Swallowing Kinematic Analysis Might Be Helpful In Predicting Aspiration And Pyriform Sinus Stasis

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Abstract

Aspiration and pyriform sinus stasis resulting from compromised swallowing might cause aspiration pneumonia, which can have a negative impact on the patient's prognosis. Clinically, videofluoroscopic swallow study (VFSS) is considered the standard instrument that is able to provide clues that contribute to the physiological impairment of swallowing. In addition, according to previously published literature, the parameters of kinematic analyses of VFSS might provide further information for aspiration detection. In this study, 449 files of VFSS studies from 232 patients were divided into three groups: normal, aspiration, and pyriform sinus stasis. Kinematic analyses and between-group comparison were conducted. Significant between-group differences were noted among parameters, including anterior hyoid displacement, maximal hyoid displacement, and average velocity of hyoid movement. No significant difference was detected in superior hyoid displacement. Furthermore, receiver-operating characteristic (ROC) analyses using anterior hyoid displacement, velocity of anterior hyoid displacement, and average velocity of maximal hyoid displacement showed acceptable predictability for detecting aspiration. Using 33.0 mm/s as a cutoff value of average velocity of maximal hyoid displacement, the sensitivity of detecting the presence of aspiration could be about 90%. Therefore, we assumed that the average velocity of maximal hyoid displacement could be a potential screening tool to detect aspiration.

Introduction

Dysphagia is a critical clinical issue that can occur in various disease groups, including stroke, head and neck cancer, Parkinson's disease, and motor neuron disease [1–4]. Aspiration and food stasis in the pyriform sinus resulting from compromised swallowing can lead to subsequent aspiration pneumonia, which increases mortality and negatively affects the quality of life of patients [5, 6].

The swallowing mechanism can be divided into the following four phases: the oral preparatory phase, oral propulsive phase, pharyngeal phase, and esophageal phase [7]. During the complex pharyngeal phase of swallowing, the anterior–superior displacement of the hyoid bone plays a significant role in securing the airway to prevent aspiration and the opening of the upper esophageal sphincter for the smooth forward passage of food [1, 2]. Therefore, the evaluation of hyoid movement during swallowing is of great significance in clinical practice.

Clinically, the videofluoroscopic swallow study (VFSS) is considered the standard instrument that can provide clues of the factors contributing to the physiological impairment of swallowing [3]. Some established tools such as the Penetration–Aspiration Scale (PAS) and Modified Barium Swallow Impairment Profile (MBSImP) have been used to categorize the findings of VFSS studies. The PAS is an eight-point interval scale that assessed the extent to which the swallowed materials enter the airway and whether patients are able to clear the penetrated or aspirated materials [4]. The MBSImP is a comprehensive tool that assessed 17 different physiological domains during swallowing, including the extent of pharyngeal residual [5]. Despite the fact that these tools are widely used and gross swallowing impairment might be detected, when using these tools to quantify the degree of swallowing impairment, subjectivity is inevitable.

On the other hand, a swallowing kinematic study using VFSS is a more objective method for analyzing swallowing biomechanical events, with excellent interrater and intrarater reliability [6]. Nonetheless, the VFSS has several disadvantages, including inevitable radiation exposure, altered food consistency and sensory feedback due to the use of contrast medium, and limited patient accessibility, which does not allow bedside evaluation [7]. On the contrary, displacement of the hyoid bone, one of the crucial kinematic parameters, can be assessed through physical examination, ultrasound, and accelerometry, indicating potentially greater applicability in swallowing evaluation [8–10]. Results of previously published studies have implied a correlation between the extent of anterior or upward displacement of the hyoid bone, velocity and trajectory of hyoid movement during swallowing, and swallowing impairment including penetration, aspiration, and postswallow residues; however, no consensus has been achieved thus far [11–21]. Thus, it is worth exploring the relationship between hyoid bone kinematics and swallowing impairment, as findings could further expand the clinical implication of hyoid bone kinematics during swallowing.

