



Maternal microplastic exposure during pregnancy and risk of gestational diabetes mellitus associated with gut dysbiosis

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ABSTRACT

The increased production and consumption of plastic items in the modern era has resulted in the generation of numerous microplastics (MPs) in the environment. Numerous researchers and clinicians were intrigued by the world's extensive use, distribution, and abundance of MPs. They were curious to study their interactions with biological systems and their impact on human health. Microplastic exposure occurs through various routes like oral, dermal, and inhalation, leading to metabolism alteration, oxidative stress, neurotoxicity, reproductive toxicity, and carcinogenicity. Microplastics contain intentionally added additives that, when combined, act as endocrine disruptors (EDCs), disrupting the natural hormone system and can cause cancer, diabetes, and neurological impairment in a developing fetus. The EDCs in microplastics may regulate glucose homeostasis, as shown by the occurrence of gestational impaired glucose tolerance, leading to Gestational Diabetes Mellitus (GDM). As the primary route of exposure to microplastics in humans is through ingestion, microplastics, and their additives ultimately enter the gastrointestinal tract and alter the gut microflora. Numerous metagenomics studies have demonstrated that the gut microflora of women with GDM are enriched with organisms like Ruminococcae, Parabacteroides distansoni, and Prevotella. The metabolic pathways for insulin signaling and carbohydrate metabolism are connected to these microbiota populations. The impact of microplastics on maternal exposure and their possible alteration of glucose metabolism, leading to GDM, as well as their association with gut microbiome dysbiosis, are addressed in this review.

1. Introduction

Plastic plays a vital role in humans' day-to-day lives, especially during this pandemic. Their utilization rate was exponentially increased. It was highly manufactured and used to produce medical supplies and personal protective equipment such as masks and gloves. This led to an increase in the amount of plastic waste, which in turn increased the amount of microplastic being released into the environment [1]. Apart from the pandemic, they are widely used around the world due to their wide range of applications in various industries, such as electrical, mechanical, and medical [2]. Since the introduction of large-scale plastic products to the market in the 1950s, global plastic productivity has expanded substantially, from 0.5 million metric tonnes/year in 1960 to 348 million metric tonnes in 2017 [3]. Plastic is scraped together in the environment from innumerable sources owing to its stagnant degradation [3,4]. These accumulated larger plastics are weathered by wave action, wind abrasion, and UV radiation from sunlight, forming smaller plastic particles <5 mm, including nano-sized plastic <1 µm called

"microplastics" [5]. Microplastic particles can enter the gut and interact with gut microbiota [6]. These interactions can lead to changes in the microbiota composition and function which can in turn affect glucose metabolism and increase the risk of gestational diabetes mellitus. Microplastic particles have been found in the gut microbiota of pregnant women. Studies suggest that the presence of microplastics in the gut may be linked to the development of GDM [7]. This would include exploring the mechanisms of how microplastics can interact with gut microbiota and the potential impact of this interaction on glucose metabolism and glucose-related diseases such as gestational diabetes mellitus [8]. Additionally, further research is needed to identify the most effective strategies to reduce the amount of microplastic entering the human body, especially during pregnancy to prevent maternal and neonatal complications.

1.1. Microplastic and its sources

In the environs of seawater, freshwater, agro-ecosystems,

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atmosphere, food, and drinking water, biota, and other isolated areas, microplastic (MPs) particles have been identified in a wide variety of forms (microbeads, nurdles, fibers, foam, and fragments), polymers polypropylene (PP), polystyrene (PS), polyethylene terephthalate (PET), polystyrene (PS), polycarbonate (PC), Polyvinyl chloride (PVC)), sizes ((megaplastics (>50 cm), macroplastics (5–50 cm), mesoplastics (0.5–5 cm), microplastics (<0.5 cm)) with various concentrations [9–12]. Microplastics were classified as either primary or secondary based on the source of their release into the environment. Primary MPs are those that are intentionally produced less than 5 mm in size for multiple applications such as micro-beads in face cleansers and exfoliators, body washes, and scouring pads (dishwashing), as well as microfiber for clothing (towels and bath towels). Secondary MPs are substances created from plastic polymers by standard weathering mechanisms, including erosion, corrosion, abrasion, photooxidation (chemical), and biological transfiguration [13].

