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Review

Maternal dietary patterns, diet quality and micronutrient status in gestational diabetes mellitus across different economies: A review

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Abstract: Gestational diabetes mellitus (GDM) is one of the most common metabolic disorders known to develop during pregnancy. Besides obesity and sedentary lifestyles being the main predisposing factors, dietary measures play an important role in its progression too. Hence, managing GDM has become a great challenge for healthcare professionals globally. It is pertinent to establish and manage the predisposing factors for GDM. Many studies have investigated the potential dietary risk factors linked to GDM, especially dietary patterns and diet quality. While certain healthful dietary patterns incorporating wholegrain cereals, high in fruits and vegetables, low meat and saturated fats have been protective against GDM, deficiencies of micronutrients such as potassium, magnesium, and possibly zinc and chromium may predispose one to carbohydrate intolerance. The alterations in iron and zinc body stores could also affect GDM. Dietary iron, vitamin C and D are amongst the micronutrients associated with the development and prevention of diabetes in pregnant women. However, evidences on the effects of vitamins, minerals other indices of maternal diet quality on GDM are inconclusive. This review provides an overview of the emerging evidences on the role of maternal dietary patterns, diet quality and micronutrients, which may contribute in the prevention of GDM across the different economies in the world. The results will empower the healthcare professionals to prevent and manage GDM effectively.

Keywords: gestational diabetes mellitus; dietary patterns; diet quality; micronutrients

1. Introduction

Gestational diabetes mellitus (GDM) is one of the most common metabolic disorders known to develop during pregnancy. Besides obesity and sedentary lifestyles being the main predisposing factors, dietary measures play an important role in its progression too. Risk factors for gestational diabetes mellitus (GDM) are similar to type 2 diabetes mellitus (T2DM) (older age and greater adiposity) [1]. The risk factors are classified as modifiable and non- modifiable risk factors (Figure 1). The modifiable risk factors are of prime interest, as they can be reversed thereby reducing likelihood of GDM. Studies of diet-GDM relationships suggested that high intakes of red and processed meats, saturated fats, refined grains, sweets, high fat dairy and fried foods were associated with significantly elevated risks of GDM [2–4]. The variation in dietary patterns has impacted the intake of the overall nutrients with dietary micronutrients contributing to the development of GDM [5].

Therefore, it is pertinent to explore the effects of maternal dietary patterns, diet quality and the micronutrient status and/or intake with the risk of GDM to prevent adverse birth outcomes. Given the lack of existing reviews specifically focusing on dietary pattern, diet quality and maternal micronutrient status in GDM, the present paper reviews latest evidences in this area across different economies of the world.

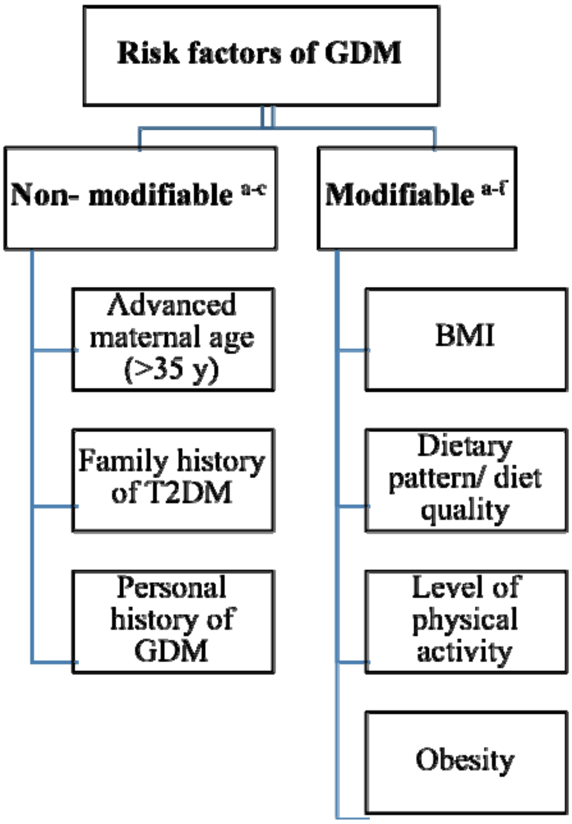

Figure 1. Risk factors of GDM. [a]Solomon, Willett, & Carey, 1997 [6]; [b]Zhang & Ning, 2011 [4]; [c]Bo et al., 2001 [7]; [d]Chu et al., 2007 [8]; [e] Saldana, Siega-Riz, & Adair, 2004 [9]; [f]Wang et al., 2000 [10].

2. Methodology

Dietary patterns and diet quality affect the nutritional status of the pregnant mothers during their physiological transition and on their birth outcomes. These factors are complex and highly diverse across different geographical locations. This paper aims to provide an update on the association between dietary patterns, diet quality and micronutrient status among mothers with GDM across the different economies of the world.

2.1. Operational definitions

2.1.1. Dietary pattern

It is defined as the quantities, proportions, variety or combination of different foods, drinks, and nutrients in diets, and the frequency with which they are habitually consumed [11].

2.1.2. Diet quality

This concept involves the assessment of both quality and variety of the entire diet, enabling examination of associations between whole foods and health status, rather than just nutrients, by scoring the food patterns [12]. However, some studies interchangeably use the terms dietary pattern and diet quality.

2.2. Search strategy

Studies published in English between 2000 and 2018 were selected. The electronic databases search included, PUBMED, Web of Science, Clinical Key, Clinical Key for Nursing, EbscoHost, Nature, Ovid, ProQuest, Science Direct, Scopus, Springer Link and Google Scholar. The key terms used in the search for relevant articles were as follows: GDM AND risk factors AND diet* patterns AND micronutrients status AND dietary intake OR Nutrient intake; Dietary patterns AND GDM AND nutrient status OR nutrient intake OR dietary intake; GDM AND diet* quality OR diet* variety OR food variety OR diet* diversity.

2.3. Search protocol

All studies identified during the database search was assessed for relevance based on the information contained in the title, abstract and description/MESH heading. Full articles were retrieved for all studies that appeared to meet the inclusion criteria and those requiring further investigation. Studies were described in terms of design, sample characteristics, measurement of dietary pattern/quality exposure or micronutrients status/intake and outcomes across high, middle and low income countries.

2.4. Study participants

This review considered any studies that included all pregnant women diagnosed with or without GDM.

2.5. Types of studies

Analytical observational studies (case-control studies, cohort studies, analytical cross-sectional studies, prospective studies) and intervention studies that evaluated the risk of developing and managing GDM were included. However, systematic reviews and other categories of review papers were excluded during the search. The studies included were further categorised into economies per capita of the country according to United Nations classifications (2014) [13] and the origin where the study was conducted.

3. Results

3.1. Overall description of included studies

The included studies are listed according to area of focus (dietary patterns or dietary quality or micronutrients) in relation to GDM (Tables 1–7). The studies were subsequently grouped by economies according to United Nations (2014) [13] classification.

Table 1. Maternal dietary pattern and/or quality and the risk of gestational diabetes mellitus in high-income countries.

