



Particulate contamination of human placenta: Plastic and non-plastic

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ABSTRACT

Recent evidence indicates that the human womb is contaminated with a variety of particulate contaminants. Microplastics (MPs, tiny plastic particles, 0.1 – 5000 µm) generated by the breakdown of larger plastic products in the environment) accumulation in human placenta has recently been described. In addition, recent evidence has correlated the number of air pollution particulates in term placentas to the loading of these particles in dust from the gestational parent home. The current study sought to characterize the accumulation of plastic and non-plastic particles (NPP) within the term human placenta. Placenta tissues were collected from healthy, singleton pregnancies following vaginal ($n = 5$) and caesarean section ($n = 5$) deliveries at a tertiary care centre located in an urban Canadian city (Ottawa, ON), with particles detected and characterized by Raman micro-spectroscopy. Both plastic and non-plastic particles were identified in all placentas examined, with an average of 1 ± 1.2 MPs /g and 4 ± 2.9 NPP /g of tissue. Similar tissue concentrations of MPs and NNP were identified in all regions of the placenta (basal plate, chorionic villous, chorionic plate), and did not differ according to mode of delivery. MPs ranged in size (2 – 60 µm), with the most abundant MPs being polyethylene (PE), polypropylene (PP), polystyrene (PS) and polyvinyl chloride (PVC). The most abundantly identified NPP were carbon, graphite, and lead oxide. Collectively, these results demonstrate the accumulation of foreign particles, including MPs, throughout the human placenta. Given the vital functions of the placenta in supporting fetal growth and development, and a potential for MPs to induce toxicity, further investigations into the potential harmful effects of these environmental toxicants on maternal and fetal health is warranted.

1. Introduction

In the past few years, the environmental presence of microplastics (MPs) has come to the fore as a major concern for human exposure and potential health consequences. Intense plastic manufacturing and use, coupled to poor waste management, has led to an environment overwhelmed with billions of tons of plastic (Geyer et al., 2017; Jambeck et al., 2015). Plastic material abandoned in the environment leads to fragmentation and degradation (Andrade, 2017). This process yields smaller plastic fragments referred to as MPs. MPs range in size, from 1 µm to 5 mm (Hartmann et al., 2019), and are found ubiquitously in the environment, including waterways (Eriksen et al., 2013; Gaylarde et al., 2021), soil (Ramos et al., 2015), ground water (Lee et al., 2024), tap

water (Kosuth et al., 2018), household dust (Zhang et al., 2020) and food products (Afrin et al., 2022; Diaz-Basantes et al., 2020; Kosuth et al., 2018). The ubiquity of these contaminants across these media argue that widespread human exposure is inevitable.

Numerous investigations, encompassing both human and animal studies, have established that particulate – primarily MPs - have the capacity to enter the human body and collect within tissues and organ systems (Amato-Lourenço et al., 2021; Baeza-Martínez et al., 2022; Horvatis et al., 2022; Ibrahim et al., 2021; Jenner et al., 2022; Ozawa et al., 1986; Pauly et al., 1998). MPs have been detected in various human biological matrices, including human blood (Leslie et al., 2022), urine (Massardo et al., 2024; Pironti et al., 2022), sputum (Huang et al., 2022), breast milk (Ragusa et al., 2022b), semen (Montano et al., 2023),

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diverse body fluids (collected from cysts, synovia or organ effusions, etc; Guan et al., 2023) and fecal matter (Schwabl et al., 2019). Furthermore, these investigations have illuminated the distribution of MPs within various human organ systems encompassing the lungs (Amato-Lourenço et al., 2021; Baeza-Martínez et al., 2022; Jenner et al., 2022; Ozawa et al., 1986; Pauly et al., 1998), spleen (Kutralam-Muniasamy et al., 2023), liver (Horvatits et al., 2022), kidney (Kutralam-Muniasamy et al., 2023), and colon (Ibrahim et al., 2021). These discoveries are causing concern regarding the potential ramifications of environmental contaminants, specifically MPs, on the health and development of the human fetus (Jummaat et al., 2021).

In addition to MPs, humans are ubiquitously exposed to a diversity of other NPPs, both anthropogenic and natural, from many other sources (Buzea et al., 2007; Griffin et al., 2017). Recent studies have found that human tissues contain diverse NPPs. For example, ambient black carbon and other foreign particles have been discovered in human blood, as well as other tissues and organs including the heart (Calderón-Garcidueñas et al., 2019b), brain (Calderón-Garcidueñas et al., 2019a; Maher et al., 2020), ovaries (Bongaerts et al., 2023), colon (Gatti, 2004) lungs (Campion et al., 2018), liver and kidney (Gatti and Rivasi, 2002; Locci et al., 2019). However, no study to date has attempted to compare the relative levels of these diverse particle types in any tissue.

The placenta is a transitional but vital organ of pregnancy, responsible for all maternal-fetal exchange required to support fetal growth and development. Several recent studies identified the presence of MPs within the human placenta (Amereh et al., 2022; Braun et al., 2021; Garcia et al., 2024; Liu et al., 2022a, 2022b; Ragusa et al., 2022a, 2021; Zhu et al., 2023) and fetal meconium (Braun et al., 2021; Liu et al., 2022a, 2022b) suggesting that MP can cross the placenta. In rodent models of gestational MP exposure, placental uptake has been described, with observed consequences for placental function and compromised fetal growth trajectories (Amereh et al., 2022). Furthermore, studies have revealed the presence of black carbon particulate matter – derived from particulate air pollution - in the human placenta (Bové et al., 2019), cord blood (Bongaerts et al., 2022), and fetal organs (Bongaerts et al., 2022). These findings provide evidence that adverse effects of particulate pollutants – especially air pollution - may arise via direct exposure to internal organs and even in the developing human fetus (Bové et al., 2019).

While placenta may be exposed to MPs from the environment, given the heavy reliance on plastic polymer products within obstetrical health care delivery (Jummaat et al., 2021), there are additional questions surrounding the contributions of post-delivery contamination within the small observational studies reporting these findings, particularly across various delivery environments (i.e. surgical suite for C-section deliveries) (Braun et al., 2021).

