# Human Tongue Finite Element Model Validation with 3D MRI of subject specific phonemes articulations

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**Introduction.** Biomechanical models of the human tongue integrated in the vocal tract have been developed by many research groups (Stavness et al., 2011; Fang et al., 2009) to study speech production and speech motor control, with the simulation of the spatio-temporal tongue movements through muscle activations (REFs).

The objective of this paper is to address the question of model validation, with the issue of speaker-specific modeling accuracy. By improving our reference tongue finite element model (Hermant et al., 2017), in terms of morphology, finite element representations and anatomical muscle implementation, we propose to compare the simulations of speech articulations provided by this model with the actual articulations of the reference human subject used to build the model. These articulations were measured through magnetic resonance (MR) 3D images of vowels /i/, /u/ and consonant /t/.

**Methods.** The former versions of our tongue model, initially developed by Buchaillard et al. (2009) and Hermant et al. (2017), have been improved with the refinement of the sub-apical region, the repositioning of the external branches of the styloglossus muscle and the enlargement of the posterior triangular branches of the hyoglossus (ceratoglossus) muscle, to insert them on the greater horns of the hyoid bone. A mesh convergence study has also been conducted, thus providing a mesh made of 41600 tetrahedral elements with 61117 nodes.

The Yeoh constitutive law experimentally determined by Gerard et al. (2005) has been used to model passive tissues. Muscle contractions have been modeled with an active transverse isotropic law based on the work of Nazari et al. (2011, 2022a) allowing active stress within an element along two different directions simultaneously.

**Results.** Figure 1 superimposes the contours of the tongue and oral cavities simulated with our model with the corresponding MR mid-sagittal, coronal and axial views.

The styloglossus, the superior longitudinalis and the posterior genioglossus muscles were recruited to produce the vowel /u/, while the posterior and anterior parts of the genioglossus and the transversalis muscle were activated to produce vowel /i/. As concerns consonant /t/, the three parts of the genioglossus muscle (anterior, medium and posterior) are activated in conjunction with the superior longitudinalis so that contacts in the alveolar region can be obtained.

**Discussion.** As can be seen on the figure, our model is capable of generating complex shapes of the tongue in 3D space, with discrepancies to the MRI data that remain small. This is, to the best of our knowledge, the first time that tongue shapes generated with a finite element model are quantitatively compared with 3D MR data.

Some improvements will however have to be provided in the posterior part of the tongue, where the posterior genioglossus muscle is sometime not able to sufficiently compress the tongue (see Figure 1 for vowels /u/ and /i/). Dividing this muscle in two other parts might be a solution to this limitation. The constitutive law chosen for passive tissue will also have to be discussed, in particular with regard to the recent experimental uni-axial tensile tests provided by Nazari and colleagues (2022b) on human tongue tissues.

Finally, this new version of our model needs to be evaluated on other French phonemes for which MR images have been collected. The model will also be used to simulate tongue movements that will be compared to mid-sagittal trajectories already collected with electromagnetic articulography (EMA) on our reference subject.

