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Ventilator Circuits as a Potential Source of Airway Microplastics in Mechanically Ventilated Neonates

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Article

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Abstract

Background

Mechanically ventilated neonates experience sustained contact with polymer-containing respiratory devices, yet paired evidence linking used ventilator circuits with airway microplastic findings is scarce.

Methods

This prospective single-center paired observational study included 20 neonates receiving invasive ventilation. Airway secretion was retained only during clinically indicated suction, and the corresponding used inspiratory-limb patient-end inner surface was rinsed ex vivo after circuit exchange or extubation. Confocal micro-Raman spectroscopy was used for particle identification. A complementary 72-h bench experiment compared PE particle counts in patient-end gas output with system blanks and in eluates from unused and post-run circuits.

Results

Microplastics were detected in 15 of 20 airway secretion samples (75.0%) and 17 of 20 circuit rinse samples (85.0%). Airway and circuit particle counts increased across ventilation-duration groups (Kruskal-Wallis $P = 0.021$ and $P = 0.003$, respectively), and paired circuit and airway counts were correlated (Spearman rho = 0.820, $P < 0.001$). In the bench experiment, patient-end gas output contained more PE particles than system blanks (median 12.0 [IQR 8.0–17.0] versus 1.0 [1.0-1.8] particles/m3; exact $P = 0.0004$). Post-run circuit eluates also exceeded unused circuit eluates (11.0 [9.0–13.0] versus 2.0 [2.0–3.0] particles/10 mL; exact $P = 0.000041$).

Conclusions

Paired clinical findings and controlled bench results support ventilator-circuit-associated airway microplastic exposure. The data show that PE particles can be released from circuits under bench conditions and that circuit use is associated with microplastic burden in airway secretion samples. Larger studies with unused suction-device controls and repeated clinical sampling are needed to establish in vivo transfer and clinical relevance.

Introduction

Microplastics are a heterogeneous group of synthetic polymer particles for which terminology, size limits, and reporting conventions require explicit definition [1–3]. Their production, use, and fragmentation have created widespread human exposure opportunities, including through inhalation and medical care [2, 4–6]. Polymer particles have been reported in human blood, placenta, and lung tissue, although their clinical implications remain uncertain and analytical contamination remains a central concern [7–10].

The neonatal intensive care unit is a distinct exposure setting. Infants who require invasive ventilation are continuously in contact with respiratory circuits, endotracheal tubes, suction systems, humidification components, and other polymer-containing devices. Evidence from neonatal parenteral nutrition circuits demonstrates that microplastics can migrate from a medical circuit under ex vivo conditions [14]. Plastic particles have also been detected in patients undergoing cardiac surgery, underscoring the need to study iatrogenic exposure pathways without assuming causation [13, 15].

The respiratory circuit has not been adequately evaluated as a paired exposure context in neonates. We therefore combined paired clinical sampling with a controlled in vitro release experiment. We compared microplastic findings in

airway secretion retained during routine suction with rinses from the used inspiratory-limb patient end of the corresponding ventilator circuit. The in vitro experiment tested whether PE particles could be detected at the patient-end gas output and whether circuit eluates differed before and after 72 h of use. Our objective was to assess convergent evidence for ventilator-circuit-associated airway microplastic exposure while recognizing that the clinical component alone cannot establish source-to-recipient transfer or tissue deposition.

Materials and Methods

Study design and setting

This prospective, single-center, paired observational study was conducted in the neonatal intensive care unit of The Affiliated Guangdong Second Provincial General Hospital of Jinan University, Guangzhou, China, between 1 February 2026 and 1 August 2026. The analytic cohort comprised 20 neonates receiving invasive mechanical ventilation with an SLE5000-compatible single-use polyethylene respiratory circuit. One airway secretion sample and one corresponding used-circuit rinse sample were analyzed for each neonate.

The study was approved by the Medical Ethics Committee of Guangdong Second Provincial General Hospital, Jinan University (approval number: 2026-KY-KZ-146-02). Written informed consent was obtained from each participant's legal guardian.

Clinical information and group definition

Gestational age, birth weight, sex, primary diagnosis, cumulative invasive ventilation duration, airway specimen volume, and sampling time were recorded. For descriptive comparisons, participants were categorized by cumulative invasive ventilation duration as short term (< = 3 days), intermediate (4–7 days), or long term (> = 8 days). These strata were used to present exposure-duration gradients and were not interpreted as independent clinical risk categories.