The present study aimed to evaluate the accumulation of particulates in human placentas collected from healthy, gestating parents. The Raman micro-spectroscopy was used to specifically detect and characterise particle chemical composition. Detailed investigation of particulate localization across the distinct compartments of the placenta was undertaken, as well as a comparison of particulates in placentas delivered by vaginal or caesarean section (C-section), to address concerns related to delivery environment and potential post-delivery contamination. This approach allows characterization of MPs and many NPPs, thus providing a more comprehensive assessment of particulate exposures.

2. Methods

2.1. Patient recruitment

This study received approval from Health Canada-Public Health Agency of Canada Research Ethics Board (REB 2021-033H), Ottawa Health Sciences Network-The Ottawa Hospital Ethics Board OHSN-REB

20220085-01H, and the University of Ottawa Research Ethics Board (#H-03-22-7960). All recruited women+ had singleton, uncomplicated term pregnancies at The Ottawa Hospital General Campus Birthing Unit. Exclusion criteria for study participation included any obstetrical complication during pregnancy or delivery, C-section delivery for any reason other than breach presentation or repeat C-section delivery, multiple pregnancy, or participants who did not understand either English or French. A total of 10 patients were recruited: 5 undergoing a standard vaginal delivery and 5 undergoing an elective C-section delivery.

2.2. Characterization of potential sample contamination during processing

A plastic-reduced protocol was developed for both vaginal and C-section deliveries. All plastic-containing materials used during a standard vaginal or C-section delivery at The Ottawa Hospital General Campus were identified, and where available a non-plastic alternative material was identified for use during delivery. For those plastic-containing materials that could not be substituted due to institutional standard of care operational procedure (i.e., plastic surgical drape, gloves), items were sampled to determine potential post-delivery contamination signal. Briefly, in a sterile environment, the plastic-containing materials were rinsed three times with 30 ml deionized filtered water, with the rinsate collected into sterile glass bottles. The samples were filtered through a silicon membrane (1 µm retention limit, Microplastic Sample Preparation Kit, Thermo Fisher Nepean, ON) using glass vacuum filtration funnel. Silicon filter membranes were used to collect any MPs in these wash samples as their low optical interference and fine retention diameter (1 µm) ensured a high likelihood of identifying MPs compared with glass fibre membranes required for the more difficult to filter tissue samples (see below). Raman micro-spectroscopy was used to identify the presence and characterise any background plastic contamination, as described below (Section 2.4).

Similarly, plastics reduced conditions were developed for all tissue dissection and sample processing. All plastic materials (with the exception of nitrile gloves) were kept out of the biocontainment hood in which samples were handled and sample filtering was completed. Individuals working in this hood wore only clothing (including lab coats) made from natural fibres (cotton, wool or linen). Prior to use, all containers, sample vials, gloves, and glassware used in transporting, collecting, processing, or storing placenta or blank samples were vigorously rinsed with 50 % of container volume with deionized water that was filtered through glass fibre membranes (Grade F, 0.7 µm retention limit, Cat# F4700, Sterlitech, Auburn, WA).

2.3. Placenta collection

After delivery, all placentas were collected under sterile conditions, placed into a sealed metal container, and transported on ice to the laboratory for processing within 1 h of delivery. Placentas were weighed and placed into a sterile glass Pyrex tray within a biosafety hood. A metal bowl with 10 ml deionized filtered water was placed in the hood to assess the presence of contaminating MPs within the hood air (Hood Blank - HB). Micro-dissections of placental tissue were carried out midway between the placental margin and umbilical cord insertion site. A total of 3 g of placenta tissue was collected from each placenta (1 g per micro-dissection site), specifically, sampling from the basal plate (maternal surface), chorionic villous tissue (maternal-fetal exchange region), and chorionic plate (fetal surface). All samples and HBs were placed in labelled low-particle glass vials and sealed. The water rinsate (100 ml) used in the dissection process was collected into a 125 ml glass Wheaton bottle with phenol cap with polytetrafluoroethylene (PTFE) liner. Prior to sample collection, all vials and containers were rinsed 2 times with deionized water (50 % total container volume) which was pre-filtered through glass fibre membranes (Grade F, 0.7 µm pore size,

Sterlitech). All collected samples were stored at -20°C until digestion.

2.4. Digestion of placenta samples

The digestion of placenta samples used a previously published method (Jenner et al., 2022), with minor modifications, as described. All glassware used to process tissue for MP isolation was washed, rinsed 2X with deionized water then rinsed with filtered deionized water and sealed with caps (vials) or rinsed tinfoil (flasks) prior to use. Vials containing placenta tissue were thawed at room temperature, rinsed with filtered water, and placed within a biocontainment hood. Cleaned and rinsed foil-sealed glass Erlenmeyer flasks (500 ml) were weighed to the nearest 10 mg and placed into the biocontainment hood. For each micro-dissected sample from each placenta, 1 g of placenta tissue was placed into a flask, resealed, and reweighed. The flask was then returned to the hood and 100 ml of filtered (Grade F) 30 % H₂O₂ (>95 %, Thermo Scientific, Nepean) was added. The resealed flasks were then placed in a shaking incubator at 55°C for 11 days at 100 rpm. After the first 5 days of incubation an additional 50 ml of filtered (Grade F) 30 % H₂O₂ was added to the digest sample, which was then placed back in the incubator for an additional 6 days. For each batch of samples digested, an empty flask was included as a Procedural Blank (PB). The PB flask was treated identically to all other flasks except that no tissue was added.

At the end of the incubation period, digests and PBs were filtered through glass fiber membrane (Whatman Grade GF/D, 2.7 µm pore size, Cytivia, Thermo Fisher, Nepean), using a glass vacuum filtration apparatus. Glass filtration assemblies and clamp were pre-warmed to 55°C. Digests were poured through the membrane, followed by 10 ml of filtered (Grade F) deionized water warmed to 55°C to remove any remaining H₂O₂ residue. The glass fiber membranes were then individually placed in separate, clean glass petri dishes with unique identification and left in the plastic-free biosafety hood to dry.

