Original Article

Application of Real-time Submental Ultrasonography to Assess Swallowing

CME Credits

Li-Jen Liao[1,2,3]*, Yung-Hsin Tung[4], Yu-Hsuan Lin[5], Wan-Lun Hsu[5,6]

[1]Department of Otolaryngology Head and Neck Surgery, Far Eastern Memorial Hospital, Taipei, Taiwan, [2]Head and Neck Cancer Surveillance and Research Study Group, Far Eastern Memorial Hospital, New Taipei, Taiwan, [3]Department of Electrical Engineering, Yuan Ze University, Taoyuan, Taiwan, [4]Graduate Institute of Clinical Medicine, College of Medicine, National Taiwan University, Taipei, Taiwan, [5]Master Program of Big Data Analysis in Biomedicine, Fu-Jen Catholic University, New Taipei, Taiwan, [6]Data Science Center, College of Medicine, Fu-Jen Catholic University, New Taipei, Taiwan

Abstract

Background: Speech and swallowing dysfunction are common problems in head-and-neck cancer (HNC) survivors. Ultrasound (US) is a good method to assess suprahyoid muscles and hyoid bone movement, and it can provide valuable information on swallowing. The aims of this study were to measure the biometry of the supraglottic muscles and hyoid bone movement during swallowing and elucidate the application of real-time US for assessing swallowing dysfunction. **Methods:** We collected data from HNC and thyroid cancer patients with dysphagia symptoms and healthy controls without a history of cancer or dysphagia symptoms for comparison. Real-time submental US was used to check the anterior belly of the digastric muscle, geniohyoid (GH) muscles, and hyoid bone movement during swallowing. Logistic regression analysis was used to explore significant US predictors of dysphagia. Based on the regression coefficients of independent variables, we established the nomogram prediction model for dysphagia. **Results:** There were significant differences in GH size at contraction, GH size increase percentage, GH length at rest, GH length increase percentage, anterior displacement of the hyoid bone and superior displacement of the hyoid bone between the cancer survivors with dysphagia and volunteers without dysphagia. In multivariate logistic analysis, after adjusting for sex and age, the proportion of GH length contraction <22% (odds ratio [OR]: 6.8 95% confidence interval [CI]: 1.1–42.6) and hyoid bone superior displacement <3.3 mm (OR: 10.7, 1.8–64.1) were associated with a higher risk of dysphagia ($P < 0.05$). **Conclusion:** We confirmed that GH muscle and hyoid bone movement are important for normal swallowing function. US is a good method to assess the suprahyoid muscles and hyoid bone movement, which could provide valuable information on swallowing.

Keywords: Dysphagia, head-and-neck cancer, swallowing, ultrasound

Introduction

Speech and swallowing dysfunction are common problems in patients with head-and-neck cancer (HNC); this problem can occur at diagnosis or after radiation therapy or chemotherapy due to damage to swallowing-related muscles, and the sequelae may be underestimated and unreported.[1] According to our previous reports, a high proportion of HNC survivors develop dysphagia after treatment and have impaired quality of life.[2] Patients' swallowing dysfunction affects feeding, which leads to body weight loss and poor quality of life and might be related with disease progression and poor survival.

Generally, clinicians use swallowing studies, including videofluoroscopic swallow study (VFSS) or Eating Assessment Tool 10 (EAT 10) questionnaires to assess the patient's swallowing situation. When a VFSS is performed, the patient will be asked to swallow the contrast agent, and the physician can obtain a score of penetration-aspiration status (PAS) after evaluating the patient's coughing (1–8 points, the higher the score, the more severe the coughing situation). The EAT-10 uses a scale of 0–4 to assess 10 subjective questions about

Address for correspondence: Dr. Li-Jen Liao, Department of Otolaryngology, Far Eastern Memorial Hospital, No. 21, Section 2, Nan-Ya South Road, Banqiao, New Taipei 22061, Taiwan. E-mail: liaolj@ntu.edu.tw; deniro@mail2000.com.tw

Received: 01-11-2022 **Revised:** 05-12-2022 **Accepted:** 16-12-2022 **Available Online:** 24-03-2023

Access this article online

Quick Response Code:

Website: https://journals.lww.com/jmut

DOI: 10.4103/jmu.jmu_110_22

How to cite this article: Liao LJ, Tung YH, Lin YH, Hsu WL. Application of real-time submental ultrasonography to assess swallowing. J Med Ultrasound 2023;31:287-92.

swallowing divided according to severity: 0 points for no problem with eating to 4 points for the most serious problems. The highest possible score is 40 points. It is reported in the literature that if the EAT-10 total score is more than 3 points, it indicates that there is dysphagia.[3] The VFSS is the gold standard for objective swallowing function assessment. However, it is time-consuming and involves radiation exposure. In addition, not all patients can tolerate VFSS examination. Therefore, a point-of-care method with real-time ultrasound (US) would be valuable for assessing swallowing.

