5aSCb26. Anatomical considerations on the extrinsic tongue muscles for articulatory modeling

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Physiological articulatory models have evolved from simpler forms to complex ones, while recent models preserve traits of oversimplification and anatomical unreality. This work combines MRI observations at ATR-BAIC and Johns Hopkins University to point to the issue for advancing extrinsic tongue muscle modeling. The genioglossus, previously thought to arise from the genial tubercle of the mandible, has direct fiber attachments on the short tendon of the tongue. The posterior genioglossus has been modeled as linear strings traveling 'free in air' before inserting into the tongue, but the extralingual part is actually restrained by the surrounding soft tissues to lack mobility. The styloglossus has been modeled as linear strings traveling 'free in air' before inserting into the tongue, but the extralingual part is actually restrained by the surrounding soft tissues to lack mobility. The intralingual styloglossus forms anterior and posterior slings in the tongue tissue, possibly with the distal fibers of the hyoglossus. Combined styloglossus and hyoglossus shortening via the slings may be a factor shaping the tongue into various forms.
INTRODUCTION

Physiological articulatory model is a computational tool that emulates actions of speech articulators by muscle contraction (Fujimura, & Kakita, 1979; Dang, & Honda, 2001; Fujita, et al., 2007), and the work to build such models requires vast knowledge of anatomy and physiology of the speech organs in addition to the formulation of necessary algorithms. Many researchers have focused on the tongue as a central structure of the articulatory model because of its major role in determining vocal tract shape, and they effort to include the extrinsic and intrinsic muscles of the tongue adequately in the system. In the models, the tongue muscles were simplified to various degrees due to computational cost and structural complexity. The models were built so that they can fulfill the first approximation of tongue deformation for desired manners, or they are made to conform to the functions of the muscles according to the literature. The simplification was necessary, and the details of anatomy and physiology were often secondary. In this presentation, a few anatomical issues are discussed that have been neglected so far, with a hope to advance the models toward the next stages. What follow are based on anatomical and MRI observations of the three extrinsic muscles of the tongue: the genioglossus, styloglossus and hyoglossus muscles. Table 1 summarizes possible anatomical divisions and motor functions of the extrinsic muscles.

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<th>TABLE 1. Divisions of the extrinsic muscles of the tongue.</th>
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<td><strong>Extrinsic muscles</strong></td>
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GENIOGLOSSUS, A TRIANGULAR MUSCLE

The genioglossus is the largest muscle in the tongue that determines position and shape of the tongue. This muscle is fan-shaped and can be morphologically classified to a triangular muscle that has a central tendon and radiating fibers from the tendon. The central tendon provides attachments to the fibers (and an action point) in a typical triangular muscle. The genioglossus has a central tendon called “the short tendon of the tongue”, and the most of the muscle fibers arise from this tendon. Figure 1 shows the midsagittal MRI slice of the tongue that infers fiber radiation from the tendon. According to common anatomical descriptions, the genioglossus arises from the superior genial tubercle of the mandible, and thus in most of the tongue models the muscle has a wide area of muscle attachment on the mandible. But, more accurately, this muscle radiates from the short tendon, and the muscle fibers arise from the entire length of the tendon toward the oral and pharyngeal surfaces of the tongue.

The short tendon of the tongue is a soft connective tissue that shows a certain effect of muscle contraction as seen in the midsagittal MRI. Figure 2 shows the shapes of the tongue in the production of Japanese vowels /i/ and /a/ that were traced from MRI data obtained during sustained vowel production. This figure tells us that the orientation of the short tendon varies with vowels: the angle formed by the tendon and the mandible-to-hyoid line is wider for /i/ rather than in /a/, reflecting the major effect of the midsagittal muscle of the genioglossus. Thus, the short tendon can be an anatomical landmark within the tongue tissue that offers an index for quick evaluation of the goodness of model simulation.
The short tendon also offers a basis of anatomical divisions of the genioglossus. It has been stated that the genioglossus functionally divides into two or three regions; anterior and posterior divisions (GGA vs. GGP) or three divisions (GGA, GGM, and GGP). The short tendon suggests that the anatomical division is possible at least for the fibers arising from the inferior aspect of the short tendon. A recent article also suggests that the horizontal part of the genioglossus differs from the rest of the fibers (oblique part) in the pattern of endplate distribution (Mu & Sanders, 2012): the medial branch of the hypoglossal nerve has the endplates in two patterns, dual for the horizontal part while singular for the rest. Therefore, it is reasonable to state that the genioglossus has a neuroanatomical basis for divisions, one for the horizontal part arising from the inferior aspect of the short tendon, and the rest for the part that further functionally divides into the vertical and oblique parts. The division is also supported in electromyographic data: the signal from the horizontal part is much higher in amplitude than those from the rest in the production of vowel /i/.

**FIGURE 2.** The short tendon as an anatomical landmark in the tongue tissue. The orientation of the short tendon changes between vowel /i/ and /a/. The angle between the tendon-dorsum line and tendon-hyoid line can be an index of tongue tissue deformation.

**STYLOGLOSSUS, TWO DIVISIONS**

The styloglossus is the longest muscle in the tongue that travels from the skull base at the styloid process, and it is geometrically divided into the extra-lingual and intra-lingual parts. It has been described that the styloglossus muscle pulls the tongue body back and upward in speculation from the orientation of the extra-lingual part of the muscle. Each of the long muscle fibers of the styloglossus receive innervation from the lateral branch of the hyoglossal nerve with the singular endplate distribution, and thus the fibers are not compartmentalized at least along the length, predicting the simultaneous shortening of the extra- and intra-lingual parts.