2.5. Characterization of MPs by Raman Micro-spectroscopy

The Raman micro-spectroscopy method was previously published (Rahman et al., 2021). In brief, dried glass fiber membranes were examined using an integrated imaging system that couples an Enhanced Dark Field (EDF) optical microscope (CytoViva, Inc. Auburn, AL, USA) with a confocal Raman imaging system (Horiba Scientific XploRa Plus, Japan). The LabSpec 6 software suite (Horiba Ltd, Piscataway, NJ, USA) was used to acquire the Raman spectral information and KnowItAll spectral database (Bio-Rad Laboratories Inc, Hercules, CA, USA) was used to chemically identify the MPs present and other particulate matter. Membranes were visually scanned under a 10 X objective in a grid fashion to locate all particles adherent to the glass fiber membranes. Upon finding a particle, a brightfield image of the particle was captured (under 50X power) and particle size estimated based on digital image analysis. Using the 10x or 50x objective, the centre of the particle was excited at 532 nm wavelength with 1–10 mW laser power and 300 nm slit and the Raman spectrum collected with 5–25 accumulations and 10–20s exposure duration. The collected spectrum was analyzed using KnowItAll software, which compares the spectrum to a database of Raman spectra (incorporating the SLoPP and SLoPP-E microplastics databases) (Munno et al., 2020) and returns the best spectral match to predict the particle composition.

2.6. Statistical analysis

Demographic data are presented as mean ± standard deviation. Comparisons of numbers of particles between regions and delivery type proceeded in an iterative fashion, with data for MPs and NPPs evaluated separately. Initially, a 2-way ANOVA was attempted on non-transformed data, but the essential assumptions of normality (Shapiro Wilk test) and equal variance (Brown-Forsythe test) required for a parametric test were not met. Subsequently, the effects of delivery on particle numbers in

each placenta region or summed across all regions within each placenta were analysed by 2-sided T-test (if normal based on Shapiro Wilk test) or Mann-Witney rank sum test. Effects of delivery method were tested using the Friedman test, in which data for particle numbers in each separate region were considered repeated measures within each sampled placenta. Differences in particle numbers between placenta region were analysed using the Kruskal Wallis test, as normality testing failed. Significance for all statistical tests was set at p < 0.05. As no tests indicated significant differences, no post-hoc comparisons were used. All statistical analyses were carried out using SigmaPlot (v13.0, Systat Inc, San Jose, CA).

3. Results

3.1. Patient characteristics

Patient demographics, stratified according to mode of delivery, are presented in Table 1. Patients who delivered by C-section had slightly lower gestational ages compared to those delivered vaginally, but this failed to reach statistical significance (38.2 ± 1.30 vs 39.8 ± 1.09 ; p = 0.07). All patients who delivered by C-section were carrying male fetuses (5/5), compared to 60 % of patients in the vaginal delivery group (3/5). No differences were noted for maternal age, birthweight and placental weight, and no smokers were included in either group of patients.

3.2. Post-delivery and environmental MP contamination

Four plastic materials were identified in the delivery and surgical suites of the birthing unit that could not be substituted during the delivery and sampling protocol and underwent MP evaluation. Only one item tested, the surgical drape used during C-section deliveries, demonstrated evidence of MP shedding, with 3 MP particles identified in 30 ml of rinsate, identified as polypropylene (PP) polymers (Supplemental Table 1).

In both HBs and PBs some contaminating fibres were identified, with cotton or human hair source origin (Supplemental Table 2). Of note, these contaminating fiber types would be completely degraded in the sample digestion protocol employed. Nevertheless, fibres were excluded from all enumeration of observed particles in our placenta samples, regardless of their composition. Other types of contaminations shown in Supplemental Table 2 were observed in the HBs from C-section sample 1 (C1), C4, Vaginal sample 1 (V1), V2 and V3 and in PBs of C3, C4, V2 and V3. However, these contaminants were infrequently observed and did not appear to be commonly found in any biological samples tested.

3.3. Identification of MPs in placenta samples

For each patient, 1 gram of tissue was collected from each of the three distinct anatomical regions of the placenta and processed for Raman Micro-spectroscopy (Fig. 1). Identified MPs were noted in all placentas sampled, with a total of 31 MP particles detected across all ten placentas. The number of MPs per placenta varied (ranging from 1–11,

Table 1
Demographic information regarding placenta donors

	Vaginal Delivery (n = 5)	C-Section Delivery (n = 5)	T-Test P- Value
Maternal Age (yrs)	34 ± 3.71^1	33 ± 2.55	0.507
Smoker (n)	0	0	-
Gestational age at delivery (weeks)	39.8 ± 1.09	38.2 ± 1.30	0.07
Fetal Sex n males (%)	3 (60)	5 (100)	-
Birthweight percentile	46 ± 34.5	72.6 ± 29.7	0.23
Placental weight; g	663 ± 133	685 ± 121	0.79

¹ Data presented as mean + std dev.