US is a good method to access the suprahyoid muscles and provide valuable information about swallowing.[4-7] However, the clinical application of real-time US for assessing swallowing or dysphagia is still unclear. The aims of this study were to measure the biometry of supraglottic muscles and hyoid bone movement during swallowing and develop a nomogram with features of real-time US for assessing swallowing dysfunction.

Materials and Methods

This prospective case–control study was approved by the Institutional Ethical Review board (IRB no.: 109056-E), all patients signed informed consent forms and performed in accordance with the principles of the Declaration of Helsinki. We collected data from HNC and thyroid cancer patients with subjective dysphagia and healthy controls without a history of cancer and dysphagia stratified by age and gender distribution in the general population. From March 2021 to June 2022, a total of 68 volunteers were included in the study. For US measurement, we used an ultrasonic station (TOSHIBA-SSA 660A) with a linear probe (PLT-1204BT 12 MHz) and a curved probe (PVT-375BT 3.5 MHz). A schematic diagram of probe placement is shown in Figure 1a and b for the linear and curve probes, respectively.

We enrolled 50 volunteers without HNC history and dysphagia symptoms, and another group of 18 HNC or thyroid cancer survivors with symptomatic dysphagia, and all patients received VFSS to assess swallowing and completed the EAT10 questionnaire.[3] The severity of swallowing dysfunction for our included patients was <5 due to safety concerns.

Real-time submental ultrasonography

Each participant was instructed to sit upright and keep their head in a neutral position. The participant drank 1 mL of water with each swallow action. We used real-time US to record the suprahyoid muscle and hyoid bone movement.

Transverse plane

With a 5–14 MHz linear probe placed in coronal orientation in the submental region and just above the hyoid bone and real-time recording during swallowing, we assessed the transverse sections of the anterior belly of digastric (ABD) muscle and GH muscles under both resting [Figure 2a] and maximal contraction [Figure 2b]. We measured the cross-sectional area of these muscles and calculated the percentage (%) increase during maximal contraction during swallowing with grayscale US. The procedure has been well described in previous literature.[4]

Sagittal plane

With a 2–5 MHz curved probe placed in alignment with the midline of the floor of the mouth and perpendicular to the lower chin surface and real-time recording during swallowing, we assessed a vertical section of the submental area, which shows the displacement of the hyoid bone under grayscale US. We also recorded the length of the GH muscle [Figure 3a] at resting and maximal contraction [Figure 3b] during

Figure 1: Ultrasonography method. Transverse section with linear probe (a) and sagittal section with curved probe (b)

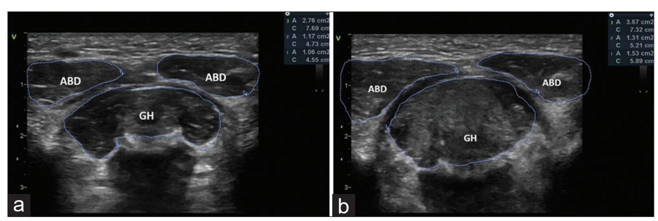

Figure 2: With a linear probe and transverse section at the submental area, we assessed the cross-sectional area of the ABD muscle and GH muscle at resting (a) and maximum contraction (b). ABD: Anterior belly of the digastric, GH: Geniohyoid

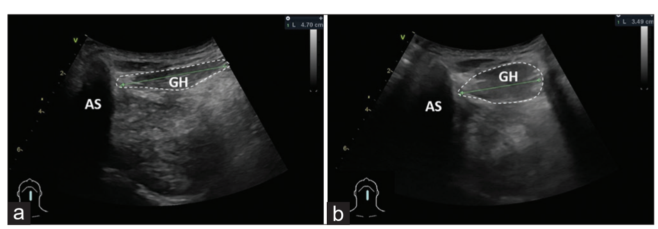

Figure 3: With a curved probe and sagittal section in the submental area, we assessed the length of the GH muscle at rest (a) and at maximum contraction (b). We also recorded the position of the hyoid bone and further calculated the anterior and superior movement of the hyoid bone with Image J software. The acoustic shadow of hyoid bone is marked as acoustic shadow (AS). GH: Geniohyoid

swallowing and further calculated the percentage increase during swallowing. We also recorded the maximum anterior and superior movement during swallowing in the sagittal plane, and the procedure has been well described in previous literature.[8,9]

Statistical analysis

Categorical variables are expressed as numbers (percentages); continuous variables are expressed as medians interquartile ranges (IQRs), and *P* values were calculated with the Wilcoxon rank-sum (Mann–Whitney) test. We used a receiver operating curve to find the best cutoff point. Finally, logistic regression analysis was used to explore significant US predictors of dysphagia. Then, based on the regression coefficients of independent variables, we established the nomogram prediction model for dysphagia. A $P < 0.05$ was considered statistically significant. All analyses were performed with STATA version 14.0 (Stata Corporation, College Station, Texas, USA).

