The Role of the Cricopharyngeus Muscle in Pitch Control
– Electromyographic and radiographic studies –

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ABSTRACT

Electromyographic studies of the cricopharyngeus muscle using hooked wire electrodes were performed in thyroidectomized patients. The shape of the cricoid cartilage and soft tissue thickness in the postcricoid area were evaluated during pitch elevation and pitch lowering using conventional neck lateral films. The cricopharyngeus muscle simultaneously activated in the initial task of speech and continuously activated. Its activity lessened in the interrogative stress contrast of sentence terminals and increased in the pitch lowered contrast of sentence terminal. On the radiologic findings the cricoid cartilage was tilted backward during high pitched phonation and tilted forward during low pitched phonation. The soft tissue thickness of postcricoid area was thicker at the low pitch than at high pitch. At low pitch the cricoid cartilage paralleled along the vertebral column. This result suggests that the bulging of cricopharyngeus muscle in contraction induce a thickened the postcricoid area thickened, and exert pressure anteriorly exerted on the cricoid cartilage. This contraction of the cricopharyngeus muscle may result in shortening the vocal fold and lowering pitch.

Keywords : Cricopharyngeus muscle, Pitch control, Electromyography, Radiology

1. Introduction

The cricopharyngeus (CP) muscle is the most definitive component of the upper esophageal sphincter. in order to function as the sphincter of the esophagus, this muscle shows a continuous tonic contraction except for a moment of deglutition. It arises from the lower part of the dorsolateral aspect of the cricoid cartilage and forms a horizontal

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loop which attach to the cricoid cartilage on the opposite side.[1] The physiological role of the cicopharyngeus muscle is to protect against reflux of food into the airways as well as to prevent the entry of air into the digestive tract.[2] However, the role of this muscle on speech production has not yet been well understood.

As for On the relationship to the to the CP muscle of cricoid cartilage, the activities of this muscle may affect the movement of cricoid cartilage. Its muscle fibers run semicircularly and attachs to the cricoid cartilage very closely to the cricothyroid joint. However, Honda[3] reported that a contraction of this muscle does not produce sufficient force to pull the cartilage posteriorly. Even if it did, the posterior movement would be stopped by the stiffened muscle itself. Instead of pulling the cricoid cartilage posteriorly, the bulging of the belly of this muscle in contraction results in pressure being exerted on the cartilage anteriorly. This effect may produce a forward movement of the cartilage.

A reviewing of the English language literature shows that only two articles were published on the phonatory function of the CP muscle. Martin et al[4] reported that the activity of the CP muscle increases continually with rising pitch but is not influenced by the vocal sound pressure level. In the lower part of the chest register, muscular pressure is lower than the pharyngo-esophageal pressure at rest. At high pitch levels, pressure is higher than during swallowing. The CP muscle has a dual function: with increasing pitch, the CP cooperates synergistically with the cricothyroid muscle, as indicated by increased muscular pressure in the upper esophageal sphincter. On the other hand, the CP shortens the vocal cords by rotating the cricoid cartilage in an anterior direction, thus acting antagonistically to the cricothyroid muscle. Honda et al[5]reported that the CP muscle shows increased activity during speech, particularly near the end of declarative sentences. He explained that the bulging of the belly of this muscle in contraction results in pressure exerted on the cartilage anteriorly. This effect may produce a forward movement of the cartilage. Furthermore, if the larynx is lowered by some other means simultaneously with the contraction of the CP muscle, the result will be that the upper parts of the cricoid cartilage, accompanied by the arytenoids on top, move forward, tilting the cartilage in such a way that the vocal folds become shortened and slack.

This present study used living persons to evaluate the activity of CP muscle during the speech production. The patterns of electrical activity of these muscles were evaluated at the beginning of speech and during speech with stress contrasts.

2. Subjects and Methods

The subjects were five women who had undergone thyroidectomies. They received ipsilateral thyroid lobectomies due to benign thyroid lesions such as adenomatous goiter and follicular adenoma. Age ranged from 34 to 53 years. The subjects did not have any organic or functional problems affecting voice and speech production before surgery. During surgery the strap muscles were dissected and retracted as gently as possible. After removal of the thyroid gland the esophagus and vertebral body were separated by finger dissection. With an anterior traction of the esophagus the posterior surface of cricoid cartilage was palpated its and semicircular muscle fibers were identified upon gross inspection. The recurrent and superior laryngeal nerves were completely preserved. Informed consent was obtained from all subjects, and the protocol was approved by the Institutional Ethic Board at Chonbuk National University Hospital.

