A study on estimation of activation patterns of lingual muscles Based on tongue deformation

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1. Introduction

The tongue is one of most important organs for human daily life, which plays an important role in mastication, swallowing and speech production. It is important to investigate and understand the properties of the lingual muscles since the tongue is driven by a woven muscular structure. Although the tongue muscles have been investigated by anatomical and experimental approaches such as EMG, it is still far from fully understanding their mechanism, especially their activation patterns in driving the tongue. In this study, we investigate muscle activations based on tagged cine MRI (tMRI) observation and model simulation. An extreme protrusion-retraction task of the tongue movement was observed using the tMRI for one male subject. Relation between muscle activities and velocity patterns are estimated by means of Analysis-by-Synthesis (AbS), where the analysis is carried out using HARP MRI analysis method and the "synthesis" is realized by using a 3D physiological model. In the velocity field from the HARP MRI analysis, it seems that the muscle activation patterns showed a wave-like propagation. To quantify the muscle activation patterns, we used the 3D tongue model to reproduce the movement by activating the concerned muscles. It is found that in the extreme protrusion-retraction movement the muscles verticalis and transversus are activated part by part, while the superior longitudinal is activated during the movement. This primary study showed that the muscle activation is able to be estimated by the AbS method.

2. Observation of interior deformation of the tongue by tagged-MRI

Since the tagged cine-MRI (tMRI) has advantage to investigate the interior

deformation of the tongue, in this study, we attempt to estimate muscle contributions in a large-scale deformation using the tMRI approach. To investigate stress and strain of the tongue with a large-scale deformation, one task was designed for the tongue: protrusion-retraction. Motion of the tongue was measured from tagged MR images using Harmonic Phase (HARP)-MRI. Consequently, in this study, the tongue was observation using principal strain. When it is actually just less expanded than the reference, the principal strains are all defined by the reference frame (i.e., maximum protrusion). Therefore the principal strain obtained from HARP analysis is not able to always provide reliable results. In contrast, the velocity obtained with reference to the neighbor frames is possible to provide reliable information on the tissue deformations. For this reason, we used velocity filed for estimating the muscle activation instead of the principal strain.

3 . Muscle Activation based on the Velocity Field

To obtain more reliable estimations, we calculated the velocity filed for protrusion phase and release phase. One can see that in the beginning the tissue movement is seen in the median part of the anterior portion of the tongue. It is interesting to find that the velocity show a wave-like propagation along the protrusion direction. Since the tongue tissue can be considered as incompressible tissue and obey the hydrostatic law, we can use a balloon to explain the activities of the tongue. As a force is loaded on a balloon, the velocity in the loading points is zero, and in the velocity field inside the balloon, the velocity of the particles in two sides of the force loading plane should have opposite directions pointing away from the force loading plane. It can be thought that the velocity fields obtained from HARP analysis is also similar. Therefore we estimated muscle activations using velocity field by HARP MRI analysis.

4. Physiological Model and Muscular Structure

To obtain a more accurate estimation, in this study, we employed a model based analysis-by-synthesis (AbS) method for the estimation. The section gives a brief description of the physiological model and the muscular structure in the model tongue. In normal speech, the tongue tends to move symmetrically while the tongue moves asymmetrically in mastication activities. To realize those functions, all the muscles are designed symmetrically on the left and right sides, while they can be controlled independently on the left side and right side. In the following chapter, desired tongue movements are generated by activating the muscles and the generated movements are compared with observations of tMRI.

5. Simulation of the tongue movement using Analysis-by-Synthesis(AbS)

Since a number of muscles are co-activated even in forming a simple movement, it is often difficult to determine accurately the mechanical load of a muscle because the load depends on the situation of other muscles. In this study, we propose an analysis-and-synthesis (AbS) method to estimate muscle contributions by comparing model simulation and observation.

6. Exterior tongue movement analysis by microbeam

Based on the movement position data by x-ray micro beam, how the movement position data was projected to 3D model to develop the algorithm that presumed the muscle activity by the tongue transformation was examined. The relation between 3D tongue model and the observational data used the linear recurrence analysis method.

7. Discussion and Conclusion

In this study, we proposed an analysis-by-synthesis method to estimate activation pattern of tongue muscle, in which the muscle activation was estimated based on the tMRI observation and refined by model simulation. This primary study showed that a systematic combination of the tagged-MRI observation and model simulation can accurately estimate more complicated muscle activations. One of remaining work is how to automatically realize the comparison of the simulation pattern and the observation patterns.