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Toxicity of Particles Generated from a Consumer Fused Deposition Modeling 3D Printer Using Animal, Cellular and Acellular Models

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Introduction

- Fused deposition modeling (FDM) 3D printers are popular with the general public and usually used in indoor environments not designed for manufacturing
- High levels of ultrafine particle and gas emissions from 3D printers have been reported, levels depended on printer and filament properties[1], which may cause adverse health effects
- Particle chemical composition and potential health impacts have not been systematically investigated

Objectives

- Examine chemical composition of 3D printer-emitted particles and compare with bulk filament material
- Investigate potential toxicity of emitted particles based on oxidative stress mechanism and compare between filament materials

Methods

Chamber experiment

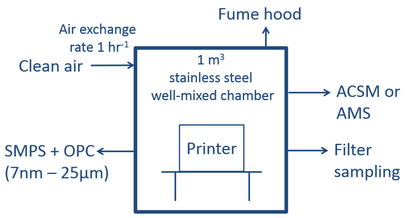


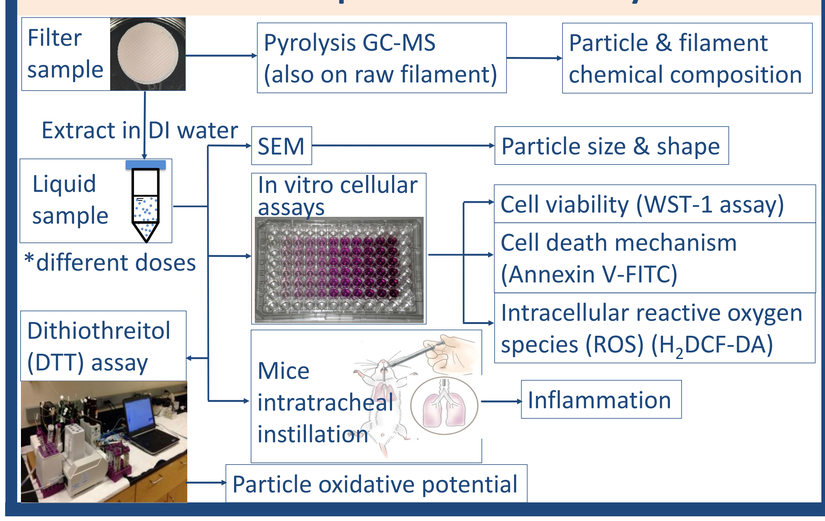
Fig.1 Experimental chamber system

- Print conditions

Material	Acrylonitrile butadiene styrene (ABS)	Polylactic acid (PLA)	Nylon
Filament	High/Regular	1 type	1 type
Temp.	270	210	243

- Online particle measurements
  - Particle size distribution (SMPS)
  - Particle mass spectra (ACSM)

Particle sample and offline analyses



Results

Particle emission

- High levels of ultrafine and fine particle emissions

Material	High ABS	Regular ABS	PLA	Nylon
Number yield (#/g)	1.4×10^{11}	1.5×10^{10}	1.4×10^{9}	1.6×10^{9}
Dp (nm)	49	123	51	134
Mass yield (µg/g)	58	59	0.4	6.2

- Yield = emission/print object mass
- ABS>Nylon>PLA
- Difference between ABS filament brands

- Solid particles (i.e. water insoluble) shown by SEM images

Particle chemical composition

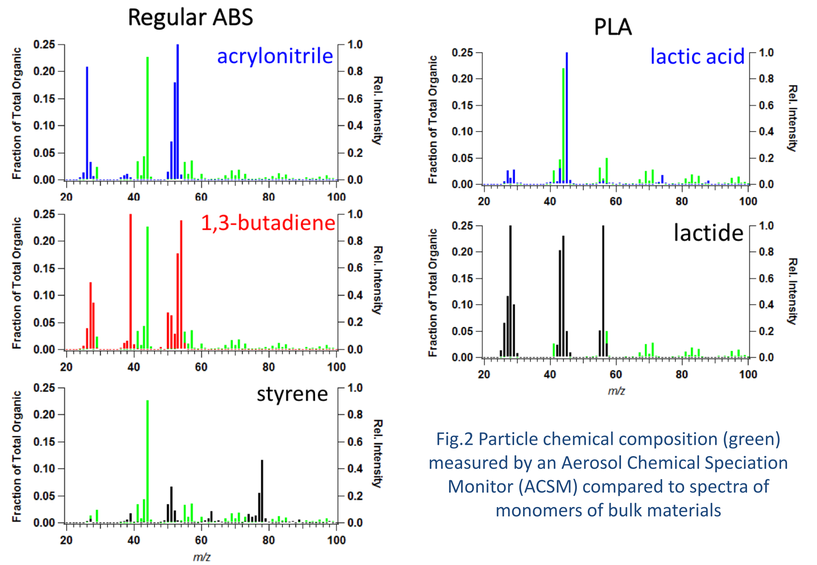


Fig.2 Particle chemical composition (green) measured by an Aerosol Chemical Speciation Monitor (ACSM) compared to spectra of monomers of bulk materials