Paired specimen collection

Airway secretion was retained only when endotracheal suction was clinically indicated; no suctioning was performed for research purposes. The retained specimen volume was recorded. In the same sampling window, and only after planned circuit replacement or extubation, the used inspiratory-limb patient-end section was sealed and transferred for analysis. The patient-end internal surface was rinsed ex vivo with a standardized 10 mL volume of ultrapure water. Thus, circuit sampling did not require circuit rinsing while a patient remained connected.

Collection and processing followed contamination-minimizing procedures used in the investigators' prior neonatal microplastic work. Samples were handled in cleaned glass containers where feasible; glass test tubes, beakers, and pipettes were used for laboratory processing. The circuit and routine suction hardware are themselves potential plastic-contact sources, which is considered explicitly in the interpretation of the results.

In vitro circuit release experiment

A complementary 72-h bench experiment was performed with single-use polyethylene respiratory circuits. Patient-end gas output was sampled after a total gas volume of 1,000 L in nine runs. Six system blanks underwent the same gas-output sampling workflow. In a separate eluate comparison, nine unused circuits and nine circuits after 72 h of bench use, distributed across production lots L1-L3, were rinsed with 10 mL ultrapure water. PE particle counts were normalized to particles/m3 for gas output and particles/10 mL for circuit eluates. The same digestion, filtration, confocal micro-Raman identification, and spectrum-match criteria used for clinical samples were applied to the bench samples.

Microplastic isolation and identification

Airway secretion and circuit-rinse samples underwent nitric-acid digestion in glass vessels at 50 degrees C for 3 days. Digestates were filtered onto 1.0 micrometer silicon membranes. Confocal micro-Raman analysis was performed on a Thermo DXR3xi system using a 532-nm laser, 6-mW laser power, a 50x objective, 0.05-s exposure, and five scans. Spectra were assessed against the configured Raman and microplastic libraries; a library-match score of at least 80 was required for polymer assignment. A sample was considered microplastic-positive when at least one Raman-confirmed particle was identified. Particle count, abundance (particles/mL), mean particle diameter, and polymer classification were recorded.

Quality assurance and quality control

Reagent, transport, equipment, and procedural blanks were processed with the clinical analytic batch. An airborne blank was also included. The bench experiment included system blanks and unused-circuit eluate controls. The blank framework was reported transparently rather than used to infer absence of contamination, in keeping with recommendations that field, laboratory, and procedural contamination be documented in microplastic research [17–20].

Statistical analysis

Continuous variables are summarized as median (interquartile range [IQR]) and categorical variables as n (%). Kruskal-Wallis tests compared clinical continuous outcomes and Fisher exact tests compared clinical detection frequencies across duration groups. Paired detection status was summarized by an exact McNemar test and Fisher exact test. Spearman correlations assessed associations among ventilation duration, circuit particle count, and airway particle count. An exploratory partial Spearman correlation between circuit and airway count was calculated controlling for ventilation duration. In vitro two-group comparisons used two-sided exact permutation tests based on the rank ordering of normalized PE particle counts. Production lot was retained as descriptive metadata and was not a prespecified primary comparison. Because the clinical sample was small and gestational age and birth weight were strongly correlated with ventilation duration, no multivariable causal model was fitted. All P values are two-sided and unadjusted; $P < 0.05$ was considered statistically significant. Analyses were performed in R (version 4.5.2).

Results

Participant and sampling characteristics

The 20 participants had a median gestational age of 33.4 weeks (IQR 30.8–34.6) and birth weight of 1,985 g (IQR 1,462-2,152); 10 (50.0%) were male. Median cumulative invasive ventilation duration was 118.5 h (IQR 68.8–198.0). Seven participants were classified as short term, seven as intermediate, and six as long term (Table 1).

Table 1
Participant and sampling characteristics by cumulative invasive ventilation duration.

Characteristic	Overall (n = 20)	Short term (n = 7)	Intermediate (n = 7)	Long term (n = 6)
Gestational age, weeks	33.4 (30.8, 34.6)	35.1 (34.6, 35.9)	33.2 (32.6, 33.8)	29.6 (29.0, 30.3)
Birth weight, g	1985 (1462, 2152)	2270 (2165, 2435)	1960 (1840, 2030)	1225 (1138, 1372)
Male sex, n (%)	10 (50.0)	4 (57.1)	3 (42.9)	3 (50.0)
Invasive ventilation duration, h	118.5 (68.8, 198.0)	60.0 (46.5, 67.5)	122.0 (109.0, 138.0)	270.0 (225.0, 324.0)
Airway specimen volume, mL	0.30 (0.28, 0.31)	0.29 (0.28, 0.30)	0.31 (0.29, 0.33)	0.29 (0.28, 0.31)

Values are median (IQR) unless otherwise indicated. Groups were defined by cumulative invasive ventilation duration.