1.2. Microplastics and their routes of exposure to humans

In recent years, public and scientific attention has focused on microplastics and their impact on human health. The routes of micro and nano plastic infiltration into humans through the food chain have indicated prominent health consequences [14]. Based on European Food Safety Authority (EFSA) guidelines, the risks proffered by micro- or nano polymers to human health will be defined by their chemical compositions and physiochemical properties, their potential for uptake and interactions with tissues, and their likely potential exposure concentration [15]. Microplastics enter the human body through various routes of exposure like inhalation, ingestion, and dermal contact.

1.2.1. Ingestion

Among the various routes, ingestion is considered as a significant route of microplastic exposure [16]. According to estimations of caloric intake, the range of annual microplastic consumption per individual ranges between 39,000 and 52,000 particles [17]. Few studies have estimated the amount of human microplastic consumption quantitatively in various foodstuffs like sea salt [18] seafood (fish, mussels, shrimp, crab, and oysters) [19,20] beer [21] honey [22] milk [23], sugar [24] teabags [25] seaweed [26], canned and packaged food [27] etc., in various countries and these reported data were compared with the annual consumption of microplastic contained food in India (Table 1).

1.2.2. Inhalation

In spite of low pollution levels in the air, the majority of the population carries a significant number of particles in their respiratory system, that may contribute to disease development [47]. Hence, air pollution has been shown to positively correlate with mortality from lung cancer and cardiopulmonary disease, even when health risk factors have been controlled for [48]. As a result of their small size and low density, microplastics are easily transported by the wind [49]. Humans are exposed to MPs through inhalation. To enter the respiratory system of the human body, the MPs must attain an airborne state with a size that is conceivable to reach the system, i.e., it must have a length >5 mm, a diameter < 3 mm, and a length of diameter ratio lesser than 3:1 [50–52]. Several studies have estimated an average inhalation of about 0.685 p/m³ airborne Micro-nano plastics (MNPs) concentration in the human system. Considering the respiratory frequency of 12 breaths/min and a 0.5 L tidal volume, the breathing rate is estimated at 8.64 m³/day. The calculated average concentration of humans was 5.918 p/day [53]. Estimating airborne MNPs depends on sampling methods, air renovation rates, human impacts, furniture, or cleaning practices. In light of the COVID-19 pandemic, it was expected that the extent of MNP inhalation would be underestimated because the use of prolonged masks was widespread throughout the world [54]. According to Lombardi et al. their systematic review has raised several negative health concerns associated with the absorption of microplastics and plastic additives. Inhalation of these particles can potentially lead to the development of exacerbation of respiratory diseases. The presence of MPs in the respiratory system may cause inflammation and damage to lung tissues, leading to conditions such as asthma, chronic obstructive pulmonary disease (COPD), and even lung cancer [55]. It has been reported that on 13 out of 20 tissue samples, 33 polymeric particles and 4 fibers were observed. In all observed cases, polymeric particles ranged from <5 µm in size and fibers ranged in size from 8.12 to 16.8 µm in which polypropylene and polyethylene were the most frequently determined polymers [56]. It is important to recognize that inhalation is a major route of exposure to microplastic While ingestion to MPs through food and water has received significant attention, the inhalation of these particles should not be underestimated [57]. Inhaled microplastics can easily enter the respiratory system and reach the lungs where they can interact with lung tissues and potentially cause harm [58]. This highlights the need for further research and awareness regarding the potential risks associated with the inhalation of microplastics.

Table 1

Average microplastic concentrations in human through ingestion.

