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Thyroid cartilage loci and hyoid bone analysis using a video fluoroscopic swallowing study (VFSS)

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Abstract

Introduction: Hyoid bone movement can be useful for diagnosing oropharyngeal dysphagia. In most clinical settings, the movement can be evaluated by a video fluoroscopic swallowing study (VFSS) that induces radiation exposure. In contrast with the hyoid bone, the thyroid cartilage is easily seen through the anterior neck surface. We hypothesized that the movement of thyroid cartilage correlates with hyoid bone movement in various axis and can be used as a parameter to evaluate swallowing. The purpose of this study was to investigate whether thyroid cartilage and hyoid bone movement were correlated and to collect basic data to determine if thyroid cartilage can be used as a parameter to evaluate swallowing.

Methods: A total of 25 subjects were included, and the VFSS image with normal swallowing function was collected retrospectively. The VFSS image was analyzed by specially developed semi-automatic software. Laryngeal prominence and anterior-superior margins of the hyoid were automatically extracted during swallowing. Two-point sets of the loci during swallowing were obtained in all VFSS frames. The X-coordinates showed an anterior-posterior axis, and the Y-coordinates showed a superior-inferior axis. Pearson correlation coefficients for each X- and Y-coordinate component were computed.

Results: X- and Y-coordinates of the thyroid cartilage and hyoid bones in all subjects showed movement in similar patterns, although each subject's movement differed. Pearson correlation coefficients of X- and Y-coordinate components of all subjects ranged from 0.611 to 0.981, which indicated that thyroid cartilage and hyoid bone movement was strongly correlated in anterior-posterior and superior-inferior axes, respectively.

Conclusion: We analyzed thyroid cartilage and hyoid bone movement using a specifically developed semi-automatic software and concluded that the movement of thyroid cartilage and hyoid bone was strongly correlated in anterior-posterior and superior-inferior axes, respectively, during swallowing. The present study implies that analysis of thyroid cartilage movement can be used as a parameter for swallowing evaluation.

Abbreviations: MRI = magnetic resonance imaging, PCC = Pearson correlation coefficient, ROI = region of interest, VFSS = video fluoroscopic swallowing study.

Keywords: dysphagia, hyoid bone, swallowing, thyroid cartilage

1. Introduction

Instruments that measure oropharyngeal dysphagia symptoms are mostly invasive. The video fluoroscopic swallowing study (VFSS) is the most widely used method and is now the gold standard for oropharyngeal dysphagia examination.[1,2] This approach uses an X-ray photography instrument and is very accurate; however, there is an associated risk of excessive radiation exposure. In addition, this approach requires the patients to undergo testing in a hospital. Thus, the measurements are limited to specific time and place with the risk of radioactive exposure or nosocomial infection, and for patients with poor mobility, it is very inconvenient. Therefore, there is a strong need to develop a portable device, as well as corresponding assessment software, so physicians can perform the measurements at bedside.[3]

Some studies have assessed hyoid bone movement in patients with dysphagia. Paik et al found that hyoid bone and epiglottis movement patterns differed according to the cause of dysphagia.[4] There was also a study that evaluated swallowing by analyzing the upward and downward motions of the thyroid cartilage.[3] However, to our knowledge, the relationship between hyoid bone and thyroid cartilage movement has not been studied.

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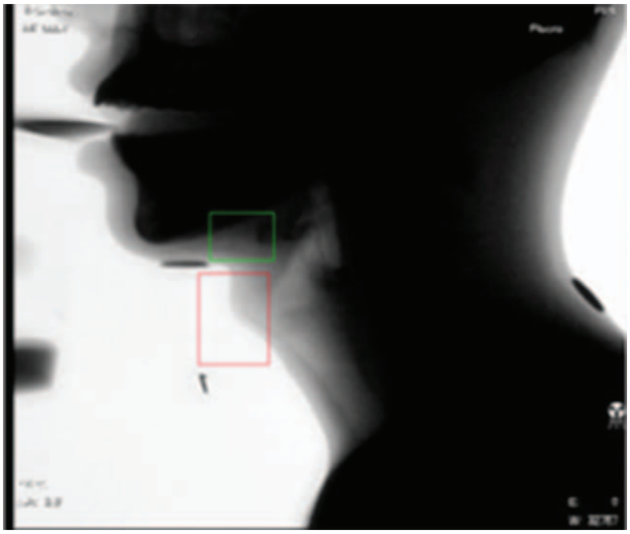

Figure 1. Definition of ROI in the first frame of VFSS by a user. The red box is the ROI for the thyroid cartilage and the green box for the hyoid bone. Both contains their featured points and estimated loci.