High Income Country	Study	Dietary Pattern/Quality	Study Purpose	Participants' characteristics	Classification criteria of GDM	Key findings
US	Zhang et al., 2006 Prospective cohort study [14]	Dietary pattern • Prudent: High intake of fruit, green leafy vegetables, poultry and fish • Western: High intake of red meat, processed meat, refined grain products, sweets, French fries and pizza	Association between major pre-gravid dietary patterns and GDM risk	758 women with first diagnosis of GDM	Self-reported information	• Significantly and inversely associated with GDM risk after multivariate adjustment • Significantly and positively associated with GDM risk after multivariate adjustment
US	Radesky et al., 2008 Prospective cohort study [15]	Dietary pattern • Prudent: High intake of vegetables, fruit, legumes, fish, poultry, eggs, salad dressing and whole grains • Western: High intake of red and processed meats, sugar-sweetened beverages, French fries, high-fat dairy products, desserts, butter and refined grains	Association of Western dietary pattern with risk of GDM and impaired glucose tolerance (IGT)	Pregnant women at 22 weeks of gestation	Screened during 26 to 28 weeks of gestation; referred for Oral Glucose Tolerance Test (OGTT), if needed	• IGT women had lower average dietary glycaemic load and slightly higher intake of total energy, total fat, saturated fat, fibre and whole grains as that of normoglycaemic women • GDM women had a higher average n−3 fatty acid intake, lower n−6/n−3 ratio, and slightly higher polyunsaturated fat intake as compared to normoglycaemic women
Australia	Morrison et al., 2012 Cross-sectional study [16]	Diet Quality • Australian Recommended Food Score (ARFS)	Describe the diet quality of women with recent history of GDM & determine risk factors associated with GDM	1499 women with GDM ≤3 years previously	History of GDM recruited from the National Diabetes Service Scheme database	• Mean ARFS: 30.9 ± 8.1 (maximum score of 74), overall poor diet quality • Nuts/legumes, grains and fruits were the most poorly scored

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High Income Country	Study	Dietary Pattern/Quality	Study Purpose	Participants' characteristics	Classification criteria of GDM	Key findings
US	Tobias et al., 2012a Prospective cohort study [17]	Dietary pattern • Wholegrain, cereal fibre, vegetables and fruit, red and processed meats, saturated fatty acids Diet Quality • Dietary Approach to Stop Hypertension (DASH) scores • Alternate Mediterranean Diet (aMED) scores • Alternate Healthy Eating Index (aHEI)	Association between adherence to healthful dietary patterns and progression to T2DM among GDM population	4413 White women with a history of GDM in Nurses' Health Study II cohort between 1991 and 2005	Self-reported and confirmed by medical records	Dietary pattern & Diet Quality • Dietary pattern adherence scores were strongly and inversely associated with T2DM risk (after adjusting for age and total energy intake) • Compared participants with the highest adherence (quartile 4) vs lowest (quartile 1) with risk of T2DM: 1. aMED pattern, with 40% lower risk 2. DASH pattern, with 46% lower risk 3. aHEI pattern, with 57% lower risk
US	Tobias et al., 2012b Prospective cohort study [18]	Dietary pattern • Fries, high-fat dairy products, desserts, butter and refined grain Diet Quality • Dietary Approach to Stop Hypertension (DASH) scores • Alternate Mediterranean Diet (aMED) scores • Alternate Healthy Eating Index (aHEI)	Assessment of usual pre-pregnancy adherence to well-known dietary patterns and GDM risk	15254 White women with no history of GDM from the Nurses' Health Study II cohort between 1991 and 2001	Self-reported on questionnaire and confirmed by medical records	Diet Quality • All 3 scores (DASH, aMED, aHEI) were inversely associated with GDM risk after adjustment for covariables: 1. 24% lower with the aMED score 2. 34% lower with the DASH score 3. 46% lower with the aHEI score

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High Income Country	Study	Dietary Pattern/Quality	Study Purpose	Participants' characteristics	Classification criteria of GDM	Key findings
Australia	Louie et al., 2013 Randomized controlled trial [19]	Usual dietary pattern	Investigate nutritional intakes of women with GDM and compare to Australian recommendations	99 women with GDM, between 26 and 28 weeks of gestation	Screened during 26 to 28 weeks of gestation and if positive referred for OGTT	• 66%–99% of women did not meet the national recommendation value for fibre, folate, vitamin D, iodine and iron • Higher carbohydrate intake was associated with lower intake of all types of fat except LCn3PUFA, vitamin E, and zinc • Higher tertiles of grains and cereal intake predicted lower intakes of total fat, saturated fat, and polyunsaturated fat • Grain and cereal products were negatively associated with intake of riboflavin, niacin equivalents, and calcium (insignificant after adjustment with Bonferroni)
South Korea	Lim et al., 2013 Cross-sectional study [20]	Usual dietary pattern	Investigate the calorie, macronutrient, and micronutrient intake of pregnant women	125 women, diagnosed with T2DM before pregnancy or diagnosed with GDM during pregnancy but have received no proper education on dietary intakes during pregnancy	OGTT	• >90% consumed 3 meals a day, and approximately 35% consumed 3 snacks a day • Both groups consumed relatively high carbohydrate at breakfast (23.1% and 24.9%, respectively), with relatively low percentage at snacks • GDM mothers had lower proportion of carbohydrate intake at dinner than women with T2DM (27.8 ± 8.2 vs. 33.7 ± 11.1, $p = 0.043$) • Caloric intake of the GDM and T2DM groups was 86.1% and 91.4% of the recommended level respectively • Women with GDM had higher intakes of protein, fat, calcium, zinc, vitamin B1 and vitamin B2 than women with T2DM

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High Income Country	Study	Dietary Pattern/Quality	Study Purpose	Participants' characteristics	Classification criteria of GDM	Key findings
US	Ferranti et al., 2014 Cross-sectional study [21]	Diet Quality • alternate Healthy Eating Index (aHEI)	Perception of the threat of type 2 diabetes, perceived self-efficacy and benefits/barriers of healthy eating and diet quality	75 women were within 5 years of a GDM pregnancy	Not indicated	• aHEI scores indicated an average level of diet quality. None fully met the aHEI recommendations • Poorest aHEI scores included alcohol consumption and red to white meat ratio
US	Xiao et al., 2015 Cross-sectional study [22]	Diet Quality • Healthy Eating Index (HEI)	Comparison of diet quality among childbearing women with and without history of GDM	2,557 aged 20 to 44 years without GDM, live infant ≤10 years with available diet recalls in National Health and Nutrition Examination Survey (2007–2010)	Self-reported	• Women with a history of GDM had 3.4 points lower score of overall diet quality, 0.9 points lower score for consumption of green vegetables and beans • Other dietary component scores did not differ by history of GDM
Australia	Gresham et al., 2016 Prospective cohort study [23]	Diet Quality • Australian Recommended Food Score (ARFS)	Assessment of diet quality before or during pregnancy and its prediction on adverse pregnancy and birth outcomes	1907 women classified as pre-conception or pregnant in the Australian Longitudinal Study on Women's Health	Reported if diagnosed by a doctor or treated for GDM for each pregnancy	• Women with GDM had a higher score for the vegetable component only • Diet quality by quintile was not associated with GDM

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High Income Country	Study	Dietary Pattern/Quality	Study Purpose	Participants' characteristics	Classification criteria of GDM	Key findings
Finland	Meinilä et al., 2016 Intervention Study [24]	Diet Quality • Healthy Food Intake Index (HFII)	Develop and validate a food-based diet quality index for measuring adherence to the Nordic Nutrition Recommendations in a pregnant population with high risk of GDM	443 pregnant participants either obese or had a history of GDM, part of the Finnish Gestational Diabetes Prevention Study	Not indicated	• Average HFII was 10.2 (SD 2.8, range 2–17) • SFA, MUFA, PUFA, sucrose, and fibre intakes showed linearity across the HFII categories • Higher the HFII, closer is the nutrient intake to the recommended levels
Singapore	de Seymour et al., 2016 Randomized controlled trial [25]	Dietary pattern • Vegetable-fruit-rice-based-diet: High in vegetables, fruit, white rice, bread, low-fat meat and fish, and low in fried potatoes, burgers, carbonated and sugar-sweetened beverages • Seafood-noodle-based-diet: High in soup, fish and seafood products, noodles (flavoured and/or in soup), low-fat meat, and seafood, and low in ethnic bread, legumes and pulses, white rice, and curry-based gravies • Pasta-cheese-processed-meat-diet: High in pasta, cheese, processed meats, tomato-based and cream-based gravies	Determine cross-sectional relationship between maternal dietary patterns during pregnancy and the risk of GDM in a multi-ethnic Asian cohort	909 women with 160 of them as GDM	OGTT (26–28 weeks' gestation)	• Significant association between the reported consumption of a seafood-noodle based-diet during pregnancy, and a lower risk of GDM • Consumption of the vegetable-fruit-rice-based diet was linearly associated with reduced fasting blood glucose • Seafood-noodle-based-diet consumption showed a marginal negative linear association with blood glucose levels following an OGTT (75 g glucose load)

