THE BIOROBOTICS INSTITUTE

Scuola Superiore Sant'Anna

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A physical model of the human larynx and a biorobotic prototype of vocal cords

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RESEARCH OBJECTIVES

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Prof.ssa Laschi and Dott.Cianchetti

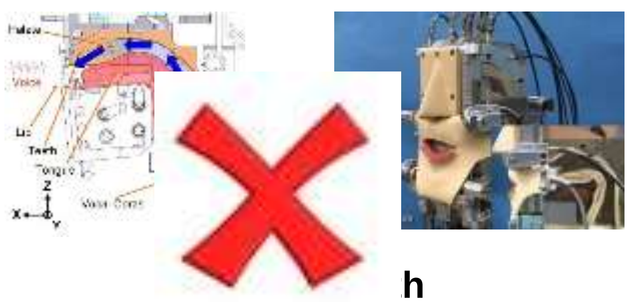
Cisanello Hospital, University of Pisa
Prof. Ursino

Development of a biorobotic platform of the human larynx that replicates its **main components** and **functions**. It will be able to improve the knowledge on human larynx physiology as a preliminary step for the development of new diagnostic, therapeutic and rehabilitative devices.

STATE OF THE ART

ROBOTIC LARYNX

Waseda Talker WT-7R2



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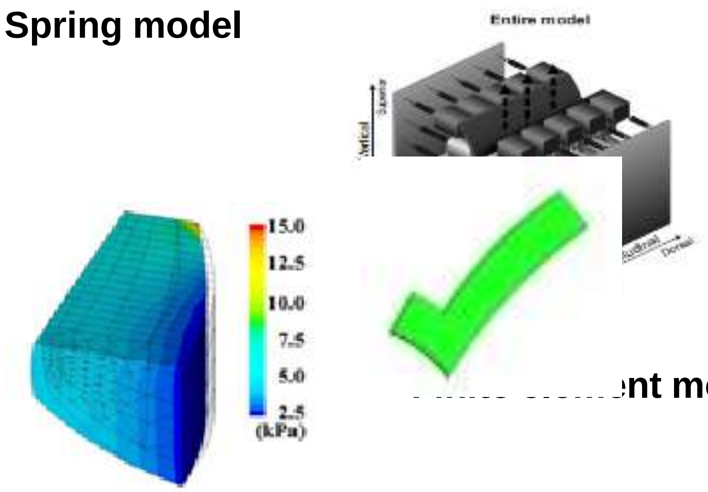
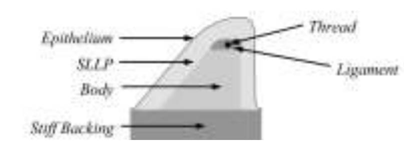
THEORICAL AND EXPERIMENTAL MODELS

Mass – Spring model



nt model

Synthetic model



SYNTHETIC MULTILAYER SELF-OSCILLATING MODELS

Direct control on the characteristics of the platform

(shapes, position, dimension and mechanical properties)

The combination between **morphology** and **mechanical properties** defines the vocal fold oscillation

MATERIALS & METHODS

ANATOMY OF HUMAN LARYNX

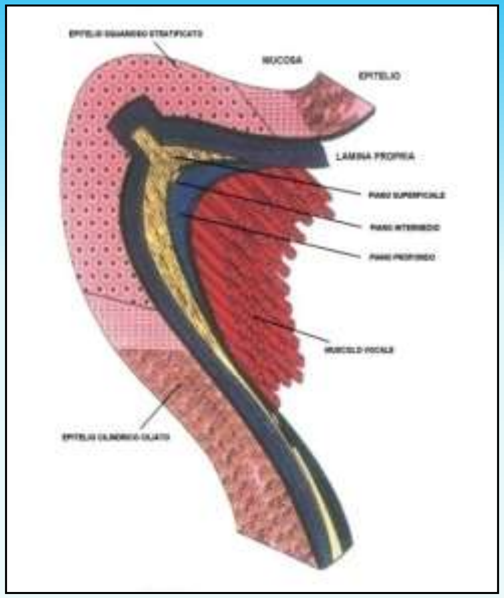
Morphology of vocal cords

MULTILAYER VOCAL CORD

- **EPITHELIUM**
- **LAMINA PROPRIA**
  - *Superficial*
  - *Intermediate*
  - *Deep*
- **THYROARYTENOID MUSCLE**

COVER-BODY THEORY [1]