In this retrospective study, we aimed to investigate the relationship between hyoid movements and penetration, aspiration, and pyriform sinus stasis using the kinematic analysis of VFSS studies. We hypothesized that impaired hyoid bone kinematics would be detected in groups with aspiration or pyriform sinus stasis and the result of kinematic analyses would be possibly utilized to predict the presence of aspiration and pyriform sinus stasis.

Material And Methods

Data Collection

In this study, we retrospectively reviewed the files of VFSSs collected from May 1, 2015, to May 1, 2020. The study protocol was approved by the National Taiwan University Hospital Research Ethics (Institutional Review Board: 202006027RINC). The VFSSs were conducted in the lateral plane and recorded with 30 frames per second. All studies were performed at the Department of Medical Imaging of National Taiwan University Hospital. We excluded files with difficult recognition of hyoid bone, an anteroinferior extreme point of the mandible bone, and C2 to C5 vertebral bodies.

Image Analysis

Personal information, including patient age, sex, and disease entity, was removed before we initiated the data analysis. One speech and language pathologist who was well trained in swallowing kinematic analysis sorted the video into three categories using the MBSImP and the PAS. The normal swallowing group was defined as those with a PAS score of 1 and MBSImP score of 0–1. Images with residue at the pyriform sinus were defined as having an MBSImP score of 2–4. Finally, the aspiration group was defined as those with a PAS score of 6–8.

For further swallowing kinematic analysis, two trained physiatrists (K.-C.W. and S.-H.C.) and two speech and language pathologists (Y.-C.W. and Y.-Y.P.) marked the following points of interest in each video frame using the aetherAI platform (Fig. 1): (1) anterior–inferior corner of the C2 vertebral body, (2) anterior–inferior corner of the C3 vertebral body, (3) anterior–inferior corner of the C4 vertebral body, (4) anterior–inferior corner of the C5 vertebral body, (5) anterior–inferior corner of the hyoid bone, and (6) the most prominent point at anterior–inferior corner of the mandible bone. The images were analyzed with the anterior–inferior corner of the C4 vertebral body set as the origin. The *y*-axis was defined as the line connecting (2) and (4). The perpendicular line intersecting with (3) was defined as the *x*-axis. Based on the established coordinate axis, were recorded parameters including the maximal displacement of hyoid bone during swallowing, the maximal displacement in the *x*-axis direction, and the maximal displacement in the *y*-axis direction. The distance was measured by transforming the image pixels to corresponding millimeters (mm). The average velocity of the hyoid bone displacement including the x-vector and y-vector components were also calculated.

Statistical Analysis

A preliminary Shapiro–Wilk test demonstrated that the data did not follow a normal distribution; thus, the Kruskal–Wallis test was used to compare the between-group differences of maximal displacement of the hyoid bone, maximal displacement of the hyoid bone in both the *x*- and *y*-axis directions, and the velocity of the hyoid bone displacement including the x-vector and y-vector components. All analyses were performed using SPSS version 25 (IBM, Armonk, NY). Significant between-group differences were defined as having a P value < .05. When the results of the Kruskal–Wallis test showed significant between-group differences, post hoc analysis using pairwise Mann–Whitney test was applied. To investigate whether the displacement and velocity of hyoid movement could be applied to further detect aspiration and pyriform sinus stasis, a receiver-operating characteristic (ROC) analysis was conducted as well. An area under curve (AUC) should at least surpass 0.7 to be considered to possess an acceptable discrimination ability [22].

Results

Between-Group Difference

In total, 449 VFSS files from 232 patients were analyzed: 230 files in the normal group, 87 files in the aspiration group, and 132 files in the stasis group. The mean age of the enrolled patients was 64.7 years old. The disease entities were summarized in Table 1 as various kinds of patient groups including stroke, head and neck cancer, Parkinson’s disease and traumatic brain injuries were recruited in this study.