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High Income Country	Study	Dietary Pattern/Quality	Study Purpose	Participants' characteristics	Classification criteria of GDM	Key findings
US	Gicevic et al., 2018 Prospective cohort study [26]	Diet Quality • Dietary diversity scores (DDS): - Food Groups Index (FGI) - Minimum Dietary Diversity-Women (MDD-W) • Diet quality index: - Alternate Healthy Eating Index (AHEI-2010) - Prime Diet Quality Score (PDQS)	Examine the associations between dietary diversity scores and dietary quality scores with risks of GDM	21,312 women without major chronic disease or GDM/HDPs from the Nurses' Health Study II cohort between 1991 and 2001	Self-reported and confirmed by medical records	• MDD-W and FGI were not associated with risk of GDM • AHEI-2010 and PDQS were associated with a lower risk of GDM • RR's of GDM comparing the highest vs. lowest quintiles were: 1. MDD-W: 1.00 2. FGI: 0.96 3. AHEI-2010: 0.63 4. PDQS: 0.68

Table 2. Maternal dietary pattern and/or quality and the risk of gestational diabetes mellitus in upper middle-income country.

Upper Middle Income Country	Study	Dietary Pattern/Quality	Study Purpose	Participants' characteristics	Classification criteria of GDM	Key findings
Brazil	Nascimento et al., 2016 Prospective cohort study [27]	Dietary pattern • Traditional pattern: Dairy products, fruits, vegetable and fish • Mixed pattern included fried food, pizza, juice, manioc flour, red meat and candies • Western pattern: Eggs, white bread, cookies, pasta, pizza, fried food, chicken, candies, chocolate, salty snacks and soft drinks	Examine association between dietary patterns and GDM	841 pregnant women from the 15th–20th gestational week until delivery, singleton pregnancy	• IADPSG criteria	• No differences among GDM incidence according to three dietary patterns • Eating patterns studied during early pregnancy were not associated to the development of GDM
Iran	Izadi et al., 2016 Case control study [28]	Diet Quality • Dietary Approach to Stop Hypertension (DASH) scores • Mediterranean Diet (MED) scores	Assessment of risk for GDM across tertiles of DASH and MED scores	200 GDM and 260 healthy pregnant women	GDM defined as fasting glucose >95 mg/dL or 1-h postprandial glucose > 140 mg/dL	• Participants in the highest tertile of the MED diet had 80% lower risk for GDM compared with those in the lowest tertile ($p < 0.006$) • Greater adherence to the DASH eating plan was associated with 71% reduced risk for GDM ($p < 0.006$)

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Upper Middle Income Country	Study	Dietary Pattern/Quality	Study Purpose	Participants' characteristics	Classification criteria of GDM	Key findings
Iran	Sedaghat et al., 2017 Case control study [29]	Dietary pattern • Western: Sweet snacks, jam and tinned fruits, mayonnaise, sugar-sweetened beverages, salty snacks, solid fats, high-fat dairy, potatoes, organ meats, eggs, red and processed meat, and tea and coffee • Prudent: Liquid oils, legumes, nuts and seeds, fruits and dried fruits, fish and poultry whole, and refined grains	Association between pre-pregnancy dietary patterns and risk of GDM	123 GDM and 268 healthy pregnant women aged 18–40 years, screened between 24th and 28th weeks of gestation	Carpenter and Coustan criteria	• Risk of developing GDM among women in the second median of Western dietary pattern scores was higher compared to the first median (OR = 1.97, 95% CI: 1.27–3.04) • After adjusting for pre-pregnancy weight, gestational age, physical activity, family history of diabetes, housing ownership, and building area, the association was still significant (OR = 1.68, 95% CI: 1.04–2.27) • No significant association was found between Prudent dietary pattern scores and risk of GDM
Iran	Zareei et al., 2018 Case control study [30]	Dietary pattern • Unhealthy: High intake of mayonnaise, soda, pizza and sugar • Healthy: High intake of leafy green vegetables, fruits, poultry and fish	Comparison of dietary pattern among women with or without a history of GDM	Pregnant women (104 case and 104 control)	Glucose challenge test (GCT) during 24–28th weeks of pregnancy for all pregnant mothers	• Unhealthy: After modifying the effect of confounding variables, a significant relationship was observed between dietary pattern and having gestational diabetes (OR = 2.838, 95% CI: 1.039–7.751) • Healthy group: Participants in fourth quartile had 149% and 184% higher chance not developing GDM before and after modification with confounders, respectively (OR = 0.284, 95% CI: 0.096–0.838), when compared with those in first quartile

Table 3. Maternal dietary pattern and/or quality and the risk of gestational diabetes mellitus in lower middle-income country.

Lower Middle Income Country	Study	Dietary Pattern/Quality	Study Purpose	Participants' characteristics	Classification criteria of GDM	Key findings
India	Sahariah et al., 2016 Non-blinded, randomized controlled trial [31]	Dietary pattern • Diet supplemented with a daily snack made from leafy green vegetables, fruit, and milk, (from preconception through pregnancy) • Control of snacks made from low-micronutrient vegetables such as potato and onion	Determine whether increasing women's dietary intake of leafy green vegetables, fruit, and milk before conception and throughout pregnancy reduced their risk of GDM	6513, aged < 40 y, married, not pregnant, not sterilized, planning to have more children, and intending to deliver in Mumbai	OGTT (28–32 weeks' gestation)	• Prevalence of GDM was reduced in treatment group (7.3% compared with 12.4% in controls; OR: 0.56; 95% CI: 0.36, 0.86; p = 0.008) • Reduction in GDM remained significant after adjusting for pre-pregnancy adiposity and fat or weight gain during pregnancy

Table 4. Maternal micronutrients intake and/or status and the risk of gestational diabetes mellitus in high-income countries.

High Income Country	Study	Micronutrient (s)	Study Purpose	Participants' characteristics	Classification criteria of GDM	Key findings
Hong Kong	Lao, Chan, & Tam, 2001 Prospective cohort study [32]	Fe	Association of non-anaemic GDM diagnosed in third trimester and their Fe stores compared with matched non-GDM controls.	401 pregnant women: 97 with GDM,194 normal pregnant	World Health Organization criteria	• Increased Fe stores and glucose intolerance at third trimester in non-anaemic women
Hong Kong	Lao & Ho, 2004 Retrospective case control study [33]	Fe	Association between Fe deficiency anaemia and GDM.	726 pregnant women; 242 with Fe deficiency anaemia, 484 non-anaemic	World Health Organization criteria	• GDM was inversely correlated with the severity and duration of anaemia (p = 0.045)
Hong Kong	Chan et al., 2009 Randomized placebo controlled trail [34]	Fe	Fe supplement from early pregnancy and the risk of GDM.	1164 singleton pregnancy, <16 weeks of gestation; 565 receive 300mg/day of $FeSO_4$ (60mg of Fe), 599 women on placebo for 16 weeks	World Health Organization criteria	• No significant difference in the incidence of GDM in the Fe supplement and placebo groups • Fe supplement from early pregnancy does not increase the risk of GDM
Italy	Bo et al., 2009 Case control study [35]	Fe	Association between Fe supplementation during mid-pregnancy and metabolic abnormalities.	500 GDM and 500 normoglycaemic Caucasian women	Carpenter and Coustan criteria	• Fe supplement users showed significant higher prevalence of GDM • Glucose values in OGTT test were significantly higher in Fe supplemented women, both in GDM and normoglycaemic individuals