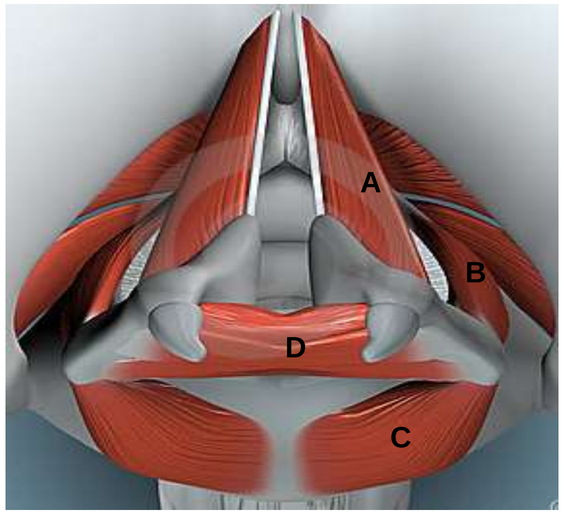
- **COVER**
- **LIGAMENT**
- **BODY**



Functional synthesis

The robotic simulator of the human larynx has to catch the key principles and the key components of the natural counterpart.

	BIOLOGICAL MODEL	FUNCTIONAL SYNTHESIS
A	Thyroarytenoid muscle	Body of the vocal fold
B	Lateral Cricoarytenoid muscle	Adduction/abduction movements
C	Posterior Cricoarytenoid muscle	
D	Interarytenoid muscle	



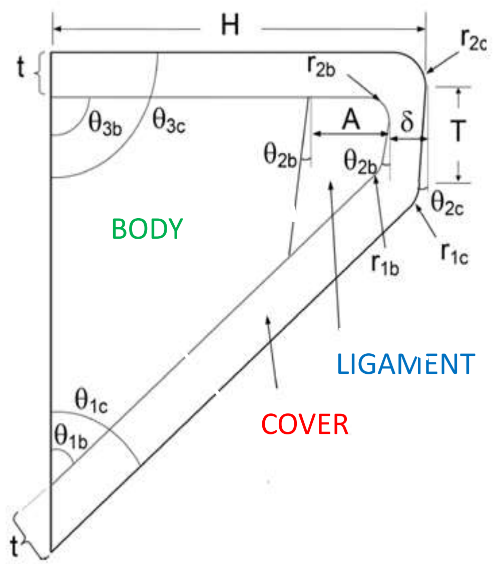
[1] M. Hirano, Y. Kakita, *Cover-body theory of vocal fold vibration*, Speech Science: Recent Advances, 1985, pp. 1-46.

MATERIALS & METHODS

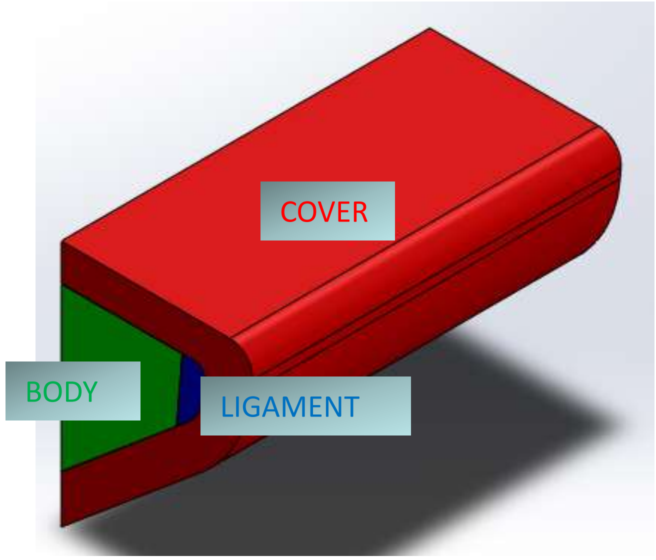
PROTOTYPE DEVELOPMENT

MULTILAYER VOCAL CORDS

Soft materials have been used to fabricate the prototype vocal cords with a multi phase casting procedure. **Silicone** has been chosen for its capability in recreating behavior close to the natural tissue



Vocal cord model geometry [2]

