Flow-induced Vibrations of Uvula and Implications on Snoring

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Introduction:

Sleep disorders such as snoring and obstructive sleep apnea (OSA) are often associate with abnormal breathing arising from deformations of the respiratory anatomy [1]. However, influences from the anatomical factors remain largely unclear. It will be of great benefit to understand:

- What structural changes cause the symptom
- How such changes relate to the symptom severity.

Benefits: By linking the symptom to one particular anatomy, a specific therapy to that origin can be developed.

Objectives:

- To simulate the flow-induced vibrations of a uvula (soft palate) with varying flexibilities;
- To identify the fundamental snoring frequencies from static and vibrating uvulas.
- To refine the correlations between snoring and the uvula movements

Problem Description:

1. Image-based nasal airway models

- A 2D and 3D nose-throat airway was developed based on medical images of a adult male.
- Images were segmented using MIMICS (Materialise) into 3-D model
- internal surface geometry was constructed in Gambit (Fig. 1c).
- Elastic properties of the airway were specified differently for hard and soft tissues [2].

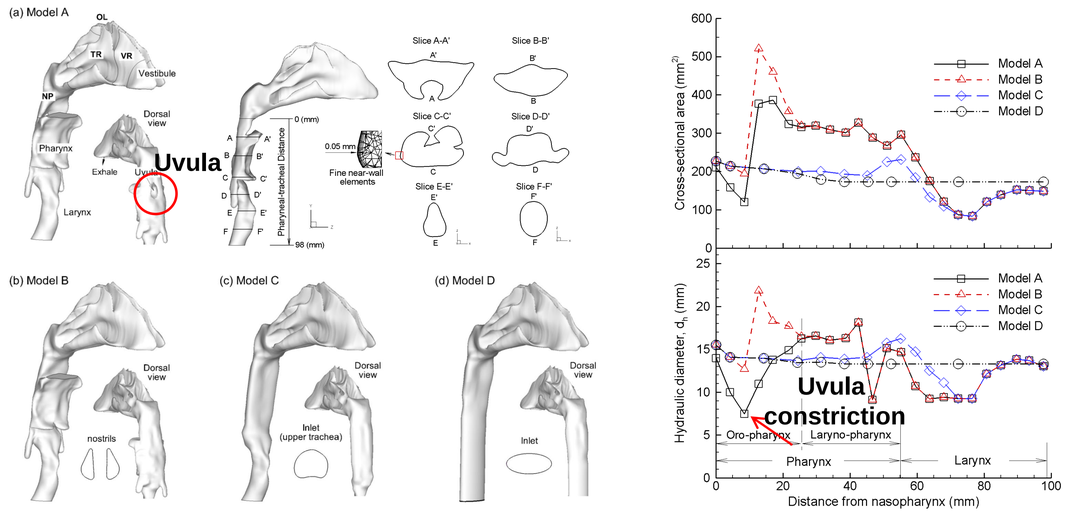

Figure 1. Nasal airway physiology with uvula constriction in Model A.

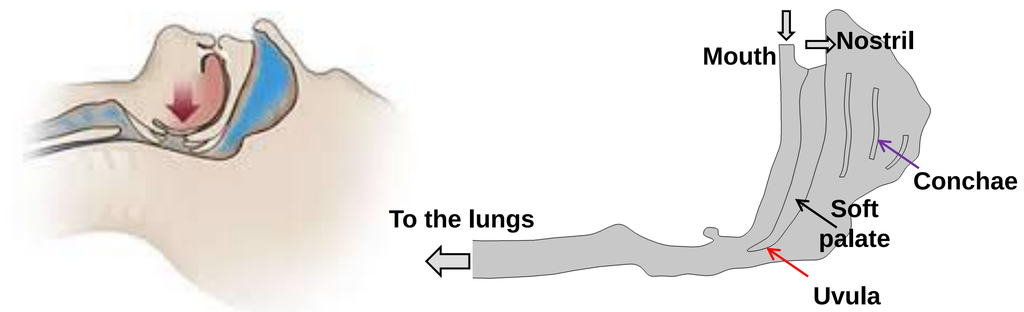

Figure 2. MRI-based 2-D nasal airway geometry.

Computational Methods:

1. Comsol Module:

- Fluid structure interactions

2. Operating Conditions

- Effect of breathing mode: nasal breathing vs. mouth breathing
- Effect of breathing rate, slow (0.2 m/s) vs. high (2 m/s)
- Effect of soft palate property (Young's Modules): 500 Pa, 5,000 Pa

Results: (Mouth Breathing 1m/s, Young's M = 500 Pa)

1. Flow-induced structure deformation noticeably deformed and altered the flow field.
2. A weak soft palate could result in flow occlusion, which causes sleep apnea.