The extra-lingual part of the styloglossus enters to the sides of the posterior tongue body bilaterally passing through the soft tissue in the parapharyngeal region. Figure 3 shows the coronal slice at the pharynx, where the extra-lingual styloglossus is surrounded by the palatine tonsil and the pharyngeal constrictor muscle medially, by the median pterygoid muscle laterally, and by the submandibular gland inferiorly. The geometry surrounding the part of the muscle in the figure suggests that the orientation of the extra-lingual part is almost constant regardless the
changes in tongue shape and position because the fibers pass closely by the sheath of the pharyngeal constrictor near the base of the tonsil. This situation leads to a reasonable conjecture to re-evaluate the function of this part. It is well-known that the pharyngeal surface of the tongue in the midsagittal slice shows displacement and deformation across vowels, while the location of the entrance of the styloglossus to the tongue body must remain nearly constant due to the tight fiber binding to the surrounding tissues. This also suggests that the measured length of the part is also nearly constant across vowels, in agreement with MRI-based measurement (Takano & Honda, 2007). Those observations lead us to a conclusion that the extra-lingual part applies a force to the intra-lingual part to pull the tissue in and along only posteriorly with no upward force component on the tongue.

FIGURE 3. Coronal MRI slice of the pharynx showing the anatomical relation of the extra-lingual part of the styloglossus at the location near the fiber entrance into the tongue. (Figure from Honda, Takano, & Takemoto, 2010).

The intra-lingual part of the styloglossus has been known to have a few segments. In the lateral view in common literature showing tongue muscle anatomy, the part divides into two: one to travel toward the anterior tongue and another to join the hyoglossus. In the transverse view, it is known to divide into two segments called the anterior and posterior slings: the anterior segment stretches to the tongue tip finally joining together with the contralateral segment to form a sling, and the posterior segment fuses together in the midline to form another sling. Figure 4 shows a transverse slice of the tongue that indicating a trace suggesting the posterior sling of the muscle in the tissue near the posterior surface of the tongue, while the anterior sling is not clear, perhaps due to a wide distribution of the sling fibers in the anterior tongue. The two possible slings of the styloglossus suggest a conjecture for this muscle: the posterior sling shortens the looped tissue to approximate the pharyngeal surface of the tongue to the posterior pharyngeal wall, while the anterior sling causes tongue bunching by drawing the tongue tip to the back.

FIGURE 4. Schematic oblique view of the anterior part of the styloglossus, showing the anterior and posterior slings. The posterior sling is visible in transverse MRI, while the anterior is obscure.
The combined effects of muscle fiber shortening in each part contribute to elevation and backing of the tongue body as seen in the tongue shape for vowel /u/ in English. The function of the styloglossus in articulation may be realized in two steps: retraction by the extra-lingual part and bunching by the intra-lingual part.

HYOGLOSSUS, A FEW QUESTIONS

The hyoglossus is a quadrilateral muscle in the side view, which has two parts: the ceratoglossal part that arises widely from the greater horn of the hyoid bone and the chondroglossal part that arises from the lesser horn of the hyoid bone. The hyoglossus require further work in conjecturing its functions in speech production. Three questions are given to interpreting the roles of the muscle in producing low vowels: 1) Since the hyoglossus attaches to the hyoid bone that rise and fall during speech, the action of the muscle reflects the position of the hyoid bone that changes also with the action of the supra- and infra-hyoid bone muscles. 2) In a high front vowel the ceratoglossal fibers are oblique, while in a low-back vowel they are vertical. Extreme co-contraction of the hyoglossus and styloglossus for a low-back vowel may contribute to stabilization of the tongue, as previously noted for the effect of co-contraction of the anterior and posterior parts of the genioglossus muscle for the stabilization of the vowel /i/ (Fujimura, & Kakita, 1979). 3) An electromyographic data from the extrinsic muscles show that the hyoglossus exhibits both patterns of suppression and activation in production of a short word, while the genioglossus and styloglossus only demonstrate activation patterns for vowels (Baer, Alfonso, & Honda, 1988). In MRI the hyoglossus is not easy to track the fibers of the two parts to the end, and electromyographic recordings of this muscle have been particularly difficult. Future studies using physiological articulatory models with the tongue and the related structures may help our understanding about the uniqueness of this muscle. For example, in relation to the third question above in particular, it is not unrealistic to speculate that the hyoglossus may be a sensory organ to monitor the tongue shape and position during speech articulation.

SUMMARY

In the above, the authors reported a few anatomical details that help advance physiological articulatory models by improving model structure of the tongue. While anatomy is often regarded secondary in the effort to make a model operational, the accurate anatomical modeling should minimize researchers’ time and effort in the course of studies, and it will also make the outcome more convincing. The short tendon of the tongue offers an anatomical landmark to divide the genioglossus into two parts and to evaluate deformation performance of the tongue model as well. The anatomical relation of the styloglossus to the surrounding structures gives us an insight into intricate functions of muscle in the deformation of the organs of muscle. The chain of actions in articulatory realization is another topic to consider for model control as imagined for the hyoglossus. At conference presentation, the authors will show MRI data processed at two institutes in US and Japan separately to support the details discussed above.

ACKNOWLEDGMENTS

This work is supported by WQ20111200010, and 2013CB329301 in China, and by NIDCD K99/R00-DC009279 in the United States. It is also supported jointly by JSLP and ATR-Promotions.

REFERENCES