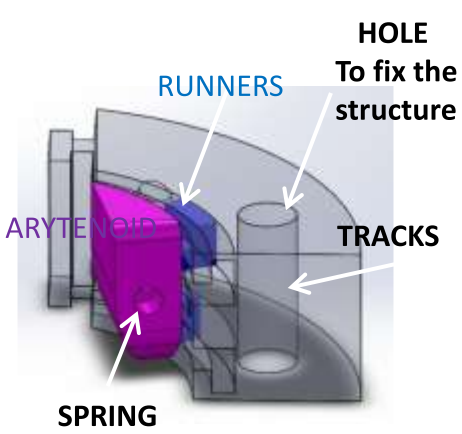


CAD Model

Physical Model

ABD/ADDUCTION MECHANISM

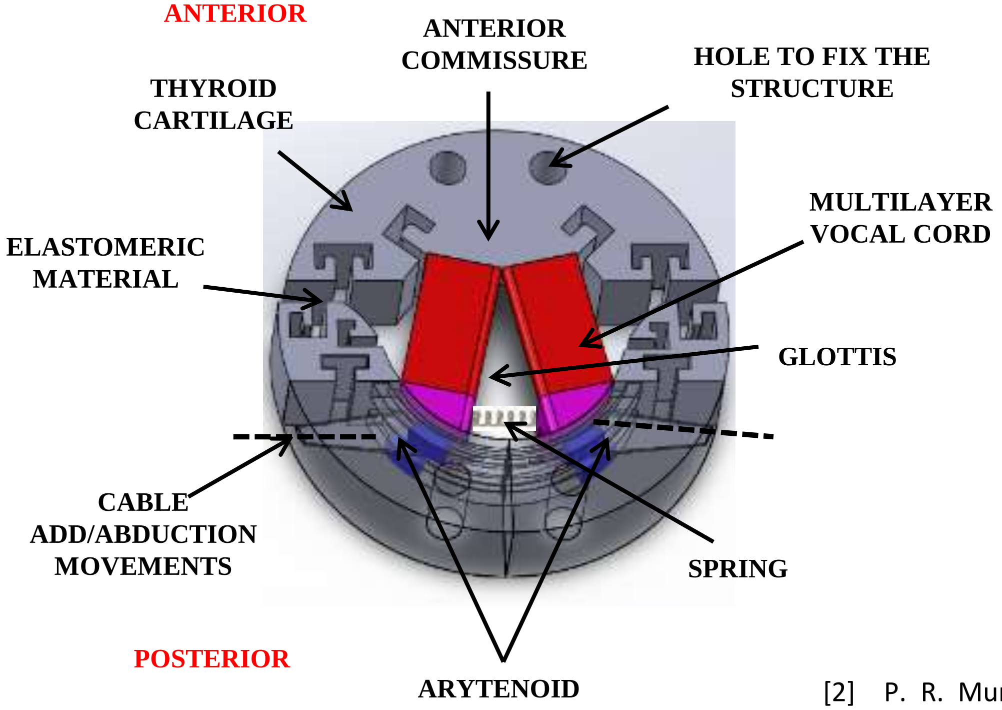
Main components reconstructed using a rapid prototype machine which allows a fast and precise fabrication of very complex parts