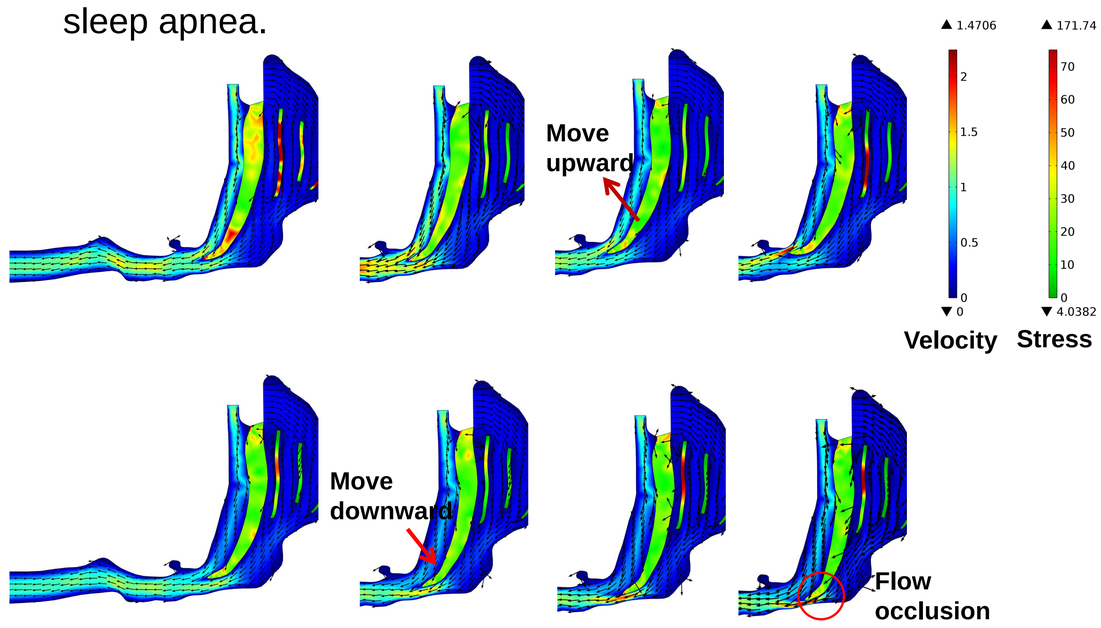

Figure 3. Nasal airflow and the induced von Mises stress on the soft palate at different instants.

2. Displacement of the uvula

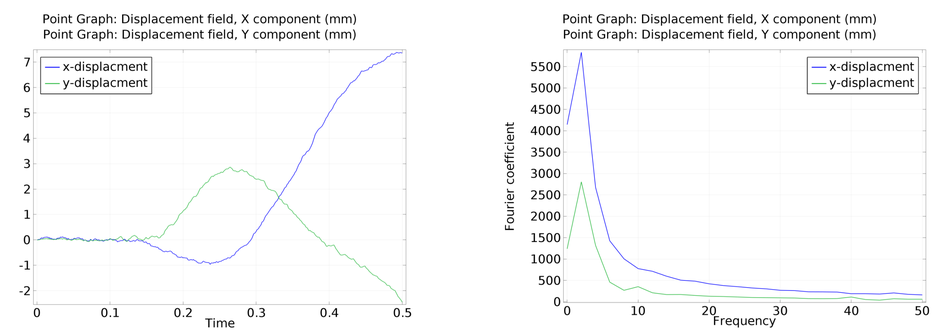

Figure 4. (a) Uvula displacement, (b) frequency spectrum.

- Uvula displacements are large in this test case (weak soft palate).
- An fundamental frequency of 3 was observed in this test case.

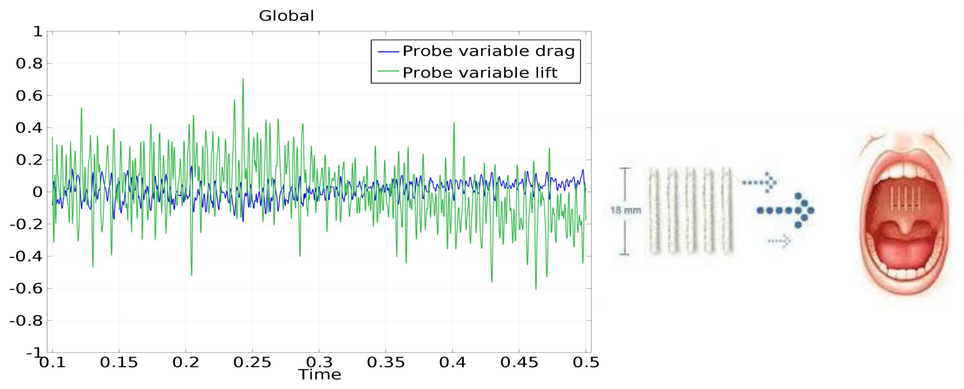

Figure 5. (a) Lift and drag force on the soft palate, (b) Possible remedy: reinforcement surgery.

Conclusions:

- Flow-induced uvula deformation considerably altered the flow dynamics inside the nose.
- For a weak soft palate, complete flow occlusion can occur (sleep apnea).
- Vibration of the airway structures is crucial to better understand snoring generation mechanisms and breathing-related disorders.
- Future studies are warranted that include the two-way coupling of flow-airway interactions and represent more breathing scenarios.

References:

1. Rappai M, Collop N, Kemp S, et al. The nose and sleep-disordered breathing: what we know and what we do not know. *Chest* **124**, 2309-2323 (2003)
2. Gao L, Parker KJ, Lerner RM, et al. Imaging of the elastic properties of tissue - A review. *Ultrasound in Medicine and Biology* ***22***, 959-977 (1996)

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