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High Income Country	Study	Micronutrient (s)	Study Purpose	Participants' characteristics	Classification criteria of GDM	Key findings
USA	Bowers et al., 2011 Prospective cohort study [36]	Fe	Association of pre-pregnancy dietary and supplemental Fe intakes with GDM risk.	13475 singleton pregnancy between 1991–2001 in the Nurses' Health Study II	Self-reported information validated against medical records	• 867 incidents of GDM • Higher pre-pregnancy dietary heme Fe intake was significant and positively associated with GDM risk (*p* for linear trend = 0.0001, RR = 1.22 with every 0.5mg per day of increase intake) • No significant associations between total dietary, non-heme or supplemental Fe intake with GDM risk
USA	Qiu et al., 2011 Prospective cohort study [37]	Fe	Association of maternal pre-conceptional and early pregnancy heme and non-heme Fe intake and subsequent GDM risk.	3,158 pregnant women began prenatal care before 20 weeks gestation	American Diabetes Association guideline	• Approximately 5% of the women developed GDM • GDM risk increased with increasing levels of heme Fe (*p* for trend = 0.04) • GDM risk reduced with increasing non-heme Fe intake (*p* for trend = 0.08)
Finland	Helin et al., 2012 Prospective cohort study [38]	Fe	Association between total daily Fe intake during pregnancy, haemoglobin in early pregnancy and the risk of GDM in women at increased risk of GDM.	399 pregnant women at increased risk of GDM; 219 in intervention group, 180 in usual care group	Fasting blood glucose ≥5.3 mmol/l, >10.0 mmol/l at 1 h or >8.6 mmol/l at 2 h	• 18.1% of the women developed GDM • High Fe intake during pregnancy increases the risk of GDM, especially in women who are not anaemic and at increased risk of GDM (OR = 2.35, *p* = 0.023).

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High Income Country	Study	Micronutrient (s)	Study Purpose	Participants' characteristics	Classification criteria of GDM	Key findings
USA	Darling, Mitchell, & Werler, 2016 Retrospective cohort study [39]	Fe	Impact of pre-conceptional heme and non-heme Fe on GDM.	7229 participants enrolled in the Slone Epidemiology Center Birth Defects study between 1998 and 2008	Self-reported	• Pre-conceptional dietary heme Fe was modestly associated with an elevated risk of GDM (OR = 1.55) • Pre-conceptional dietary non-heme Fe was associated with a decreased risk of GDM (OR = 0.48) • Women who consumed iron supplement during preconception had a decreased risk of GDM (OR = 0.78)
Italy	Bo et al., 2005 Cohort study [40]	Zn, Se, antioxidant vitamins	Comparison of dietary intake of antioxidant vitamins, Zn, Se and serum levels of Zn and Se in gestational hyperglycaemia and normoglycaemia.	FFQ: 210 gestational hyperglycaemia and 294 normoglycaemia pregnant women Serum Zn and Se: 71 gestational hyperglycaemia and 123 normoglycaemia pregnant women	Carpenter and Coustan criteria	• Dietary intakes of Zn and Se were significantly lower and negatively associated with gestational hyperglycaemic group (OR Zn = 0.89, OR Se = 0.97) • No significant differences in vitamin intakes • Serum Zn and Se were significantly lower and negatively associated with gestational impaired glucose tolerance (OR Zn = 0.93, OR Se = 0.92)
Saudi Arabia	Nabouli et al., 2016 Prospective cohort study [41]	Mg	Comparison of total Mg between GDM and normal pregnant women.	99 pregnant women in 24–28 weeks of gestation	American Diabetes Association guideline	• Prevalence of GDM is 19.2% • Serum Mg concentration of GDM women was lower than normal pregnant women but not significant

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High Income Country	Study	Micronutrient (s)	Study Purpose	Participants' characteristics	Classification criteria of GDM	Key findings
USA	Zhang et al., 2008 Nested case control study [42]	Vitamin D	Association between maternal plasma 25-[OH] D concentrations in early pregnancy and the risk for GDM.	953 pregnant women were enrolled under prenatal care before 20 weeks gestation	American Diabetes Association guideline	• Approximately 6.0% of the women developed GDM • Maternal plasma 25-[OH] D were significantly lower (3.62 ng/ml lower) among women who developed GDM (*p* = 0.018)
UK	Makgoba et al., 2011 Case control study [43]	Vitamin D	Association between 1st trimester serum levels of 25-hydroxy vitamin D (25-OH-D) and development of GDM.	248 women in the 1st trimester of pregnancy; 90 GDM, 158 normoglycaemic	World Health Organization criteria	• Negative correlation between 1st trimester 25-OH-D and OGTT test (*p* < 0.05) • No significant differences in the mean of 25-OH-D levels and subsequent development of GDM
USA	Baker et al., 2012 Nested case control study [44]	Vitamin D	1st trimester vitamin D deficiency and the prevalence of GDM	60 GDM and 120 controls	National Diabetes Data Group criteria	• Vitamin D deficiency was not associated with GDM
USA	Burris et al., 2012 Prospective cohort study [45]	Vitamin D	Association of 2nd trimester plasma 25-OH-D with GDM.	1314 pregnant women participated in Project Viva, a birth cohort study	American Diabetes Association guideline	• Low 25-OH-D levels (<25 nmol/L) have higher OR of GDM (OR = 2.2) • Inverse association between 2nd trimester 25-OH-D and OGTT test (*p* < 0.01)

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High Income Country	Study	Micronutrient (s)	Study Purpose	Participants' characteristics	Classification criteria of GDM	Key findings
UK	Whitelaw et al., 2014 Cross sectional study [46]	Vitamin D, Ca	Association of Ca and 25-OH-D with GDM in European and South Asian women.	1467 women at 26 weeks of gestation	World Health Organization criteria	• Prevalence of GDM is 9.3% • Weak inverse association between 25-OH-D and fasting plasma glucose • Weak association between PTH and fasting plasma glucose • Serum Ca was strongly associated with fasting insulin, post-challenge glucose and GDM
USA	Arnold et al., 2015 Nested case-cohort study [47]	Vitamin D	Association of vitamin D status with GDM.	135 GDM and 517 non-GDM controls	American Diabetes Association guideline	• GDM has lower mean total 25-OH-D and 25-OH-D_3 ($p < 0.05$) • Significant association between 25-OH-D_3 and GDM risk • A 5 ng/ml increase in 25-OH-D_3 concentration was associated with a 14% decrease in GDM risk ($p = 0.02$) • Women in the lowest quartile for 25-OH-D_3 concentration had a 2-fold higher risk of GDM (p for trend <0.05)
Israel	Wolak et al., 2010 Retrospective population-based study [48]	K	Association between K level during the beginning pregnancy and the development of GDM.	8114 registered births in Soroka University Medical Center between the years of 2001 to 2007	Fourth International Workshop-Conference on GDM	• A significant linear association between K level in the first half of pregnancy and the prevalence of GDM in the second half of the pregnancy ($p = 0.008$) • K level was an independent risk factor for GDM

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High Income Country	Study	Micronutrient (s)	Study Purpose	Participants' characteristics	Classification criteria of GDM	Key findings
Israel	Wolak et al., 2016 Case control study [49]	K	Effect of high K levels during pregnancy on the risk factors for atherosclerotic morbidity.	21419 registered births in Soroka University Medical Center between the years of 2001 to 2012	Fourth International Workshop-Conference on GDM	• High K level during pregnancy had a significantly higher rate of GDM
Australia	Gunton et al., 2001 Prospective cohort study [50]	Cr	Association of plasma Cr with glucose and insulin concentrations during pregnancy.	79 pregnant women with abnormal results of 50g glucose challenge test in the 3rd trimester	Australasian Diabetes in Pregnancy Society guideline	• Plasma Cr during pregnancy does not correlate with glucose intolerance and insulin resistance
UK	Houldsworth et al., 2017 Retrospective, observational, case control study [51]	Cr	Relationship between insulin resistance and serum Cr level during pregnancy	115 pregnant women in 12-40 weeks of gestation	World Health Organization criteria	• Significant correlation was found between insulin resistance and serum Cr in all (p = 0.009) and non-GDM (p = 0.01) pregnant women but not within the GDM women • Significant correlation for increased urine creatinine associated with urine Cr levels (p = 0.049) in GDM women
USA	Zhang et al., 2004 Prospective cohort study [52]	Vitamin C	Association of maternal plasma ascorbic acid concentration with subsequent GDM risk.	755 pregnant women began prenatal care before 16 weeks gestation	National Diabetes Data Group criteria	• Approximately 4.0% of the women developed GDM • Plasma ascorbic acid inversely associated with the risk of GDM (p for trend = 0.023)

Table 5. Maternal micronutrients intake and/or status and the risk of gestational diabetes mellitus in upper middle-income countries.