Table 1
Demographic data of VFSS files analyzed

Disease entity	Number of videos (%)
Stroke	150 (33.4%)
Head and neck cancer	83 (18.5%)
Parkinson's disease	34 (7.8%)
Traumatic brain injury	15 (3.3%)
More than one of the above	10 (2.2%)
Others	157 (34.8%)

Table 2 shows significant between-group differences among the parameters, including anterior hyoid displacement, maximal hyoid displacement, and average velocity of hyoid displacement. No significant difference was detected in superior hyoid displacement.

Table 2
Comparisons of swallowing kinematic parameters between the normal population and populations with aspiration and pyriform sinus stasis

Parameters	Groups	N	Mean	First quartile	Third Quartile	95% Confidence Interval		p-value
						LL	UL	
Anterior Hyoid Displacement (mm)	Normal group	230	17.03	12.12.	21.67	16.12	17.93	0.00
	Aspiration group	87	11.51	7.37	14.8	10.09	12.94	
	Stasis group	132	12.98	8.72	16.99	11.85	14.11	
Superior Hyoid Displacement (mm)	Normal group	230	20.63	13.3	26.96	19.19	22.07	0.426
	Aspiration group	87	19.73	12.22	24.85	17.24	22.23	
	Stasis group	132	18.88	12.84	24.13	17.35	20.4	
Maximal Hyoid Displacement(mm)	Normal group	230	29.85	21.26	33.09	27.47	32.25	0.00
	Aspiration group	87	25.37	18.31	28.64	21.09	29.65	
	Stasis group	132	23.69	18.15	28.33	22.14	25.24	
Velocity of Anterior Hyoid Displacement (mm/s)	Normal group	230	19.18	7.78	25.47	17.18	21.19	0.00
	Aspiration group	87	7.88	2.05	9.51	5.88	9.88	
	Stasis group	132	15.76	7.8	20.02	13.9	17.62	
Velocity of Superior Hyoid Displacement (mm/s)	Normal group	230	24.49	11.53	34.15	22.31	26.67	0.024
	Aspiration group	87	16.32	5.91	22.67	13.48	19.17	
	Stasis group	132	24.86	13.06	34.04	22.15	27.56	
Average velocity of Maximal Hyoid Displacement (mm/s)	Normal group	230	28.27	14.73	40.41	27.01	29.53	0.00
	Aspiration	87	16.48	5.75	23.3	13.23	19.73	

	group						
	Stasis group	132	29.54	16.99	38.46	26.12	32.95

We conducted a pairwise comparison. Comparing the normal group and aspiration group, significantly greater anterior hyoid displacement, velocity of anterior hyoid displacement, velocity of superior hyoid displacement, and average velocity of maximal hyoid displacement were noted in the normal group. In the comparison between the normal group and stasis group, we found a significant between-group difference in anterior hyoid displacement and maximal hyoid displacement. For the comparison between the aspiration group and stasis group, we noted a significant between-group difference in the velocity of the anterior, superior, and maximal hyoid displacement.

ROC Analyses

Figures 2 and 3 present the ROC curves assessing the predictability of hyoid kinematics for aspiration and pyriform sinus stasis, respectively. The AUC and best cutoff values are shown in Tables 3 and 4. The AUC of anterior hyoid displacement, velocity of anterior hyoid displacement, and average velocity of maximal hyoid displacement in Table 3 were 0.736 (cutoff value: 13.5 mm), 0.787 (cutoff value: 5.4 mm/s), and 0.798 (cutoff value: 33.0 mm/s) respectively, showing acceptable predictability for aspiration. For the prediction of pyriform sinus stasis, none of the obtained AUC values were greater than 0.7.

