack of focus on preventative health requires innovative methodological approaches,107 which digital technology can potentially offer by delivering consumer centered behavior change interventions targeting modifiable risk factors, designed to evolve with a woman’s goals, health priorities, and behaviors and life stage.

While women are embracing digitally delivered health programs and information, and see a role for it in augmenting traditional care, health professionals and organizations hold a range of views and many see technology delivered interventions as external or parallel to traditional care.108, 109 There are an increasing number of small-scale digitally delivered diet and physical activity antenatal interventions showing promise for diet and physical activity quality and GWG outcomes,110 postpartum diabetes prevention following GDM,111 management of GDM,112-114 and pre-conception care for women with diabetes,115 but a limited number in those with the primary aim of preventing GDM.116-118 Large scale, well designed, digitally delivered interventions could enable significant advances in the prevention of GDM by engaging women before, during and between pregnancies.

**Diet, physical activity and weight recommendations before, during and between pregnancies**

While there are currently no specific clinical guidelines on diet, physical activity and weight for the prevention of GDM, it is prudent for women to follow general evidence-based recommendations before, during and between pregnancies. These guidelines are in line with the evidence described previously on potential benefits of improving health behaviors for reducing GDM risk. A summary of current diet, physical activity and BMI guidelines for the general population recommended by the World Health Organization (WHO) is presented in **Figure 2**.119-121 Additional specific guidance is available for women intending to become pregnant77, 122-126 or pregnant (Figure 2).126-131

 Adherence to these guidelines among women of reproductive age is poor. The majority of women in high-income countries (50-70%), and approximately one-third of women in low-income countries, enter pregnancy with overweight or obesity.132 Moreover, a recent systematic review summarizing evidence on adherence to dietary guidelines during the pre-conception period and pregnancy found that adherence to recommendations was generally low, with <50% of women complying with recommended intakes for vegetables, grains, folate, iron, calcium and fat.133 Similarly, adherence to physical activity guidelines is low among non-pregnant women of reproductive-age134-136 and throughout all trimesters of pregnancy.137-139

Dietary and physical activity habits are often formed early in life and during sensitive periods such as adolescence, and track in adulthood.140, 141 Women with pre-conception overweight or obesity are more likely to exceed GWG guidelines,142 and poor diet quality and low level of physical activity prior to pregnancy are strong predictors of continuation of these behaviors during pregnancy.139, 143-145 While health services may focus on medical and lifestyle determinants of GDM aimed at the individual at a specific point of care, it is important to also consider the wider determinants of health behaviors across the life course. Women with poor diets, low physical activity levels and overweight or obesity may have limited choices to change their health behaviors. Financial difficulties, unemployment, mental health concerns, deprivation, stress of poverty, dangerous neighborhoods, lack of green space, pedestrian or cycling paths, and availability of cheap unhealthy foods need to be addressed through changes in structures and policies.

Collectively, this suggests that a multi-faceted life course approach is needed across individual, community and policy levels to enable women to consume a healthy diet and be physically active in line with guidelines before and into pregnancy, with the potential to reduce GDM risk.

**Barriers and facilitators of translation of research into practice**

Despite the ample evidence on the importance of health behaviors before, during and after pregnancy for the prevention of GDM, translation of evidence into guidelines, and into clinical and public health policy and practice remains inadequate. It is widely documented that the existence and dissemination of evidence alone does not change practice.146 An implementation science approach is required to facilitate this change and adoption process.147 This approach applies theories, models and frameworks in a rigorous and systematic way to guide evidence selection, to adapt knowledge to a local context, to understand barriers and enablers to its use, to select appropriate interventions to support its adoption, to monitor and evaluate outcomes, as well as to support sustained knowledge use at individual, team, organisation and system levels.148-151

As the prevention of GDM spans pre-conception, inter-conception and early pregnancy care, so too do the barriers to best practice care. In many cases, healthcare systems are fragmented, with a range of organizations and professionals involved in care with confusion about ‘ownership’ over whose role the implementation of preventive programs and advice is.152 This is a particular concern during the pre-conception period, when healthcare professionals identify the lack of awareness and knowledge of the need and effectiveness of pre-conception care, as well as the poor coordination and organization of pre-conception care within the health system, as barriers towards it’s routine implementation.149 To overcome provider and organizational barriers towards supporting women to optimize their health behaviors before conception, provision of training for healthcare providers, and multi-system efforts to integrate pre-conception care into existing health services, will be crucial.

A lack of service capacity to deliver care due to limited resources, time and a lack of knowledge or confidence from health care providers to deliver lifestyle advice are concerns globally.152-157 This capacity to deliver is further complicated by health professionals’ attitudes and perceptions about women’s ability to change behavior, or the belief that advice won’t make a difference.149

At an individual level, engagement in pre-conception care by many women poses a significant challenge for prevention opportunities. The reasons for low level of engagement are varied and may include emotions and beliefs, knowledge and experience, perception of risk and needs, social factors as well as access to care.158 The majority of women do not perceive the preconception period as a key life stage when optimal health is important, mainly due to lack of awareness of the links between health and health behaviors leading up to pregnancy and subsequent maternal and child health.158 These barriers are not isolated to the pre-conception period, and require careful consideration in service design.158 Engagement and delivery of care is also less than optimal due to the difficulty of engaging with women after a GDM-affected pregnancy due to priorities of childminding, time restrictions and other conflicting family demands,159, 160 and lack of a clear pathway for women to receive effective pre- or inter-conception care within the community/primary care setting.161