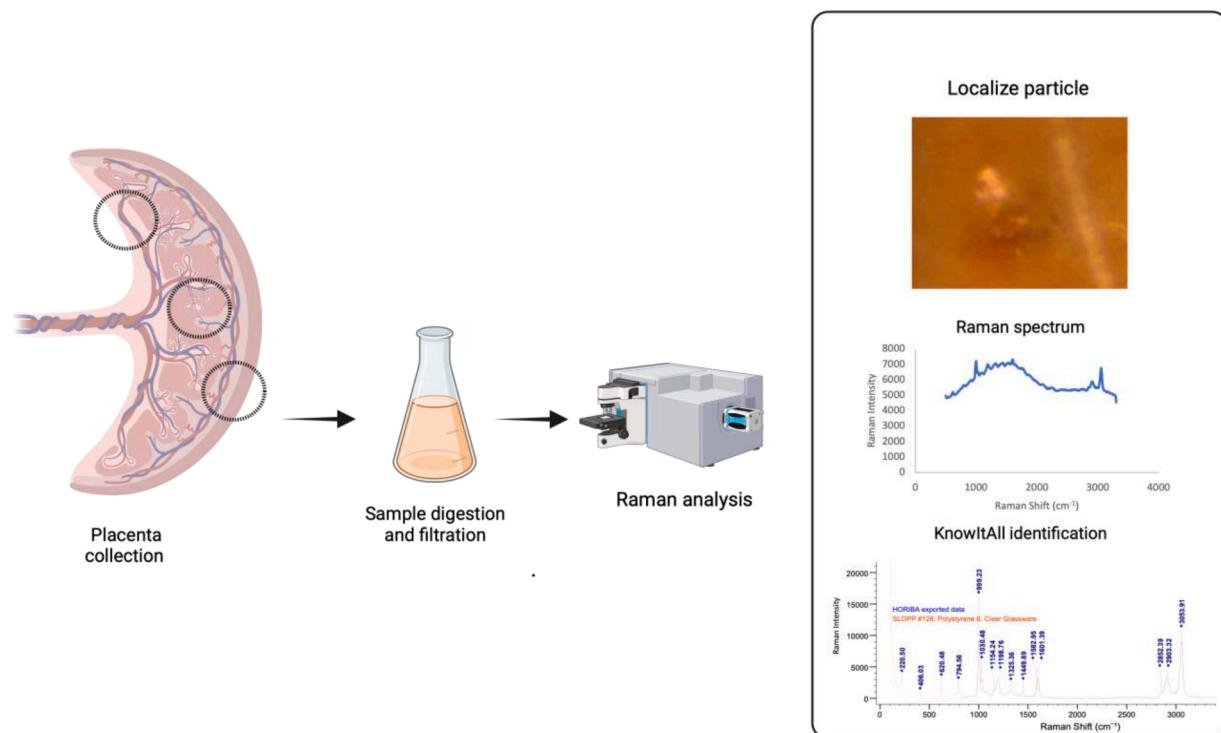


Fig. 1. A description of the methodology by which placenta tissue was sampled and processed for microplastic detection. One gram of placental tissue was collected from each anatomical site (chorionic plate, chorionic villus, and basal plate). Samples were digested in concentrated hydrogen peroxide and filtering through a glass fibre (GF/D) membrane. Microplastics were identified on dried GF/D using Raman micro-spectroscopy, with the generated spectra compared to the KnowItAll database to determine the particulate identity.

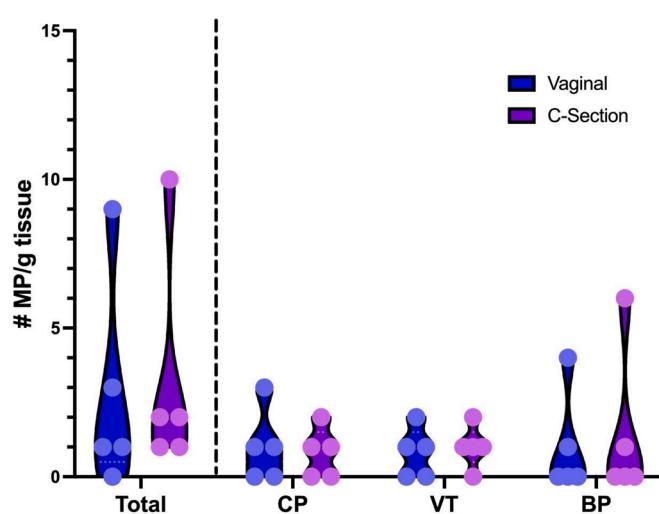


Fig. 2. Violin plots showing all observed microplastics (MP) observed in each placenta – based on region sampled or summed for all samples (Total) – collected from vaginal (blue) and C-section (purple) deliveries. One gram of tissue was collected and processed from each anatomical site for each placenta. BP = basal plate; VT = chorionic villous tissue; CP = chorionic plate.

Fig. 2, with an average of 1 ± 1.2 MP/g of tissue. The identified MPs ranged in size from approximately 2 - 60 μm . No significant differences were observed in the number of identified MPs across the three anatomical regions sampled – the basal plate, the chorionic villous and chorionic plate ($p > 0.05$; **Fig. 2**). There was likewise no difference in the total or localized number of MPs identified according to mode of delivery ($p > 0.05$; **Fig. 2**)

3.4. Characterization of MPs identified within placenta samples

Raman spectra were analyzed for each identified particle and exported into the KnowItAll database software for comparison to a library of spectra from known materials. In the collected placenta samples, the most abundant MP detected was unidentified polymers containing Copper-phthalocyanine, found in 6/10 placentas (range: 0 – 10 /g tissue), however no significant differences were observed according to anatomical location within the placenta or mode of delivery ($P = 0.54$; **Tables 2, and 3**). Polyethylene (PE), polystyrene (PS) and polyvinyl chloride (PVC) were each identified in 2/10 placentas (with 0.3 particles/g tissue for each polymer type and sample). Other common polymers identified in at least one placenta, included polypropylene (PP) and polymethyl methacrylate (PMMA) (both with 0.3 particles/g tissue). While PE was only observed in 1/10 placentas sampled, a total of 7 particles of PE were found across all three placental compartments in that placenta (range: 2 – 3 MP/g tissue). As sample numbers were too small, statistical analysis of differences in MP polymer type according to placental distribution or mode of delivery was not possible for PP, PMMA, and PE. Representative bright field images with associated raman spectra for each of these MPs are depicted in **Fig. 3**. Additional polymers were observed, including 1 styrene isoprene and 1 phthalocyanine (Mortoperm blue - polymer dye), however the polymer matrix containing the dye was not identifiable.

3.5. Identification of non-MPs particles in placenta samples

Raman spectroscopy revealed that most particles observed in digested placenta samples were not MPs: All placenta samples contained NPPs, with a total of 121 NPPs detected across all 10 placentas. The number of NPPs per placenta varied (ranging from 2-34, **Fig. 4**), with an average of 4 ± 2.9 NPPs/g of tissue. The identified NPPs ranged in size from 2 - 100 μm (**Table 4**). There was no significant difference in the total number of NPPs identified according to mode of delivery ($p =$

Table 2

The total number, size distribution, and polymer character of microplastic particles in detected in each subregion of placentas collected following C-section and vaginal deliveries.