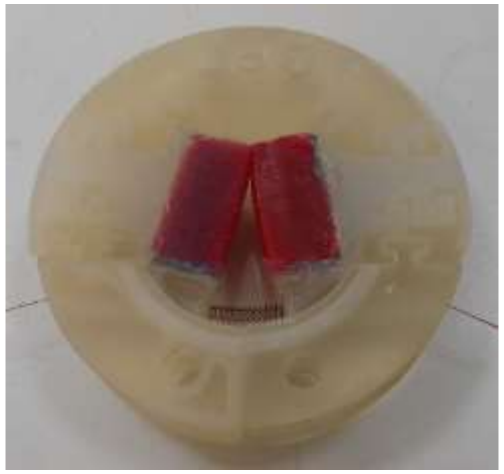
CAD Model

3D printer

CAD model of human larynx



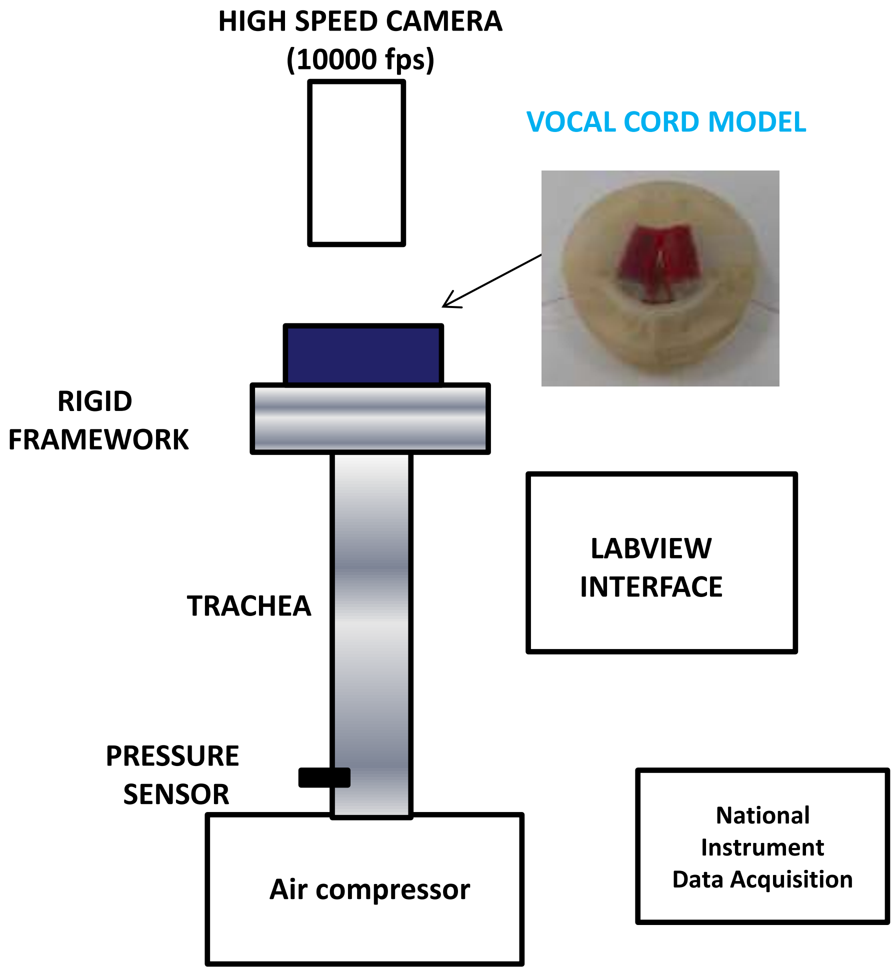
Physical model of human larynx

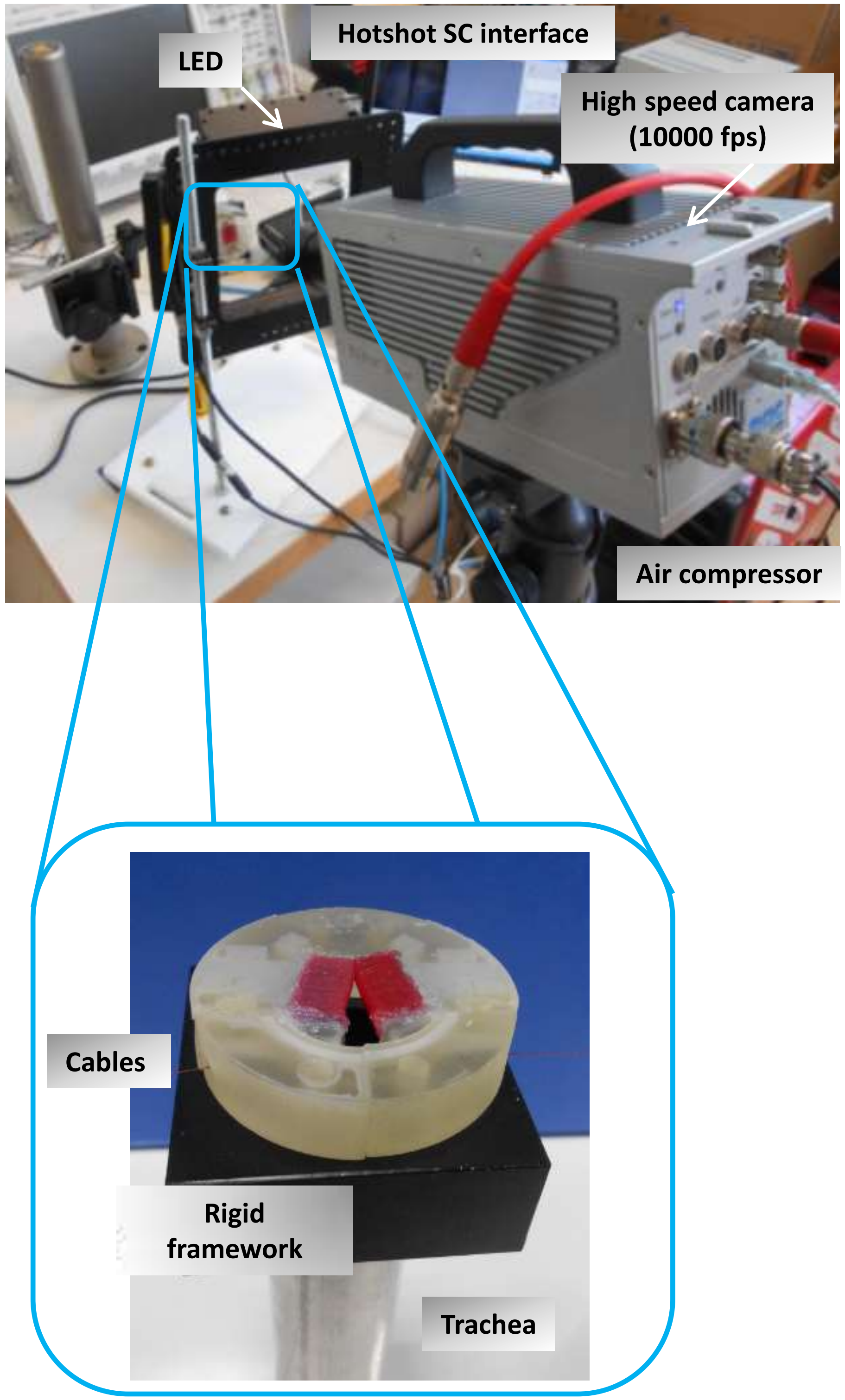


[2] P. R. Murray, S. L. Thomson, *Synthetic, multi-layer, self-oscillating vocal fold model fabrication*, J. Vis. Ex, 2011, p. 58,e3498

EXPERIMENTAL SET UP

Measurements were performed with the physical model in an experimental platform comprising a controlled air flow and a high-speed camera for measuring vocal