Pairs of 44 gauge × 100 mm hooked wire electrodes with 25 gauge × 50 mm cannula (Nicolet Biomedical, #019-772900, Medison, USA) were inserted exactly into the CP muscle under visual obervation. The wires were secured into the muscles with loose-stitch 5.0 vicryl sutures to ensure that the electrode placement would be maintained. The wires were brought through the side of the incision, labeled and taped to the neck skin. At 5 to 7 days after the thyroidectomy, subjects were asked to participate in the study of electrical signals and speech signals. The Nicolet II EMG system(Nicolet Biomedical, Medison, USA) was used and EMG signals were passed through differential amplifiers with filters. Along with confirmation of electrical activity of the CP muscle was observed with the decreasing activity during swallowing. As a swallow began, there was a burst of activity followed by a sharp decrease. After swallowing, another burst of activitywas observed, followed by a return to a high base-line resting activity. Two channels were obtained, an upper one channel was for acoustic signals and a lower channel were for the electrical signals of the CP muscle. EMG signals were then rectified and smoothed using a programmed Nicolet II EMG system. For the speech samples, the simple sentences were used to obtain pitch changes, a simple sentence and an interrogative sentence with stress variations. Subjects were asked to produce a simple sentence (it means "good morning?") in response to a question and a non-question sentence (it means "I am fine"). Subjects produced the sentences with as comfortable a pitch and loudness as possible. The EMG and speech signals were

recorded three to five times. Measurements of EMG activities were determined through a visual inspection of processed and smoothed data (Figure 1). Intra-test reliability was determined by repeatedly measuring the EMG activities.

Neck lateral films were taken at the end of simple sentence in response to the question and a non-question sentence. The cricoid cartilage was contoured using a transparent template with a dark line. Soft tissue thickness of the postcricoid area and status of the tilting of the cricoid cartilage along the vertebral column were evaluated during pitch elevation and pitch lowering.

3. Results

The data for the patterns of EMG activities in the simple sentence in response to the question and a non-question sentence are reviewed in Figures 2, 3. As in all subjects, the CP muscle was activated simultaneously before the production of acoustic signals and then gradually activated with speech. The initial patterns of EMG activity during speech production were different, but not comparable among these subjects. After initial activation, the CP muscle tended to be less dynamically activated during speech. In cases 1 to 3, the electrical activities of the CP muscle in the sentence terminal, stress elevated, were less dynamically activated than in stress lowered. The maximum EMG activity range during speech seemed to be nearly equal. In cases 4 and 5, the electrical activities of the CP muscle in the sentence terminal, stress elevated, were not comparable to the sentence terminal, stress elevated and stress lowered.

The lateral x-ray film of the neck was evaluated in response to the question and the non-question sentence in Figure 4. In the all cases, the cricoid cartilage shows elevation along the cervical spine and tilted posterior tilting in the stress elevated sentence terminal, as well as and lowering along the cervical spine and tilted posterior tilting in the stress lowered sentence terminal. The retropharyngeal space from the posterior cricoid line to the anterior cervical spine shows narrowed in the stress elevated sentence terminal and definitely widened in the stress lowered sentence terminal. The upper space of the retrocricoid area definitely widened in the stress lowered.

4. Discussion

The upper esophageal sphincter is a functional unit composed of the CP muscle, the inferior pharyngeal constrictor muscle and the upper esophageal muscle. This muscle plays a pivotal role in the mechanical control of swallowing and regurgitation. Its baseline contraction gives way to a brief inhibitory state preceding the passage of a swallowed bolus followed by a burst of contraction during the height of a swallow.[6] Recently, the role of the CP muscle in disorders of swallowing has become of intense interest.