Food containing microplastics	Average microplastic concentrations in human	Source location/Site	Year	Reference	Annual per capita consumption in India
Seafood	1.48 MP/g	Canada	2019	[28]	5–8 kg per capita [29]
Sugar	0.44 MP/g				25 kg per capita [30]
Honey	0.10 MP/g				50 g per capita [31]
Salt	0.11 MP/g				11 g/day [32]
Alcohol	32.27 MP/g				18.3 L per capita [33]
Bottled water	94.37 MP/g				–
Tap water	4.23 MP/g				–
Apple (<i>M. domestica</i>)	4.62 E + P/kg day	Italy	2020	[34]	1.96 kg per capita [35]
Pears (<i>P. communis</i>)	4.48 E + P/kg day				–
Broccoli (<i>B. oleracea</i> Italia)	9.55 E + P/kg day				–
Lettuce (<i>L. sativa</i>)	3.83 E + P/kg day				–
Carrot (<i>D. carota</i>)	2.96 E + P/kg day				–
Beer	16–254/L	Germany	2014	[36]	1.02 L [35]
Dried fish	0–3 P/individual fish	Malaysia	2017	[37]	2.6 kg/month [38]
Milk	3 ± 2–11 ± 3.54	Mexico	2020	[23]	406 g (g)/day [39]
Packed meat (chicken)	4.0 to 18.7 MP-XPS/kg	France	2020	[40]	2.60 kg per capita [35]
Fish (<i>Coilia dussumieri</i>)	28.84 ± 10.13 item/g	India	2021	[41]	5–8 kg per capita [29]
Vinegar	3.68 P/kg/body weight/year	Iran	2021	[42]	4.1 kg per capita [43]
Tomato	15.60 P/kg day	Turkey	2023	[44]	–
Onion	2.15 P/kg day				16.8 kg per capita [35]
Potato	3.01 P/kg day				25.0 kg per capita [35]
Cucumber	2.60 P/kg day				–
Sea salt	56–103 MP/kg	India	2018	[45]	14 kg per capita [46]

1.2.3. Dermal contact

Though the routes of microplastic exposure to the human system are almost established, the accurate concentration of MPs in the human system and the various impacts of accumulated MPs are unknown. Skin contact is yet another pathway for microplastics to enter our bodies. Cosmetics and personal care products, such as exfoliating scrubs and toothpaste, often contain microbeads that can be absorbed through the skin. These particles can then penetrate deep layers and potentially have systemic effects. Even though there were only few studies that do not provide a comprehensive understanding of human dermal exposure to MPs, they provide evidence that this route should not be ignored [59] (Table 2).

The human skin has the capacity to act as a barrier to large particles. However, studies have shown that only particles sized <100 nm (ie., nanoplastics) can directly pass through the dermal barrier. There are other mechanisms through which large particles may penetrate the skin, including sweat glands, hair follicles or open wound in the skin. The dermal exposure to MPs has been associated with skin damage associated with inflammation and oxidative stress [60]. Further research is necessary in order to determine whether human dermal exposure to MPs has been caused by cosmetics, settled dust particles, fabric fibres etc., as well as its significance as well as its associated health risks.

2. Effects of microplastics on pregnancy

2.1. Maternal exposure and placental transfer of microplastics

In addition to providing nutrients and gas exchange for the maternal-fetal system, the placenta also acts as a connecting bridge between the vascular beds of the maternal-fetal system [63]. The first study revealing the presence of microplastic particles in the human placental tissues was conducted in 2021 by Antonio Ragusa et al. There were almost twelve microplastic fragments in the human placental tissue, including polypropylene, polyethylene terephthalate, and polyvinyl chloride. A majority of the microplastics listed above have been identified as mutagenic or carcinogenic. In light of the placenta's crucial role in the protective function of the fetus, such toxic microplastics may impact the fetus' development and growth [64]. The juvenile fetuses were more prone to endocrine-disrupting substances/chemicals, as various types of EDCs were transferred from the maternal system to the fetus through the connecting placenta. In personal care products, particularly cosmetics, the EDCs present have antithetical effects on fetal growth and development, as well as restricting the normal physiological characteristics of the placenta [65]. There has been evidence that MPs may affect several cellular regulatory pathways in the placenta, potentially leading to adverse pregnancy outcomes such as preeclampsia and fetal growth restriction [66]. In light of the fact that the placenta plays a vital role in the development of a healthy pregnancy, more attention should be given to environmental factors affecting its function.

Table 2

Microplastic exposure to humans through Dermal contact (Cosmetics and personal care products)

Cosmetics and personal care products containing microplastics	Amount of microplastics in the product	Location	Year	References
Facial cleanser	8.30 ± 3.27 P/g product	China	2017	[61]
Shower gels	6.27 ± 3.65 P/g product			
Hand cleanser	440.07 tonnes	Europe	2022	[62]
Face scrubs	72.95 tonnes			
Face masks	0.1 tonnes			
Shampoo	7.02 tonnes			
Soap bars	0.046 tonnes			
Body foot scrubs	126.1 tonnes			