- ABS-emitted particles' mass spectra not like ABS monomers → not formed from monomers directly
- PLA-emitted particles' mass spectra similar to PLA monomers
- Pyrolysis GC-MS showed ABS-emitted particles not like bulk ABS filament

Particle toxicity via biological models

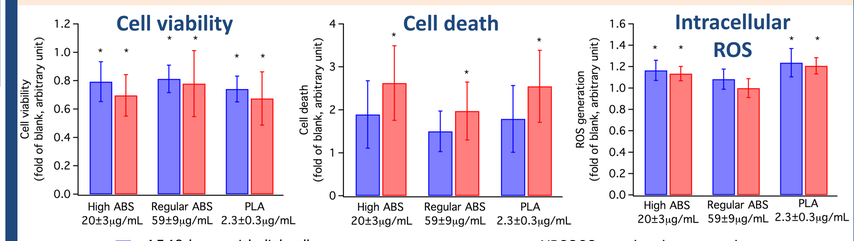


Fig.3 In vitro cellular toxicity responses to particle samples with indicated concentrations

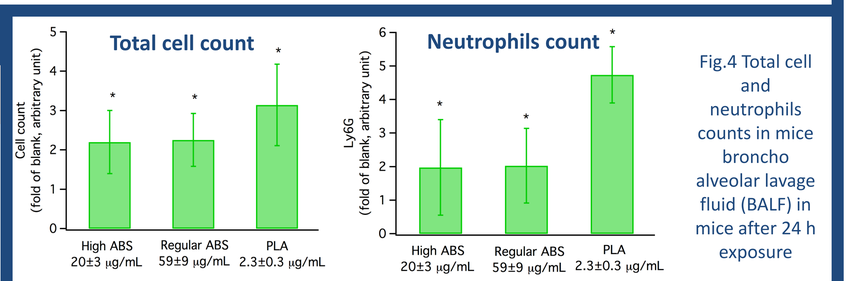


Fig.4 Total cell and neutrophils counts in mice broncho alveolar lavage fluid (BALF) in mice after 24 h exposure

- All biological analyses (in vitro & in vivo) showed toxic responses when exposed to 3D printer emitted particles
- PLA-emitted particles induced similar levels of responses as ABS-emitted particles, but at much lower doses

Particle Oxidative Potential (OP)

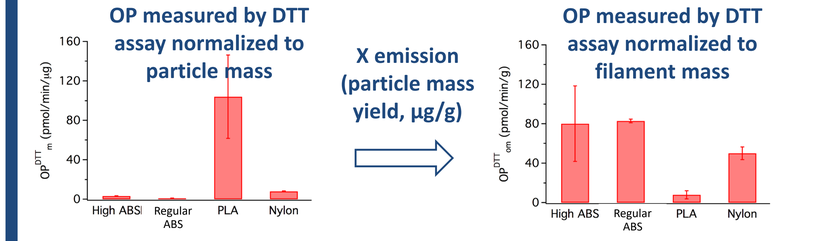


Fig.5 Particle OP measured by DTT assay and estimated exposure responses considering emissions

- OP of PLA-emitted particles comparable to combustion emissions
- OP of ABS and nylon emitted particles lower than general ambient PM
- Considering emissions, ABS-emitted particles showed highest toxicity

Conclusions

- Chemical composition of particles not always the same as bulk material → particle formation associates with bulk material (PLA) or additives (ABS) → particle toxicity may not be the same as bulk material and may vary largely by filament brands
- Various testing methods showed 3D printer emitted particles can induce toxic responses, depending on material type, etc. → PLA-emitted particles more toxic on a particle mass basis
- Real exposure levels mostly driven by emission levels → ABS-emitted particles of more concern when using the same amount of filament

References

1. Zhang, Q., Wong, J. P. S., Davis, A. Y., Black, M. S., Weber, R. J. (2017). Characterization of Particle Emissions from Consumer Fused Deposition Modeling 3D Printers. *Aerosol Sci. Technol.*
2. Zhang, Q., Sharma, G., Wong, J. P. S., Davis, A. Y., Black, M. S., Biswas, P., Weber, R. J. (2018). Investigating Particle Emissions and Aerosol Dynamics from a Consumer Fused Deposition Modeling 3D Printer with a Lognormal Moment Aerosol Model. *Aerosol Sci. Tech.*
3. Zhang, Q., Pardo, M., Rudich, Y., Kaplan-Ashiri, I., Wong, J. P. S., Davis, A. Y., Black, M. S., Weber, R. J. (under review). Chemical Composition and Toxicity of Particles Emitted from a Consumer-level 3D Printer using Various Materials. *Environ. Sci. Technol.*