Deposition Estimation of Workplace Ultrafine Particle in the Worker's Lower Airways

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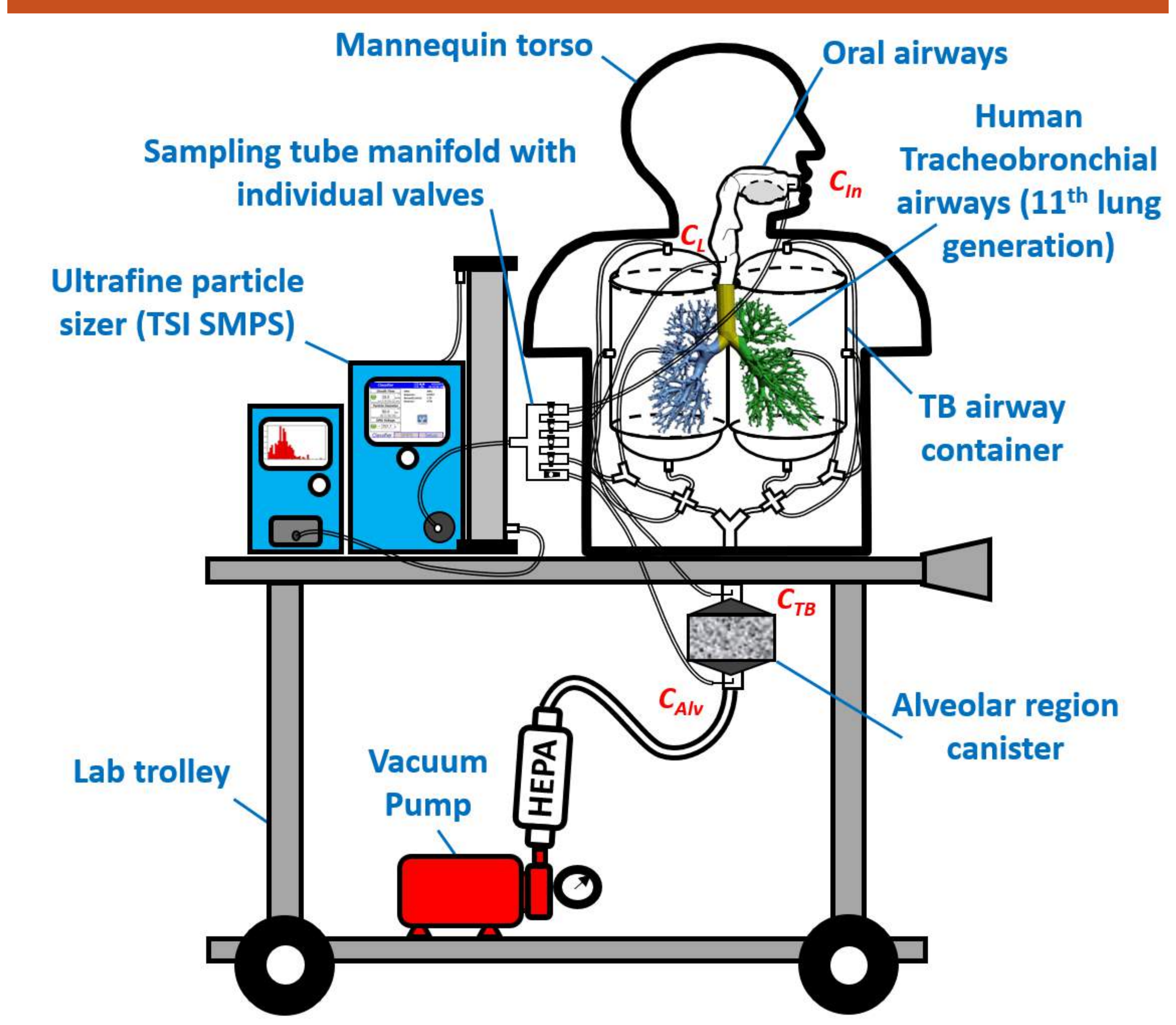
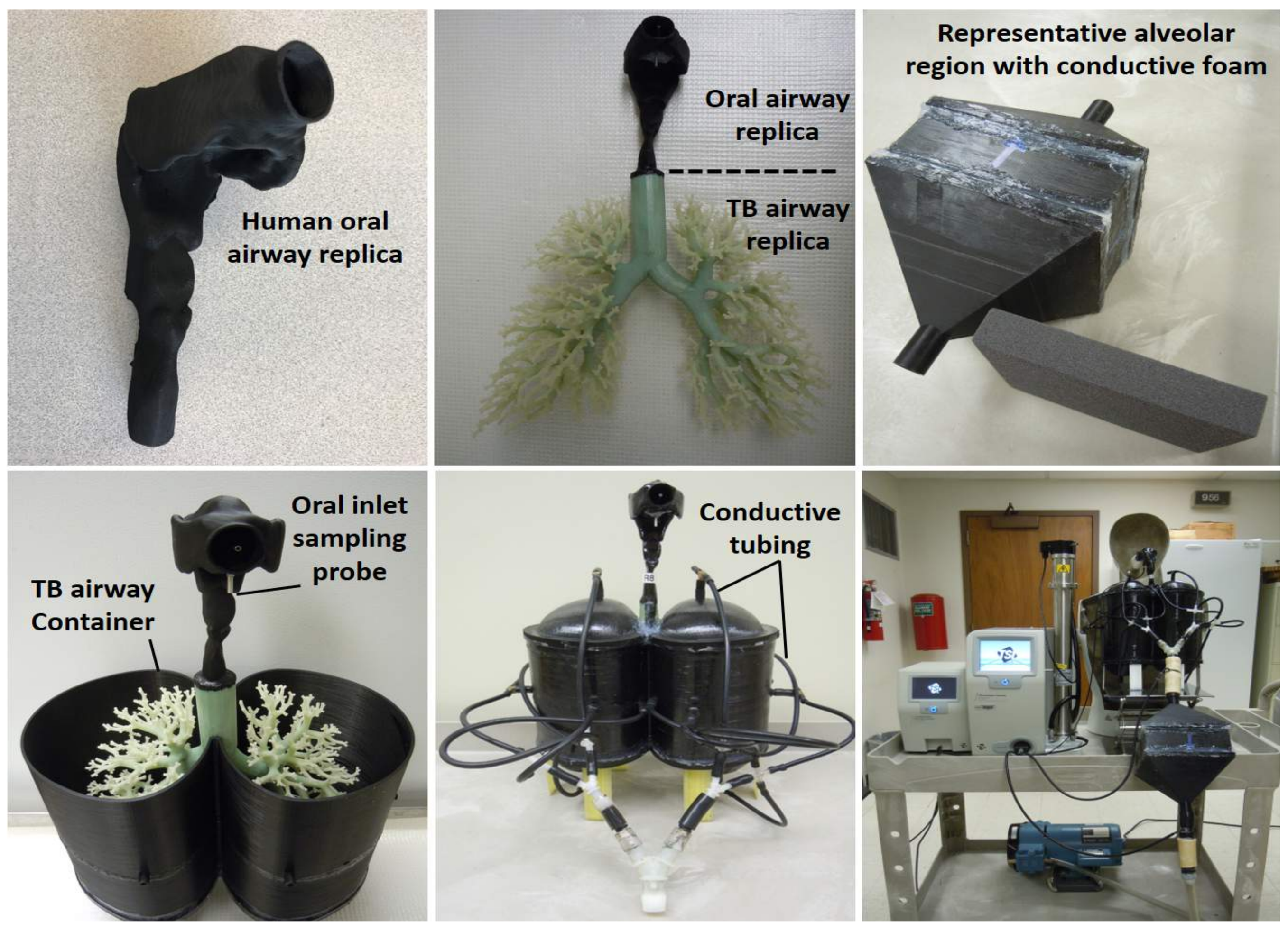
Introduction