cord vibrations. Data included **subglottal pressure**, **glottal width** and **oscillation frequency**.





RESULTS (I)

MECHANICAL PROPERTIES: uniaxial tensile test and shear test have been performed to identify soft materials with elastic and rheological properties, as similar as possible, to the natural tissue.

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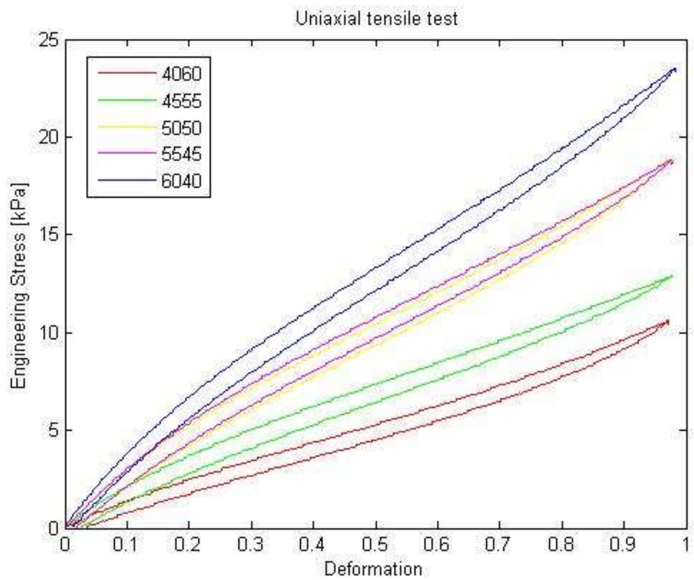
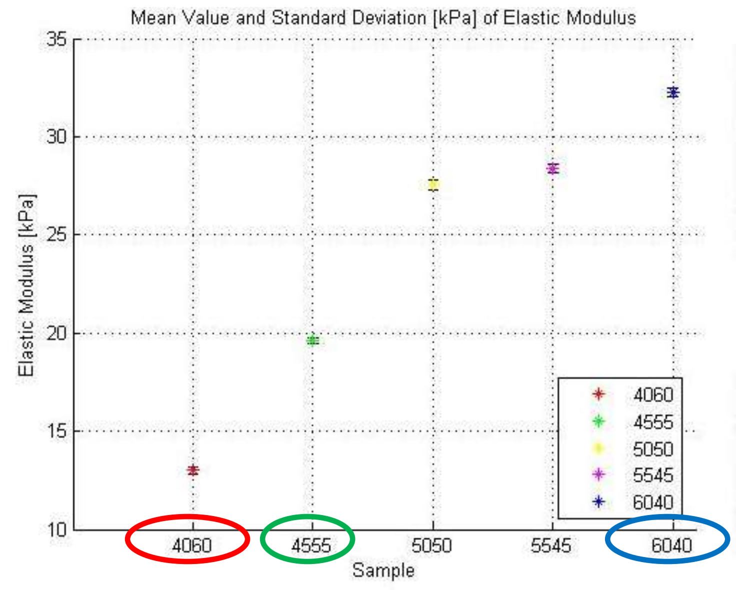
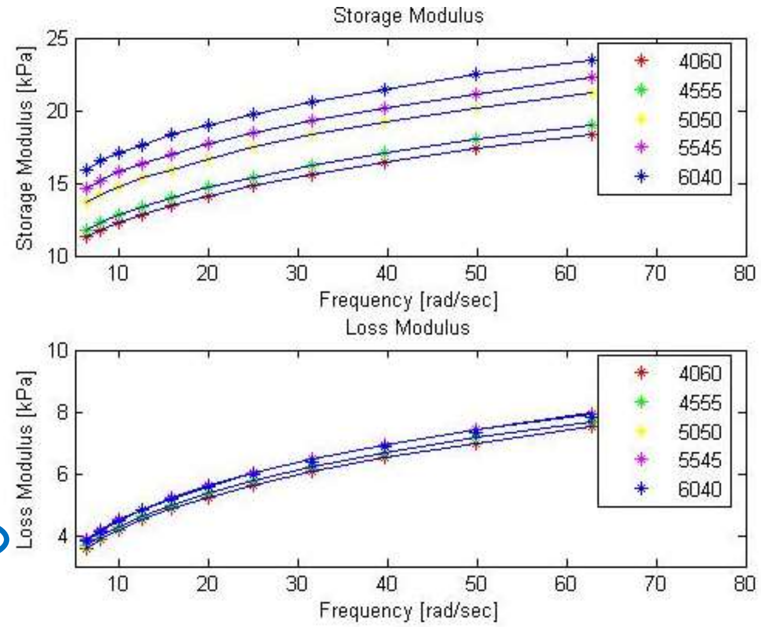
(Smooth-On Inc.)