The purpose of this study was to investigate the relationship between the movement of the thyroid cartilage and hyoid bone movement, which has already proven useful in the VFSS test. In addition, the authors worked to accumulate preliminary data for developing new diagnostic techniques for dysphagia.

2. Methods

2.1. Participants

A total of 25 subjects' VFSS images with normal swallowing function were retrospectively collected and analyzed using specially developed semi-automatic software.

This retrospective study is, using imaging tests, already been performed in the past. It is practically impossible to obtain consent for the image results already made in the past and also there is no risk to the patient due to participation in this study. Therefore, ethical approval was not necessary. Institutional review board approved this study.

2.2. Determination of hyoid bone movement in VFSS settings

The laryngeal prominence position and the anterior-superior margin of the hyoid were automatically extracted during swallowing. Two-point sets of the loci during swallowing were obtained in all frames of VFSS. The X-coordinate showed the anterior-posterior axis, and the Y-coordinate showed the superior-inferior axis. Pearson correlation coefficients for each X- and Y-coordinate component were computed.

2.3. Semi-automatic software

To develop the semi-automatic software, the authors defined thyroid cartilage and hyoid bone movements, which are represented by the positional changes of featured points in every VFSS frame (such as footprints). Due to distinct intensity and featured shape, a laryngeal prominence and an anterior-superior margin of the hyoid were chosen as the featured points in this paper (Fig. 1a).

Using these parameters, the semi-automatic software is able to automatically extract the position of the thyroid cartilage (or hyoid bone) from every frame, once a region of interest (ROI), including its featured point and estimated locus, is defined in the first frame of VFSS by a user (Fig. 1b).

2.4. Algorithm

The semi-automatic software repeatedly performs two sequential tasks from the first to the end frame to extract featured point movements. One task is to outline the ROI, and the other is to specify the positions of the featured points from the outline. In general, the featured points are expected to be along the outlines, including parts of thyroid cartilage and hyoid bone contours, with convex points in a frame. In the semi-automatic software, the Marching squares algorithm was applied to find the outlines.[5] The algorithm determines an outline that travels between fore- and background where a specific intensity is placed. To accurately find the outline, a good intensity should be defined to determine whether the pixel is fore- or a background. The Otsu's thresholding method provided context to define the judging intensity. This method finds an intensity to minimize the variance between fore- and background.[6]Figure 2 shows that the anticipation is correct for the Marching squares algorithm with the Otsu's thresholding method applied for the ROIs. The featured points were set on the outline for most of the frames, especially the exposed portions, because the laryngeal prominence and the bottom part of the hyoid bone have distinct intensity ranges compared to neighbor pixels in the VFSS frames.

To specify featured point positions, we considered that the featured points had a maximum curvature on the outlines. Thus, the curvatures of all points on the outline were calculated using the method of,[7] and we searched for the maximum value and corresponding index. As shown in Fig. 3, the points with maximum negative curvature were specified as the featured points in this application.

2.5. Analysis

Once two tasks were finished on every frame, the two-point sets of the loci (one for thyroid cartilage and another for hyoid bone) during swallowing could be obtained. To analyze the movements, the point sets were plotted along the frame. In addition, the authors adopted the Pearson correlation coefficient (PCC) to find the correlations between variables by covariance and standard

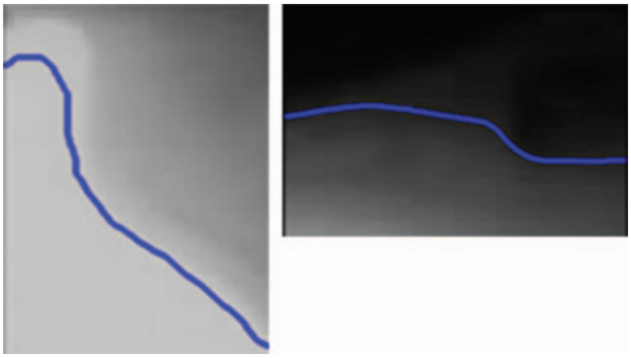

Figure 2. The outline in each ROI by using Marching squares with Otsu thresholding (left: thyroid cartilage, right: hyoid bone).

