Podium Presentation, Session 8, Friday 15:20 – 17:00

Reconstructing the tongue in the oral cavity. The first step towards application to fossils

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The emergence of the capacity for spoken language in humans during the course of evolution is a widely debated question. It has been renewed recently by the paradigm shift undermining Lieberman's 1960s theory of laryngeal descent, as studies have shown that non-human primates are capable of producing vocal tract shapes compatible with the articulation of speech sounds [1] and of pronouncing differentiated sounds covering a vowel spectrum similar to that of humans [2].

For fossil hominines, the complexity of this question lies in the difficulty of studying their phonatory apparatus due to the poor preservation. Soft tissues and cartilage do not fossilize, while bones can be damaged, deformed, or eroded. For this reason, the capacity for language in fossil hominins is often estimated indirectly, by considering that a faculty for abstraction is necessary, and by identifying tangible evidences of the latter in various productions (carved tools, burials, cave paintings...).

For the first time, we have attempted a direct approach, aiming to reconstruct the soft tissues making up the vocal apparatus, starting with the tongue. This work benefits from long-term research carried out at the TIMC & Gipsa-lab laboratories (University Grenoble Alpes, France), which has generated a fine model of the organs of the vocal apparatus in a present-day *Homo sapiens* used as a reference. This model accurately reflects the morphology and the constitutive behaviors of tongue soft tissue (including its muscular structures) and simulates tongue deformations due to muscles activations and/or to the mechanical interactions with the mandible, palate and hyoid bone.

Here, we present the results of the first stage of this project predicting the morphology of the missing tongue and surrounding soft tissues in the oropharyngeal cavity from the geometries of the skull, mandible, and vertebrae (i.e. based only on the bone structure). To test the effectiveness of our protocol, data from a Baboon head were used because of its significant morphological differences from humans. 3D CT images enabled us to consider only the bone structure to predict the tongue of this individual from one side and to control this prediction thanks the actual soft tissues from the other side. The method generates a geometric deformation field from the reference model to build up a 3D Finite Element mesh of the baboon tongue using mathematical tools combining rigid transformations (translations, homotheties, rotations) and non-rigid transformations (i.e. non-uniform over the entire volume, with localized refinements).

The results are very encouraging [3] and will allow us to consider an application to fossil hominins with two objectives: (1) constructing a biomechanical model of the predicted fossil tongue and its surrounding structures in the oral cavity, incorporating the muscles responsible for its movements and shaping; (2) using this model to evaluate the maximal movement magnitudes of the tongue in the antero-posterior and vertical dimensions, the range of variation of achievable vocal tract shapes, and the capacity of fossil hominins to maintain stable, differentiated tongue postures, providing a basis for the production of distinctive articulated sounds.

References: [1] Fitch, W.T., de Boer, B., Mathur, N., Ghazanfar, A.A., 2016. Monkey vocal tracts are speech-ready. Science Advances. 2, e1600723. [2] Boë, L.-J., Berthommier, F., Legou, T., Captier, G., Kemp, C., Sawallis, T.R., Becker, Y., Rey, A., Fagot, J., 2017. Evidence of a Vocalic Proto-System in the Baboon (Papio papio) Suggests Pre-Hominin Speech Precursors. PLOS ONE. 12, e0169321. [3] Fitch, W.T., de Boer, B., Mathur, N., Ghazanfar, A.A., 2016. Monkey vocal tracts are speech-ready. Science Advances. 2, e1600723