Results

From March 2021 to June 2022, a total of 68 participants were included in the study [demographic data are summarized in Table 1]. The volunteer group without a history of cancer included 50 participants (25 males and 25 females). The median age (IQR) was 41.5 (23) years, the median height was 161.5 (13) cm, the median weight was 64.5 (19) kg, and the median body mass index (BMI) was 24.2 (4.8) kg/m^2. Nine participants (53%) had hypertension, 4 (80%) had hyperlipidemia, and 3 (50%) had diabetes. The patient group included 18 people (15 males and three females); the median age (IQR) was 59 (7) years, the median height was 166 (11) cm, the median weight was 59 (17) kg, and the median BMI was 22.7 (6.8) kg/m^2. Eight (47%) had hypertension, 1 (20%) had hyperlipidemia, and 3 (50%) had diabetes. For the EAT-10 questionnaire, the results show that the volunteer group without a history of cancer had no swallowing-related problems. The cancer survivor group had an overall median (IQR) of 22.5 (13) for the EAT-10 score [Table 1].

Of the 18 patients in the patient group, 7 (38%) had oral cancer, 5 (27%) had nasopharyngeal cancer, 3 (17%) had thyroid cancer, and 1 each had oropharyngeal cancer, submandibular cancer, and hypopharyngeal carcinoma. The characteristics are summarized in Table 2. Among them, one was stage I cancer (6%), four were stage II cancer (22%), three were stage III cancer (17%), six were stage IVA cancer (33%), and four were stage IVB cancer (22%). Of these, 11 (61%) underwent surgery, 12 (67%) underwent concurrent chemoradiotherapy, and the median PAS score (IQR) was 3.5 (3).

Table 3 shows that there were significant differences in GH size at contraction, GH size percentage increase, GH length at rest, GH length percentage increase, anterior displacement of the hyoid bone, and superior displacement of the hyoid bone between the cancer survivors with dysphagia group and volunteers without dysphagia group.

Table 1: Characteristics of recruited volunteers (expressed as number (%) or median, interquartile range)

Variables	Volunteers without cancer, dysphagia (*n*=50)	HNC, thyroid cancer survivors with dysphagia (*n*=18)
Gender, *n* (%)		
Male	25 (50)	15 (83)
Female	25 (50)	3 (17)
Age	41.5, 23 (33-56)	59, 7 (56-63)
BH (cm)	161.5, 13 (159-172)	166, 11 (159-170)
BW (kg)	64.5, 19 (54-73)	59, 17 (55-72)
BMI (kg/m^2)	24.2, 4.8 (21.4-26.2)	22.7, 6.8 (20.3-27.1)
HTN, *n* (%)		
Yes	9 (18)	8 (44)
None	41 (82)	10 (56)
CAD, *n* (%)		
Yes	0	0
Hyperlipidemia, *n* (%)		
Yes	4 (8)	1 (5)
None	46 (92)	17 (95)
DM, *n* (%)		
Yes	3 (6)	3 (17)
None	47 (94)	15 (83)
EAT-10 questionnaire (total scores)	0, 0 (0-0)	22.5, 13 (16-29)

BH: Body height, BW: Body weight, BMI: Body mass index, HTN: Hypertension, CAD: Coronary artery disease, DM: Diabetes mellitus, EAT-10: Eating assessment tool-10, HNC: Head-and-neck cancer

Table 2: Characteristics of head-and-neck cancer and thyroid cancer survivors

Variables	Patient (*n*=18)
Cancer site	
Oral cancer	7 (38)
NPC	5 (27)
Thyroid cancer	3 (17)
Oropharyngeal cancer	1 (6)
SM cancer	1 (6)
Hypopharyngeal cancer	1 (6)
Stage (7th AJCC)	
I	1 (6)
II	4 (22)
III	3 (17)
IVA	6 (33)
IVB	4 (22)
Treatment: OP	
Yes	11 (61)
Treatment: CCRT	
Yes	12 (67)
VFSS: PAS score	3.5, 3 (2-5)