Worker's exposure to work-related ultrafine particles (UFPs) has been and continues to be an important occupational health issue. Thus, it is essential to investigate the deposition of UFP in worker's airways in order to estimate UFP inhalation dose for an associated risk assessment. However, traditional UFP respiratory deposition experiments were conducted with surrogate particles and only used human upper airways. It is considered that surrogate particles are not representative to the UFPs found in real workplaces and using only upper airway replicas failed to consider the main UFP respiratory deposition site - the lower airways. As a result, useful information acquired from previous UFP respiratory deposition studies was limited. With above in mind, the purpose of this study was to apply the newly developed Mobile Aerosol Lung Deposition Apparatus (MALDA) for conducting a series laboratory-based UFP respiratory deposition experiments using work-related UFPs to acquire preliminary data for evaluating and improving the current MALDA prototype to be ready for future real-workplace applications.

MALDA



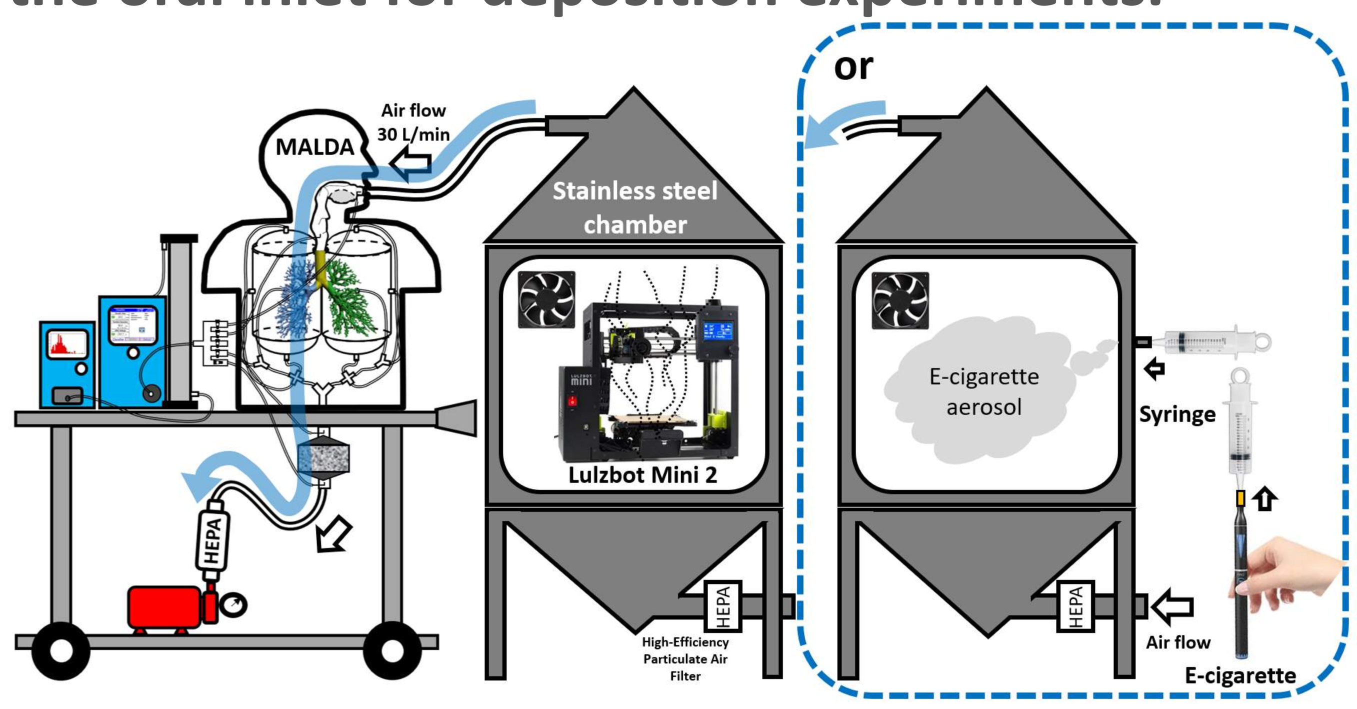
MALDA consists a human airway system and a UFP sizer (TSI 3938 SMPS). The human airway system incorporates a set of human airway replicas from the mouth, throat, trachea, tracheobronchial (TB) airways down to the 11th lung generation, and a representative alveolar region. All the airway replicas were made by 3D printing. The alveolar region was made by conductive foams (in a container). The human airway system is installed inside a mannequin torso and placed on a lab trolley together with the UFP sizer to enhance its mobility for workplace application.



The human airway replicas, representative alveolar region, human airway system, and MALDA

Method

To generate consistent UFP concentration for respiratory deposition experiments, 3D printing particles (ABS) and e-cigarette aerosols (Juul: Virginia Tobacco) were generated separately in a chamber with a mixing fan. The well mixed UFPs were then delivered by conductive tubing to the MALDA under a 30 L/min inspiratory flow rate through the oral inlet for deposition experiments.



The experimental set-up of UFP respiratory deposition using MALDA and a mixing chamber (the dimension of the central area: 2 ft x 2 ft x 2 ft)