Paired microplastic findings

Microplastics were detected in 15/20 airway secretion samples (75.0%; exact 95% CI 50.9%-91.3%) and 17/20 circuit rinse samples (85.0%; exact 95% CI 62.1%-96.8%). Median particle count was 2.0 (IQR 0.8–4.2) in airway secretion and 2.5 (IQR 1.0-5.2) in circuit rinse samples. All positive sample polymer classifications were polyethylene. Among paired detection results, 13 pairs were positive in both matrices, 1 pair was negative in both, 2 were airway-positive/circuit-negative, and 4 were airway-negative/circuit-positive. Detection positivity was not associated across matrices (Fisher exact P = 1.000; exact McNemar P = 0.688).

Table 2
Paired microplastic findings in airway secretion and ventilator circuit rinse samples.

Outcome	Overall (n = 20)	Short term (n = 7)	Intermediate (n = 7)	Long term (n = 6)	P value
Airway secretion samples					
Microplastic-positive samples, n (%)	15 (75.0)	4 (57.1)	6 (85.7)	5 (83.3)	0.545
Particle count, n	2.0 (0.8, 4.2)	1.0 (0.0, 1.0)	3.0 (1.5, 4.0)	8.0 (4.0, 10.5)	0.021
Abundance, particles/mL	6.15 (2.50, 13.35)	3.33 (0.00, 3.73)	10.00 (4.85, 12.16)	26.45 (12.97, 34.37)	0.020
Mean particle diameter, micrometers	27.3 (22.8, 33.6)	20.5 (19.4, 22.8)	26.6 (24.6, 29.0)	38.7 (35.1, 41.3)	0.008
Predominant polymer	PE	PE	PE	PE	-
Ventilator circuit rinse samples					
Microplastic-positive samples, n (%)	17 (85.0)	5 (71.4)	6 (85.7)	6 (100.0)	0.742
Particle count, n	2.5 (1.0, 5.2)	1.0 (0.5, 1.5)	3.0 (2.5, 5.0)	10.5 (6.0, 13.5)	0.003
Abundance, particles/mL	0.25 (0.10, 0.53)	0.10 (0.05, 0.15)	0.30 (0.25, 0.50)	1.05 (0.60, 1.35)	0.003
Mean particle diameter, micrometers	27.4 (22.5, 34.2)	20.7 (20.1, 22.4)	28.6 (24.5, 30.8)	38.5 (34.9, 42.3)	0.004
Predominant polymer	PE	PE	PE	PE	-

Values are median (IQR) unless otherwise indicated. P values are from Kruskal-Wallis tests for continuous outcomes and Fisher exact tests for categorical outcomes. Mean particle diameter is reported for positive samples only. PE, polyethylene.

A representative Raman-confirmed polyethylene particle from an airway secretion sample is shown in Fig. 1.

Ventilation duration and particle burden

Airway particle count increased across the three duration groups (median 1.0, 3.0, and 8.0 particles for short, intermediate, and long duration; P = 0.021). Circuit particle count likewise increased (median 1.0, 3.0, and 10.5 particles; P = 0.003). The same directional pattern was observed for abundance and mean particle diameter in both matrices (Table 2 and Fig. 3). Ventilation duration was strongly associated with airway particle count (rho = 0.775, P < 0.001) and circuit particle count (rho = 0.880, P < 0.001).

Paired circuit and airway count association

Circuit and airway particle counts were strongly correlated in the paired samples (rho = 0.820, P < 0.001; Fig. 4). In exploratory analysis controlling for cumulative ventilation duration, the partial Spearman correlation remained positive (r = 0.459, P = 0.042). This result is compatible with a relationship between particle burdens but does not identify the direction or source of exposure.

Individual paired particle counts, abundances, and the recorded specimen or rinse volumes are shown in Table 3. Dry weight was not measured in this study and is therefore not reported.

Table 3
Individual paired microplastic findings and recorded specimen volumes.