2.2. Developmental effects during pregnancy

The term developmental toxicology refers to any structural or functional alteration caused by an adverse environmental stimulus, diet or toxic chemicals, or physical factors that affect the normal development, differentiation, or behaviour of organisms [67]. Early developmental periods have been found to be particularly sensitive to chemicals and other stressors which can cause adverse health effects later in life, as indicated by the concepts described in Developmental Origins of Health and Disease (DOHaD) and increasingly compelling evidence [68]. As the child's body load mirrors its mother's exposure status and correlates with nursing time, there will be a transfer of chemical metabolites from the mother's breast milk to the child during the early developmental stage. According to the study conducted by Deng et al. early exposure to PS-MPs shows an accumulation of MPs particles in the liver, gut, and kidney, inducing oxidative stress, disturbance of energy, and lipid metabolism [69]. A study conducted by Luo et al. showed decreased percentage of Th17, induced intestinal dysbacteriodes, and inflammation of the intestine, especially in the duodenum and colon [70]. Preschoolers and toddlers were vulnerable to microplastic exposure and other related pollutants present in plastic toys, fabrics, and plastic feeding bottles by chewing and licking them. Nearly all the toys in the market were mostly made up of plastic and other toxic plastic additives such as BPA, plasticizer, cadmium, etc., to support and maintain the product's physical and chemical properties [71].

2.3. Inflammation and oxidative stress

Pregnancy is a state of increased oxidative stress, a phenomenal reaction induced by a normal systematic inflammatory response, which produces high levels of ROS (Reactive oxygen species) being released into the bloodstream. Thus, pregnancy is characterized by excessive levels of ROS produced by the placenta, which was responsible for the regulation of the condition [72]. According to multiple animal studies, ingestion of microplastics accumulated in the gut and alters its normal physiology. In the gut, microplastics whose maximum size exceeds 150 µm are not absorbed, instead, they were connected to the mucus layer of the intestine and have direct contact with the epithelial cells of the intestine. However, microplastic particles which were smaller can migrate through the mucus barrier, which leads to inflammation in the intestine and other immunological consequences [73]. A study conducted by Boqing Li et al. assessed the effects of polystyrene microplastics in mice at different amounts (10–150 µm, 2,20,200 µg/g of food, for 5 weeks). After standard exposure, the mice have shown ample evidence of inflammation in the histological colon and duodenum, and higher levels of protein expression of the innate immune receptors toll-like receptor 4 (TLR4), interferon regulatory factor 5 (IRF5) and proinflammatory transcription factor activator protein 1 A P 1 [74]. Wu et al. stated that exposure to PS-MPs leads to fibrosis in the ovaries through the activation of the TLR4/NADPH oxidase 2 signaling pathway. Also showed that there was an increase in oxidative stress, which activates the NOTCH signaling and transforms growth factor β (TGF-β) – mediated fibrosis in the endometrial epithelial cells and uterus [75].

2.4. Immune system effects

During gestation, it is crucial to maintain a balance between the maternal and fetal immune systems [76]. The immune system can be altered by environmental pollutants which include carbon monoxide, smoke from the kitchen, and particulate matter which might lead to a higher probability of spontaneous abortion [77]. Various studies showed that early exposure to Microplastics has a significant capacity to alter immune homeostasis by persuading reproductive toxicity, mainly at the maternal-fetal crosslink [76]. Studies have shown that 5 weeks of exposure to PE-MPs significantly alter serum levels of interleukin-1 (IL-1) and granulocyte colony-stimulating factor, lowers regulatory T

cells, and increases the number of Th17 cells in the splenocytes [74]. Furthermore, MPs and DEHP alter the composition of gut microbiota, leading to a dramatic change in the relative abundance of bacteria involved in energy metabolism and immune function [78].

3. Gut microbiota and human health

The gut microbiota, a complex community of microorganisms residing in our digestive system, plays a crucial role in maintaining our overall health [79]. This diverse ecosystem of bacteria, fungi, and viruses helps us digest food, synthesize vitamins, and support our immune system [80]. Furthermore, emerging evidence suggests that the gut microbiota influences various aspects of our health, including metabolism, mental well-being, and even the development of chronic diseases [81]. In a healthy individual, the gut microbiota exists in a delicate balance. However, disruptions to this balance, known as dysbiosis, can occur due to various factors, including diet, stress, and exposure to environmental pollutants [82]. Recent studies have started to investigate the potential impact of microplastics on the consumption and function of the gut microbiota, with implications for our overall health.