SM: Submandibular, OP: Operation, CCRT: Concurrent chemoradiotherapy, VFSS: Videofluoroscopic swallow study, PAS: Penetration-aspiration scale, NPC: Nasopharyngeal carcinoma, AJCC: American Joint Committee on Cancer

The results of logistic regression analysis are shown in Table 4. In the univariate analysis, male sex, age >50 years, GH size at rest, GH length at rest, GH length contraction percentage, hyoid bone

Table 3: Comparisons of ultrasound parameters (median, interquartile range, and range) among participants with (*n*=18) and without (*n*=50) dysphagia (Wilcoxon rank-sum test)

Variables	Cancer survivors (*n*=18)	Volunteers without cancer (*n*=50)	*P*
Resting ABD size (cm^2)	0.67, 0.25 (0.57-0.82)	0.75, 0.30 (0.61-0.91)	0.2971
ABD size at contraction (cm^2)	0.77, 0.26 (0.65-0.91)	0.83, 0.34 (0.67-1.01)	0.4528
ABD contraction (%)	14.0, 15.2 (8.36-23.6)	10.1, 11.9 (4.79-16.7)	0.1645
Resting GH size (cm^2)	1.50, 0.67 (1.07-1.74)	1.44, 0.77 (1.15-1.92)	0.5640
GH size at contraction (cm^2)	1.8, 1.04 (1.44-2.48)	2.36, 1.05 (1.79-2.84)	0.0424*
GH size (increase %)	19.6, 35.4 (13.2-48.6)	55.8, 37.9 (34.9-72.8)	0.0006*
Resting GH length (cm)	3.80, 1.20 (3.16-4.36)	4.23, 0.76 (3.94-4.70)	0.0116*
Contraction GH length (cm)	2.60, 1.01 (2.11-3.12)	2.74, 0.75 (2.32-3.07)	0.2457
GH contraction (decrease length %)	32.2, 16.7 (20.4-37.1)	35.8, 13.8 (29.4-43.2)	0.0226*
Anterior hyoid bone displacement (cm)	0.97, 0.77 (0.38-1.15)	1.31, 0.94 (1.04-1.98)	0.0009*
Superior hyoid bone displacement (cm)	0.34, 0.30 (0.28-0.58)	0.64, 0.48 (0.40-0.88)	0.0057*

*$P<0.05$. ABD: Anterior belly of the digastric, GH: Geniohyoid

Table 4: Logistic regression for the predictors of dysphagia

	Univariate			Multivariate		
	OR	95% CI	*P*	OR	95% CI	*P*
Gender						
Female	Reference			Reference		
Male	5.0	1.3-19.4	0.020*	5.494	1.1-28.5	0.042*
Age (years)						
<50	Reference			Reference		
≥50	9.7	2.5-38.2	0.001*	21.126	3.2-141.1	0.002*
GH size at contraction (cm^2)						
≥2.0	Reference					
<2.0	2.4	0.8-7.3	0.114			
GH contraction size (%)						
Increase size ≥25	Reference					
Increase size <25	14.1	3.8-53.1	0.000*			
Resting GH length (mm)						
≥35	Reference					
<35	5.8	1.4-23.7	0.015*			
GH contraction length (%)						
Decrease length ≥22	Reference			Reference		
Decrease length <22	6.0	1.3-28.6	0.024*	6.8	1.1-42.6	0.042*
Anterior hyoid bone displacement (mm)						
≥10	Reference					
<10	4.0	1.3-12.7	0.019*			
Superior hyoid bone displacement (mm)						
≥3.3	Reference			Reference		
<3.3	5.3	1.6-17.3	0.006*	10.7	1.8-64.1	0.009*

*$P<0.05$. OR: Odds ratio, CI: Confidence interval, GH: Geniohyoid

anterior displacement, and hyoid bone superior displacement were significantly related to dysphagia ($P < 0.05$). In the multivariate logistic regression analysis, after adjusting for sex and age, the proportion of GH length contraction <22% (odds ratio [OR]: 6.8 95% confidence interval [CI]: 1.1–42.6) and hyoid bone superior displacement <3.3 mm (OR: 10.7, 1.8–64.1) were associated with a higher risk of dysphagia ($P < 0.05$).

Finally, we developed a nomogram with demographics and these two US features to predict the probability of dysphagia [Figure 4]. The higher the score, the higher the chance of developing a swallowing disorder.