Participant ID	Ventilation duration, h	Airway specimen volume, mL	Airway count, n	Airway abundance, particles/mL	Circuit rinse volume, mL	Circuit count, n	Circuit abundance, particles/mL	Predominant polymer
Num.1	29	0.28	0	0.00	10.0	0	0.00	Not detected
Num.2	43	0.31	0	0.00	10.0	1	0.10	PE
Num.3	50	0.25	1	4.00	10.0	1	0.10	PE
Num.4	60	0.30	1	3.33	10.0	0	0.00	PE
Num.5	65	0.27	0	0.00	10.0	2	0.20	PE
Num.6	70	0.33	2	6.06	10.0	2	0.20	PE
Num.7	72	0.29	1	3.45	10.0	1	0.10	PE
Num.8	96	0.28	0	0.00	10.0	2	0.20	PE
Num.9	103	0.32	2	6.25	10.0	0	0.00	PE
Num.10	115	0.30	3	10.00	10.0	3	0.30	PE
Num.11	122	0.29	1	3.45	10.0	3	0.30	PE
Num.12	132	0.35	4	11.43	10.0	5	0.50	PE
Num.13	144	0.31	4	12.90	10.0	5	0.50	PE
Num.14	168	0.34	5	14.71	10.0	6	0.60	PE
Num.15	192	0.30	3	10.00	10.0	5	0.50	PE
Num.16	216	0.28	0	0.00	10.0	2	0.20	PE
Num.17	252	0.32	7	21.88	10.0	9	0.90	PE
Num.18	288	0.29	9	31.03	10.0	12	1.20	PE
Num.19	336	0.31	11	35.48	10.0	14	1.40	PE
Num.20	384	0.27	13	48.15	10.0	16	1.60	PE

Abundance is particles per mL. PE, polyethylene.

Quality control findings

No particles were detected in the reagent, transport, equipment, or procedural blanks from the clinical analytic batch. One particle, with a mean diameter of 32 micrometers, was detected in the airborne blank. These clinical blank results

document background contamination but cannot exclude collection-related contribution from the suction pathway. The separate system-blank and unused-circuit controls from the bench experiment are reported with the in vitro results (Table 5).

Table 4
Quality assurance and quality control findings.

Control	n	Particle count	Finding
Reagent blank	1	0	Not detected
Transport blank	1	0	Not detected
Equipment blank	1	0	Not detected
Procedural blank	1	0	Not detected
Airborne blank	1	1	Mean diameter 32 micrometers

In vitro evidence for circuit-associated PE release

In the 72-h bench experiment, all nine patient-end gas-output samples contained Raman-confirmed PE particles. The normalized count was 12.0 particles/m3 (IQR 8.0–17.0), compared with 1.0 particles/m3 (IQR 1.0-1.8) in six system blanks (exact P = 0.0004). In the circuit-eluate comparison, post-run circuits contained 11.0 particles/10 mL (IQR 9.0–13.0), whereas unused circuits contained 2.0 particles/10 mL (IQR 2.0–3.0; exact P = 0.000041). These results show a controlled, circuit-associated increase in PE particle counts at the patient end and on the circuit inner surface (Table 5 and Fig. 5).

Table 5
In vitro polyethylene particle counts in ventilator-circuit release experiments.

Comparison	Control	After 72 h	Exact P value
Patient-end gas output, particles/m3	System blank (n = 6)	Patient-end output (n = 9)	0.0004
	1.0 (1.0, 1.8)	12.0 (8.0, 17.0)	
Circuit eluate, particles/10 mL	Unused circuit (n = 9)	Post-run circuit (n = 9)	0.000041
	2.0 (2.0, 3.0)	11.0 (9.0, 13.0)	

Values are median (IQR). Counts were normalized to the stated gas or eluate volume. All reported particles were classified as polyethylene by confocal micro-Raman spectroscopy.

Discussion

In this paired clinical cohort, microplastics were frequently detected in both airway secretion and used ventilator-circuit rinse samples, and particle counts increased with cumulative invasive ventilation duration. The complementary bench experiment detected PE particles at the patient-end gas output and showed higher PE counts in post-run than unused-circuit eluates. Together, these data provide convergent support for ventilator-circuit-associated microplastic exposure in mechanically ventilated neonates.