4. Gestational diabetes mellitus: prevalence and screening

According to the International Association of Diabetes in Pregnancy Study Group (IADPSG)'s criteria, the global prevalence of gestational diabetes mellitus (GDM) was estimated at 14.0% with a 95% confidence interval of 13.97–14.04% [83]. The incidence of gestational diabetes mellitus in women has increased primarily as a result of rising changes in lifestyle and dietary patterns, along with other associated pregnancy complications [84]. According to the American Diabetes Association (ADA), Gestational Diabetes Mellitus (GDM) is “diabetes first diagnosed during the second or third trimester of pregnancy that excludes the possibility of pre-existing type 1 or type 2 diabetes [85,86] This disease is a common and potentially serious condition that can have adverse effects on mothers and babies. It is associated with preeclampsia, macrosomia, and increased rates of cesarean sections [87] apart from these, GDM causes other associated complications, including the death of the fetus in utero, neonatal hypoglycemia, respiratory distress syndrome, shoulder dystocia, and congenital anomalies [88] The American College of Obstetricians and Gynaecologists (ACOG) recommends screening for GDM in a two-step approach that includes a 50-g glucose challenge test (50-g GCT) followed by a 100-g oral glucose tolerance test (100-g OGTT) in the event of a positive screen (>140 mg/dL). According to the International Association of Diabetes and Pregnancy Study Groups (IADPSG), the strategy of the one-step approach has simplified diagnostic testing, which was a 75-g 2-h OGTT that requires a single elevated value for screening and diagnosis; it is also more sensitive in identifying the risk of adverse outcomes in pregnancy when compared to a 100-g 3-h OGTT, as recommended by ACOG [89] A recent study shows that GDM can be screened by measuring the levels of glycated haemoglobin, especially in the second trimester of pregnancy, Glycated haemoglobin (HbA1c) is a non-enzymatic, irreversible conversion of glucose to haemoglobin binding (Hb). The mean erythrocyte plasma glucose is correlated with glycosylation. A non-fasting blood test indicates glucose levels over 4–8 weeks. HbA1c levels may be used to characterize patients with undiagnosed diabetes or those at risk of developing diabetes [90, 91] The measurement of HbA1c can be used to detect women at risk for gestational diabetes mellitus as early as 3–4 weeks into gestation [90] According to the CDC (Centers for Disease Control and Prevention), the normal glycated A1C range is below 5.7%, and a level of 5.7%–6.4% represents prediabetes. The range of the glycated A1C level is above 6.5%, which indicates diabetes. The higher the A1C range, the greater the risk of developing type 2 diabetes mellitus (T2DM). During pregnancy, the mother's biological system undergoes a series of physiological changes to support the fetus's growth and to meet the demands of the growth environment, including the adaptation of the cardiovascular,

renal, respiratory, hematologic, and metabolic systems [92]. Early in pregnancy, insulin sensitivity eventually increases, promoting glucose uptake into adipose tissue stores for later pregnancy [93] In recent years, the World Health Organization (WHO) revised its recommendations for the diagnosis of GDM and distinguished this category from the highly intolerant group known as gestational diabetes. GDM is ubiquitous and serves as the most prevalent pregnancy complication. Globally, an estimated 21.3 million births (16.2%) were affected by intrauterine hyperglycemia, and 86.4% were due to GDM. GDM has been linked to gestational hypertension and preeclampsia in pregnant women, in addition, to type 2 diabetes mellitus and cardiovascular disease after pregnancy [7]. The fetus of women with GDM is at increased risk for fetal macrosomia, metabolic syndrome, obesity, and type 2 diabetes. GDM is a significant public health concern that tends to affect both mother and child [7,94].