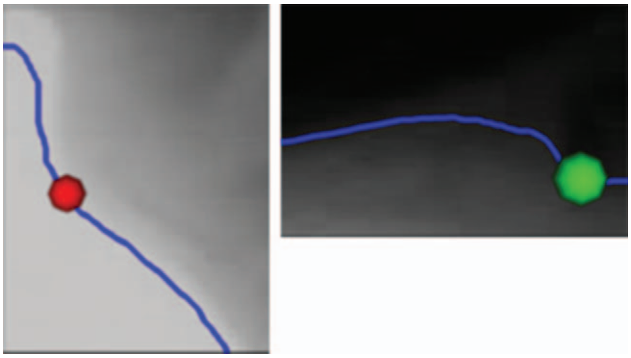

Figure 3. The featured point of each outline in the ROI. These points can be automatically calculated by the maximum negative curvature in this application (red circle in the left: laryngeal prominence, green circle in the right: anterior-superior margin of the hyoid).

variations.[8] In this paper, the authors respectively computed the PCC for the X- and Y-coordinate components in the point sets.

3. Results

The featured point sets of the thyroid cartilage and the hyoid bone of the subjects were well extracted, from more than 140 frames obtained during swallowing for each VFSS movie, using the semi-automatic software. Table 1 shows the correlation analysis results. All PCC figures were > 0.8 in both X- and Y-directions, which indicated that the X- and Y-directional movements of the thyroid cartilage and the hyoid bone were strongly correlated. In summary, the movements were similar in shape, even though the displacements from the movements were different for each subject.

As seen in Fig. 4, which shows the plots of the loci along the frame of the sample subject, the X- and Y-coordinates travel with similar footprints. The plots also show that the large displacements of feature points nearly simultaneously occurred at the start and end of swallowing. Figure 5 represents the two-dimensional loci of the feature points of the subject shown in Fig. 4 and shows that the loci move in a similar pattern after the initial state (0–30 frames) to maintain the liquid in the patient's mouth.

4. Discussion

Swallowing is a complex process that begins with reshaping food into the appropriate form by chewing and then transferring the food to the pharynx. Then, by moving the pharynx forward and upward, spontaneously closing the larynx, and opening the upper esophageal sphincter, the food passes to the pharynx without entering the airway. Dysphagia occurs when a defect occurs in any part of this process. If a problem occurs in the pharyngeal phase, complications such as airway aspiration and pneumonia can occur.

To quantitatively measure hyoid bone movement in VFSS, manual and semi-automatic computer programs have been introduced in many studies.[1,2,4,9–18] Manual programs were generally performed by selecting points with a mouse cursor or recording the location from all frames in VFSS.[4,9–11] As the number of frame in VFSS increases, this approach could become more time consuming. Therefore, some research groups have developed a customized commercial program. Previous studies customized the image analysis software developed by Peak Performance Technologies (Englewood, CO, USA).[12,13] Crary et al also customized a commercial software from different company. The software measured time and trajectories across the image sequences with specific customization. However, user

Table 1

Results of the Pearson correlation.