To close the existing evidence-practice gaps requires a parallel approach of influencing health practitioner and service approaches, as well as facilitating the design and delivery of appropriate interventions, programs and services for women and their families for sustained and effective change. No one implementation science approach is recommended; it must be carefully selected and applied for purpose.162 An essential step will be engaging stakeholders from the outset, including health services and those who use them, to ensure co-creation of programs and services that are meaningful, relevant, and acceptable.163

**Conclusion**

The prevention of GDM is a public health imperative to reduce the growing and intergenerational burden of diabetes. The pre- and inter-conception periods and early pregnancy are all critical time periods, providing multiple opportunities to optimize dietary intake, physical activity and weight for the prevention of GDM (**Figure 3**). Given the large proportion of women with poor health behaviors at the start of pregnancy and the limited ability to modify this during pregnancy, health behaviors need to be addressed as early as possible. Based on current evidence, health services in early pregnancy that support women to increase physically activity and achieve appropriate GWG, as well as routine pre-conception care and public health interventions that enable young women to optimize their health behaviors prior to pregnancy, have the potential to reduce rates of GDM. For this evidence to be translated into practice, further research is required to design and test innovative interventions that are co-designed with women and stakeholders to determine how women can be reached and supported to optimize their health behaviors before, during and between pregnancies to reduce GDM risk.

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**Figure legends**

**Figure 1.** Summary of pooled estimates from meta-analyses of effects of antenatal diet-based, physical activity-based, combined diet and physical activity and mixed (diet and/or physical activity) interventions on gestational diabetes risk.

Abbreviations: RCT, randomized controlled trial; RR, relative risk.

a Effects are odds ratios with 95% confidence intervals.

**Figure 2.** Summary of diet, physical activity and weight recommendationsa for women before, during and between pregnancies.

a Recommendations may differ across countries and regions, and in subgroups of women for example women at risk of vitamin D deficiency are advised to take a daily 10 mcg vitamin D supplement, women at high risk of neural tube defect are recommended to take a higher dose of 5 mg daily folic acid supplement, and contraindications for physical activity in pregnancy may include persistent bleeding, cardiovascular disease, multiple gestation, preeclampsia or pregnancy induced hypertension, premature contractions and thyroid disease.

**Figure 3**. Summary of evidence and key research gaps on the role of diet, physical activity and weight for the prevention of gestational diabetes.

Abbreviations: GDM, gestational diabetes mellitus; GWG, gestational weight gain; HIIT, high-intensity interval training; RCT, randomized controlled trial.

**Table 1.** Systematic reviews with meta-analyses and individual-patient data (IPD) meta-analyses on the effects of antenatal lifestyle interventions on gestational diabetesa

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| --- | --- | --- | --- |
| **Reference** | **Intervention(s) evaluated** | **Population/study inclusion criteria** | **Primary outcome(s) of review** |
| Guo et al, 201935 | Diet-based, physical activity-based, and combined diet and physical activity | Meta-analysis of RCTs. Studies with severely unbalanced risk factors or dropout rates were excluded. | GDM |
| Davenport et al, 201836 | Physical activity-based, and combined diet and physical activity | Meta-analysis of RCTs among pregnant women without absolute or relative contraindication to exercise. | GDM, gestational hypertension and pre-eclampsia |
| Bennett et al, 201837 | Diet-based, physical activity-based, and combined diet and physical activity | Meta-analysis of RCTs with a primary or secondary aim to reduce excessive GWG. | GDM |
| International Weight Management in Pregnancy (i-WIP) Collaborative Group, 201733 | Diet-based, physical activity-based, and combined diet and physical activity | Meta-analysis of individual participant data (IPD) of RCTs on diet and/or physical activity-based interventions in pregnancy, supplemented with similar studies that did not contribute IPD. | GWG, composite of maternal outcomes, and composite of offspring outcomes |
| Song et al, 201634 | Diet-based, physical activity-based, and combined diet and physical activity | Meta-analysis of RCTs conducted in the first or second trimester of pregnancy among women with no type 1 or 2 diabetes before pregnancy. | GDM |
| O’Brien et al, 2016164 | Mixed diet-based, physical activity-based, and/or combined diet and physical activity | Meta-analysis of RCT results from women with a normal BMI (18.5-24.9 kg/m2) and not at high-risk of GDM or large-for-gestational-age infant. | GWG |
| Gresham et al, 2016165 | Diet-based | Meta-analysis of RCTs among women with no health conditions related to dietary intake, such as pre-pregnancy diabetes. | Any maternal, neonatal or infant outcome |
| Russo et al, 2015166 | Physical activity-based | Meta-analysis RCTs. No in- or exclusion criteria reported. | GDM |
| Sanabria-Martinez et al, 2015167 | Physical activity-based | Meta-analysis of RCTs among healthy pregnant women who were sedentary or had low levels of physical activity.  | GDM and GWG |
| Bain et al, 2015168 | Combined diet and physical activity | Meta-analysis of RCTs among women with no type 1 or 2 diabetes before pregnancy. | GDM and associated health outcomes |
| Madhuvrata et al, 2015169 | Diet-based, physical activity-based, and combined diet and physical activity | Meta-analysis of RCTs among women with GDM risk factors (raised BMI, previous GDM, macrosomia, family history of diabetes, high-risk ethnic group or PCOS). | GDM |
| Rogozinska et al, 2015170 | Diet-based, and combined diet and physical activity | Meta-analysis of RCTs. No in- or exclusion criteria reported.  | GDM |

Abbreviations: GDM, gestational diabetes mellitus; GWG, gestational weight gain; PCOS, polycystic ovary syndrome; RCT, randomized controlled trial.

a Articles published between January 2015 and October 2020