Upper Middle-Income Country	Study	Micronutrient(s)	Study Purpose	Participants' characteristics	Classification criteria of GDM	Key findings
Iran	Afkhami-Ardekani & Rashidi, 2009 Case control study [53]	Fe	Comparison of Fe status in GDM and control group.	34 GDM and 34 non-GDM women at 24–28 weeks of pregnancy	American Diabetes Association guideline	• Serum ferritin, Fe, transferrin saturation and haemoglobin, MCV and MCH was significantly higher in the GDM group ($p < 0.05$) • TIBS was significantly lower in the GDM group
Iran	Akhlaghi, Bagheri, & Rajabi, 2012 Case control study [5]	Fe, Cu, Zn, Mg, Cr, Al, Sn, Ni	Relation between micronutrients and GDM.	30 women with GDM and 30 women as control, between 24 and 28 weeks of pregnancy	American Diabetes Association guideline	• Serum concentration of Fe in GDM women was significantly lower than normal pregnant women • No significant difference in concentration of micronutrients (Se, Cu, Zn, Mg, Cr, Al, Sn, Ni) except Fe between study group and control group
Iran	Nasiri Amiri et al., 2013 Case control study [54]	Fe	Comparison of serum Fe and ferritin levels and total iron binding capacity in women with and without GDM.	100 women with GDM and 100 healthy pregnant women as control, between 24 and 28 weeks of pregnancy	Carpenter and Coustan criteria	• Serum ferritin was significantly higher in women with GDM in comparison with normal pregnant women • High serum ferritin level increased the risk of GDM by 2.4folds
Iran	Behboudi-Gandevani et al., 2013 Prospective cohort study [55]	Fe, Zn	Association between Fe/Zn serum levels and their nutritional intake in early pregnancy with GDM.	1033 singleton pregnant women aged 20–35	Carpenter and Coustan criteria	• Prevalence of GDM is 6.96% • Significant relationship between early pregnancy maternal serum Fe and GDM (OR = 1.006) • No significant difference in Zn levels, Fe and Zn nutritional intake between normal and GDM groups

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Upper Middle-Income Country	Study	Micronutrient(s)	Study Purpose	Participants' characteristics	Classification criteria of GDM	Key findings
Iran	Javadian et al., 2014 Case control study [56]	Fe	Effect of Fe supplementations in normal and GDM women	52 GDM and 50 normoglycaemic women between 24 and 28 weeks of pregnancy	American Diabetes Association guideline	• Serum ferritin and plasma haemoglobin levels were significantly higher in the GDM group
China	Wang et al., 2002 Cross sectional study [57]	Cu, Zn, Ca, Sr, Mg, P, Fe, Al	Comparison of serum Cu, Zn, Ca, Sr, Mg, P, Fe and Al in normal, impaired glucose tolerance, GDM pregnant women and normal non-pregnant women.	251 women; 90 normal pregnant, 98 impaired glucose tolerance, 46 GDM and 17 normal non-pregnant women	Verified by clinic	• Increased serum Cu levels in GDM women • Decreased serum Zn levels in GDM women • Inverse correlation between serum Ca and gestational period
Iraq	Hussein, 2005 Case control study [58]	Cu, Zn	Comparison of serum Cu and Zn in GDM and healthy pregnant women.	62 pregnant women; 31 GDM and 31 healthy pregnant women	Diagnosed by gynaecologist	• Significant increase in serum Cu in GDM ($p < 0.05$) • Significant decrease in serum Zn in GDM ($p < 0.05$)
Iran	Roshanravan et al., 2017 Case control study [59]	Cu, Zn, Mg	Comparison of serum Cu, Zn and Mg between healthy and impaired glucose tolerance pregnant women.	46 impaired glucose tolerance and 35 healthy pregnant women	American Diabetes Association guideline	• Significant higher serum Cu in healthy pregnant women • Significant lower serum Zn in impaired glucose tolerance women • No significant difference in serum Mg between the 2 groups

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Upper Middle-Income Country	Study	Micronutrient(s)	Study Purpose	Participants' characteristics	Classification criteria of GDM	Key findings
Iran	Behrashi, Mahdian, & Aliasgharzadeh, 2011 Randomized placebo-controlled trail [60]	Zn	Effects of Zn supplementations on glycaemic control in GDM women	60 GDM women at 32 weeks of gestational; 30 receive 25 mg/day $ZnSO_4$, 30 on placebo until term	American Diabetes Association guideline	• Significant lower insulin requirement ($p < 0.001$) in the supplementation group
Bulgaria	Genova et al., 2014 Case control study [61]	Zn	Estimate plasma and intracellular Zn in third trimester pregnant women with and without GDM	45 GDM, 45 healthy pregnant and 45 non-pregnant healthy women	International Association of Diabetes and Pregnancy Study Groups	• Positive correlation between plasma Zn levels and pro-insulin in GDM • No significant differences in plasma haemolysate Zn between the healthy pregnant and GDM women • Pregnant women have higher level of intracellular erythrocyte Zn
Iran	Roshanravan et al., 2015 Matched, controlled clinical trial [62]	Zn	Effects of Zn supplementation on serum glucose level and insulin resistance in pregnant women with impaired glucose tolerance.	44 pregnant women with impaired glucose tolerance; 22 receive 30 mg/day Zn gluconate, 22 on placebo for 8 weeks	American Diabetes Association guideline	• Slightly decreased on the fasting serum glucose, insulin concentration, HOMA-IR in supplemented group but not statistically significant
Iran	Karamali et al., 2015 Randomized placebo-controlled trail [63]	Zn	Effects of Zn supplementation on glucose homeostasis parameters in GDM women.	58 GDM women; 29 receive 233 mg/day Zn gluconate (30 mg Zn) and 29 on placebo for 6 weeks	American Diabetes Association guideline	• Significant reduction on the fasting plasma glucose, serum insulin levels, HOMA-IR, HOMA-B and significant increase in quantitative insulin sensitivity check index in supplemented group

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Upper Middle-Income Country	Study	Micronutrient(s)	Study Purpose	Participants' characteristics	Classification criteria of GDM	Key findings
Bulgaria	Genova et al., 2016 Case control study [64]	Zn	Relationship between insulin resistance in GDM with plasma and erythrocyte levels on Zn.	35 normal glucose tolerance and 37 GDM pregnant women	International Diabetes in Pregnancy Study Group	• Negative correlations between glucose and plasma Zn levels, between erythrocytes Zn and FBG in GDM group
Iran	Parast & Paknahad, 2017 Case control study [65]	Vitamin E, Se, Zn	Antioxidant capacity and antioxidant nutrient intake between healthy pregnant and GDM women.	40 healthy pregnant and 40 GDM women	American Diabetes Association guideline	• Significant lower total antioxidant capacity concentration in serum of GDM women ($p < 0.001$) • Significant lower intakes of vitamin E ($p < 0.001$), Se ($p < 0.05$) and Zn ($p < 0.001$) in women with GDM
Bulgaria	Genova et al., 2014 Case control study [66]	Mg	Estimate plasma and intracellular haemolysate Mg in third trimester among women, with or without GDM	40 GDM, 40 healthy pregnant and 40 non-pregnant healthy women	International Association of Diabetes and Pregnancy Study Groups	• No significant differences in plasma and intracellular Mg between the healthy pregnant and GDM women
Iran	Asemi et al., 2015 Randomized placebo-controlled trail [67]	Mg	Effect of Mg supplementation on metabolic status in Mg-deficient among GDM women.	70 GDM women; 35 receive 250 mg/day MgO, 35 on placebo for 6 weeks	American Diabetes Association guideline	• Significant improvement on the fasting plasma glucose, serum insulin concentration, HOMA-IR, HOMA-B and the quantitative insulin sensitivity check index in supplemented group
Iran	Mostafavi et al., 2015 Cross sectional study [68]	Mg	Comparison of plasma Mg concentrations in the development of GDM among pregnant women with and without abdominal obesity.	40 pregnant women with abdominal obesity and 40 pregnant women without abdominal obesity	US National Cholesterol Education Program	• 16 in obese and 1 in control group developed GDM • Significant lower in plasma Mg levels between diabetic and non-diabetic groups ($p = 0.05$) • Abdominal obesity with low plasma Mg are more likely to show abnormal OGTT results