MP Polymer	C-section (n= 5)				Vaginal (n=5)			
	BP	VT	CP	Size (um)	BP	VT	CP	Size (um)
PE	-	-	-	-	2	2	3	5 – 20
PP	1	-	-	60	-	-	-	-
PS	-	1	-	7	1	-	-	40
PVC	-	2	-	9 – 15	-	-	-	-
PMMA	-	-	1	3	-	-	-	-
Copper phthalocyanine [#]	6	3	2	2 – 40	2	1	2	12 - 44
Styrene-isopropene	-	-	1	10	-	-	-	-
Mortoperm blue [#]	-	-	-	-	1	-	-	7
All polymers	7	6	4	2 - 60	6	3	5	5 - 44

#Dye used in plastic.

MP = microplastic;; BP = Basal Plate; VT = Chorionic Villous Tissue; CP = Chorionic Plate; PE = Polyethylene; PS = Polystyrene; PP = Polypropylene; PVC = Polyvinyl Chloride; PMMA = Polymethyl methacrylate.

Table 3

The number of microplastic particles identified in placenta tissue - according to polymer type and mode of delivery – observed in each placenta sampled.

MP Polymer	C-Section (n= 5) # MPs identified*					Vaginal delivery (n = 5) # MPs identified*					Total # MPs identified by polymer type
	C1	C2	C3	C4	C5	V1	V2	V3	V4	V5	
PE	-	-	-	-	-	-	-	7	-	-	7
PP	-	-	-	1	-	-	-	-	-	-	1
PS	1	-	-	-	-	-	1	-	-	-	2
PVC	-	-	1	1	-	-	-	-	-	-	2
PMMA	-	-	1	-	-	-	-	-	-	-	1
Copper phthalocyanine [#]	-	1	-	-	10	1	1	2	-	1	16
Styrene-isopropene	-	-	-	-	1	-	-	-	-	-	1
Mortoperm blue [#]	-	-	-	-	-	-	-	-	1	-	1
Total # MPs identified/ Placenta*	1	1	2	2	11	1	2	9	1	1	31

*Total of 3 grams collected per placenta.

#Dye used in some plastic.

Polyethylene (PE); Polystyrene (PS); Polypropylene (PP); Polyvinyl Chloride (PVC); Polymethyl methacrylate (PMMA).

0.155; Fig. 4, Table 4).

3.6. Characterization of non-MPs particles in placenta samples

Non-MP particle composition was also identified in placenta samples using Raman micro-spectroscopy, with confirmation of particle identity through KnowItAll database. A total of 29 unique particle identities were captured (Supplemental Table 3), with the most abundant particles identified as carbon, graphite, lead oxide and bayerite composition (Tables 4 and 5). Each of these particles were observed in 2-3 different placentas, ranging from 1-22 total particles per placenta (1.5 ± 1.1 particles/g of tissue). No significant differences were observed in the

specific non-MP particle type according to anatomical location within the placenta or mode of delivery ($P > 0.05$; Tables 4 and 5). Representative bright field images with associated raman spectra for each of these MPs are depicted in Fig. 5. It should be noted that there were 12 particles for which Raman spectral analysis was inconclusive and, therefore, could not be identified (Table 5).

4. Discussion

The major findings of this study indicate the presence of both MP and NPPs in all placentas sampled, distributed across all placental compartments and unrelated to the mode of delivery. This small sample size

