Observation of Cricothyroid Joint Motion using 3D High-resolution MRI

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Abstract

Actions of the cricothyroid joint were observed by high-resolution MRI with a phonation-synchronized scan technique to examine the two components; rotation and translation. In the results from a male speaker for two fundamental frequencies of 110 Hz (low) and 165 Hz (high), rotation of the joint was 7.3 degree for the left side and 4.4 degree for the right side. Translation of the joint was 2.3mm for the left side and 0.5 mm for the right side. This suggests that the joint action with translation provides an efficient mechanism in fundamental frequency control.

1. Introduction

The action of cricothyroid joint for controlling voice fundamental frequency (F0) is thought to have two components; rotation and translation [1]. It has been widely acknowledged that rotation of the cricothyroid joint plays a major role in determining F0, while questions remain as to whether translation of the joint actually takes place or exerts significant effects on F0. The cricothyroid joint motion has been discussed mostly based on x-ray experiments [2], examinations of cadaver specimens [3,4], and computer simulations [5]. These previous methods, however, failed to provide evidence of three-dimensional (3D) positional changes of the thyroid and cricoid cartilages in speech.

2. Imaging Method

2.1. MRI techniques

This study aims to determine cricothyroid joint actions by measuring positions of the thyroid and cricoid cartilages in 3D using Magnetic Resonance Imaging (MRI). To this purpose, we have developed a custom laryngeal coil and phonation-synchronized scan technique to acquire high-resolution still images of the larynx [6]. The laryngeal coil has an oval antenna so that it can be placed in front of the neck with a comfortable neck posture of subjects. This design of the coil also insures a high signal-to-noise ratio near the antenna. The phonation-synchronized technique was developed to obtain static images from phonation phases with minimum motion artifacts due to respiratory movements for inhalation. Subjects adjust the rhythm of repetitive phonation to a sequence of guide tones that is synchronized with a scan sequence [7].

2.2. Experiments

A Japanese male subjects participated in the experiment, and the high-resolution images were acquired for low F0 (110 Hz), mid F0 (136 Hz), and high F0 (165 Hz) with vowels /a/ and /i/. The settings of the scan sequence were RF-FAST (TE=3.5 ms ATR=390 ms NEX=2), with 0.25 mm per a pixel, 2 mm thick, and 21 slices.

3. Image Analysis

3.1. Extraction of the cartilages

The surface of the laryngeal cartilages is ossified in most part, which results in a low signal shown as darker regions in the images. These ossified regions are identified from the surrounding brighter regions of internal cartilagenous tissues and external muscular or fatty tissues (Fig. 1, left). The 3D model of the thyroid cartilage and cricoid cartilages were reconstructed from the sequential 2D data (Fig. 1, right).

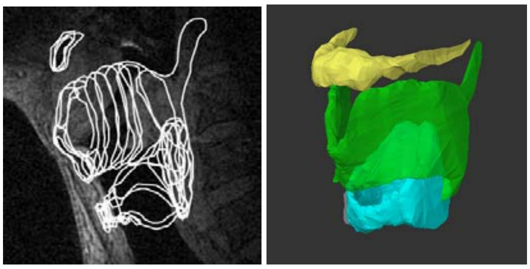

Fig. 1 Tracings of thyroid and cricoid cartilages (left) and reconstruction of laryngeal framework (right)

3.2. Analysis of joint actions

Rotation and translation of the thyroid and cricoid cartilages were computed using a 2D template matching method. The template data were tracings of the cartilages obtained from the sagittal MRI slices for vowel /a/ with high F0. Since movements of the cartilages show left-right asymmetry, image slices for the processing were chosen from the both sides of images. Target images for the thyroid cartilages in each vowel and F0 were the slice number 8~12 for the right side and the slice number 14~17 for the left side. Similarly, target images for the cricoid cartilage were the slice number 6~7 for the right side and 14~15 for the left side.

The regions of the interest on the target images were defined manually, and then rotation and translation of the template were computed using a template-matching algorithm to obtain the parameters deriving the highest correlation between the template and each of the target images. The minimum step for the template-matching calculation was 0.5 degree for rotation and 0.25 mm (one pixel) for translation.

4. Results

Figure 2 and 3 show the result for one subject. The left-right asymmetry of movements of the cartilages was obvious on the 2D slices. Vertical movement was larger than horizontal movement, possibly due to the movements of the hyoid bone.