The detection of polymer particles in human blood, placenta, and lung tissue has motivated investigation of exposure routes in especially vulnerable populations [7–12]. The neonatal intensive care unit contains several plausible polymer-contact pathways. A recent ex vivo study of neonatal parenteral nutrition circuitry found particle migration under simulated infusion conditions [14], and our prior neonatal study associated microplastic burden with parenteral-nutrition exposure duration [22]. The present study extends this exposure framework to the respiratory circuit by combining paired clinical specimens with a bench release experiment.

The clinical association between circuit and airway particle counts remained positive after exploratory control for ventilation duration. The bench findings make a circuit contribution more plausible because they show PE particles at the patient-end gas output and increased surface-associated PE after standardized circuit use. Nevertheless, a count-level association does not identify an individual particle's pathway into a specific airway secretion specimen. Shared environmental exposure, circuit shedding, suction-device contributions, and residual contamination remain possible explanations for part of the clinical signal.

Polyethylene was the predominant polymer in positive clinical samples and the polymer identified in the bench experiment. The agreement between the clinical and bench findings is consistent with a circuit-related exposure pathway, but polymer concordance alone is not source confirmation because polyethylene is common in clinical and environmental materials. Source attribution would be strengthened further by Raman comparison of the unused circuit material, lot-specific unused-circuit controls, and matched unused suction-catheter or specimen-trap controls.

The study has several strengths. It used paired airway and used-circuit specimens, avoided research-specific airway suctioning, standardized the circuit-rinse volume, and documented multiple clinical blank types. It also added a controlled 72-h bench experiment with system-blank and unused-circuit eluate comparators. Raman-based polymer identification and transparent reporting of analytic parameters align with recommendations for microplastic research [17–20].

Limitations are substantial. The clinical cohort was small, single-center, and selected from infants requiring invasive ventilation. A single post-use circuit rinse cannot quantify individual release over time or distinguish material shedding from all external sources. The bench experiment demonstrates release under controlled conditions but does not recreate neonatal airway physiology, clinical humidification conditions, or the full sampling pathway. No unused-suction-device or specimen-trap controls were available, and the positive airborne blank indicates that background contamination cannot be assumed to be zero. Particle counts were not blank-corrected. The 1.0-micrometer filtration pore size is not equivalent to the lower limit of reliable Raman identification, and micro-Raman findings depend on spectral quality and library assignment. Finally, airway secretion is not airway tissue; the data should not be described as demonstrating tissue deposition or clinical harm.

A larger confirmatory study should prospectively collect unused-circuit, suction-device, and specimen-trap controls by lot; repeated time-point samples; recovery spikes across the targeted size range; and detailed information on humidification and ventilation mode. Linking clinical airway samples to matched circuit lots and direct material spectra would clarify the contribution of circuit release. Such a design could distinguish circuit-associated release from shared environmental contamination and test whether microplastic burden relates to respiratory inflammation or outcomes.

Conclusions

Microplastics, predominantly polyethylene, were detected in airway secretion and used ventilator-circuit rinse samples from mechanically ventilated neonates. Airway and circuit particle burdens increased with cumulative ventilation duration and were correlated in paired analysis. In a complementary 72-h bench experiment, PE particle counts were higher at the patient-end gas output than in system blanks and were higher in post-run than unused-circuit eluates. These convergent findings support an association between ventilator-circuit use and microplastic burden in airway secretion samples and demonstrate the capacity of circuits to release PE under bench conditions. They do not establish individual in vivo particle transfer, tissue deposition, or clinical harm.

Declarations

Data Availability

Deidentified participant-level clinical and bench-experiment data supporting the findings are provided in the Supplementary Material. Additional deidentified data may be made available by the corresponding authors on reasonable request, subject to ethics approval and institutional data-governance requirements.

Ethics Statement

The protocol was approved by the Medical Ethics Committee of Guangdong Second Provincial General Hospital, Jinan University (approval number: 2026-KY-KZ-146-02). Written informed consent was obtained from each participant's legal guardian.

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Conflict of Interest

The authors declare no commercial or financial relationships that could be construed as a potential conflict of interest.