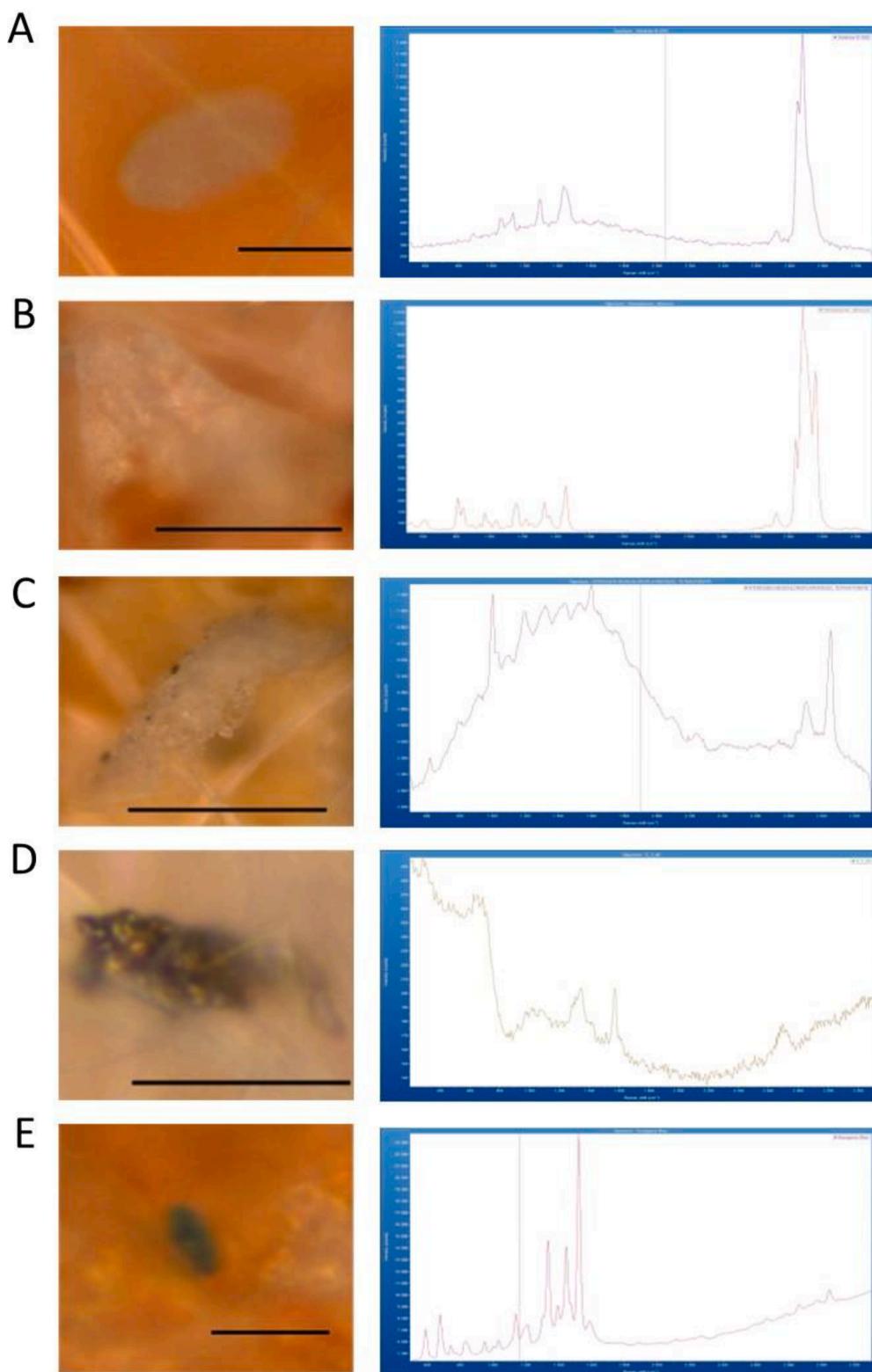


Fig. 3. Representative brightfield images (left) and associated Raman spectra (right) of common types of microplastics observed in human placenta samples. **A**) Polyethylene (PE) – scale bar represents 5 µm, **B**) Polypropylene (PP) – 10 µm, **C**) Polystyrene (PS) – 10 µm, **D**) Polyvinyl Chloride (PVC) – scale bar 10 µm, **E**) Copper phthalocyanine – 5 µm.

was selected from individuals whose singleton pregnancies were uncomplicated, delivering within a tertiary care hospital setting, in a large Canadian city (Ottawa, Ontario). While these exposure levels may not represent the diversity of exposures across the Canadian population, it provides insight regarding routine particulate exposures of pregnant

individuals within a major urban region in Canada. To the best of our knowledge this study is the first to report presence of MPs in human placentas within a Canadian population.

Our findings are mostly consistent with those reported in recent publications (Amereh et al., 2022; Braun et al., 2021; Garcia et al., 2024;

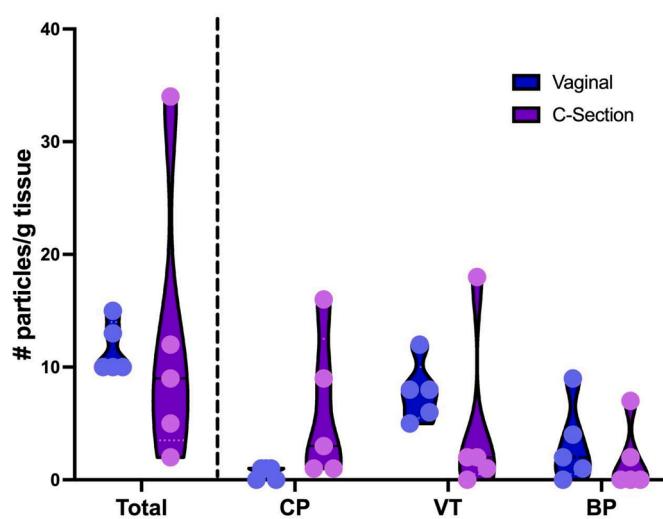


Fig. 4. Violin plots depicting total and region-specific number of non-microplastic particles identified in placenta tissue collected from vaginal (blue) and C-section (purple) deliveries. One gram of tissue was collected and processed from each anatomical site for each placenta. BP = basal plate; VT = chorionic villous tissue; CP = chorionic plate.

Ragusa et al., 2021; Weingrill et al., 2023). Notably, the current study found MP contamination in all placentas sampled (100 %, n = 10), whereas smaller observational studies carried out in Italian and German urban city obstetrical populations (Braun et al., 2021; Ragusa et al., 2021) have reported MPs in less than 70 % of placentas analysed. The current study further identified the presence of NPPs in all placentas sampled, many composed of synthetic materials. This is consistent with a recent study that used reflectance-Fourier transform infrared spectroscopy to identify particles in digests from human placentas and estimated that roughly one quarter and three quarters of observed foreign particles were NPP and MP particles, respectively (Garcia et al., 2024). Unlike the current study where pure carbon particles were the most common NPP observed, Garcia and colleagues did not observe any pure carbon particles in placenta samples (Garcia et al., 2024). Carbon particle contamination of term placentas has previously been found to correlate with levels of black carbon found in dust within an individual's home during pregnancy (Bové et al., 2019).

An important consideration when interpreting the scope of the presented MP (1 ± 1.2 MPs/g tissue) and NPPs (4 ± 2.9 non-MPs/g tissue) accumulation within the placenta, is the total size of this organ of

pregnancy at the time of delivery – typically ranging from 550–650 grams. As such, in our sampled Canadian population, we estimate that the average placenta may contain upwards of 650 MPs and 2,600 NPPs at the end of gestation. A second critical consideration for data interpretation, is the current technical limitations of MP and NPPs identification by Raman Micro-spectroscopy at the lower end of the particle size spectrum (<1 μm). The smallest particles detected in the current study were ~2 μm – aligned with both the pore size of the glass fibre filters used to harvest particles from the sample digests and the lower threshold of detection of this current technology (Araujo et al., 2018). Due to the higher bioavailability of smaller particles throughout the human body and placenta (Wick et al., 2010), it is likely that smaller particles are present in the placenta that were not accounted for in the presented measurements. As such, the reported concentrations are underestimates of total particle accumulation in the placenta. Importantly, we did note considerable variability in total placenta particle load between individuals, ranging from 0.3 to 11.3 particles/g tissue. The placenta is also a large and highly heterogeneous organ, and as such there may also be variability based on sampling site. Future work, focused on better understanding the associations between gestational MP/NPPs exposures and geo-demographical variables, along with placental distribution is warranted.