5. Impacts of microplastic exposure in gestational diabetes mellitus

Several epidemiological studies have found that exposure to diethylhexyl phthalate (DEHP), an endocrine disruptor that is used in making cosmetics, plastics, and food packaging and is ubiquitous in the environment, may be associated with GDM. DEHP could increase TNF- α , downregulating GLUT4, an insulin-regulated glucose transporter responsible for insulin-regulated glucose uptake into fat and muscle cells, which leads to downregulation of the glucose uptake process and could lead to gestational diabetes mellitus. On the contrary, as the pregnancy develops, a combination of maternal and placental hormones (estrogen, progesterone, leptin, cortisol, placental lactogen, and placental growth hormone) enhances insulin resistance [95] The result is a modest rise in blood glucose, which is effectively transferred across the placenta to replenish the developing fetus. As microplastics contain endocrine-disrupting chemicals (EDCs) like bisphenol A, it is known that they may disrupt the maternal endocrine system and change the level of estrogen, progesterone, and other maternal hormones. This can lead to insulin sensitivity and resistance, a major cause of gestational diabetes mellitus [96].

6. The effect of microplastics on the gut microbiome

Among the various routes of microplastic exposure into the biological system via ingestion, inhalation, and dermal contact, humans were mainly exposed to microplastic through ingestion. When microplastic reaches the gut, it will ultimately disrupt the gut microbiota. Human gut microflora are increasingly acknowledged as a crucial component in host metabolism [97]. The gut microbiome is a nucleic factor in regulating human health and disease. In recent decades studies on the *Gut microflora* have shoot up drastically owing to the fact that it plays a pivotal role in regulating the immune system by metabolizing proteins and complex carbohydrates [98]. A study conducted in France by Stephanie et al. revealed that incessant exposure to Polyethylene microplastics on the Mucosal artificial colon (*M-ARCOL*) model, which mimics the adult human gut microbiota and gut's intestinal barrier coupled with a co-culture of intestinal epithelial and mucus-secreting cells, have shown increased abundances of significantly detrimental pathobionts such as *Desulfovibionaceae* and *Enterobacteriaceae* and decreased number of beneficial gut bacteria *Christensenellaceae* and *Akkermansiaceae* [99]. Another study by Muriel et al. shows that ingestion of polyethylene microplastics by infants through breastfeeding, bottle feeding, and dust particles could cause commotion and alterations in gut microflora composition and gut microbiome activity [100,101]. It has been shown that potential and occasional ingestion of takeaway food in disposable plastic containers (TFDPC) may induce microbial flora alteration in the digestive tract of humans and cause ailments such as gut microbial dysbiosis, cough, and gastrointestinal dysfunction [102] Chronic exposure to pristine polystyrene micro-nano plastics, particularly

amino-modified polystyrene micro-nano plastics, damages the biological system due to the undermined function of the intestinal epithelial barrier. The dysregulation of the intestinal barrier was potentially influenced by the impaired intestinal flora affected by polystyrene micro-nano plastics [103].

7. Gut microbiome and gestational diabetes mellitus

Microbial dysbiosis in the human gastrointestinal tract, maybe a significant environmental risk factor for dysregulated host metabolism [104]. An experimental animal study conducted by Cani et al. divulged that decreased *Bifidobacteria* led to magnified production of endogenous lipopolysaccharide and associated obesity and insulin resistance [105]. According to Liu et al. exposure to environmental chemicals and elements can alter the gut microflora and are associated with the disease [106]. In consonance with Yuqing Zhang, the microbiome components that may act as a facilitator of the effects of element exposure on GDM has been identified, exemplifying an increased risk of GDM due to the effect of trace element exposure on specific gut microbiome features [107]. Regulation of the gut microbiota may open new horizons for managing GDM caused by exposure to environmental components. Metabolic dysfunction, such as gestational diabetes mellitus, may be attributed to the gut microbiota's significant changes during pregnancy [108,109]. In current years, one of the most active research hotspots has been focused on the correlation between gut microbiota and gestational diabetes mellitus. Multiple macro genomic studies found that patients with GDM had a lower diversification of gut microbiota than healthy pregnant women. This finding remained consistent across all of the studies. The gut microbiota of pregnant women who have GDM comprises an elevated abundance of *Ruminococcae*, *Desulfovibrionaceae*, *Prevotella*, *Megamonas*, *Phascolarctobacterium*, and *Parabacteroides distansoni* [110]. When compared with normoglycemic control, pregnant women with GDM have shown a reduced abundance of *Bifidobacterium* spp., *Eubacterium* spp., *Dialister*, *Bacteroides*, *Faecalibacterium*, *Akkermansia*, *Marvinbryantia*, *Anaerosporebacter*, and *Parabacteroides*. There is a link between the microbiota, lipid, and glucose metabolic pathways, and insulin signal transduction [111]. The gut microbiota is significantly related to the prevalence of diabetes in pregnant Chinese women. The above study demonstrates that despite significant individual differences in the gut microbiome, the functional profile of GDM patient populations is substantial compared to that of patients with overt diabetes. It currently provides novel insights into *B-dorei*'s increasingly intriguing role in the pathways of carbohydrate metabolism and the host-microbiome immunoregulatory interface. Certain microorganisms, such as *Bacteroides dorei*, could be potential diagnostic and curative markers for GDM [7,112].