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Figures

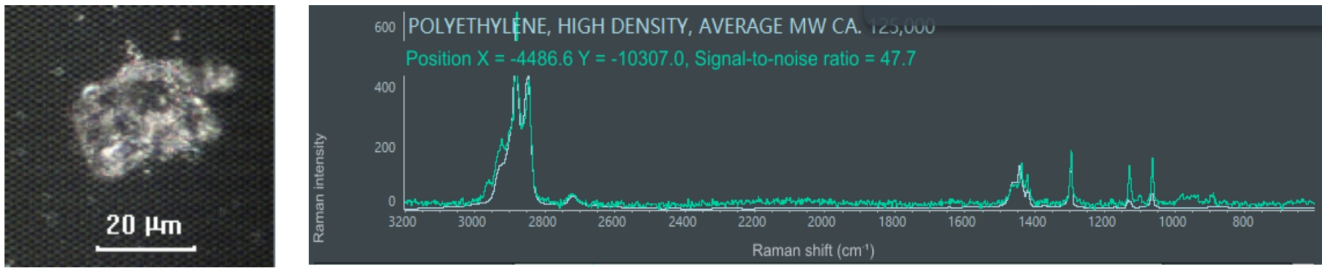


Figure 1

Representative polyethylene particle identified in an airway secretion sample. (A) Micrograph of a representative particle (scale bar, 20 micrometers). (B) Corresponding confocal micro-Raman spectrum, assigned as high-density polyethylene.

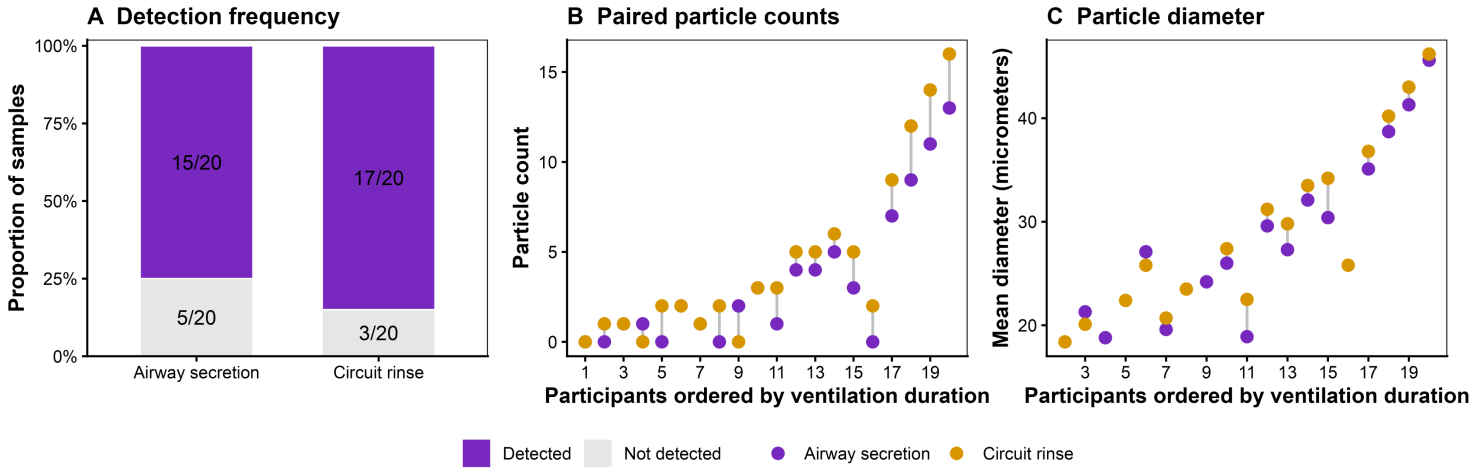


Figure 2

Paired microplastic findings in airway secretion and ventilator circuit rinse samples. (A) Detection frequencies among 20 paired samples. (B) Particle counts in each participant, ordered by cumulative ventilation duration. (C) Mean particle diameter in positive samples. Purple denotes airway secretion and amber denotes circuit rinse samples.