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Upper Middle-Income Country	Study	Micronutrient(s)	Study Purpose	Participants' characteristics	Classification criteria of GDM	Key findings
Turkey	Tasdemir et al., 2015 Cross sectional study [69]	Mg	Comparison of ionized and total Mg levels in normal and among GDM women.	85 women in 26–28 weeks of pregnancy; 45 normal and 40 GDM	American Diabetes Association guideline	• Significant relationship between low total and ionized Mg levels and GDM
Iran	Karamali et al., 2018 Randomized placebo-controlled trail [70]	Mg, Zn, Ca, Vitamin D	Effects of Mg, Zn, Ca and vitamin D co-supplementation on glycaemic control	60 GDM women; 30 receive 100 mg Mg, 4 mg Zn, 400 mg Ca plus 200 IU vitamin D, 30 on placebo twice a day for 6 weeks	American Diabetes Association guideline	• Significant reduction on the fasting plasma glucose, serum insulin levels, HOMA-IR and significant increase in quantitative insulin sensitivity check index in supplemented group
Iran	Maktabi et al., 2018 Randomized placebo-controlled trail [71]	Mg, Vitamin E	Effects of Mg and vitamin E co-supplementation on metabolic status among GDM women.	60 GDM women; 30 receive 250 mg/day MgO plus 400 IU/day vitamin E, 30 on placebo group for 6 weeks	American Diabetes Association guideline	• Significant lower on the fasting plasma glucose, serum insulin levels, HOMA-IR and significant higher in quantitative insulin sensitivity check index in supplemented group
China	Tan et al., 2001 Cross sectional study [72]	Se	Relationship between serum Se and GDM.	234 pregnant women; 98 with impaired glucose tolerance, 46 with GDM and 90 normal pregnant women	Verified by clinic	• Significant lower serum Se levels in pregnant women with impaired glucose tolerance ($p < 0.001$) and GDM ($p < 0.001$) • Inverse correlation between serum Se concentration and the gestational period

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Upper Middle-Income Country	Study	Micronutrient(s)	Study Purpose	Participants' characteristics	Classification criteria of GDM	Key findings
Turkey	Kilinc et al., 2008 Cross sectional study [73]	Se	Comparison of serum Se levels in pregnant women with GDM, glucose intolerants and glucose-tolerant	178 pregnant women; 30 GDM, 47 glucose intolerants, 101 glucose-tolerant	Carpenter and Coustan criteria	• Significant lower serum Se levels in GDM and glucose intolerants than the normal pregnant women ($p < 0.001$) • Significant inverse correlation between Se and blood glucose level
Iran	Asemi et al., 2015 Randomized placebo-controlled trail [67]	Se	Effects of Se supplementation on metabolic status among GDM women.	70 GDM women; 35 receive 200 ug/day Se tablet and 35 on placebo for 6 weeks	American Diabetes Association guideline	• Significant reduction on the fasting plasma glucose, serum insulin levels, HOMA-IR and significant increase in quantitative insulin sensitivity check index in supplemented group
Iran	Asemi, Karamali & Esmaillzadeh, 2014 Randomized placebo-controlled trail [74]	Vitamin D, Ca	Effects of Ca and vitamin D supplementation on the metabolic status of GDM women.	56 GDM women; 28 receive 1,000 mg/day Ca plus 50,000 U vitamin D_3 pearl twice (baseline and day 21), 28 on placebo for 6 weeks	American Diabetes Association guideline	• Significant reduction in fasting plasma glucose, serum insulin levels, HOMA-IR and significant increase in the quantitative insulin sensitivity check index in supplemented group

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Upper Middle-Income Country	Study	Micronutrient(s)	Study Purpose	Participants' characteristics	Classification criteria of GDM	Key findings
China	Zhang et al., 2016 Randomized placebo-controlled trail [75]	Vitamin D	Effect of various doses of vitamin D supplementation on glucose metabolism among GDM women.	133 pregnant women with GDM; 20 receive placebo, 38 receive 200 IU/day, 38 receive 50000 IU/month and 37 receive 50000 IU/2 weeks of vitamin D (calciferol) until delivery	Diagnosed by doctor	• Insulin and HOMA-IR were significantly reduced by high dose (50000 IU/2 weeks) vitamin D supplementation ($p < 0.05$)
Iran	Jamilian et al., 2017 Randomized placebo-controlled trial [76]	Vitamin D, omega-3 fatty acid	Effects of vitamin D and omega-3 fatty acids co-supplementation on glucose metabolism in GDM women.	140 GDM women; 35 receive 1000mg omega-3 FA plus vitamin D placebo, 35 receive 50000 IU/2 weeks vitamin D plus omega-3 FA placebo, 35 receive 50000 IU/2 weeks vitamin D plus 1000mg omega-3 FA twice/day, 35 on placebo for both vitamin D and omega-3 FA, for 6 weeks	American Diabetes Association guideline	• Significant decreased fasting plasma glucose, serum insulin levels, HOMA-IR and significant increased quantitative insulin sensitivity check index in combined vitamin D and omega-3 FA supplemented group

Table 6. Maternal micronutrients intake and/or status and the risk of gestational diabetes mellitus in lower middle-income countries.

Lower Middle-Income Country	Study	Micronutrient(s)	Purpose of the study	Participants' characteristics	Classification criteria of GDM	Key findings
India	Prasad et al., 2013 Cross sectional study [77]	Fe, P	Correlation of serum Fe, P and haemoglobin levels with GDM	100 pregnant women with gestational period of 24–28 weeks	World Health Organization criteria	• Prevalence of GDM was 8% • Increase in serum Fe was associated with the development of GDM • No correlation was observed for P and haemoglobin levels
India	Joseph et al., 2017 Cross sectional study [78]	Fe, Ca, carotene, folate acid, thiamine, riboflavin, niacin	Association of nutrient intake of pregnant women with GDM.	85 pregnant women; 59 GDM and 26 pre-GDM	International Diabetes Federation	• Deficit intake of Fe, Ca, carotene, folate acid, thiamine, riboflavin and niacin in both groups • Pre-GDM women had a significantly better nutrient intake
Sudan	Hamdan et al., 2014 Case control study [79]	Zn, Se	Association of Zn and Se with GDM	31 GDM, 31 healthy pregnant women	Carpenter and Coustan criteria	• No significant differences in the Zn and Se levels between the healthy pregnant and GDM women
India	Asha et al., 2014 Prospective cohort study [80]	Cu, Mg	Comparison of serum Cu and Mg levels in GDM and healthy pregnant women.	85 GDM and 91 healthy pregnant women	American Diabetes Association guideline	• Significant increase in Cu level in GDM • No significant change in Mg level in GDM
India	Sundararaman et al., 2012 Case control study [81]	Cr	Serum Cr level in women with GDM	30 GDM and 60 controls women age 20–35 years, 22–28 gestational weeks	Diagnosed by doctor	• Significant lower serum Cr levels among the GDM women

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Lower Middle-Income Country	Study	Micronutrient(s)	Purpose of the study	Participants' characteristics	Classification criteria of GDM	Key findings
India	Muthukrishnan & Dhruv, 2015 Case control study [82]	Vitamin D	Effects of vitamin D replacement on vitamin D and GDM status.	78 pregnant women; 59 GDM and 19 normal glucose tolerance as controls Women with vitamin D levels below 20 ng/ml receive 60,000 IU of oral cholecalciferol twice weekly for 4 weeks	75 g OGTT with plasma glucose estimated at 2 h after ingestion > 140 mg/dl	• Serum 25-OH-D was significantly lower in GDM group ($p = 0.004$) • Frequency of GDM was similar irrespective of vitamin D status ($p = 0.09$) • Advice on diet and exercise, with or without vitamin D supplementation, did not significantly differ in the conversion of GDM to normal glucose tolerance
India	Krishnaveni et al., 2009 Cohort study [83]	Vitamin B_{12}, Folate	Association of low plasma vitamin B_{12} and high folate in pregnancy with GDM.	785 pregnant women	Carpenter and Coustan criteria	• Vitamin B_{12} deficient women had higher insulin resistance ($p = 0.02$) and a higher incidence of GDM (OR = 2.1) • The incidence of GDM increased with folate concentration from lowest to highest tertile ($p = 0.04$) among vitamin B_{12} deficient women

Table 7. Maternal micronutrients intake and/or status and the risk of gestational diabetes mellitus in low-income countries.