Table 3
AUC and corresponding cutoff value, sensitivity, and specificity obtained from the ROC analyses for predicting aspiration

Measure	Cutoff Value	AUC	Aspiration Present	
			Sensitivity	Specificity
Anterior Hyoid Displacement (mm)	13.5	0.736	0.701	0.670
Superior Hyoid Displacement (mm)	26.3	0.532	0.793	0.287
Maximal Hyoid Displacement (mm)	10.8	0.572	0.17	0.99
Velocity of Anterior Hyoid Displacement (mm/s)	5.4	0.787	0.609	0.87
Velocity of Superior Hyoid Displacement (mm/s)	16.6	0.658	0.586	0.648
Average Velocity of Maximal Hyoid Displacement (mm/s)	33.0	0.798	0.874	0.396

Table 4
AUC and corresponding cutoff value, sensitivity, and specificity obtained from the ROC analyses for predicting pyriform sinus stasis

Measure	Cutoff Value	AUC	Stasis Present	
			Sensitivity	Specificity
Anterior Hyoid Displacement (mm)	17.5	0.668	0.795	0.461
Superior Hyoid Displacement (mm)	24.5	0.538	0.864	0.283
Maximal Hyoid Displacement (mm)	33.5	0.576	0.902	0.387
Velocity of Anterior Hyoid Displacement (mm/s)	20.1	0.550	0.758	0.374
Velocity of Superior Hyoid Displacement (mm/s)	15.9	0.482	0.379	0.67
Average Velocity of Maximal Hyoid Displacement (mm/s)	15.8	0.520	0.24	0.86

Discussion

The primary findings of this study showed significant between-group differences among the normal, aspiration, and stasis groups, considering parameters including anterior hyoid displacement, maximal hyoid displacement, and velocity of hyoid movement in detecting aspiration. The ROC analyses and the corresponding AUC calculated from anterior hyoid displacement, velocity of anterior hyoid displacement, and average velocity of maximal hyoid displacement showed acceptable discrimination ability. Our findings add to the growing body of evidence suggesting that the kinematic analysis of hyoid bone movement could aid in detecting aspiration [20]. Nonetheless, one of the huge drawbacks of VFSS is the limited patient accessibility, which favors patients with good cognition and mobility [7]. To expand the utility, further research is needed to investigate the diagnostic power of other tools such as ultrasound examination based on the results of the kinematic analysis obtained with VFSS studies.

Abnormal swallowing kinematic parameters including anterior or superior hyoid displacement, timing of hyoid bone excursion, and velocity of hyoid bone movement during swallowing have been postulated as possible contributing factors for aspiration [11–20]. Nonetheless, there is no consensus thus far. Several studies suggested that anterior hyoid displacement is related to pharyngeal processes during swallowing, including opening of the upper esophageal sphincter, whereas vertical displacement of the hyoid bone was highly variable because of the different resting positions in anatomical variations and its relation to oral processes only [23]. In this study, pairwise comparison between aspiration and normal groups showed a significantly lower value of anterior hyoid displacement and velocity of anterior hyoid displacement, superior hyoid displacement, and maximal hyoid displacement in the aspiration group. Nevertheless, whether there is a single convincing parameter of swallowing kinematics that leads to aspiration still requires further evidence.

Pyriform sinus stasis is a crucial factor that might be correlated with the severity of aspiration [24]. Reduced anterior movement of the hyoid bone might lead to insufficient opening of the cricopharyngeal muscle, causing stasis in the pyriform sinuses and after swallowing aspiration [24, 25]. Likewise, kinematic analysis of the hyoid bone displacement between the stasis group and the normal group in this article revealed significantly reduced anterior and maximal movement of the hyoid. To the best of our knowledge, the current study is the first to attempt to use kinematic parameters to predict the presence of pyriform sinus stasis. Nonetheless, our data showed suboptimal predictability. One important explanation is that not only anterior and superior hyoid movement but also neuronal inhibition of the tonic cricopharyngeal muscle and sufficient intrabolus pressure are crucial in the adequate opening of the cricopharyngeal muscle [25]. VFSS could provide detailed information for structural and timely kinematic analyses [26]. However, other tools including manometry or electromyography for the cricopharyngeal muscle might be needed to delineate the underlying process of inadequate cricopharyngeal muscle opening leading to pyriform sinus stasis [25].