Several studies have been published on the recording of electromyographic (EMG) activity of the CP muscle in experimental animals and humans,[6-10] and some of data are contradictory. However, only a few studies of the role of the CP muscle in speech have been published. Shin et al suggest that the CP muscle functions in cooperation with the intrinsic laryngeal adductor muscle to reinforce glottic closure during swallowing. Martin et al[4] reported that the CP muscle has a dual function in speech. The activity of the CP muscle increases continually with rising pitch but is not influenced by the vocal sound pressure level. In the lower part of the chest register, muscular pressure is lower than the pharyngo-esophageal pressure at rest. At high pitch levels, pressure is higher than during swallowing. With increasing pitch, the CP cooperates synergistically with the cricothyroid muscle, as indicated by increasing muscular pressure in the upper esophageal sphincter. On the other hand, the CP muscle shortens the vocal cords by rotating the cricoid cartilage in an anterior direction, thus acting antagonistically to the cricothyroid muscle.

Honda's electromyographic studies showed[3] that the CP muscle demonstrats an activity which correlated inversely with fundamental frequency (Fo). The CP muscle shows increased activity during speech, particularly near the end of declarative sentences. At the end of such sentences, this muscle shows an increase in activity approximately twice as high as that for the preceding portions. He also indicated the possibility that laryngeal adjustments for Fo are executed by different physiological mechanisms depending on the particular linguistic function, such as final lowering or accentual fall, even for the same physical effect, namely Fo lowering. Thus the use of the CP muscle near the end of a major phrase or an utterance may well be motivated by the fact that in an extremely low frequency range which is likely to be the case at the

end of a phrase, this mechanism is the most effective and reliable means to achieve Fo lowering as required by the phonology of the language.

In this study, the activity of the CP muscle simultaneously activated in the initial task of speech and continuously activated. Its activity lessened in the interrogative stress contrast of sentence terminals and increased in the pitch lowered contrast of sentence terminals. The radiologic findings indicated that the cricoid cartilage was tilted backward during high pitched phonation and tilted forward during low pitched phonation. The soft tissue thickness of the postcricoid area was thicker at low pitch than at high pitch. At low pitched the cricoid cartilage paralleled along the vertebral column.

An anatomical view of the CP muscle shows that this muscle is located in the pharyngoesophageal segment, the area where the hypopharynx meets the vervical esophagus. The CP muscle consists of horizontal muscle fibers which have no median raphe. These fibers attach to the lateral aspects of the cricoid cartilage on each side and travel around the foodway lumen on a semicircular path. Since the muscle fibers run semicircularly and the attachments to the cricoid cartilage are located very close to the cricothyroid joint, and since the linkage of this muscle to the posterior structures is loose, a contraction of this muscle does not produce sufficient force to pull the cartilage posteriorly, Honda[3] suggested that there is no possibility of shortening the distance between the center of the muscle and the back wall. Instead of pulling the cricoid cartilage posteriorly, the bulging of the belly of this muscle in contraction results in a pressure exerted on the cartilage anteriorly. This effect may produce a forward movement of the cartilage. Furthermore, if the larynx is lowered by some other means simultaneously with the contraction of the CP muscle, the result will be that the upper parts of the cricoid cartilage, accompanied by the arytenoids on top, move forward, tilting the cartilage in such a way that the vocal folds become shortened and slack. This mechanism is in conformity with the vertical movement theory for Fo lowering, even though the exact mechanism for laryngeal lowering is not yet well understood.[5] In this study the radiologic findings showed the cricoid cartilage tilted backward during high pitched phonation and tilted forward during low pitched phonation. The soft tissue thickness of the postcricoid area was thicker at low pitch than high pitch. During low pitch the cricoid cartilage paralleled along the vertebral column.

5. Conclusion

The CP muscle functions inversely with pitch in the sentence terminal. This results suggests that the bulging of cricopharyngeus muscle in contraction inducs a thickening of the postcricoid area thickened, and exerts a pressure on the cricoid cartilage anteriorly. This contraction of cricopharyngeus muscle may result in shortening the vocal fold and lowering pitch.