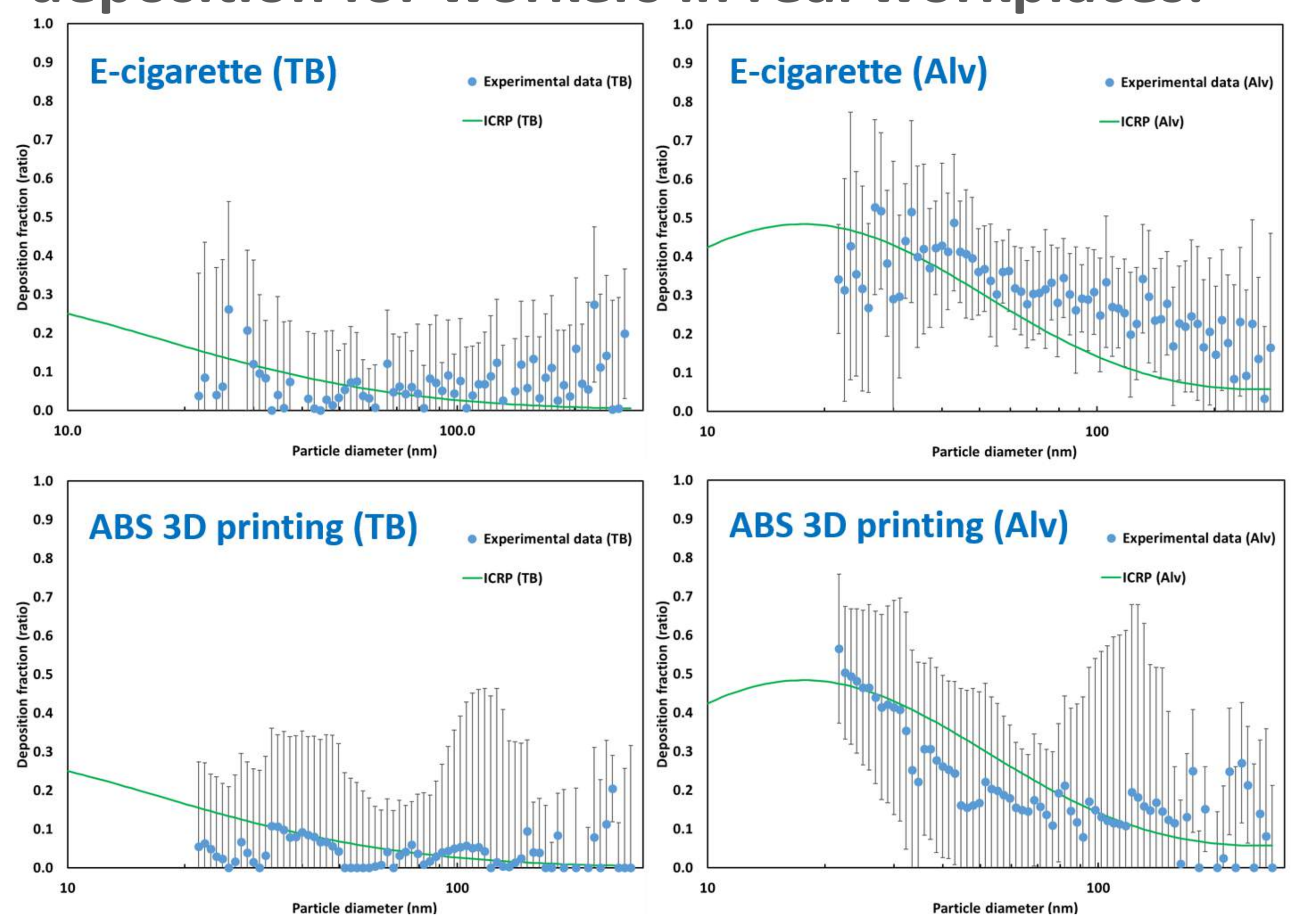
There are four sampling probes at four locations on the human airway system (oral inlet: C_{In}, larynx: C_L, TB outlet: C_{TB}, and Alveoli outlet: C_{Alv}) for measuring UFP size distributions before and after the UFP passes through a certain airway region. Based on this design, the UFP respiratory deposition fractions (values from 0 to 1.0) for a specific ultrafine particle diameter, *d,* in the lower airways (TB airways: $D_{TB,d}$; alveolar region: $D_{Alv,d}$) can be calculated according to the following equation:

$$D_{TB,d} = (C_{L,d} / C_{In,d}) - (C_{TB,d} / C_{In,d})$$
$$D_{Alv,d} = (C_{TB,d} / C_{In,d}) - (C_{Alv,d} / C_{In,d})$$

In this study, at least five measurements were conducted for each sampling location to obtain average concentration for both test UFPs.

Results

Deposition of ultrafine 3D printing particles and e-cigarette aerosols in the human TB airways and alveolar region were efficiently and systematically obtained using MALDA. For the particle size measured (20 to 270 nm), the estimated deposition fractions were generally less than 0.3 and 0.6 for TB airways and Alveolar region, respectively. The acquired experimental results fairly agreed with the conventional respiratory deposition curves. This result implies that the respiratory deposition of non-agglomerated, sphere-like UFPs in worker's lower airways follows the convention curve closely. Results obtained also showed that the newly developed MALDA could be a useful tool for estimating UFP respiratory deposition for workers in real workplaces.



Calculated respiratory depositions for ultrafine 3D printing particles and e-cigarette aerosols in human tracheobronchial airways and alveolar region (also shown in the graph are convention curves of aerosol respiratory deposition for TB and Alveolar region)

Future Studies

To further evaluate the function and performance of the MALDA prototype, respiratory deposition experiments using work-related UFPs with complex particle morphology, such as welding fume and diesel engine exhausts, will be conducted. It is expected that the deposition fraction acquired will be significantly different from the conventional deposition curve due to the irregular particle shape.

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