The chemical character of MP and NPPs were identified for most particles detected in the current study – with the most common MP identified as PE, PP, PS and PVC, and the most common NPP identified as carbon, graphite and lead oxide. While these characterizations are important for understanding relevant gestational exposures, concrete determination of original sources of the exposures is not possible. However, we can look to commonly known sources to gain perspective on potential sources. PE is widely used in packaging – including food packaging - and items with short functional lifespans including plastic bags, plastic cling film packaging, bottles, etc (Geyer et al., 2017; Kadac-Czapska et al., 2023). PP is widely used in packaging, transportation of materials, and consumer products including plastic bottles, indoor-outdoor carpets, microwavable containers, and disposable face masks (Geyer et al., 2017; "Science of Plastics," n.d.). PS is found as a solid or expanded foam (styrofoam) and has a broad array of uses including many of single use products used in biomedical applications, disposable food containers and cutlery and packaging (American Chemistry Council, 2022; Geyer et al., 2017) while PVC has diverse uses in building material, consumer products, be found in plastic pipes, synthetic leather, clear food wrap, flooring materials and soft toys, among others (Geyer et al., 2017). Likewise, the most abundant NPPs identified are pervasive in the environment. Black carbon particle is a major constituent of air pollution, the result of incomplete combustion

Table 4

Total number, distribution, and composition of detected non-MP particles per gram tissue in placentas collected following C-section and vaginal deliveries.

Non-MP Particle	C-section (n= 5)				Vaginal (n=5)			
	BP	VT	CP	Size (μm)	BP	VT	CP	Size (μm)
Carbon [#]	5	-	-	10 - 25	-	3	2	3 - 15
Graphite	5	4	-	2 - 25	-	8	1	5 - 16
Lead Oxide	4	5	1	12 - 40	-	-	-	-
Bayerite	3	2	-	6 - 60	-	5	-	12 - 34
Other [^]	11	10	3	3 - 80	3	23	11	4 - 100
Unknown ⁺	2	6	1	3 - 40	-	1	2	8 - 80

[#]Includes black carbon, diamond like carbon

[^]Includes less frequently found polymers, details included in **Supplemental Table 4**

⁺Spectrum could not be identified through Raman spectra and KnowItAll database.

Basal Plate (BP); Chorionic Villous Tissue (VT); Chorionic Plate (CP)

Table 5

The number of non-microplastic particles identified in placenta tissue according to particle type and mode of delivery.

Particle type	C-Section (n= 5) # particles identified*					Vaginal delivery (n = 5) # particles identified*					Total # of particles identified by type
	C1	C2	C3	C4	C5	V1	V2	V3	V4	V5	
Carbon [#]	5	-	-	-	-	2	-	-	3	-	10
Graphite	-	-	9	-	-	-	-	8	-	1	18
Lead Oxide	-	-	9	1	-	-	-	-	-	-	10
Bayerite	-	-	4	-	1	-	-	-	5	-	10
Other [^]	4	-	6	11	3	11	13	2	2	9	61
Unknown ⁺	-	2	6	-	1	2	1	-	-	-	12
Total # particles identified/ Placenta*	9	2	34	12	5	15	14	10	10	10	121

*Total of 3 grams collected per placenta.

[#]Includes black carbon, diamond like carbon[^]Includes frequently observed particle types, details included in Supplemental Table 3⁺Spectrum could not be identified through Raman spectra and KnowItAll database.

of fossil fuels (Canada, 2023). There are multiple industrial uses of natural and synthetic graphite that result in significant environmental release of airborne particulates (Zhang et al., 2023), whereas lead oxide particles could arise from the use of lead in old batteries, from pigments in old white paint (especially white), or gas sensors (Bratovicic, 2020). The prominent uses and potential sources of exposure to NPP are listed in Supplemental Table 4. The frequency of use of these products and materials represents a wide range of potential exposures to humans.

The distribution of MPs and NPPs across all three regions of the placenta sampled suggest that the placenta does not act as a barrier to fetal particulate exposure. Had there been a notable concentration uniquely located on the maternal surface (basal plate), one could have inferred a selective barrier function of the placenta regarding MP and NPPs transfer to the fetal compartment. The presence of MPs throughout the placenta certainly warrants concern regarding the functional impact of these particles on placental integrity and function (i.e., maternal-fetal exchange, hormone production etc.) and certainly infer MP translocation into the fetal compartment. Indeed, ex vivo placenta perfusion studies have confirmed the transfer of PS nanoplastics from maternal to fetal compartments (Grafmueller et al., 2015; Wick et al., 2010). Furthermore, the detection of MPs in the meconium of newborn infants (Braun et al., 2021; Liu et al., 2022a, 2022b) and amniotic fluid at term (Xue et al., 2024) provides clear evidence of *in utero* fetal exposure to MPs.

The widespread distribution of MPs across all placenta samples underscores the significance of investigating their potential consequences on placental function and fetal development, an area of investigation that has been relatively unexplored, particularly in human populations. Evidence collected using rodent models of gestational MP exposure have demonstrated smaller placentas (Fournier et al., 2020; Hu et al., 2021; Nie et al., 2021), impaired feto-placental and utero-placental vasculature development (Chen et al., 2022; Hu et al., 2021), disturbances in uterine immune cell balance (Hu et al., 2021) and placental metabolic disruption (Aghaei et al., 2022; Chen et al., 2022). In vitro exposure of human placental tissue to MPs has also been shown to alter expression of genes and proteins related to inflammation and iron homeostasis (Chortarea et al., 2023). A recent study showed an inverse correlation between the accumulation of MPs in the placenta and birthweight (correlation coefficient, $r = -0.82$, $p < 0.001$), with similar associations observed for neonatal length at birth, head circumference, and 1 min APGAR scores (Amereh et al., 2022). In addition, the levels of MPs

detected in amniotic fluid collected at delivery was inversely related to gestational age (Xue et al., 2024) suggesting that *in utero* exposures to MPs tends to cause earlier labour. Notably, non-MP black carbon particles have also been identified in higher concentrations within placentas of pregnancies complicated by pre-term delivery and/or FGR, compared to healthy controls (Amereh et al., 2022; Bové et al., 2019).