8. Association between microplastics, gut microbiota and GDM

Although the exact mechanism underlying the potential link between microplastics, gut microbiota, and GDM is still being elucidated, several hypotheses have been proposed [113]. One mechanism involves the direct physical interaction between microplastics and gut bacteria, altering their growth and function [114]. Microplastics may also act as carriers for other harmful chemicals, such as endocrine disruptors, which can further impact the gut microbiota [115]. Furthermore, the inflammatory response triggered by the presence of microplastics in the gut may disrupt the delicate balance of the gut microbiota [116]. Chronic inflammation can lead to changes in gut permeability, allowing harmful substances to enter the bloodstream and potentially contribute to the development of GDM. Additionally, microplastics may interfere with hormone signaling pathways, further exacerbating metabolic imbalances associated with GDM [117].

9. Future research in this emerging field and potential implications for maternal health

As the understanding of the link between microplastics, gut microbiota, and GDM continues to evolve, future research holds great promise for identifying preventive measures and interventions. It is essential to conduct large-scale epidemiological studies to establish a more definitive association between microplastics and GDM, taking into account various confounding factors. Moreover, the potential implications for public health cannot be ignored. If the link between microplastics, gut microbiota, and GDM is confirmed, it would necessitate public health initiatives to reduce exposure to microplastics, particularly for pregnant women. This could involve policy changes, such as the regulation of microplastic content in consumer products, as well as educational campaigns to raise awareness about the potential risks of microplastic exposure.

10. Conclusion

To date, numerous studies have investigated the potential impact of microplastics on the gut microflora and the effects of gut dysbiosis on gestational diabetes mellitus pathways individually. It is still unknown what mechanism links the imbalanced dysregulation of gut microbiota caused by microplastic exposure and its impact on GDM and lost metabolism. An in-depth discussion of maternal microplastic exposure during pregnancy and its adverse effects on GDM risk is presented in this review. There will be changes and adaptations in the biological system during pregnancy; the gut microbiome may be naturally altered during the pregnancy, thus directly or indirectly paving the way for metabolic changes related to Gestational diabetes mellitus. Hence, there will be a multitude of changes and shifts wandering during the gestational period; the research on the potential impacts of maternal microplastic exposure on the gut microbiome and the role of the gut microbiome in the modification of size, shape, and chemical composition of microplastics, the prevalence of GDM in the various microplastic exposure groups, ethnicity, BMI, gestational age, gravidity, parity, diet, lifestyle, physical activity, and socio-economic status is needed. It is our duty as researchers, scientists, and clinicians to educate and raise awareness about microplastics and their impact on maternal-fetal health among pregnant women. Human and maternal health research on microplastics is urgently needed to create a plastic-free population in the future.

The potential link between microplastics, gut microbiota, and GDM represents a fascinating area of research with significant implications for public health. While the field is still in its early stages, recent studies have provided compelling evidence suggesting a possible association between microplastic exposure, alterations in gut microbiota, and the development of GDM. Further research is needed to elucidate the mechanisms through which microplastics may influence gut microbiota and contribute to GDM. Longitudinal studies, combined with experimental models, will help establish a more definitive causative relationship. Additionally, efforts to reduce exposure to microplastics and advocate for policy changes are essential in addressing this emerging environmental and health concern.

By understanding the link between microplastics, gut microbiota and GDM, we can take proactive steps to protect both the health of pregnant women and the well-being of future generations. Continued research in this field is imperative to inform evidence-based interventions and drive policy changes that prioritize the reduction of microplastic pollution and the preservation of our gut microbiota. Together, we can create a healthier and more sustainable future for all.

Author contribution

Deboral Panneerselvam: made the original, and wrote the manuscript. **Anuradha Murugesan:** examined and reviewed the manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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