Only a few previously published studies have postulated that some parameters might be helpful in detecting aspiration [11, 17, 20]. Seo et al analyzed multiple VFSS swallowing kinematic parameters among populations with poststroke dysphagia and found that the maximal tilt angle of the epiglottis had predictive value for the detection of aspiration [11]. According to the results of the study by Steele et al, the sensitivity of anterior hyoid displacement as a diagnostic parameter for detecting aspiration was as high as 90% [20]. In addition, only maximum anterior hyoid displacement might predict the risk of penetration and aspiration according based on the research from Zhang et al, but the predicted and observed probability did not always match[17]. In this article, acceptable predictability was attained while using anterior hyoid displacement and average velocity of maximal hyoid displacement to conduct ROC analyses, which was similar to the result from Steele et al [20]. In addition, the results of our study showed that the sensitivity was close to 90% using 33.0 mm/s as the cutoff value for the average velocity of maximal hyoid displacement. Therefore, we assumed that the average velocity of maximal hyoid displacement might be used as a screening parameter for the detection of populations with aspiration.

This study has several limitations. First, the analysis was not conducted in accordance with stratification of different food consistencies. Available evidence has shown that different bolus textures have a possible influence on hyoid movement [27, 28]. Therefore, the predictability of kinematic analysis of the hyoid bone in aspiration or pyriform sinus stasis with regard to specific food consistency requires further research. Second, the populations studied in this research included various kinds of disease entities. Our research result provided a general scope of using swallowing kinematic analysis to detect aspiration, but disease-specific analysis is needed in clinical scenarios such as possible aspiration in patients with stroke, Parkinson’s disease, and head and neck cancer as well as in elderly individuals [11, 29–31]. Third, our study focused on the analysis of hyoid movement, and the result showed that the distance and velocity of anterior hyoid displacement and the average velocity of maximal hyoid displacement were acceptable predictors of aspiration. Nonetheless, other clinical parameters including epiglottic movement, larynx movement, and maximum pharyngeal constriction might also be contributing factors of aspiration and pyriform sinus stasis [11, 13, 32]. Further studies are required to investigate other potential parameters in detecting aspiration.

Conclusions

Significant between-group differences in anterior hyoid displacement and the velocity of hyoid displacement were observed in this study among the normal, aspiration, and pyriform sinus groups. ROC analysis revealed that anterior hyoid displacement and velocity of the anterior and maximal hyoid displacement had acceptable predictability in detecting aspiration. In addition, the sensitivity obtained when using 33.0 mm/s as the cutoff value for average velocity of maximal hyoid displacement was close to 90%. We assumed that the velocity of the maximal hyoid displacement could be used as a potential screening tool for the detection of aspiration. However, whether there is possible indicator of pyriform sinus stasis requires further evidence.

Abbreviations

AUC, area under curve; MBSImP, Modified Barium Swallow Impairment Profile; PAS, Penetration–Aspiration Scale; ROC, receiver-operating characteristic; VFSS, videofluoroscopic swallow study.

Declarations

Author contributions:

Conceptualization:

Tyng-Guey Wang, MD, Ming-Yen Hsiao, MD, PhD, Yu-Chen Wang, MS, Chi-Hung Weng, MS and Jo-Yu Chen, MD conceptualized the study. Tyng-Guey Wang, MD, Yu-Chen Wang, MS, Chi-Hung Weng, MS designed the methodology of the study. Yu-Chen Wang, MS, Kuo-Chang Wei, MD, Sheng-Hao Cheng, MD analyzed the data. Kuo-Chang Wei drafted the manuscript. All authors reviewed and edited the manuscript and approved the final version of the manuscript.

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Competing interests:

The authors declare no competing interests.