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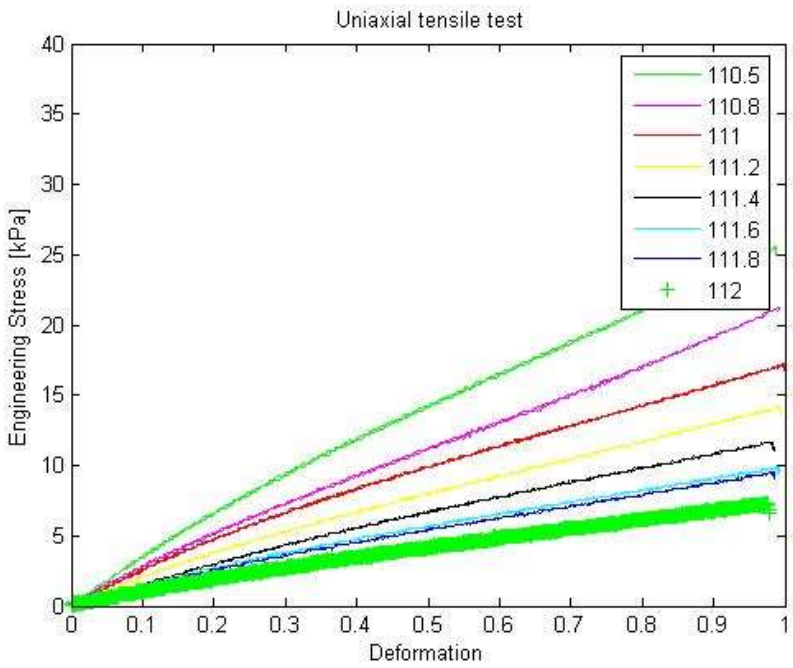
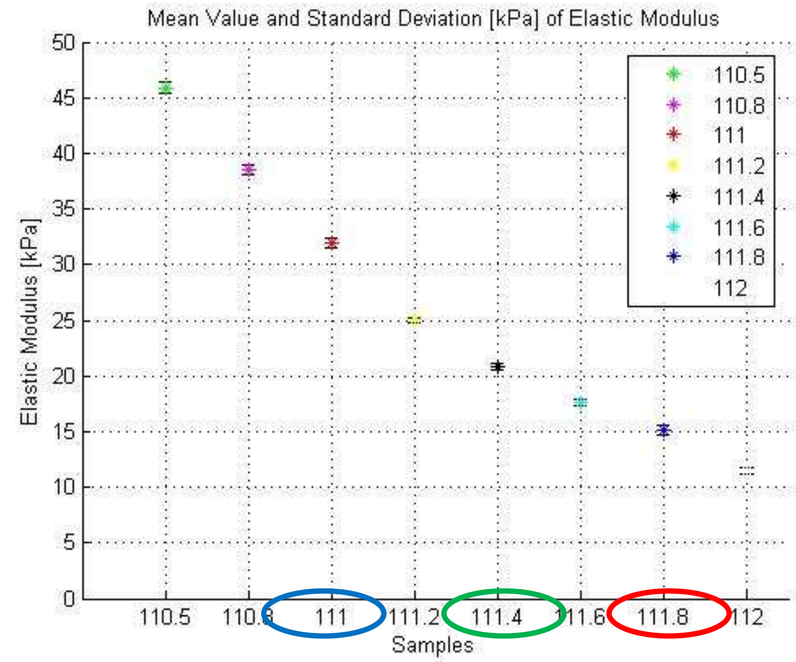
SILICONE THINNER
(Smooth-On Inc.)