Case	Subject no.	Sex	Food	Coordinate	Pearson correlation coefficient
1	1	M	Water	X	0.946
				Y	0.834
2	1	M	Yogurt	X	0.825
				Y	0.949
3	2	M	Yogurt	X	0.948
				Y	0.848
4	3	M	Pudding	X	0.938
				Y	0.934
5	3	M	Yogurt	X	0.845
				Y	0.981
6	4	M	Water	X	0.817
				Y	0.878
7	5	M	Water	X	0.965
				Y	0.946
8	6	M	Water	X	0.915
				Y	0.903
9	7	M	Water	X	0.959
				Y	0.942
10	8	F	Water	X	0.933
				Y	0.766
11	8	F	Yogurt	X	0.875
				Y	0.974
12	9	F	Congee	X	0.958
				Y	0.902
13	10	F	Water	X	0.869
				Y	0.949
14	11	M	Water	X	0.79
				Y	0.748
15	12	M	Water	X	0.75
				Y	0.88
16	13	F	Water	X	0.921
				Y	0.859
17	14	F	Water	X	0.885
				Y	0.802
18	15	F	Water	X	0.853
				Y	0.896
19	16	M	Water	X	0.889
				Y	0.899
20	17	F	Water	X	0.717
				Y	0.738
21	18	M	Water	X	0.892
				Y	0.732
22	19	M	Water	X	0.972
				Y	0.836
23	20	M	Water	X	0.945
				Y	0.875
24	21	M	Water	X	0.861
				Y	0.8
25	22	M	Water	X	0.611
				Y	0.722
26	23	M	Yogurt	X	0.590
				Y	0.553

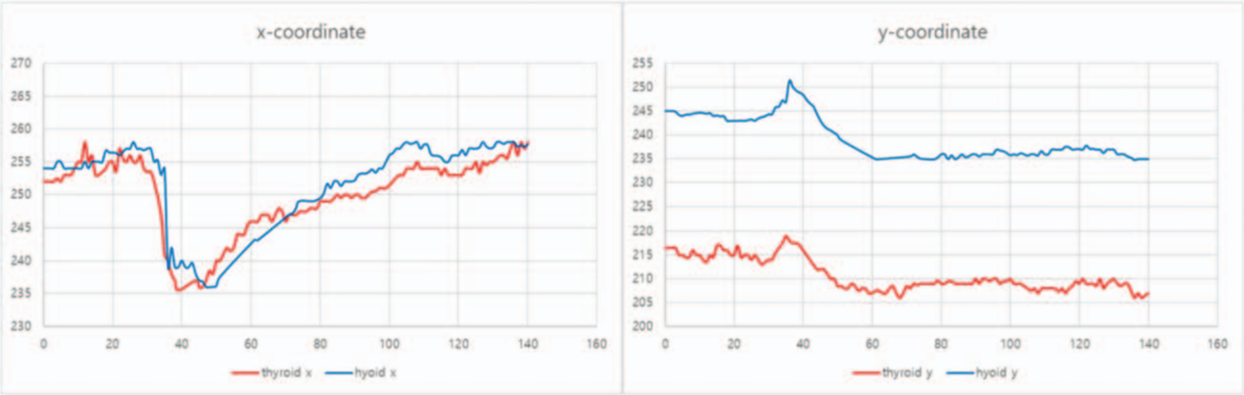

Figure 4. The plots of the loci along the frame of the sample subject. It shows their x- and y-coordinates travel with the similar footprints.

input for structural identification on every frame in VFSS remained tedious.[14] To overcome the manual program limitations, other groups developed semi-automatic computer programs to extract hyoid bone movement. Kellen et al extracted hyoid bone movement during the swallowing process. In their system, once the radiologists identified the hyoid bone ROI on one frame, the program was able to identify and track the center of mass for the hyoid bone based on template matching.[15] Hossain et al developed a special semi-automatic program that can track the hyoid bone movement from VFSS using a classification-based method.[16] Noorwali showed his own distinctive method for tracking the hyoid bone position using feature point matching, known as SURF.[17,18] While these studies proposed a specific measuring method or software for only hyoid bone movement, analysis of the thyroid cartilage loci and hyoid bone after simultaneous extraction in VFSS has not been reported.

In this paper, the movements of the thyroid cartilage and hyoid bone were measured in a VFSS movie using specially developed semi-automatic software. The method developed by Mokhtarian et al is generally effective for finding curvature of a two-dimensional digital curve, such as the outlines.[7] When calculating the curvatures, the sign should be noted, because it changes depending on the direction of an outline. Through the software, the user identifies the ROI on the first frame of the VFSS, and the software simultaneously finds the image edge structure around the hyoid bone and the thyroid cartilage and calculates the representative points (the maximum curvature points) across all frames of the VFSS. The hyoid bone and thyroid cartilage positions are then reported for each frame. Finally, the correlation between movements was computed using the Pearson correlation coefficient.