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Figure Legends

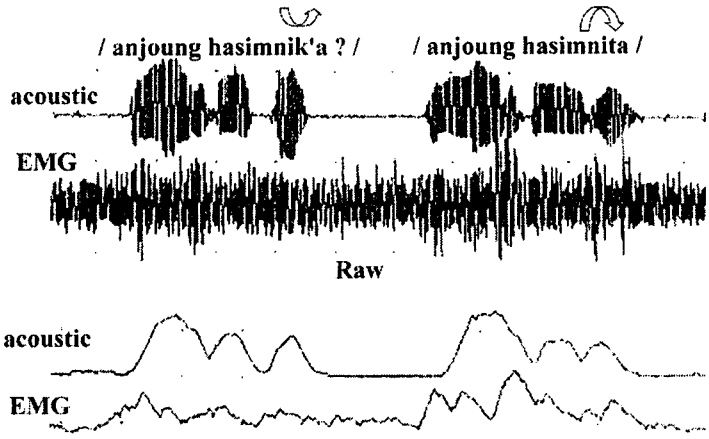


Fig. 1. Acoustic and electromyographic signals, raw(upper) and rectified and smoothed (lower), during the production of simple sentence.

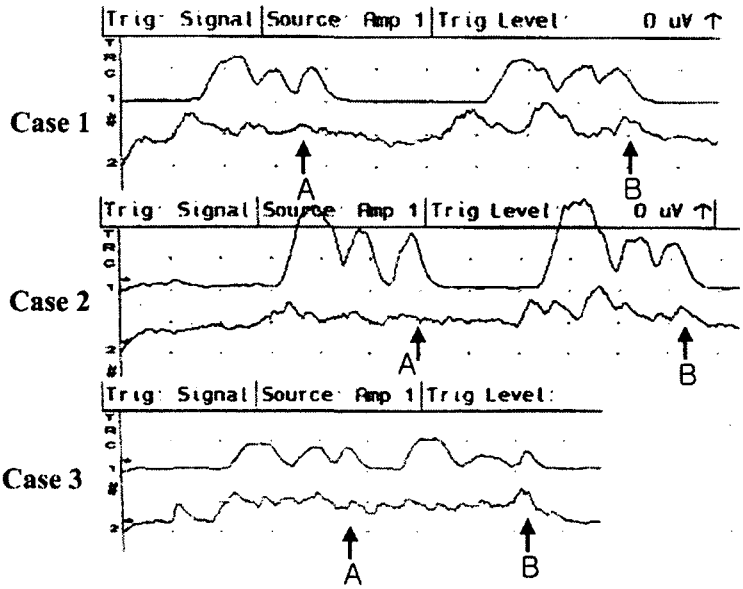


Fig. 2. Acoustic and electromyographic signals, rectified and smoothed, for the interrogative stress contrast of sentence terminal(A) and the pitch lowered contrast of sentence terminal(B). Larger activities(B) of the cricopharyngeus muscle are noted.

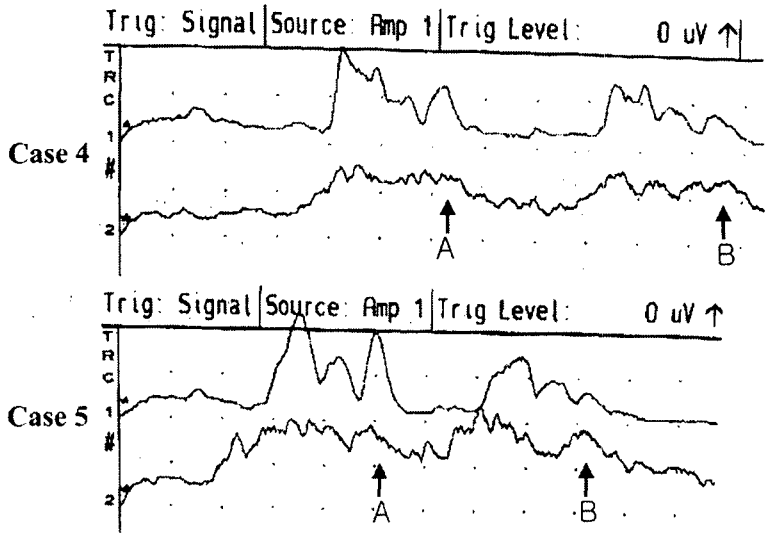
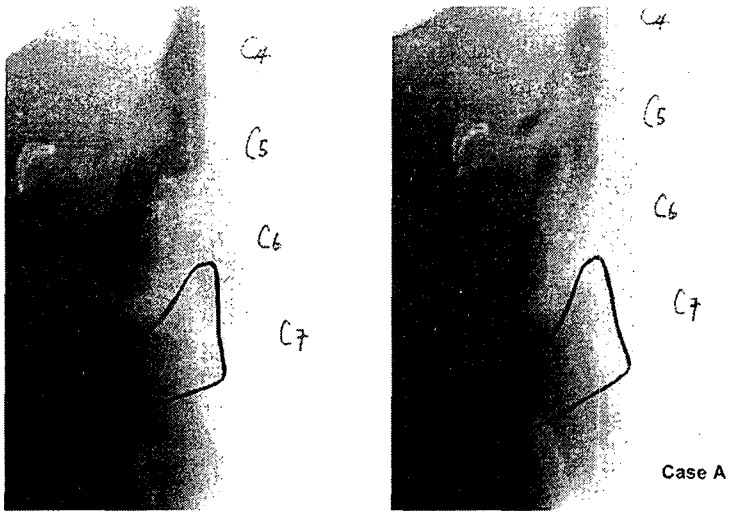


