Understanding airflow in the human nasal passage

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Background

Understanding airflow in nasal passage during natural breathing and therapy is clinically and physiologically important. The nasal passage conditions the air and acts as a ventilation passage to the lungs.

Three-dimensional human nasal passage was reconstructed from CT-images. Two case studies are reported:

- Airflow during nasal high flow therapy
- Airflow in normal, pre-operative and post-operative Chronic Rhino Sinusitis (CRS) subjects

Quasi-steady and transient airflow is solved using Navier-Stokes equations with face boundary condition and trachea velocity boundary condition.

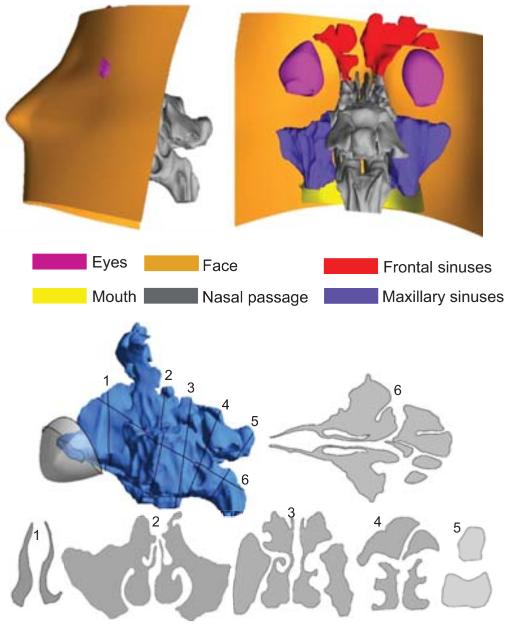

Figure1: Anatomy of the human nasal passage

Methods and Results

Case 1: Nasal high flow at Q_C=20,40 and 60 L/min through A_c=16mm^2 prongs into each nostril were simulated at peak inhalation and exhalation. Peak inhalation at 32 L/min. Peak exhalation at 20 L/min. Minimal airway geometries were created with nasal valve (A_V) areas of 98, 70 and 50 mm^2, and nostril (A_N) areas of 120, 90 and 72 mm^2.

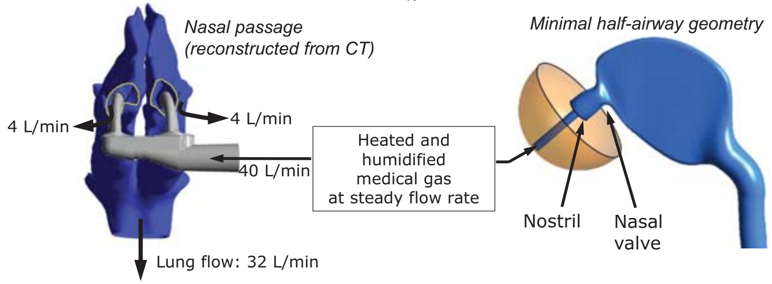

Figure 2: Nasal high flow setup

Results:

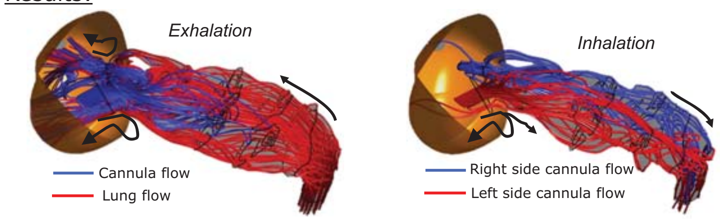

Figure 3: Flow streamlines

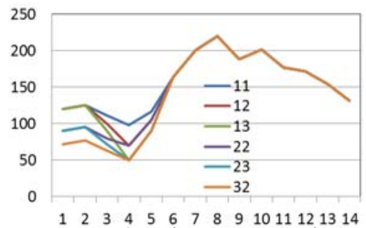

Figure 4: Centerline cross-sectional area (in mm^2) of different nasal airways

$$\text{Peak Pressure} = \frac{(a + bQ_C^2)}{A_V^m([A_N / A_C] - 1)^n}$$

Optimization yielded following coefficients:

Inhalation: (a,b,m,n) = (-40.6, 0.08,1.1,0.2)
Exhalation: (a,b,m,n) = (3.97,0.13,1.06,0.18)

- Peak pressure correlation is obtained from flow simulations in different minimal airway geometries. Nasopharyngeal pressure showed strong correlation with NHF rate and nasal valve area
- Breathing with high flow showed significant flushing out of nasal passage during both inhalation and exhalation

Case 2: Normal breathing at lung flow rate of 10L/min was simulated in normal, pre-operative and post-operative nasal passages.

Results: Airflow results from post-operative subject are shown

	Nasal wall area (cm²)	Nasal cavity volume (cm³)	Valve area (Left, Right) (mm²)	Nasopharynx area (mm²)
Normal	421.5	85.3	(76,86)	206.1
Pre-Op	467.1	99.5	(76,85)	206.1
Post-Op	446.5	121.4	(97,84)	149.1
Drill-Out	407.5	118.5	(46.5,112)	166.4

Table 1: Morphometry of nasal passage

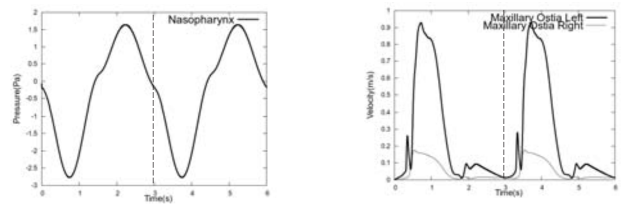

Figure 5: Time history of pressure and velocity

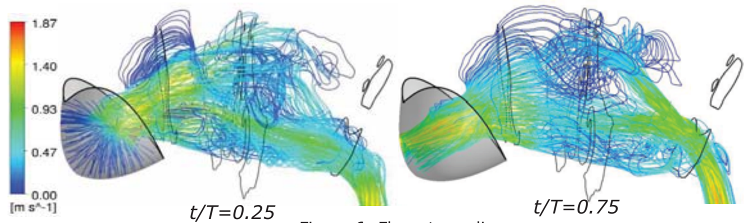

Figure 6: Flow streamlines

Summary

Improved understanding of airflow in nasal passage was obtained by studying

- Airflow during quiet breathing
- Changes in nasal pressure drop during nasal high flow therapy
- Alterations in airflow caused by surgery
- Nasal-sinus ventilation exchange
- Effects of anatomy: Strong subject-specific effects were seen in nasal flow structure and sinonasal flow

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