Discussion

We confirmed that GH muscle contraction and hyoid bone movement are important for swallowing. We also developed a nomogram to predict dysphagia with demographics and two US parameters. The contraction of the GH muscle during swallowing is closely related to the displacement of the hyoid bone and

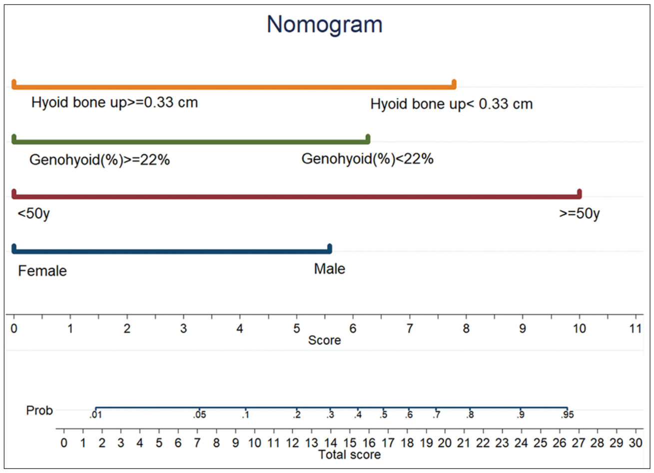

Figure 4: A proposed nomogram based on demographic and US characteristics to predict the probability (Prob) of dysphagia. US: Ultrasound

swallowing. Therefore, training GH muscles during rehabilitation is important. In the future, it is expected that strengthening GH muscles can be used to improve dysphagia in patients with HNC.

Shimizu *et al*. reported good reliability of US in GH muscle length and area measurement during swallowing.[9] Cheng *et al*. reported good reliability of US in assessing GH cross-sectional area and hyoid bone movement, and the results were related to PAS score.[4] Sonographic measurement of the suprahyoid muscles and hyoid bone movement may provide valuable information about swallowing. However, the role of US in dysphagia assessment is still unclear.

Previous US findings assessing swallowing in HNC showed variability in anatomical structure assessment and methodology applied.[10] Hyoid bone movement was the most explored parameter because hyoid bone movement is associated with laryngeal elevation during swallowing. Lower hyoid bone displacement indicates a higher risk of aspiration.[5] GH muscle mass was also reported to be associated with PAS and to predict the severity of dysphagia.[11] Our results are comparable to previous studies, and the percentage decrease in GH length and superior displacement are independent predictors of dysphagia [Table 4]. With the proposed nomogram, it will be easy to assess the probability of dysphagia.

US is also a valuable modality for the measurement of the ABD muscle.[12] However, the cross-sectional size of the ABD at rest, contraction, and the percentage increase in the ABD muscle were not significantly different in those with dysphagia and those without dysphagia in our study [Table 3]. The role of ABD measurement in assessing swallowing needs further clarification.

Aging is related to GH muscle atrophy and contributes to swallowing dysfunction.[13] After controlling for age and sex, the proportion of GH length contraction <22% (OR: 6.8 95% CI: 1.1–42.6) and hyoid bone superior displacement <3.3 mm (OR: 10.7, 1.8–64.1) were associated with a higher risk of dysphagia ($P < 0.05$) in multivariate logistic regression [Table 4]. We confirmed that the GH muscle is important for swallowing. Tongue-strengthening exercises were reported to be useful for increasing GH muscle strength and the tongue muscles in healthy young adults.[14] Tongue strength exercises with real-time US biofeedback for the GH muscle may be helpful for dysphagia rehabilitation for HNC survivors in the future.

There are some limitations of this study that need to be mentioned. First, the case number is limited. Second, according to a previous study, an EAT-10 score >3 could be regarded as significant swallowing dysfunction.[3] In this study, the median (IQR) for our patients was 22.5 (13), which indicated significant dysphagia [Table 1].

For safety, the severity of swallowing dysfunction for our included patients was <5 on the PAS and without nasogastric tube feeding. Therefore, more severe dysphagia patients were not enrolled. Third, some reports used M-mode US to measure pharyngeal wall motion[15] and GH muscle motion during swallowing.[16] These parameters for assessing swallowing still need further study.

Conclusion

We confirmed that GH muscle and hyoid bone movement are important for normal swallowing. US is a good method to assess the suprahyoid muscles and hyoid bone movement and provide valuable information on swallowing.

Acknowledgment

We thank colleagues in the HNC Surveillance and Research Group, Far Eastern Memorial Hospital.

Financial support and sponsorship

This work was supported by grants from the Far Eastern Memorial Hospital Research Program (FEMH-2021-C-011).

Conflicts of interest

This funding source had no role in the design of this study or in its execution, analyses, interpretation of the data, or decision to submit the results.

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