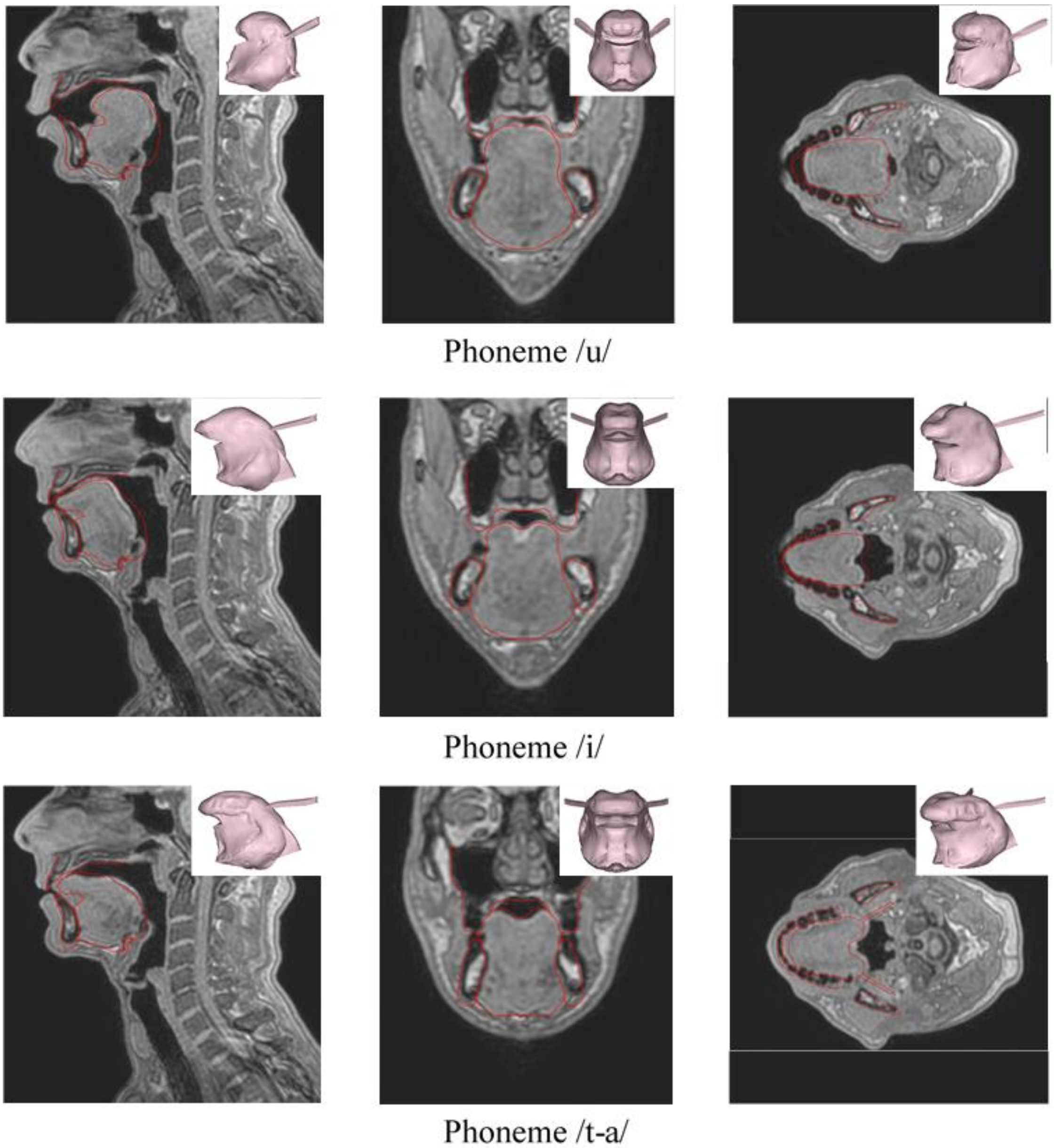


Figure 1: *Phonemes /u/, /i/ and /t/ (in context /t-a/). Contours of the tongue model (in red) in its final position superimposed with mid-sagittal, coronal and axial MR slices. 3D views of the tongue are added in sub-panels.*

References

Buchaillard, S., Perrier, P., & Payan, Y. (2009). A biomechanical model of cardinal vowel production: Muscle activations and the impact of gravity on tongue positioning. *The Journal of the Acoustical Society of America*, *126*(4), 2033-2051.

Fang, Q., Fujita, S., Lu, X., & Dang, J. (2009). A model-based investigation of activations of the tongue muscles in vowel production. *Acoustical Science and Technology*, *30*(4), 277-287.

Gérard, J. M., Ohayon, J., Luboz, V., Perrier, P., & Payan, Y. (2005). Non-linear elastic properties of the lingual and facial tissues assessed by indentation technique: Application to the biomechanics of speech production. *Medical engineering & physics*, *27*(10), 884-892.

Hermant, N., Perrier, P., & Payan, Y. (2017). Human tongue biomechanical modeling. In *Biomechanics of Living Organs* (pp. 395-411). Academic Press.

Nazari, M. A., Perrier, P., Chabanas, M., & Payan, Y. (2011, July). A 3D finite element muscle model and its application in driving speech articulators. In *ISB 2011-XXIII Congress of the International Society of Biomechanics 2011* (pp. Paper-ID).

Nazari, M. A., Perrier, P., & Payan, Y. (2022a). Interwoven muscle fibers: a 3D two-fiber muscle active model. In *47th congress of the Society of Biomechanics, Computer Methods in Biomechanics and Biomedical Engineering* (Vol. 25, No. sup1, pp. S226-S228).

Nazari, M. A., Perrier, P., Jeannin, C., Veyre, S., Masri, C., & Payan, Y. (2022b). Ex-vivo human tongue muscle mechanical characterization. In *27th Congress of the European Society of Biomechanics (ESB'2022)*.

Stavness, I., Lloyd, J. E., Payan, Y., & Fels, S. (2011). Coupled hard–soft tissue simulation with contact and constraints applied to jaw–tongue–hyoid dynamics. *International Journal for Numerical Methods in Biomedical Engineering*, *27*(3), 367-390.