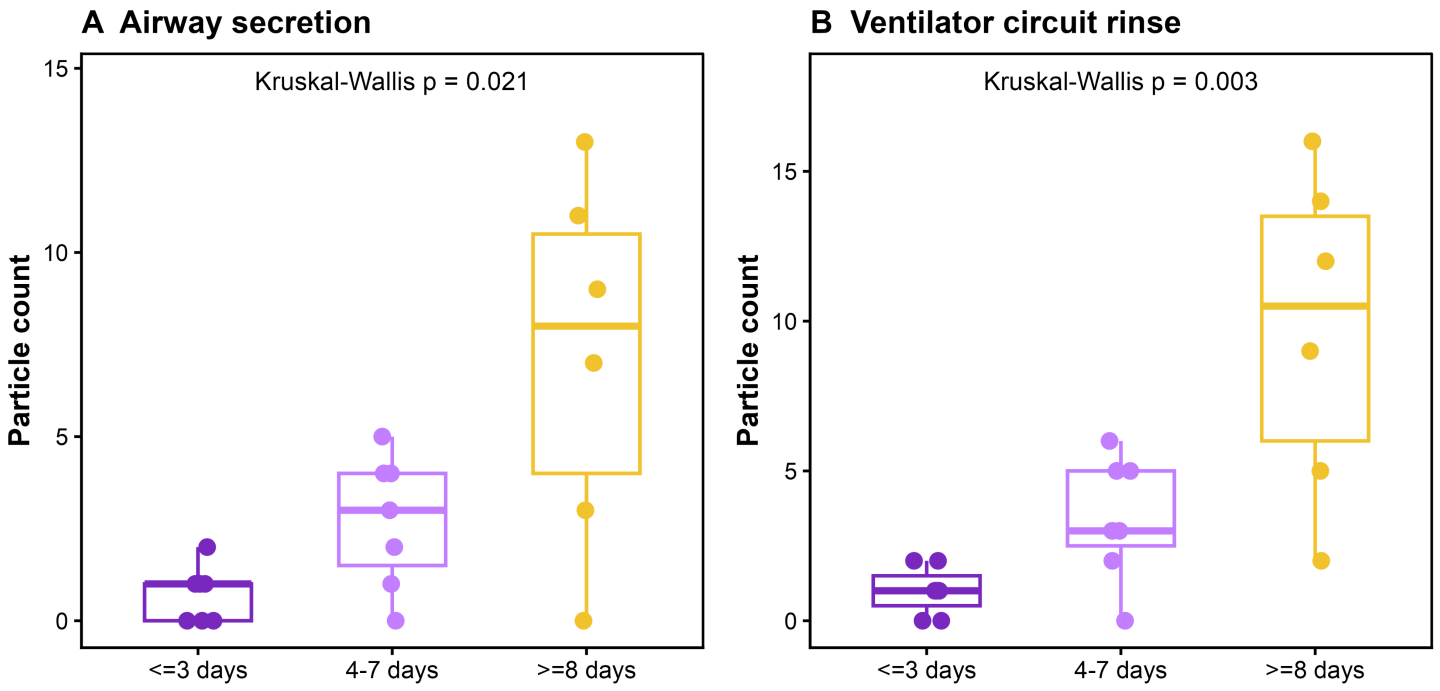


Figure 3

Microplastic particle counts across cumulative invasive ventilation-duration groups. Boxes show medians and interquartile ranges; individual points represent participants. Displayed P values are from Kruskal-Wallis tests.

