Simulating Nasal Spray Deposition: Effects of Spray Nozzle Presence in the Nasal Vestibule

Julia S. Kimbell, PhD,[1] Daniela Stricklin, Ph.D.,[2] and Jeffry D. Schroeter, Ph.D.[3]

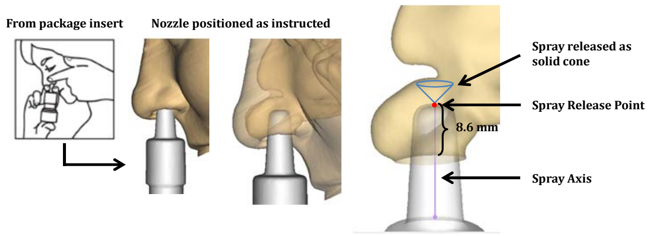
[1]Department of Otolaryngology - Head and Neck Surgery, University of North Carolina at Chapel Hill, Chapel Hill, NC, USA; [2]Applied Research Associates, Arlington, VA, USA; [3]Applied Research Associates, Raleigh, NC, USA

Introduction

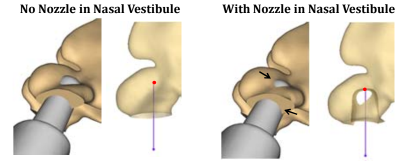
- Intranasal corticosteroids are often used to treat nasal symptoms.
- Regional nasal deposition estimates of sprayed corticosteroid droplets are needed to quantify drug delivery.
- Computational fluid dynamics (CFD) can be used to simulate and quantify airflow and sprayed particle transport in three-dimensional (3D) reconstructions of the nasal cavity.
- Many computational fluid dynamics (CFD) studies have shown that inspiratory airflow affects spray deposition, but most have not included effects from the presence of a spray nozzle in the nasal vestibule.
- The objective of this study was to compare sprayed particle deposition simulated with and without a spray nozzle in the nasal vestibule.

Simulation of Nasal Spray

Positioning of Release Point



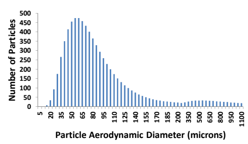
Nasal Vestibule Models



No alteration was made to the original nasal vestibule.

Nasal vestibule and nostril were manually distended around nozzle (arrows); nozzle was subtracted from vestibular airspace.

Particle Size Distribution



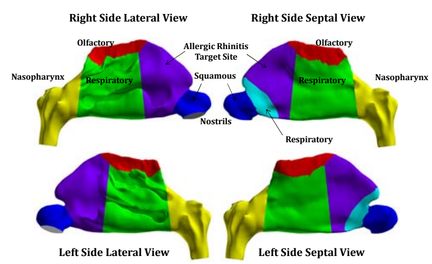
From Cheng et al. (2001), with volume of spray limited to 100 µL. 50-µm increments in particle diameter were used above 200 µm to keep # particles per size above 5.

Methods

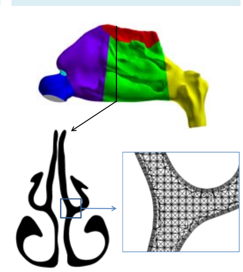
- Subject: Healthy 37 year old, 56.7 kg female with no radiological evidence of nasal abnormalities.
- A 3D model of the main nasal cavity was previously created (Schroeter et al., 2014) from a CT scan (0.7-mm resolution) using Mimics™ (Materialise, Inc., Plymouth, MI).
- Using ICEM-CFD™ 15.0 (ANSYS, Canonsburg, PA), a computational mesh of approximately 4 million tetrahedral elements with 4 0.1-mm-thick layers of prism elements was created.
- Anatomical regions were designated for analysis using ICEM-CFD, including a primary target site for nasal sprays (posterior nasal valve area and anterior turbinates).
- A nasal spray bottle was CT-scanned, reconstructed in 3D, and used to create a second version of the left nasal vestibule, distended, with a spray nozzle in position according to package insert instructions.
- Steady-state, inspiratory airflow and sprayed particle transport were simulated using Fluent™ 14.0 (ANSYS) under pressure-driven, laminar conditions.
  - Steady-state airflow rates were 15.7 and 15.5 L/min, with and without nozzle in place, respectively.
  - Simulated spray parameters were:
    - Particle size distribution of 5 to 1,100 µm (Cheng et al., 2001)
    - Spray cone angle = 70° (Cheng et al., 2001)
    - Spray speed = 3 or 12.8 m/sec (Foo et al., 2007; Liu et al., 2011)

