Modeled Deposition of Inhaled Particulate Matter in Athletes at Exertion

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Introduction

- Beyond well-described concerns about inhaled particles, there is a developing interest on effects of particulate matter (PM) on athlete performance in high-ventilation sports.
- It is generally thought that athletes practicing or competing in environments high in PM will have a greater exposure due to higher minute ventilation.
- Few studies have examined the effects of air pollution (especially inhaled particles) on athletic performance.
- No research on long-term exposure effects of air pollution on performance.


Worldwide Concern in Sports

- A single, acute exposure to particulates during exercise or competition may not cause long-term effects in otherwise healthy athletes, however, while effects may initially seem trivial, the impact on performance may be substantial.
- Cutrufello et al. cite a performance decrement of 3-5% in acute exposures.


Background

- It is yet to be determined whether pulmonary (deep lung) effects of PM, and subsequent inflammation and oxidative stress in the acute phase are of greater concern than the acute irritant and bronchoconstrictive effects of PM coupled with inflammation in the more proximal tracheobronchial region.
- The majority of studies in sports medicine and related literature involve extrapolating breathing data from “otherwise healthy” individuals at exertion to elite athletes, whose breathing parameters and overall exercise capacity at exertion may differ greatly from the non-athletic study subjects.

**Background**

- To formulate a framework on which future studies may be developed regarding regional airway deposition of inhaled particles in athletes during exertion, appropriate modeling of particle deposition in elite athletes is indicated.
- An accessible, computerized modeling interface that is considered reliable in the field of inhalation toxicology and an appropriate study population were selected.
- The purpose of this initial modeling research is to elucidate whether or not there is truly a global increase in deposition in all airway regions, regardless of particle diameter, with increasing exertion in a population of athletes.

**Study Design**

- In order to assess regional airway deposition of inhaled particles at increasing levels of exertion, Multiple-Path Particle Dosimetry (MPPD) modeling was indicated. The MPPD interface incorporates asymmetries in the airway and has become the preferred model.
- The model assumes dichotomous airway branching, with each branch composed of a straight cylindrical tube having a measurable length, diameter, and branching angle from both its parent airway and with respect to the direction of gravity.

**Study Population**

- Breathing data including tidal volume ($V_t$) and breathing frequency ($f_b$) were collected from 26 male athletes in Europe. Upon request via personal communication, the primary author provided unpublished individual demographic and breathing data from the original study (without patient identifying information).
- Using MPPD v 2.11, deposition fractions of inhaled particles were modeled in each athlete according to their individual breathing parameters at the six levels of exertion from rest to maximum exertion per the original treadmill protocol.
- Rest, three-minute warm-up at 8.0 km/h, then every 3 minutes (with speed increasing by 0.2 km/h every 20 seconds, keeping the incline steady at 1.0%) until maximum speed of 16.2 km/h completed.

**Modeling Parameters and Dose Calculation**

- Particle diameters of 10.0 m, 2.5 m, 1.0 m, 0.1 m, and 0.05 m were selected, representing a broad spectrum of typical particulates in urban areas and locations common to athletic competition and training, ranging from ultrafine particles to larger particles generated by various sources including combustion engine exhaust, industrial processes, etc.
- Properties for inhaled particles (Mass Median Aerodynamic Diameter, MMAD, for large particles) were set in each case at a density of 1.0 g/cm³, and a 1.0 (spherical) aspect ratio. Deposition fractions by airway region - naso-oro-laryngopharyngeal (NOPL), tracheobronchial (TB), pulmonary (P), and total airway - were computed and reported for each individual athlete at each level of exertion. Dose for each respective airway region ($r$) was calculated from the deposition model as:

\[
\text{DOSE}_r (\text{mg}) = V_t \times f_b \times f_{dr} \times t \times C \times 10^{-3} (\text{L/mL}) \times 10^{-3} (\text{m}^3/\text{L})
\]

- Where $V_t =$ tidal volume (mL), $f_b =$ breathing frequency (min⁻¹), $f_{dr} =$ deposition fraction by region, $C =$ concentration (1 mg/m³), $t =$ time (3 min)
Statistical Analysis

- For each particle diameter, mean values of three-minute deposition dose (mg) in each airway region (NOPL, TB, P, and total airway) at each level of exertion from rest to maximum speed of 16.2 km/h were compared by using repeated measures ANOVA.

Results

- For each particle diameter, there was a statistically significant effect (p<0.01) of exertion on the mean particle dose deposited in each airway region.
- As expected, exertion increased tidal volume and breathing frequency - impacting dose not only in the entirety of the respiratory tract, but also by region.
- However, depending on particle size, and maintaining constant environmental aerosol exposure concentration of 1 mg/m³, the regional breakdown of deposition doses does not necessarily parallel the overall rise in the total airway.

Results

- As particles increase in size, increasing exertion may lead to an overall increased dose when considering the entire respiratory tract, but in the deep lung (pulmonary) region, increasing exertion appears to be negatively associated with dose after an initial spike from rest to warm-up.
- This phenomenon was most apparent with 2.5 and 10.0 μm particles. The ratio of deposition dose at maximum exertion to rest in the case of 2.5 μm particles in the TB region was impressively elevated in comparison to other particles, indicating a possible mechanism for potentially substantial performance impacts.

Conclusions

- While overall total airway deposition dose of all particle diameters increases as expected with increasing exertion, pulmonary regional deposition dose at exertion tapers off and decreases in the case of larger particles (2.5 and 10.0 μm).
- Future studies utilizing techniques of radiolabeling could provide in vivo quantitative validity assessment of the model.
- These modeled results do not account for the effects of other gases, bioaerosols, or dusts.
Conclusions

- While evidence is mounting to implicate deep lung deposition of ultrafine particles as the greatest threat to long-term health secondary to oxidative stress and inflammation, it remains to be seen as to whether these responses outweigh the threat of larger particle deposition in the more proximal tracheobronchial region from a perspective of effects on athletic performance.

- Future animal and human exercise studies should focus on comparing the acute and chronic effects of regional deposition and subsequent uptake, oxidative stress, and inflammatory responses from exposures resulting in particles deposited both in the deep lung and more proximal athlete airway (particularly the tracheobronchial region).

Acknowledgments

- I would like to thank Robert Phalen, PhD, Ulrike Luderer, MD, PhD, and Dean Baker, MD, MPH for their support and technical assistance.

References


Thank You

QUESTIONS?