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# Modeled regional airway deposition of inhaled particles in athletes at exertion

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ABSTRACT

There is a paucity of data regarding mechanisms and effects of inhaled environmental particulate matter on athletic performance. To formulate a framework on which future studies may be developed relating regional airway deposition to subsequent performance in athletes, modeling is indicated.

Multiple-Path Particle Dosimetry (MPPD) computer modeling was utilized to predict the deposition of inhaled particles in 26 male athletes at increasing levels of exertion. Deposition doses of inhaled spherical, monodisperse particles of unit density (1 g/cm$^3$) measuring 0.05, 0.1, 1.0, 2.5, and 10.0 μm in diameter were calculated. Repeated measures ANOVA testing was used to test for differences in total and regional (naso-oro-pharyngo-laryngeal, tracheobronchial, and pulmonary) airway deposition at exertion.

Increasing exertion revealed statistically significant effects ($p < 0.01$) on deposition of all particle sizes in all airway regions. Overall total airway modeled deposition dose of all particle diameters increased as expected with increasing minute ventilation. Pulmonary deposition dose at exertion tapered off and decreased in the case of larger particles (2.5 and 10.0 μm), indicating that deposited doses in the pulmonary region (deep lung) may be reduced by greater deposition in larger airways at higher levels of exertion, depending on particle aerodynamic diameter.

To assess the impact of inhaled particulate matter on athletic performance, understanding regional deposition and subsequent physiologic impacts are critical steps. Future studies should focus on modeling realistic exposures and performing studies to elucidate mechanisms of injury in both bronchial and pulmonary airways that might impact performance.



## 1. Introduction

Potential adverse effects of inhaled particulate matter (PM) on cardiopulmonary function and overall performance in athletes are of particular interest in sports medicine. It is generally recognized that athletes competing in or practicing in environments where PM concentrations are high will likely have greater internal exposures due to increased minute ventilation in comparison to people who are not undergoing exertion. A few studies have examined the effects of particulate air pollution on athletic performance (Cakmak, Dales, Leech, & Liu, 2011; Cutrufello, Rundell, Smoglia, & Stylianides, 2011; Cutrufello, Smoliga, & Rundell, 2012; Rundell, 2012; Rundell, Slee, Caviston, & Hollenbach, 2008).

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Recent data suggests athletic performance is compromised by increased volumes of inhalation of dry air, emission-related aerosol particles, and pollutant gases during exercise (Rundell, Hoffman, Caviston, Bulbulian, & Hollenbach, 2007). Inhaled PM is thought to produce oxidative stress leading to airway and vascular injury, in both acute and chronic phases (EPA, 2010). However, additional data is needed with regard to performance, especially in athletes where effects may be inconspicuous.

The literature is predominantly focused on individuals with risk factors for cardiopulmonary disease, as PM is known to induce pulmonary inflammation, decreased lung function (Barraza-Villarreal et al., 2008; Cakmak et al., 2011; Cho et al., 2007; Donaldson & Tran, 2002; Larsson et al., 2007; Pietropaoli et al., 2004; Rundell, 2004; Rundell et al., 2008), pulmonary and systemic vascular dysfunction (Brook et al., 2002; Cutrufello et al., 2011; Frampton, 2007; Nurkiewicz et al., 2006, 2008; Rundell et al., 2007), increased resting blood pressure (Cutrufello et al., 2012; EPA, 2010), increased risk for cancer (Silverman et al., 2012), reduction in heart rate variability (Chang, Tang, Pan, & Chan, 2007; Magari et al., 2001), and ST segment depression (Lanki et al., 2006).

In the case of athletic performance, it is yet to be determined whether pulmonary (deep lung) effects of particulate deposition, and subsequent inflammation and oxidative stress in the acute phase, are of more or less concern than acute irritant and bronchoconstrictive effects of PM associated with inflammation in the more proximal tracheobronchial region. Individual variability in physiologic response to respiratory insult among athletes likely plays an important role with respect to performance. In order to advance a framework on which future studies may be developed, modeling inhaled particle deposition in athletes at exertion was performed. For this purpose, computerized modeling software considered reliable in the field of inhalation toxicology, and an appropriate study population were selected. The main purpose of this initial study was to elucidate how particle size and exertion level affect global and regional airway deposition in a single lung model representative of a male athlete. A second goal was to identify areas of needed future research based on modeled deposition efficiencies and doses in various portions of the respiratory tract.

### 1.1. Concern for PM exposure in athletes

There are two main concerns related to athletes during training and competing in locations impacted by air pollution: effects on performance, and acute and delayed effects on health. Unfortunately, there is a paucity of data for examining these impacts, especially with regard to performance. While occurrences of acute exposure at rest or exertion may or may not lead to long term sequelae in healthy athletes, high elevated ambient PM concentrations may affect the outcomes of competition (Cutrufello et al., 2012). Performance decrements of 3–5% have been estimated following PM exposure (Cutrufello et al., 2012). While this decrease in performance may initially appear inconsequential, a 3–5% performance loss during elite competition can have a substantial impact on success. Similar arguments may be made with regard to other populations that engage in extreme exertion, such as military personnel, fire fighters, and law enforcement officers.

The United States Environmental Protection Agency (EPA) recognizes the strong influence of particle size on pathologic potential and therefore focuses concern on particles 10 μm or less in aerodynamic diameter because they are small enough to pass through the oral and nasal passages, transiting into the lungs and potentially causing adverse health effects (Environmental Protection Agency, 2013). Unfortunately, the EPA does not routinely include airborne biological materials (plant matter, spores, pollen, etc.) in defining PM, possibly leading to a critical misconception that biological particles are less harmful than regulated non-biological components when it comes to impacting athletic performance.

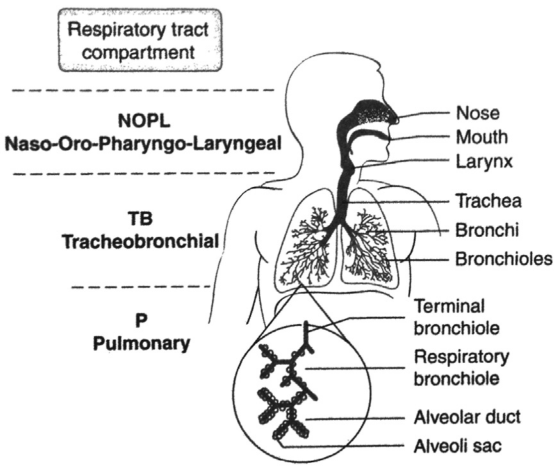


**Fig. 1.** Compartmental model of the NCRP (1997).
*Source:* The University of California Air Pollution Health Effects Laboratory, with kind permission.