Model Construction

Airspace Regions for Analysis

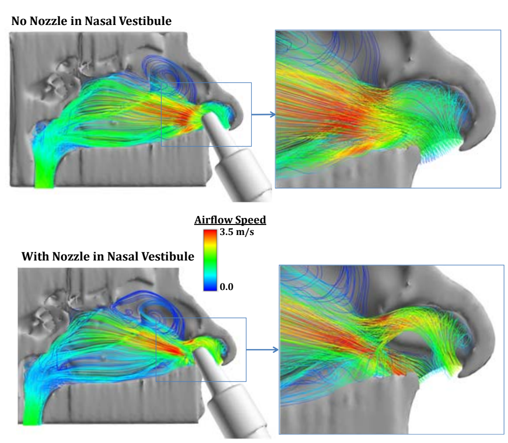


Mesh Construction

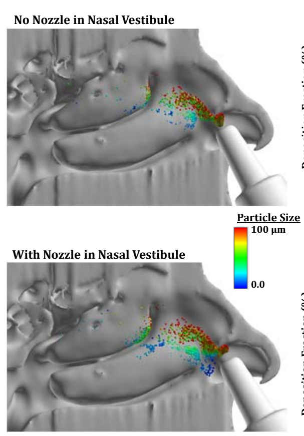


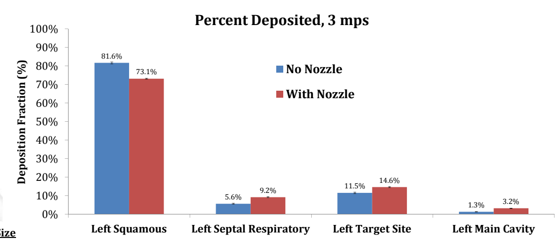
Results

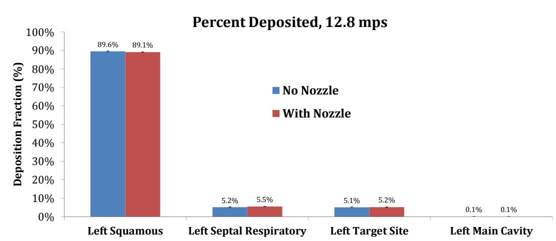
Simulated Airflow Patterns



Predicted Particle Deposition







Conclusions

- A small decrease in anterior deposition fraction (DF) with accompanying slight increases in posterior DFs were predicted with a nozzle present over predictions with no nozzle present.
- Differences between results with and without nozzle were decreased with increased spray speed.
- Nozzle presence did not significantly affect regional particle deposition.

Impact

Preliminary results indicate that inclusion of a spray nozzle may not be necessary to simulate particle size distributions accurately from common nasal spray pumps.

Future Directions

- Repeat analysis for right hand side.
- Simulate spray deposition for additional nozzle positions.
- Simulate spray deposition in rhinitic individual.
- Couple deposition predictions with a physiologically-based pharmacokinetic model to predict bioequivalent doses from alternate medication routes.

Acknowledgements

Funding was provided by Grant U01FD005201, from the Department of Health and Human Services (DHHS), Food and Drug Administration. Views expressed in this presentation do not necessarily reflect the official policies of the DHHS; nor does any mention of trade names, commercial practices or organizations imply endorsement by the United States Government.

References

Cheng, Y.S., Holmes, T.D., Gao, J., Guilmette, R.A., Li, S., Surakitbanharn, Y., and Rowlings, C. (2001). Characterization of nasal spray pumps and deposition pattern in a replica of the human nasal airway. J Aerosol Med 14:267-280.

Foo, M.Y., Cheng, Y.-S., Su, W.-C., and Donovan, M.D. (2007). The influence of spray properties on intranasal deposition. J. Aerosol Med. 20:495-508.

Liu, X., Doub, W.H., and Guo, C. (2011). Assessment of the influence factors on nasal spray droplet velocity using phase-Doppler anemometry (PDA). AAPS PharmSciTech 12:337-343.

Schroeter, J.D., Campbell, J., Kimbell, J.S., Conolly, R.B., Clewell, H.J., and Andersen, M.E. (2014). Effects of endogenous formaldehyde in nasal tissues on inhaled formaldehyde dosimetry predictions in the rat, monkey, and human nasal passages. Toxicol Sci 138:412-424.

ARA

UNC SCHOOL OF MEDICINE