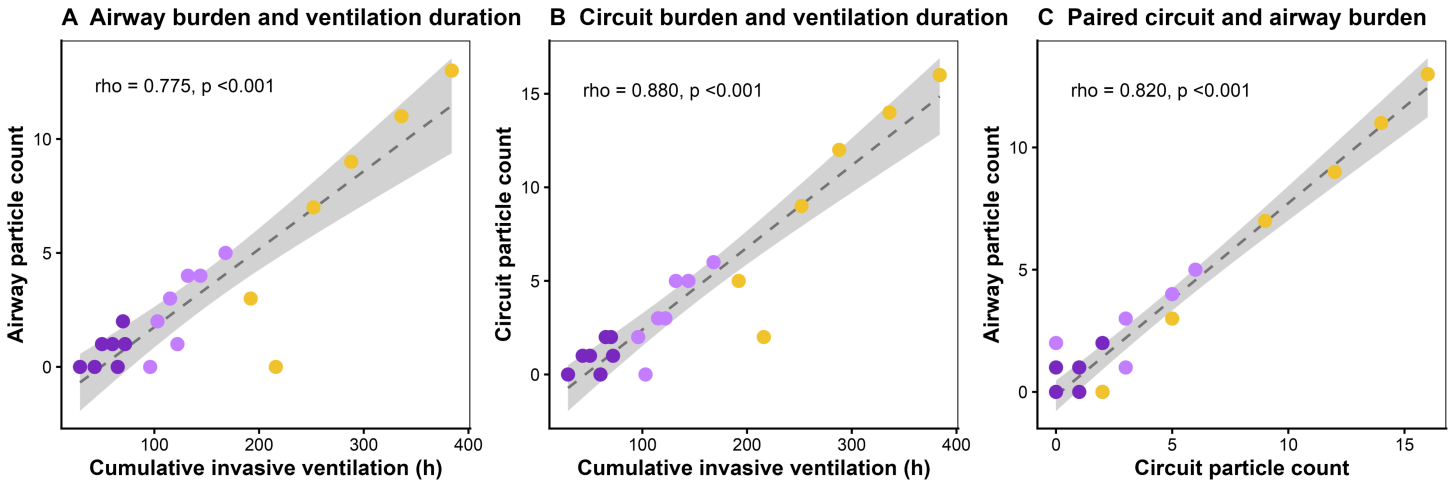


Figure 4

Exploratory associations between cumulative invasive ventilation duration and microplastic particle burden. (A) Airway secretion particle count and ventilation duration. (B) Circuit rinse particle count and ventilation duration. (C) Correlation between paired circuit and airway particle counts. Spearman correlation coefficients and two-sided P values are shown.

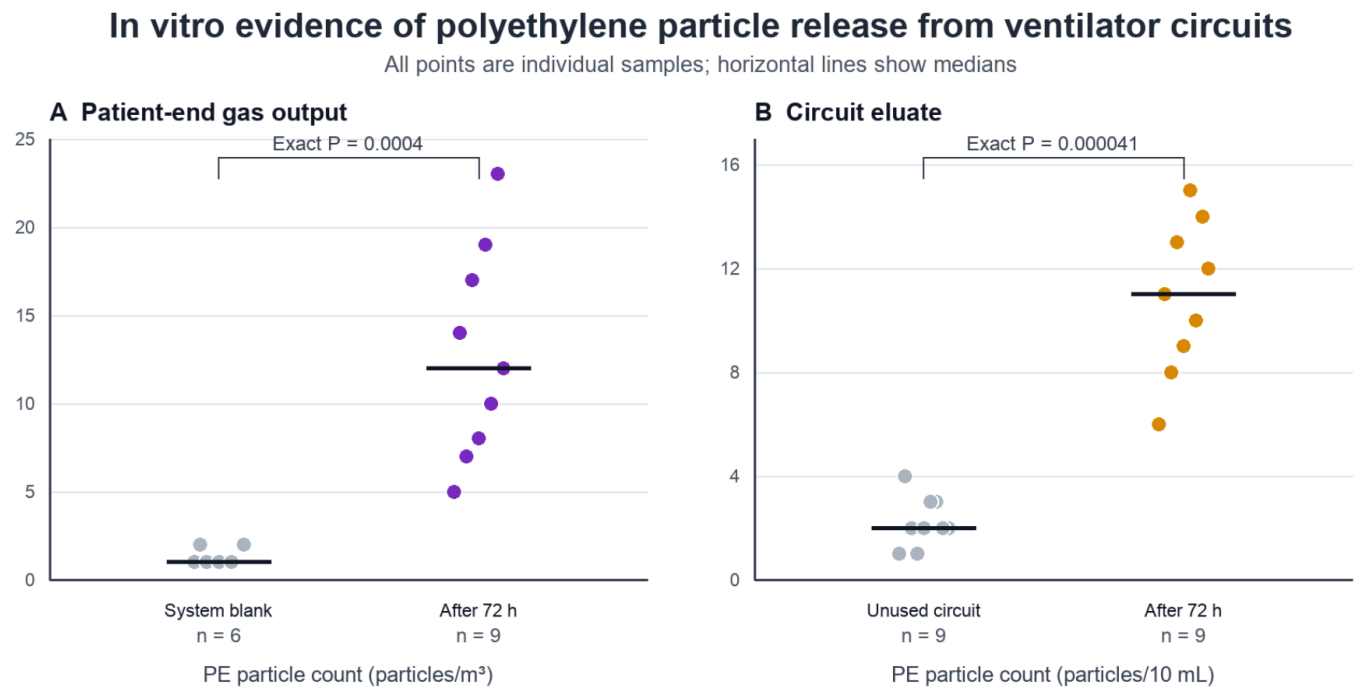


Figure 5

In vitro evidence of polyethylene particle release from ventilator circuits. (A) Raman-confirmed PE particle counts in patient-end gas output after 72 h and in system blanks. (B) PE particle counts in eluates from unused and post-run circuits. Each point represents one sample; horizontal lines show medians. P values are from two-sided exact permutation tests.

Supplementary Files

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- Tables.docx