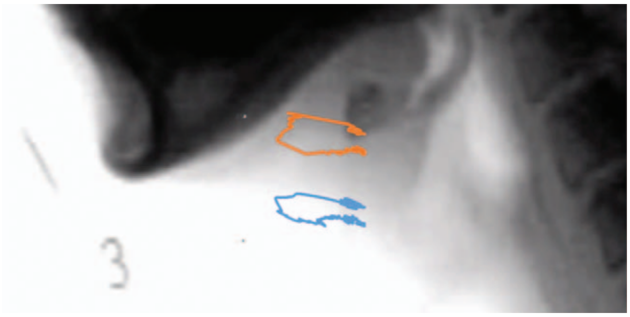

Figure 5. Two dimensional loci of the feature points of same subject in Fig. 4.

The main finding of this study was that hyoid bone and thyroid cartilage movement patterns during normal swallowing were highly correlated. The patterns of movement differed between subjects, but there were significant correlations in movement patterns of the hyoid and the thyroid cartilage. In comparison with the hyoid bone, thyroid cartilage movement can be analyzed without using X-ray. Therefore, it is possible to reduce the X-ray exposure of the subject and the tester. In addition, we can expect to easily inspect those who have difficulty with movement and postural changes, such as ward patients, using the simple test method. Hashimoto et al attempted to assess swallowing in a normal group through non-invasive quantification. By using the swallow tracking system (SSTS) devised by Hashimoto et al, the onset and termination of swallowing with mouth-width, mouth openness, and lip protrusion as mouth-related parameters and vertical motion and horizontal motion as laryngeal parameters were defined. The vertical motion and horizontal motion, which were used as laryngeal-related parameters, have been largely determined by thyroid cartilage.[19] The hypothesis that there would be high correlation between the thyroid cartilage and hyoid bone movement is important for understanding the swallowing process. Previous studies have shown that movement of the hyoid bone can be used as a parameter of dysphagia. Kuhl et al used ultrasound images to evaluate hyoid bone elevation and found that laryngeal elevation was reduced in patients with neurogenic dysphagia compared to healthy subjects. They suggested measuring the excursion of the hyoid bone as a possible application to diagnose dysphagia.[20] Paik et al suggested that the extent and pattern of movement of the hyoid bone and epiglottis during swallowing differ according to the etiology of swallowing difficulty. That study also showed that kinematic swallowing motion analysis might potentially be beneficial for understanding the pathophysiology of the pharyngeal phase of swallowing.[1] In this study, we found a correlation between movement of the thyroid cartilage and movement of the hyoid bone in the normal group, but we lack information about the movement patterns in patients with dysphagia. Therefore, it is a limitation of this study that even though it was possible to evaluate swallowing through thyroid cartilage, since we have only performed it for normal subjects, it is not known whether there would be any obstacles in evaluating patients and whether dysphagia can actually be assessed.

As we already been discussed, previous studies showed that the hyoid bone can be used as a key anatomy in the evaluation of swallowing disorders and the hyoid bone is closely related to the thyroid cartilage movement. So from this point of view, it seems evaluating dysphagia through this newly developed software would be possible. To further elucidate the mechanisms, additional studies are needed in subjects with swallowing disorders.

5. Conclusion

Hyoid bone and thyroid cartilage movements were closely correlated during oropharyngeal swallowing. This result may indicate that measuring the thyroid cartilage movement can be useful, and that hyoid bone movement can be used as a parameter to evaluate swallowing function.

Author contributions

Conceptualization: Yong Jae Na, Kyu Hoon Lee, Seung Hoon Han, Min Sung Chung.
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Formal analysis: Yu Jun Yoon.
Methodology: Jong Seong Jang.
Project administration: Seung Hoon Han.
Writing - original draft: Yong Jae Na, Seung Hoon Han.
Writing - review & editing: Yong Jae Na, Seung Hoon Han.

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