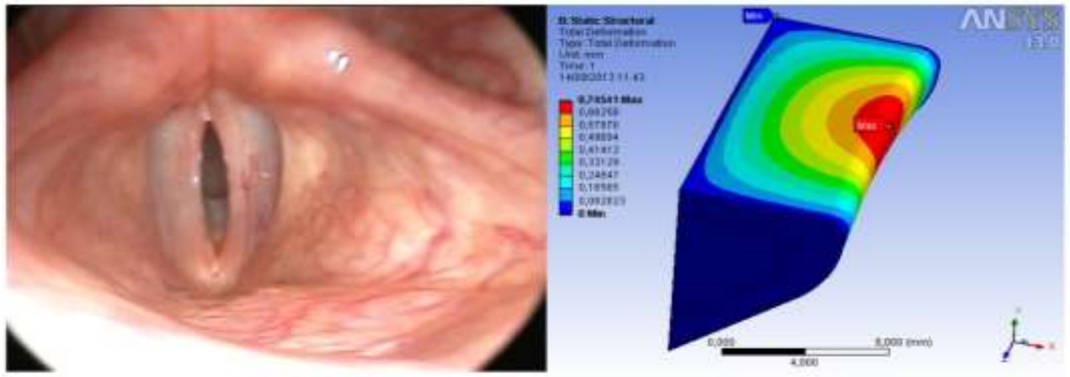


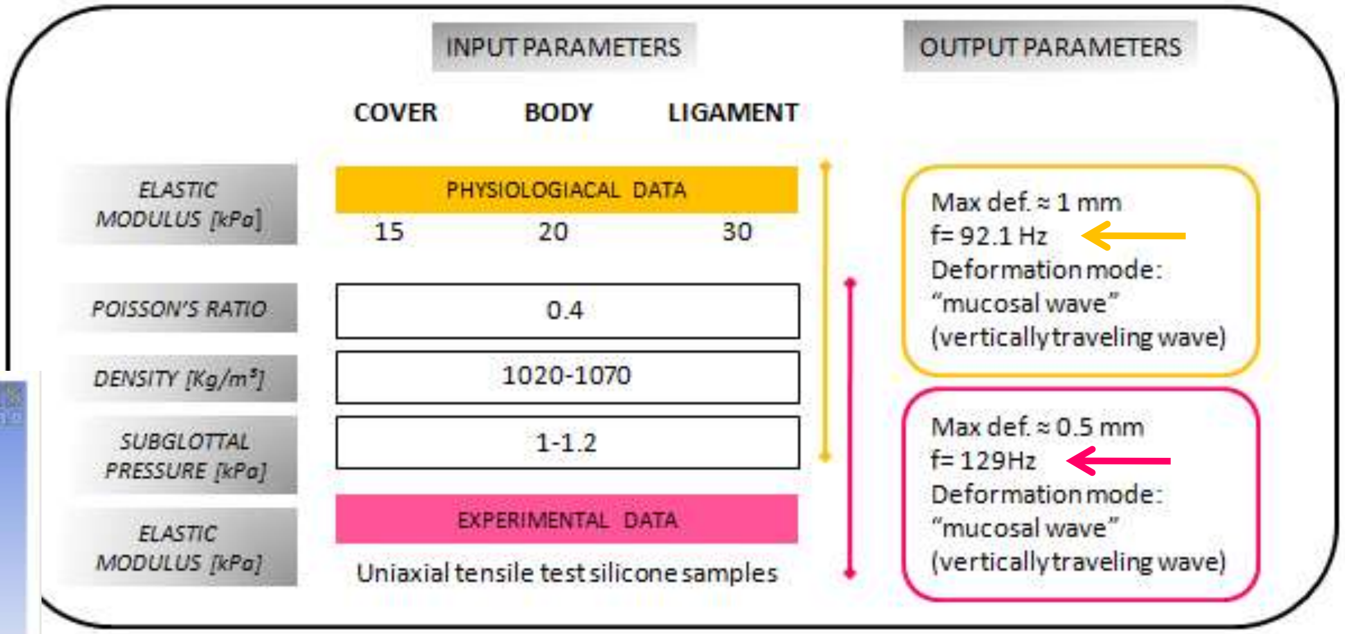


RESULTS (II)