Fig. 3. Acoustic and electromyographic signals, rectified and smoothed, for the interrogative stress contrast of sentence terminal(A) and the pitch lowered contrast of sentence terminal(B). Similar activities are noted.



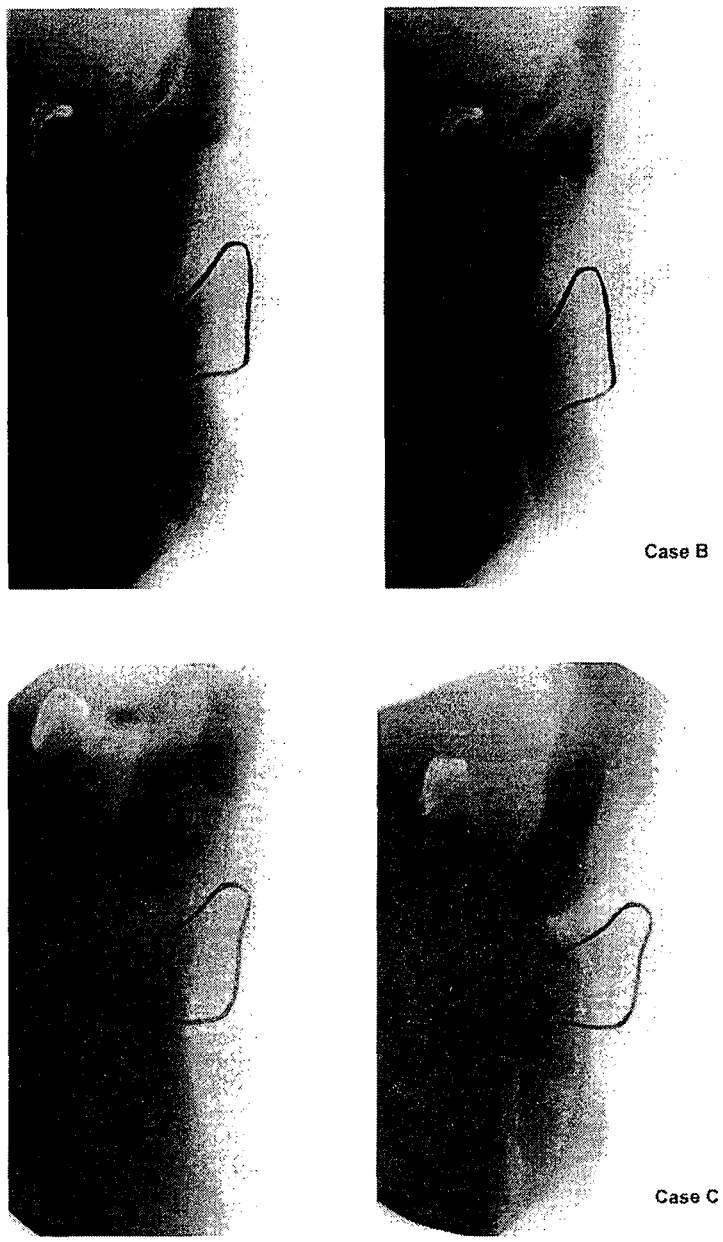


Fig. 4. The lateral x-ray films of the neck during the interrogative stress contrast of sentence terminal(left) and the pitch lowered contrast of sentence terminal (right) for the case A, B, C. The retropharyngeal space from posterior cricoid line to anterior cervical spine shows narrowed in the interrogative stress and widened in the stress lowered.