# Magnetic Resonance Elastography of the upper airways with guided pressure waves

Pascal Hagot<sup>1</sup>, Emeline Lamain<sup>2</sup>, Tom Doel<sup>3</sup>, Xavier Maître<sup>1</sup>, Redouane Fodil<sup>4</sup>, and Luc Darrasse<sup>1</sup>

<sup>1</sup>IR4M(UMR8081), Univ Paris-Sud, CNRS, Orsay, France, <sup>2</sup>Service de Neuroradiologie, Univ Paris-Sud, Hôpital Bicêtre, Le Kremlin-Bicêtre, France, <sup>3</sup>Oxford University Computing Laboratory, Univ of Oxford, Oxford, United Kingdom, United Kingdom, <sup>4</sup>IRMB, Univ Paris XII, INSERM (U955), Creteil, France

# Purpose

Localization of collapses in the upper airways of patients with obstructive sleep apnea syndrome (OSAS) is a critical issue to guide and individualize the potential surgical options and procedures [1]. Acoustic measurements may provide valuable information on the upper airway conformation and partly allow discrimination of healthy and pathological lumens but regional structural insights are missing. The latter were probed by MR-elastography in the human tongue whereas propagating waves were generated therein with a vibrating mouth guard in order to characterize the mechanical properties of the tongue and their influence onto OSAS [2]. A very different approach was taken here. By guiding pressure waves into the buccal cavity, it was possible to generate, throughout the upper airways, shear waves in the three spatial directions such that whole upper airway MR-elastography could be performed in any natural patient airway conformation and corresponding 3D maps of dynamic and loss shear moduli could be reconstructed.

## **Materials and Methods**

Pressure waves were remotely generated at 109 Hz by a loudspeaker MS 320 (Ciare, Senigallia, Italy) from the end of the scanner bed [3]. They were guided to the subject's mouth *via* a silicon mouthpiece by a 20 mm diameter and 1760 mm long altuglass<sup>®</sup> tube connected to a pressure concentrator. The subject was supine and breathing normally through the mouth. MRE measurements were obtained with a neurovascular 18-element coil array on a 3 T scanner (Achieva, Philips Medical Systems, The Netherlands) using a basic spin-echo sequence with 10 mT·m<sup>-1</sup> motion sensitizing gradients, synchronized with the mechanical wave. The upper airways were probed from the mouth down to the carena with  $(2\times2\times2)$  mm<sup>3</sup> voxel size.

FOV= $(112\times256\times56)$  mm<sup>3</sup>, TE/TR=42/1800 ms, SENSE factor=2. Four snapshots of the wave propagation were acquired during the oscillatory cycle along the three directions anterior-posterior (phase), feet-head (measurement), and right-left (slice). Shear wavelength ( $\lambda$ ), dynamic and loss shear moduli distribution maps (elastic component, G<sub>d</sub>, and viscous component, G<sub>l</sub>) were computed from the acquired displacement fields following a 3D inversion method [4]. A reference anatomical data set was acquired using a turbo spin-echo sequence with identical FOV, voxel=(1×1×1) mm<sup>3</sup>, TE/TR=78/4500 ms.

## Results

Mean amplitudes per slice ranged between 13 and 42  $\mu$ m along the anteriorposterior direction, 11 and 43  $\mu$ m along the feet-head direction, 11 and 47  $\mu$ m along the right-left direction. Displacements reached 406, 322, and 330  $\mu$ m, respectively. The wave propagation is clearly guided along the airways as shown on Figure 1. Figure 2 shows the total wave amplitude (b), the dynamic and loss shear modulus maps G<sub>d</sub> (c) and G<sub>1</sub> (d) with respect to the reference anatomy (a) for the central 2 mm thick slice. The corresponding main mean values over three manually-drawn regions of interest around the tongue, uvula, and pharynx are gathered in Table 1.

#### Discussion

The generated pressure wave is efficiently guided through the upper airways from the mouth down to the end of the trachea. The achieved wave amplitude is not technically limited as the incident pressure can easily be increased but the amplitude pattern and the penetration paths are physically determined by the structured tissues surrounding the airways. Hence, the propagating wave is largely reflected on the spine such that its amplitude is practically zeroed within. The pressure wave setup is light and it favors patient comfort. The resulting wave amplitude ensures the sensitivity of the technique in the upper airways. Structures like the tongue, uvula, and pharynx appear with different mean viscoelastic properties. Thereof, despite the local complexity of the tissue, various regions may be characterized as pointed out on the maps of Figure 2. As expected, higher values are found in the muscular tissue of the tongue. Other structures like the cricoid and thyroid cartilages or the esophageal muscles may be characterized.



Figure 1: Wave propagation in the upper airways : Displacement fields along the feet-head direction in the central slice at four times in the mechanical cycle (µm).



**Figure 2:** Viscoelastic properties in human upper airways along the central slice (a) Reference anatomical slice (b) Total wave amplitude map in  $\mu$ m (c) Dynamic shear modulus map G<sub>d</sub> in kPa (d) Loss shear modulus map G<sub>l</sub> in kPa. ROIs in red were manually drawn around the tongue, the uvula, and the pharynx.

Structures	Total wave amplitude (µm)	Shear wavelength (mm)	Dynamic shear modulus G <sub>d</sub> (kPa)	Loss shear modulus G <sub>1</sub> (kPa)
Tongue	38.8±16.2	12.3±1.6	1.18±0.40	0.99±0.40
Uvula	56.6±35.4	9.7±0.6	0.91±0.14	0.51±0.12
Pharynx	39.1±29.7	8.7±0.2	0.52±0.16	0.52±0.17

#### Conclusion

MR-elastography of the upper airways with guided pressure waves might offer a unique non invasive approach to fully characterize the mechanical properties of the upper airways of patients with OSAS such that, without long monitoring over patients' sleep, primary collapsing regions could be determined after a single MR-elastography exam on awake patients.

### References

1. Owens et al. Curr Opin Pulm Med. 14(6): 519–524 (2008) 2. Cheng et al. J. Biomech 44(3):450-454 (2011) 3. Maître et al. In: Proceedings of Annual Meeting ISMRM, Montreal, Canada, 3489 (2011)