Investigation of Particle Bounce on Human Aspiration Efficiency: A Computational Fluid Dynamics (CFD) Study

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Background

Computational fluid dynamics (CFD) was used to examine the effect of particle bounce on human aspiration efficiency estimates. Particle bounce during air monitoring can lead to oversampling, biasing exposure assessments. However, the effect on human aspiration has not been investigated.

Objective

The objective of this work was to quantify the effect of bounce in human aspiration efficiency simulations.

Methods

Generated three humanoid geometries with realistic facial features, facing the wind

- Small Nose, Small Lip
- Large Nose, Large Lip
- Small Nose, Large Lip

Ran CFD model and solved fluid flow

- Fluent, 12.1 (Ansys, Inc.)
- Freestream velocities of 0.2 and 0.4 m s^{-1}
- Mouth breathing velocities of 1.81 and 12.11 m s^{-1} to represent at-rest breathing and heavy breathing rates, respectively
- Standard κ-epsilon turbulence models, 2nd order upwinding
- Assessed mesh independence, iterative tolerance

Assigned coefficient of restitution (CoR) to facial surfaces

- 0, 0.5, 0.8, 1.0

Simulated laminar particle transport

- Determined the upstream area where particles would be inhaled (critical area)
- Computed aspiration efficiency

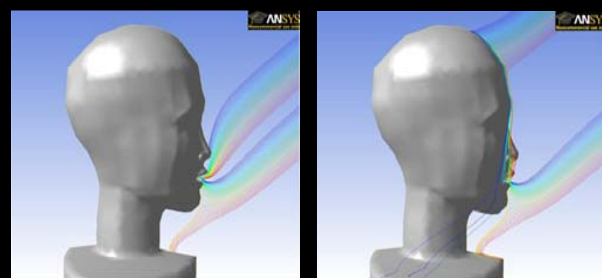
Compared aspiration efficiency estimates between CoR

- Computed differences in aspiration efficiency between No Bounce and 100% Bounce (Table 1)
- Computed paired t-test, by geometry, velocities to identify the accuracy needed in model

Results

Small Nose, Small Lip | Small Nose, Large Lip | Large Nose, Large Lip

0 CoR | 1.0 CoR



68 µm particles, released upstream in the critical area. Particles below the upper blue stream and above the lower red stream are aspirated, while particles outside are not.

Table 1: Difference in Aspiration Efficiency Between 1.0 CoR and 0.0 CoR Simulations

	Small Nose, Large Lip			Large Nose, Large Lip			Small Nose, Small Lip		
Velocity, m/s	0.2	0.4	0.4	0.2	0.4	0.4	0.2	0.4	0.4
Breathing Rate, m/s	1.81	1.81	12.11	1.81	1.81	12.11	1.81	1.81	12.11
Particle Size, µm	Difference (%)								
7	1	1	3	1	-1	1	1	1	3
22	1	1	1	1	2	1	1	2	1
52	3	11	4	25	7	-8	13	8	5
68	34	26	13	61	25	16	35	23	12
82	77	48	26	105	44	31	77	44	28
100	90	64	46	0	18	49	83	58	39
116	0	0	55	0	0	56	0	25	46

Particle bounce resulted in secondary aspiration

Significant differences between the no-bounce and 100% bounce conditions were found ($p = <0.0001$ to 0.016)

Overall, differences between the no-bounce and 100% bounce ranged from -8 to 105%

Aspiration for the 116 µm particles was zero for at rest for all CoRs, resulting in no differences

Particles $\leq$52 µm had <5% differences

Particles >52 µm on average had larger differences (37%)

Aspiration efficiency estimates between facial features were not significant ($p = 0.2$ to 0.8)

Conclusions

Facing forward, secondary aspiration from particles bouncing on the face *are less important* for *small* particles, but become *more important* as particle size *increases* above 52 µm.

If experimental studies do not quantify bounce parameters, between-study comparisons will be difficult.

Future Research

Further research is necessary to obtain a realistic value of CoR for human skin.

Additional simulations are needed to examine these differences across the full range of orientations to fully compare to the Inhalable Particulate Mass Criterion (IPM).

Acknowledgments

Funded by CDC/NIOSH R01OH009290, CFD Investigation of Particle Inhalability in Low Windspeeds

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