Low Income Country	Study	Micronutrient(s)	Purpose of the study	Participants' characteristics	Classification criteria of GDM	Key findings
Bangladesh	Mishu, Muttalib & Sultana, 2018 Case control study [84]	Zn, Cu	Association of serum Zn and Cu with GDM in 2nd and 3rd trimester.	86 GDM and 86 healthy pregnant women	World Health Organization criteria	• Significant lower serum Zn level in 2nd and 3rd trimester for GDM group ($p < 0.001$) • Significant increase in serum Cu in 2nd ($p < 0.001$) and 3rd ($p < 0.01$) trimester for GDM group

3.2 Diagnosis of GDM

Various diagnostic criteria were used in different studies. Majority of the studies on dietary pattern and quality with GDM used the criteria used by their respective healthcare sites, informed during their pregnancy period or records retrieved from the diabetes registry of the national database. However, the Iranian study defined GDM as fasting glucose >95 mg/dL or 1-h postprandial glucose >140 mg/dL for the first time in pregnancy [28]. Only one study by Ferranti et al. (2014) [21] collected information on family history of T2DM.

On the other hand, majority of the studies investigating micronutrients with GDM had utilised American Diabetes Association guideline, World Health Organisation (WHO) as well as Carpenter and Coustan criteria. Besides, National Diabetes Data Group, International Diabetes Federation, Australasian Diabetes in Pregnancy Society guideline and United States of America (USA) National Cholesterol Education Program criteria were also used as the classification criteria for GDM in the studies.

3.3 Dietary pattern, diet quality and micronutrients status in GDM

Eleven studies were published between 2006 and 2017 on dietary patterns and GDM. There were different definitions used for dietary pattern in the included studies. The studies from USA [14,15] and Iran [29] labelled the dietary pattern as prudent or Western, while the other study from Iran has classified the dietary pattern as healthy and unhealthy [30]. The study from Singapore described the dietary pattern in three ways, namely vegetable-fruit-rice-based diet, seafood-noodle-based-diet and pasta-cheese-processed-meat-diet [25].

Nine studies in diet quality and GDM was published between 2012 and 2018. The diet quality measures used were; alternate HEI (aHEI) [17,18,21]; Mediterranean Diet [28]; adjusted Mediterranean Diet (aMED) [17]; Recommended Food Score [16]; Dietary diversity scores (DDS); Food Groups Index (FGI); Minimum Dietary Diversity-Women (MDD-W); Prime Diet Quality Score (PDQS) [26]; Healthy Eating Index (HEI)-2010 [22,26] and Healthy Food Intake Index (HFII) [24].

Fifty-five studies published from 2000 to 2018, on maternal micronutrients status and/or intake and their associations or relationships with GDM were included (Table 4–7). The associations of micronutrients [iron (Fe), zinc (Zn), magnesium (Mg), vitamin D, selenium (Se), copper (Cu), chromium (Cr), calcium (Ca), potassium (K), folate, vitamin B_{12}, vitamin C and vitamin E] with GDM is reviewed. A total of 16 studies each for Fe and Zn, 11 studies each for Mg and vitamin D, respectively, were included in this review.

4. Discussion

GDM is increasing exponentially worldwide. It is in tandem with the growing rates of obesity [85]. Consequences of GDM concern both the mother and the child resulting in adverse neonatal and maternal outcomes. In the recent decade, more attention has been paid to nutritional issues and their relationship with different diseases [86]. Diet plays an important role in the management of GDM. Dietary patterns reflect the dietary habits of people, the manner of consumption of food and nutrients consumption by the individual [87]. Dietary patterns and diet quality are major modifiable risk factors of GDM, which can alleviate its consequences. Diet also affects the micronutrient status of the GDM mothers due to added foetal needs. Geographically, dietary intake depends on food availability, which explains most of the countries having their own staple crop. However, the staple food may not be complemented well by healthier choices due to less disposable income, especially in the low-income countries. In contrast, higher economies have a comparatively easy access to healthier foods, due to their status as a developed nation [88]. Hence, the present paper aims to focus on the association of dietary patterns, diet quality and micronutrient status with GDM among the pregnant mothers from different economies.

Dietary pattern consistently varies across the different geographical locations too. For example, within India itself, the dietary pattern is quite diverse, ranging from more traditional vegetarian diets characterised by consumption of fruit, vegetables and pulses, to diets characterised by consumption of sweets, snacks and meat. The main differences in dietary patterns identified were attributed to the geographical region of India (with diets in the North and West being more similar to one another, as were diets in the East and South) [88]. This variation depends upon the staple food of the population, dietary practices and availability of foods. It has evolved over time across the world with unhealthy diets taking precedence in the form of fast foods and/or junk foods replacing the preferred nutrient dense healthy options. Evidence shows that Organisation for Economic Co-operation and Development (OECD) countries are by far, the closest to the WHO nutritional recommendations being increasingly similar in terms of adherence to those norms. While developing countries also show a trend towards a better diet on average, it seems that disparities within this large group of countries are increasing and not all countries are following a virtuous path. Least developed countries are the most distant from the WHO recommendations and there is no evidence of improved diets or a reduction in disparities [89], thereby justifying the need to evaluate the dietary factors with risk of GDM across different economies.

Dietary intake is characterized, by high consumption of vegetables, fruits, and dietary fibre and low consumption of high-fat/high-sugar foods, red and processed meat, associated with lower risks of GDM [90]. Most prospective cohort studies from the high-income countries reported that prudent dietary pattern was significantly and inversely associated with GDM risk. These studies have also shown that, intakes of red and processed meats were significantly associated with a higher risk of GDM. A study from Singapore by de Seymour et al. (2016) [25], reported that there was a significant association between consumption of a seafood-noodle based diet during pregnancy and a lower risk of GDM. Meanwhile, studies from the upper middle-income countries focused on the dietary patterns of the GDM mothers rather than their diet quality [27,29,30]. Their diets typically consisted of traditional, mixed or Western pattern [27]; Western and prudent [29]; unhealthy and healthy [30]. Despite in an earlier publication by Nascimento et al. (2016) [27] reported that there was no difference among GDM incidence, in relation to the three dietary patterns (traditional, mixed or western), Sedaghat et al. (2017) [29] reported otherwise; they found that the risk of developing GDM in the second median of Western dietary pattern scores was higher, as compared to the first median. The inconsistent findings may be due to the differences in their stratification of the dietary patterns. Nevertheless, both studies concluded that Western diet (comprising of white bread, mayonnaise, sugar sweetened beverages, salty snacks, organ meats, processed meat, pasta, pizza, candies, and cookies) was unhealthy and associated with increased risk of GDM.

Diet quality indices generally aim to measure the overall quality of a diet and its adherence to evidence-based dietary guidelines (e.g. HEI or ARFS) or its contribution to a health outcome (e.g.