Analysis was also conducted to assess the impact of the mode of delivery, specifically caesarean and vaginal deliveries, on the presence of both MPs and non-MP particles within placental tissues. The objective was to discern whether any disparities in the quantity or types of MPs detected in placentas from these delivery modes could shed light on whether contamination occurred post-delivery or resulted from *in utero* accumulation during placental development. The absence of significant variations in MPs and non-MPs levels between the two delivery modes supports the hypothesis that MPs contaminate the placental tissue during gestation rather than after birth. This outcome also reflects the effectiveness of the measures taken to minimize plastic contamination throughout the delivery process, placenta dissection, sample collection, storage, digestion, and all other phases of sample handling and analysis. This confidence in the prevention of contamination is further supported by the near absence of particle contamination of PBs, which served to monitor potential sources of contamination during sample dissection and sample processing. In instances where particles were noted in the PBs, they did not bear resemblance to the particles found within the placenta samples. Furthermore, the presence of particles within the chorionic villous region of the placenta, located deep within the organ and shielded from external contact during delivery, provides evidence that these particles were present *in utero*. While this does not completely rule out the possibility that some particulate contamination of the placenta surface may have occurred post delivery, these collective observations strengthen the conclusion that most MP particles identified in placental samples are indicative of *in utero* exposure, rather than due to post-delivery contamination, and contribute to the growing body of evidence that particulate pollution reaches into the human womb.

5. Conclusions

This study observed both MPs and non-plastic foreign particles in human placentas collected at term. Particles were found in all placentas tested, and throughout the various compartments of the placenta – demonstrating the ability of these particles to translocate into the fetal

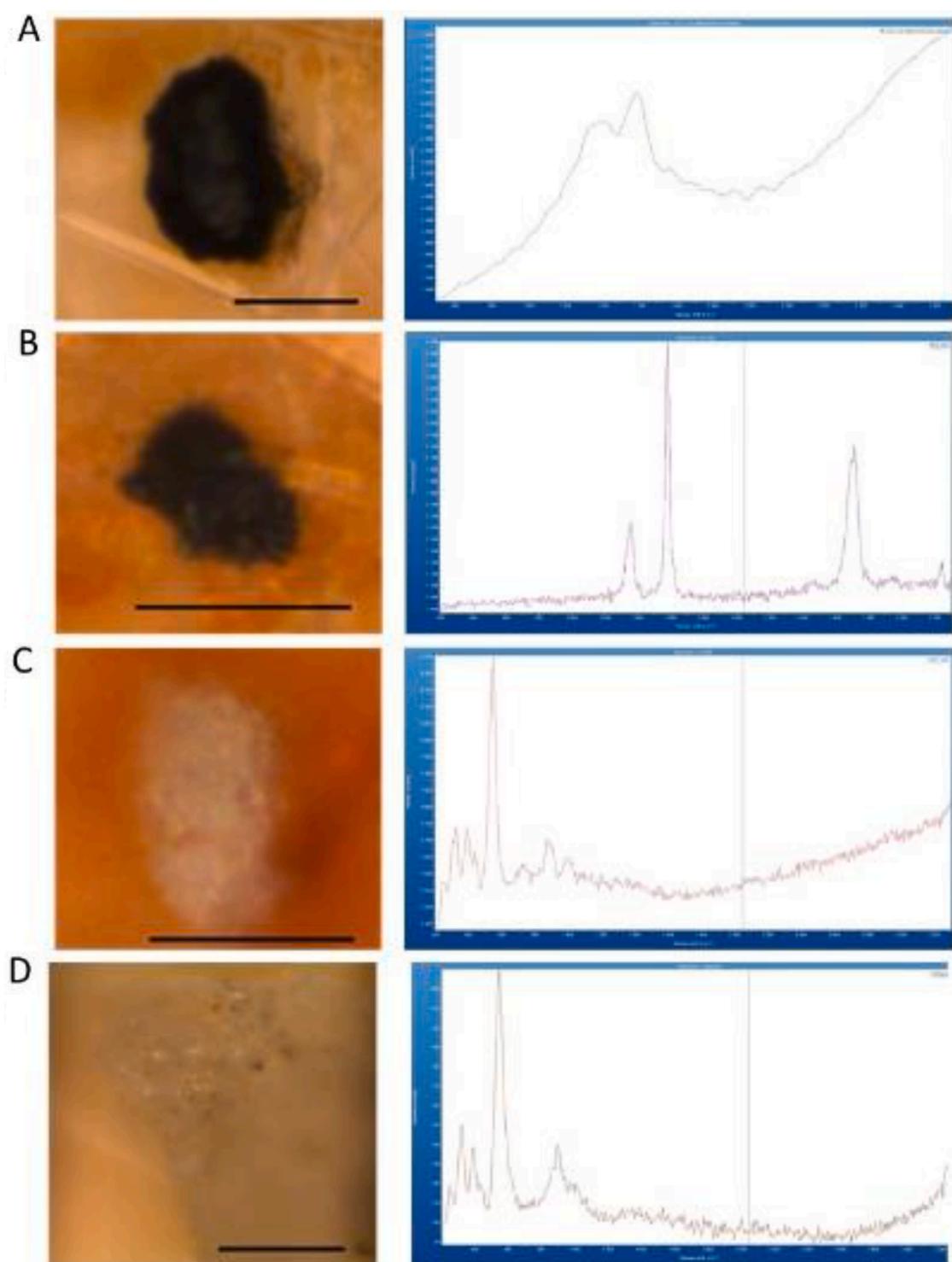


Fig. 5. Representative brightfield images (left) and their associated Raman spectra (right) of common types of non-microplastic particles observed in human placenta samples. A) Carbon – scale bar represents 5 μm , B) Graphite – 10 μm , C) Lead Oxide – 10 μm , D) Bayerite – 5 μm .

compartment. Although the analytical methodology used in this study cannot detect particles of 1 μm and below, thus, underestimating exposure to plastic particles, the ubiquitous nature of exposure observed suggests that further work is critical to understand the risks posed by plastic pollution to the health of the gestational parent and child.

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CRediT authorship contribution statement

Rewa E. Zurub: Writing – original draft, Validation, Methodology, Formal analysis, Data curation. **Shannon Bainbridge:** Writing – review & editing, Resources, Methodology, Investigation. **Luna Rahman:** Writing – review & editing, Methodology. **Sabina Halappanavar:**

Writing – review & editing, Methodology, Funding acquisition. **Darine El-Chaar**: Coordination of donor recruitment. **Michael G. Wade**: Writing – review & editing, Resources, Project administration, Methodology, Funding acquisition, Conceptualization.

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.

Data availability

Data will be made available on request.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at [doi:10.1016/j.envadv.2024.100555](https://doi.org/10.1016/j.envadv.2024.100555).

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