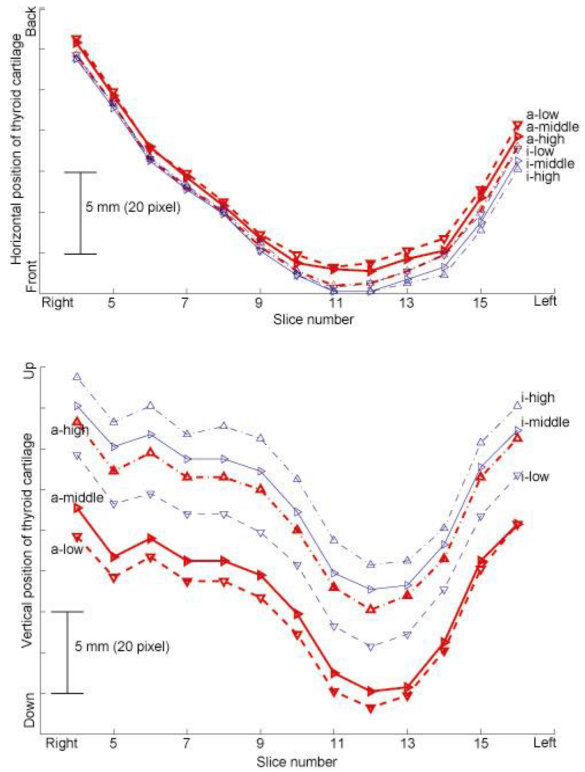

Fig. 2 Estimated center positions of the thyroid cartilage in each slice

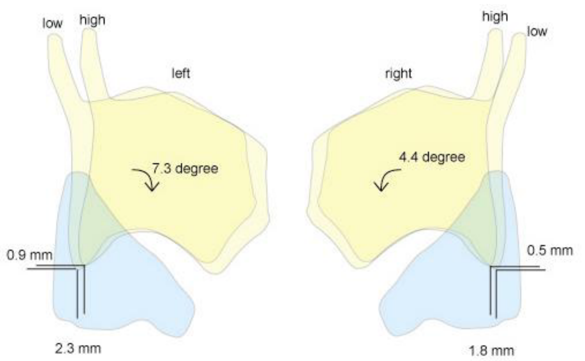

Fig. 3 Rotation and translation of the thyroid cartilage relative to the cricoid cartilage

4.1. Rotation

The rotation of the thyroid cartilage was observed from -2 to +2 degrees between low and high F0 in the entire dataset, indicating that the rotation was both forward (plus) and backward (minus). The rotation of the cricoid cartilage was more obvious compared to the thyroid cartilage; the cricoid cartilage rotated backward 2 ~ 6 degree for low to high F0.

The relative angular change between the thyroid and cricoid cartilages was 7.3 degree for the left side and 4.4 degree for the right side. This asymmetry suggests that as the thyroid cartilage rotates it tilts to the right or left, and therefore 3D analysis is needed to determine the actual movement of the larynx.

4.2. Translation

Vertical and horizontal translation of the thyroid and cricoid cartilage was calculated from each cartilage's template position. Between low and high F0, the two cartilages moved vertically about 6 mm and moved horizontally about 0.5 mm ~ 2.5 mm depending on the vowel. The cricoid cartilage tended to be more advanced in /i/ than in /a/. It appears that the cricoid cartilage moved following the hyoid bone.

The relative horizontal translation between the thyroid and cricoid cartilage was found to be 1.8 mm for the right side and 2.3 mm for the left side. The relative vertical translation was about 0.5 mm for the right side and 0.9 mm for the left side. This suggests that translation of the cricothyroid joint has both horizontal and vertical components, and that the vertical translation was about 1/2 to 1/3 times its horizontal translation.

5. Conclusion

The movement of the thyroid and cricoid cartilages during F0 change was estimated using three-dimensional MRI with a high-sensitivity larynx coil and phonation-synchronized scan technique. Results from two-dimensional analysis suggested the followings.

(1) Left-right asymmetry was evident in thyroid cartilage movement.

(2) Backward rotation of the cricoid cartilage took place in high F0.

(3) Vertical translation of the cricothyroid joint was estimated to be 0.5 ~ 0.9 mm, which distance is about 1/2 - 1/3 times its horizontal translation.

6. Acknowledgement

This research was supported in part by the National Institute of Information and Communications Technology.

7. References

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