Obstructive sleep apnea syndrome.
Part 1 : In-vitro study of the fluid-structure interaction

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Introduction
From a physical point of view airway obstruction in obstructive sleep apnea (OSA) is due to the fluid-mechanical interaction of the fluid (airflow during inspiration) and the surrounding structure (tissue). An in-vitro experimental and theoretical study of pharyngeal airflow at the origin of OSA is presented.

Material and methods
The relevant anatomical geometry is 'in-vitro' imitated by a rigid semi-cylinder of diameter D (tongue) placed inside a rectangular uniform pipe (pharyngeal wall) depicted in Fig 1. Changing the aperture between the tongue-replica and the pipe allows the study of different anatomical conditions. Incoming airflow conditions are determined by measuring the inflow pressure (p0) and air flow (q) before the replica. To validate theoretical flow simulations pressure measurements are performed at three different sites (p1, p2, p3) along the converging fourth of replica depicted in part a of Fig 2. The site p3 corresponds with the position of minimum aperture. The air flow rate and pressure distribution p(x) along the replica are predicted from the measured inflow pressure p0. p(x) reveals the fluid-wall interactions of interest. The modelling performance of Bernoulli, Poiseuille and boundary layer (Thwaites approximated solution) flow models are assessed.

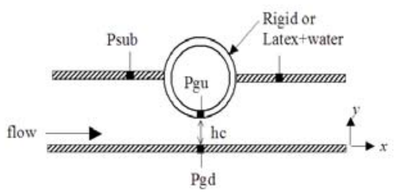

Fig. 1: Experimental set-up.

Results
Normalised pressure measurements and Bernoulli simulations are presented in part b of Fig. 2 for a minimum aperture of 1.0 mm, q ranging from 5 up to 120 l/min and ad-hoc flow separation at c=1.05. The overall model performance for 5 distinct apertures (0.7, 1.0, 1.4, 1.9, 2.3 mm) is summarised in table 1. The model accuracy is expressed by the coefficient of determination R^2. Thwaites (a,b) is obtained utilising respectively a radius D/2 and D of the cylinder. The radius D is assessed to compensate for the asymmetry of the replica (curved cylinder versus flat plate).

Discussion and conclusion
The origin of the OSA syndrome is qualitatively explained by the negative pressure at the level of the constriction as seen by all flow models. This is demonstrated in part b of Fig. 2 and quantitatively confirmed by the overall good model accuracy at the level of p3 as seen from table 1. The significant loss in accuracy at the position p1 and p2 has several reasons. As illustrated in part b of fig. 2 the steepness of the pressure slope at the sites p1 and p2 will increase the sensitivity to the exact sensor position. Secondly the asymmetry of the replica (curved cylinder versus flat plate) lowers the accuracy as seen from the significantly increase in R^2 for Thwaites (b) compared to Thwaites (a) at the sites p1 and p2. Fig. 2 illustrates the optimal choice of c=1.05 for the flow separation in Bernoulli and corresponds not with the physical site of separation obtained with the Thwaites model. The obtained pressure estimations are included in a finite element model of the tongue presented in (1).

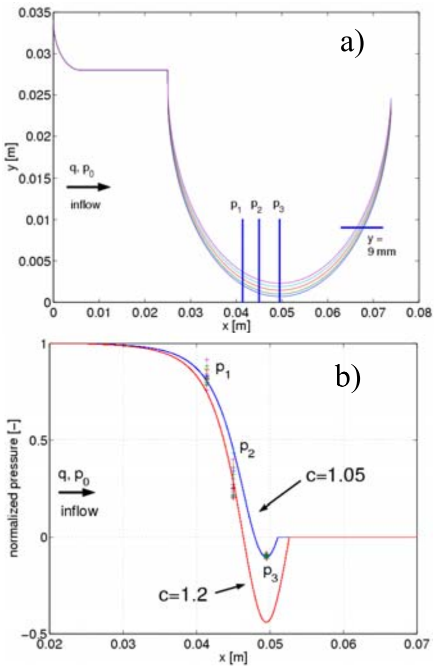

Fig. 2: a) Pharyngeal geometry and sensor sites for the 5 assessed apertures. b) Normalised pressures, y-axis [-], along the tongue replica, x-as [m] for an aperture of 1.0 mm: measurements (x), Bernoulli simulations (full).

	R^2 [-] for p1	R^2 [-] for p2	R^2 [-] for p3
Bernoulli	0.54	0.48	0.97
Poiseuille	0.54	0.45	0.98
Thwaites (a)	0.53	0.37	0.94
Thwaites (b)	0.76	0.65	0.87

Table 1: Fluid mechanical model performance.

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References
1) Chouly (2003): Computer simulation for obstructive sleep apnea syndrom. *28th Congrès de Biomecanique*, Poitiers, France.