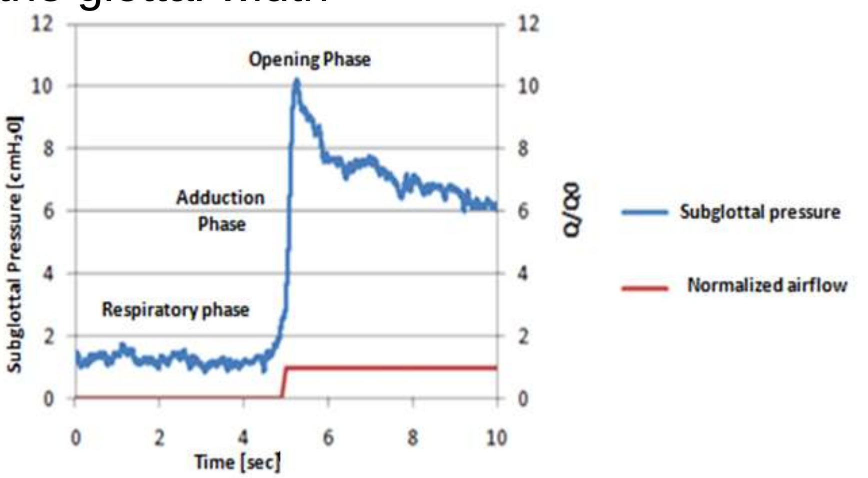
FLUID – STRUCTURE INTERACTION

A FEM model (in Ansys®) to simulate the fluid-structure interaction between the airflow and the vocal cord.





SUBGLOTTAL PRESSURE: is high enough to overcome the elastic adhesion force of the vocal cords and separate them causing an increase in the glottal width



P= 10 cmH$_2$O

Physiologic range: 7-10 cmH$_2$O

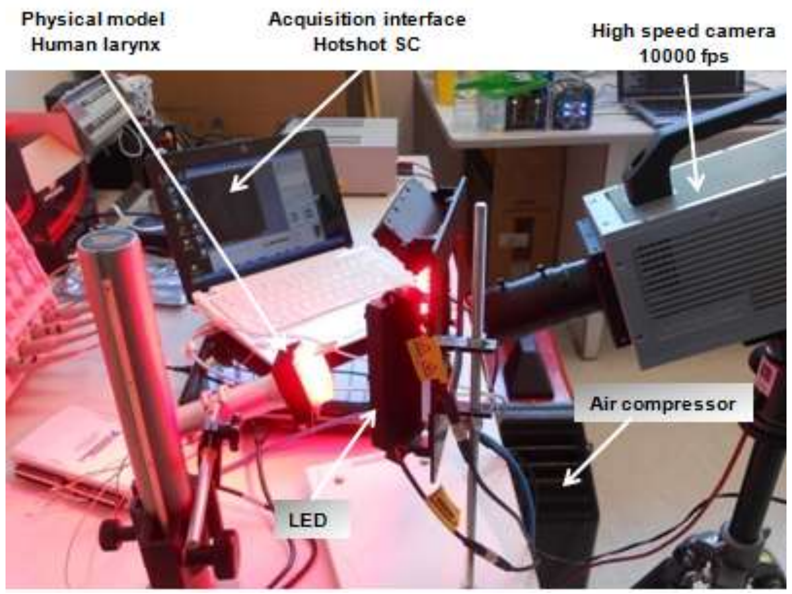
FREQUENCY: evaluated experimentally through a video analysis in order to identify the number of oscillation in the time unit.

Test	N° frame	Frequency [Hz]
1	33	151,5
2	30	166,7
3	32	156,25
4	33	151,5
5	31	161,3
6	36	139

$$T = \frac{\Delta frames}{500\,(fps)} * \frac{1}{N\,(oscillations)}$$

f= 154 Hz

Physiologic range: 97-250 Hz



CONCLUSIONS

The experimental results guarantee the feasibility of the biorobotic platform. The physical model of the human larynx will be a fundamental instrument on clinicians hands both for the study of the disease and educational purpose.

Future works:

- Robotic technologies to actively change the characteristics of the platform (namely shapes and mechanical properties)
- Study of pathological conditions
- Clinical validation

Thank you for the attention!