DASH or MED) [12]. As the indices involve scoring food/dietary patterns and nutrients tailored to the specific population, hence in this review, a wide variation of tools and their associations with risks of GDM is reported across the different economies. Several maternal diet quality indices were associated with an inversed risk of GDM although the results were equivocal. The population-specific scoring as per the national dietary recommendations and guidelines resulted in the wide variation in the indices between studies, limited the ability to elucidate a clear relationship between diet quality and GDM.

Inconsistent relationships between high scores of diet quality indices and risks of GDM were observed across the studies. Three papers from the same prospective cohort Nurses' Health Study (USA) published in different years reported higher scores of diet quality associated with lower risks of GDM [17,18,26]. The diet quality indices used in the earlier papers were the aMED, aHEI, DASH and HEI while the most recent studies added the dietary diversity scores besides aHEI-2010 and PDQS. Using comparable diet quality indices (DASH and MED); the Iranian study representing the upper middle-income country also reported similar findings [28]. However, in the Australian Longitudinal Study on Women's Health, conflicting evidence was reported as diet quality by quintile was not associated by GDM [23]. The inconsistent findings for GDM and diet quality indices might be explained by the types of food groups and nutrients incorporated into the national dietary guidelines as the basis of the diet quality indices. ARFS covered more food and food groups in the scoring criteria, despite the common elements of the indices included (high intake of fruit, vegetables, whole grains, nuts and legumes, and low intake of red and processed meats). Similar to dietary patterns, the selections of food groups and nutrients in the diet quality indices are unique to the particular country or culture affecting the quality and variety of the entire diet, thereby limiting the direct comparison across economies.

Micronutrients have a specific role during pregnancy. Fe transports oxygen, helps in cell growth and differentiation, also regulates gene expression [91,92]. In contrast, Fe overload, could result in oxidative stress which impairs the insulin response in the liver, muscle and adipose tissue [93]. Such reactions are common in GDM, which results in an increased risk of glucose intolerance. Results from the high-income countries revealed high Fe intake, particularly the heme Fe, which significantly increased the risk of GDM among normoglycemic mothers. The positive association with increased risk of GDM was also reported among those consuming red meat, rich in heme iron [14]. However, non-heme Fe showed negative correlation with the risk of GDM. Findings from the upper middle-income countries on Fe is in line with the outcomes of high-income countries; serum Fe, ferritin and haemoglobin levels were found significantly higher among the GDM mothers. Lower middle-income population reported similar findings too. The outcomes from all the studies on Fe indicated a significant positive correlation between Fe and GDM.

Zn, an important component for more than 1000 of proteins, such as antioxidant enzymes and metalloenzymes, is involved in carbohydrate and protein metabolism, DNA and RNA synthesis, cellular replication and differentiation as well as hormone regulation [91]. Zn is also crucial for the growth and development of foetus during pregnancy; the deficiency of which may result in adverse pregnancy outcomes [94]. Zn has the ability to mimic and amplify the pancreatic and peripheral functions of insulin; GDM could be related to the shift in Zn balance of the maternal physiological changes [91]. Findings from the high-income population showed a negative association between maternal Zn intakes with GDM. Similar findings were reported for the upper middle-income countries; the lower the maternal Zn status or intake, the higher the chances of GDM during pregnancy. On the other hand, study from the lower middle-income population showed no significant difference between maternal Zn status and GDM. Results from the low-income countries and high and upper-middle income countries, reported a significant lower serum Zn level among the GDM mothers from the 2nd and 3rd trimester. The only intervention trial from Singapore investigating the association of maternal dietary patterns during pregnancy and risk of GDM in multi-ethnic Asian population reported similar results. A seafood-noodle based diet (rich in Zn) was associated with a lower risk of GDM [25]. All the evidences point towards a potential preventive role of Zn in GDM.

Results from the high and lower middle-income population showed no significant differences in the Mg level among the healthy and GDM mothers. However, results from the randomized placebo control trial using Mg supplement in the upper middle-income population showed a significant reduction in the fasting plasma glucose, serum insulin levels, HOMA-IR and significant increment on the quantitative insulin-sensitivity check index. This could be closely related to Mg's functions as a cofactor in enzymatic reactions for energy metabolism, carbohydrate oxidation, insulin regulation and insulin-mediated-glucose uptake [66]. Pregnant women are susceptible to Mg loss and this condition is more prominent among the GDM women; suggesting that an elevation in female hormones and Mg deficiency during pregnancy impairs insulin sensitivity [66].

Vitamin D has a negative association with the occurrence of T2DM [44,47]. However, findings were equivocal [47,91]. Vitamin D deficiency might be associated with altered glucose homeostasis during pregnancy [91] and possible pancreatic β-cell dysfunction [44]. A significant inversed association between maternal vitamin D status with GDM, especially during the 1st and 2nd trimester was observed. Similar findings from vitamin D supplementation studies, in upper-middle income countries were reported. There was a significant improvement on the GDM indicators in the vitamin D supplementation group, which includes fasting plasma glucose, serum insulin levels, HOMA-IR and the quantitative insulin-sensitivity check index. Findings from the lower middle-income country also showed significant lower maternal vitamin D status among the GDM group.

GDM is highly associated with oxidative stress; in the recent years, the antioxidant functions of Se are gaining more attention for its association with GDM [95]. Se regulates the thyroid hormone and modulates oxidative stress [96]. In addition, it plays a role in reducing the severity of insulin resistance, maintenance of normal glucose uptake as well as regulation of cellular glucose utilisation. Thus, Se is hypothesized to demonstrate insulin-like properties [91]. Findings from both the high and upper middle-income countries reported a significant negative association between Se and GDM. However, the lower-middle income countries showed no significant difference. More studies are needed to validate these findings.

In the present review, associations of other micronutrients with GDM reported inconclusive findings. Results obtained from the high-income countries revealed a significant linear association between Ca and K with GDM; inversed association between vitamin C and GDM; but no significant association of Cr with GDM. However, a lower Cr serum level among the lower middle-income group was reported. All the included studies reported a linear association of Cu with GDM. Vitamin E intakes were observed to be lower among the GDM mothers in the upper middle-income population. Ca supplementation has showed a significant improvement on the fasting plasma glucose, serum insulin levels, HOMA-IR and the quantitative insulin-sensitivity check index. Inversed association was detected for vitamin B_{12} and folate with GDM among the lower middle-income population.

5. Strengths and limitations of the review

To the best of our knowledge, this is the first review to explore the association between maternal dietary patterns, diet quality and micronutrient status in GDM across different economies. Although findings were inconsistent due to the varied dietary patterns, diet quality and lack of standardization in assessing GDM, yet, a summary of the present state of the problem and its methodological implications for further studies is shown. Particularly in terms of the use of standardized GDM criteria and measures for dietary patterns and quality.

This review has some limitations. The review process itself may be biased by the exclusion of studies published in other languages besides English. The key limitations are in the evidence base itself; particularly in the heterogeneity of the studies and their measures of dietary patterns, diet quality and GDM standards. Hence, cannot be progressed into a meta-analysis. This review could not establish a causal relationship between dietary factors and GDM. Besides the methodological heterogeneity, comparison was challenging, as each included study reported within the context of their geographical, cultural and behavioural determinants. We were unable to assess the true magnitude and draw definitive conclusions about the associations between these dietary measures with risks of GDM due to diverse methods of diagnosis of GDM and diet quality indices. Hence a systematic review is warranted to arrive at conclusive findings.

6. Conclusion

There is a need for valid measures of dietary pattern and diet quality to ascertain the maternal dietary intake and their risks of GDM. The dietary pattern and quality differ according to the geographical region, culture and the economies per capital of a particular country as well as their population. They in turn, affect the micronutrients status of a mother directly or indirectly, and may result in compromised fetal outcomes. More studies on the relationship between dietary pattern, diet quality and various micronutrients with GDM are required, especially among the population from the low-income countries, which is currently limited. Hence, further research should be conducted to have a better understanding on the relationship between the variables, by standardizing all the determinants.

Conflict of interest

All authors declare no conflicts of interest in this paper.

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