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Nasal Airflow and Odorant Transport in Patients with Chronic Rhinosinusitis

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Introduction

Our on-going clinical project aims to quantify the conductive mechanism contributing to olfactory loss in chronic rhinosinusitis (CRS) patients, in addition to other inflammatory causes (see Yee, et al, 200 and Feng, et al, 203). CRS, a common disease affecting 32 million Americans annually, is reportedly associated with at least 15% of all olfactory losses. Airway constriction as a result of inflammation or the presence of polyps may limit odor access to the receptor sites and lead to olfactory dysfunction. As yet, the functional impact of various nasal obstructions as sequelae to CRS and their treatment outcomes have not been successfully indexed by any existing clinical tools, such as acoustic rhinometry, or rhinomanometry.

Computational fluid dynamics (CFD) techniques have shown great promises to simulate nasal airflow and predict odorant delivery rates to the olfactory epithelium based on CT scans. In this report, we provide additional support for the hypothesis that the CFD calculation is a better predictor of olfactory sensitivity among CRS patients than are conventional methods.

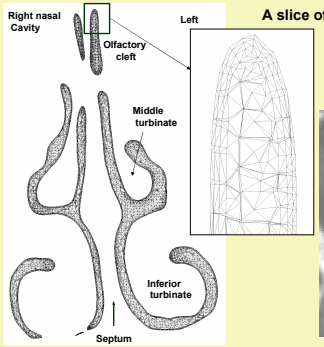
Methods

Subjects: 13 CRS patients (5 males, 8 females, 26-58 yrs).

Assessments:

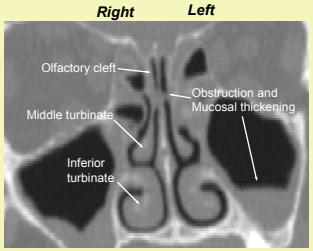
- Unilateral olfactory detection thresholds were obtained using static olfactometry for phenyl ethyl alcohol (PEA- both nostrils), and for l-Carvone, d-Limonene (on most congested side.)
- Unilateral inspiratory nasal resistance was measured by anterior Rhinomanometry, expressed in flow rate (ml/s) through the nostril at 75 Pascal.
- Numerically calculated uptake flux ($\log_{10}$ kg/m^{2}s) of PEA, l-Carvone and d-Limonene to the olfactory region mucosa during inspiration based on individualized 3D nasal airway models.

Computational 3D Nasal Airway Models were constructed for each patient based on 0.6 mm axial CT scans (Zhao, et al, 2004, Chem Sense).

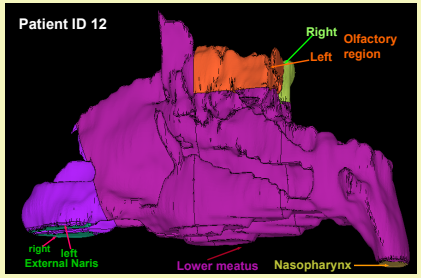


A slice of the model (patient ID 18)

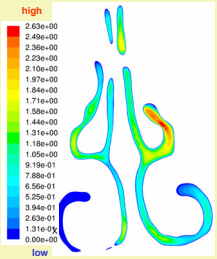
Coronal CT



Nasal airway model (patient ID 12)



Airflow velocity contour plot
(Inspiration, rest breathing, ID 18)

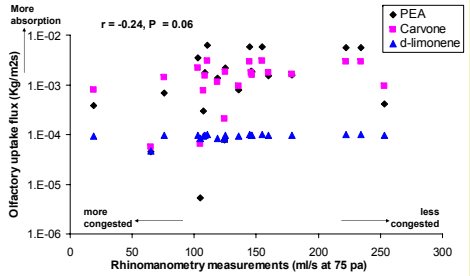


Air flow simulation: Inspiratory steady state laminar airflow was simulated by applying a static pressure drop between the nostrils and the nasal pharynx, representing resting breathing conditions (Zhao *et al*, chem. sense. 2004, 2006.)

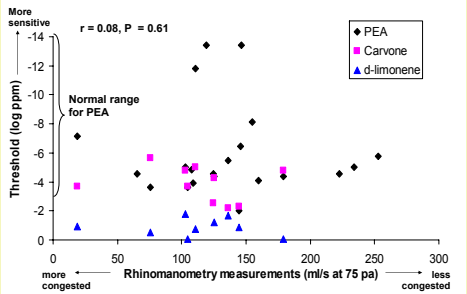
Odorant transport and absorption by nasal mucosa were simulated based on airflow calculation and the physio-chemical properties of the odorants.

Results and discussion

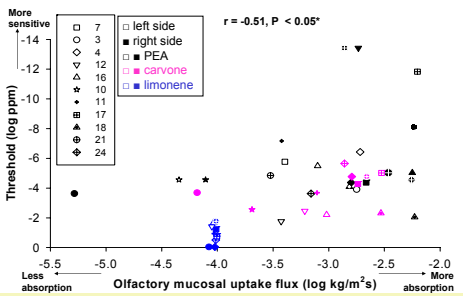
A) Nasal airflow resistance and numerically calculated odorant uptake flux to the olfactory region mucosa were not correlated.



B. Consequently, no significant correlation was found between nasal airflow resistance and detection thresholds.



C. As predicted, a strong and significant correlation was found between detection threshold and numerically calculated olfactory mucosal uptake flux.



Discussion

- Mucosal uptake flux is likely a better predictor for the delivery capability of odorants to the olfactory epithelium as modulated by inflammation-induced airway morphology changes among CRS patients than Rhinomanometry measurements, consistent with our previous findings (Zhao et al, Chem Senses, 2004) that the olfactory odorant transport process is more sensitive to changes in local airway morphology than to global flow rates.
- The changes in uptake flux likely contribute to the variation in olfactory sensitivity measured among CRS patients and may serve as **a limiting factor** especially for the high mucosal soluble odorants (e.g. PEA and Carvone). Specifically, low olfactory uptake flux would result in low sensitivity to the stimulus, whereas, high uptake flux, combined with other neurological and inflammatory factors unique to each individual, may lead to a range of sensitivity to the stimulus.
- Uptake flux for d-Limonene, a low mucosal soluble odorant, was less affected by the airway morphological changes, than was the high mucosal soluble odorants (PEA or l-Carvone), Correspondingly, the variation in thresholds to d-Limonene among the CRS patients was also smaller than for the other odorants. The application of odorant stimuli with vastly different mucosal solubilities may be utilized in future to probe the differential contribution of transport vs non-transport factors to olfactory function.
- Strong and significant correlation ($r = 0.66$, $P < 0.01$, data not shown) was also found between numerically simulated total airflow rate and that which was measured by rhinomanometry at the same pressure drop, indicating that the computational nasal airflow simulation is not significantly different from that which was measured experimentally.
- 2 patients with completely obstructed olfactory cleft were not included in the correlation analysis (uptake flux =0). Both of them also failed to detect the highest concentration in PEA and l-carvone series.

Future studies

- The impact of CRS on olfactory function is complicated and multifactorial. Results from the airflow modeling studies will be combined with clinical examinations, histological assessment (see 200) and immunological essays (see 203) to provide a comprehensive picture of diverse factors contributing to olfactory loss in CRS.
- The CFD technique can be used to investigate other nasal air flow and transport properties, e.g. mucosal wall shear stress, water vapor exchange (for drying), heat exchange, etc, which may lead us to a fuller understanding of the full spectrum of symptoms related to CRS.
- Computational airway modeling is a promising innovation to evaluate and predict the airway morphology related symptoms and treatment outcome of various nasal sinus disease that the current clinical tools lack.

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