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Figures

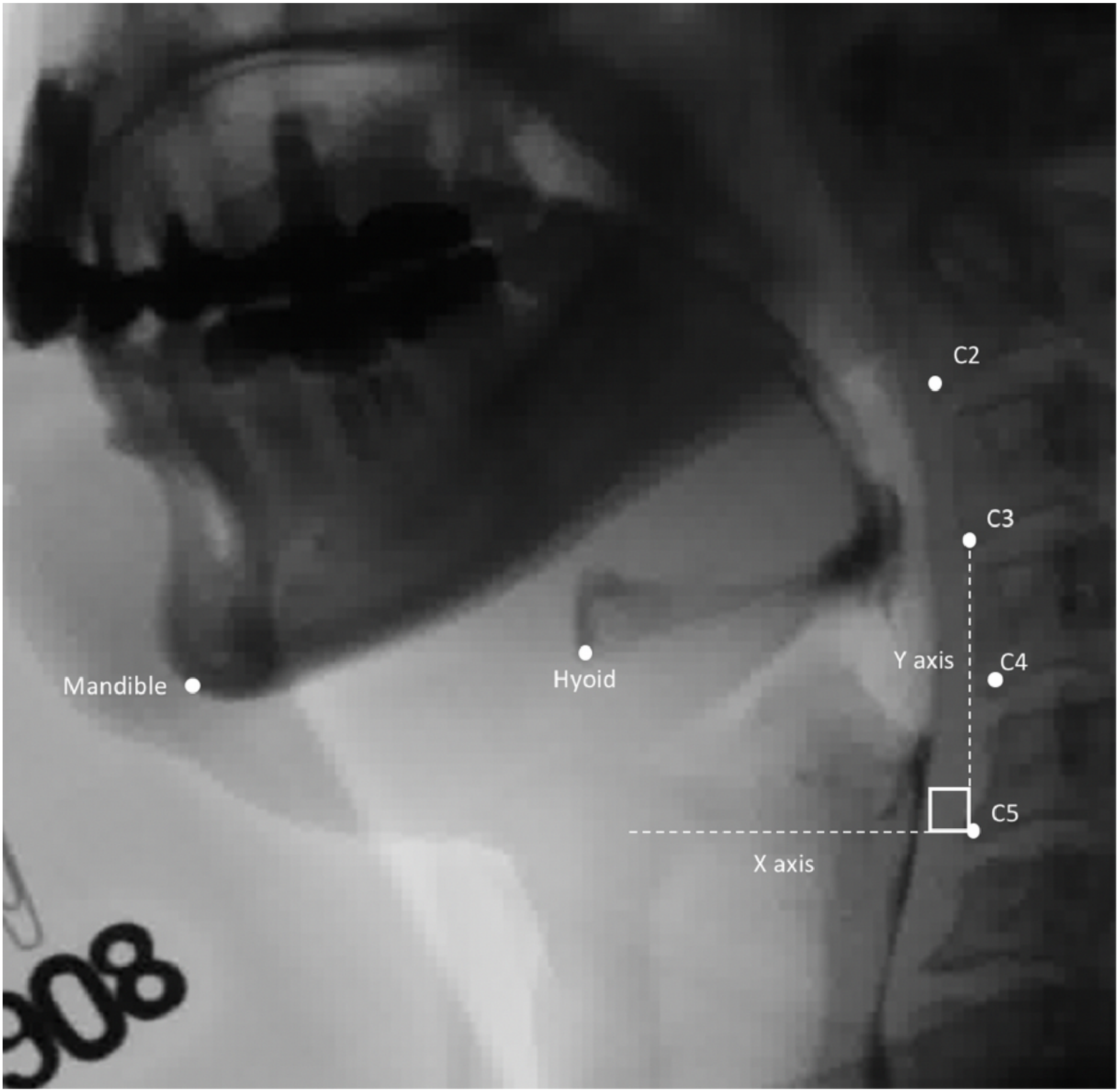

Figure 1

Points of interest and coordinate axis of VFSS image with Y-axis defined as the line connecting anterior–inferior corner of C3 and C5 vertebral bodies

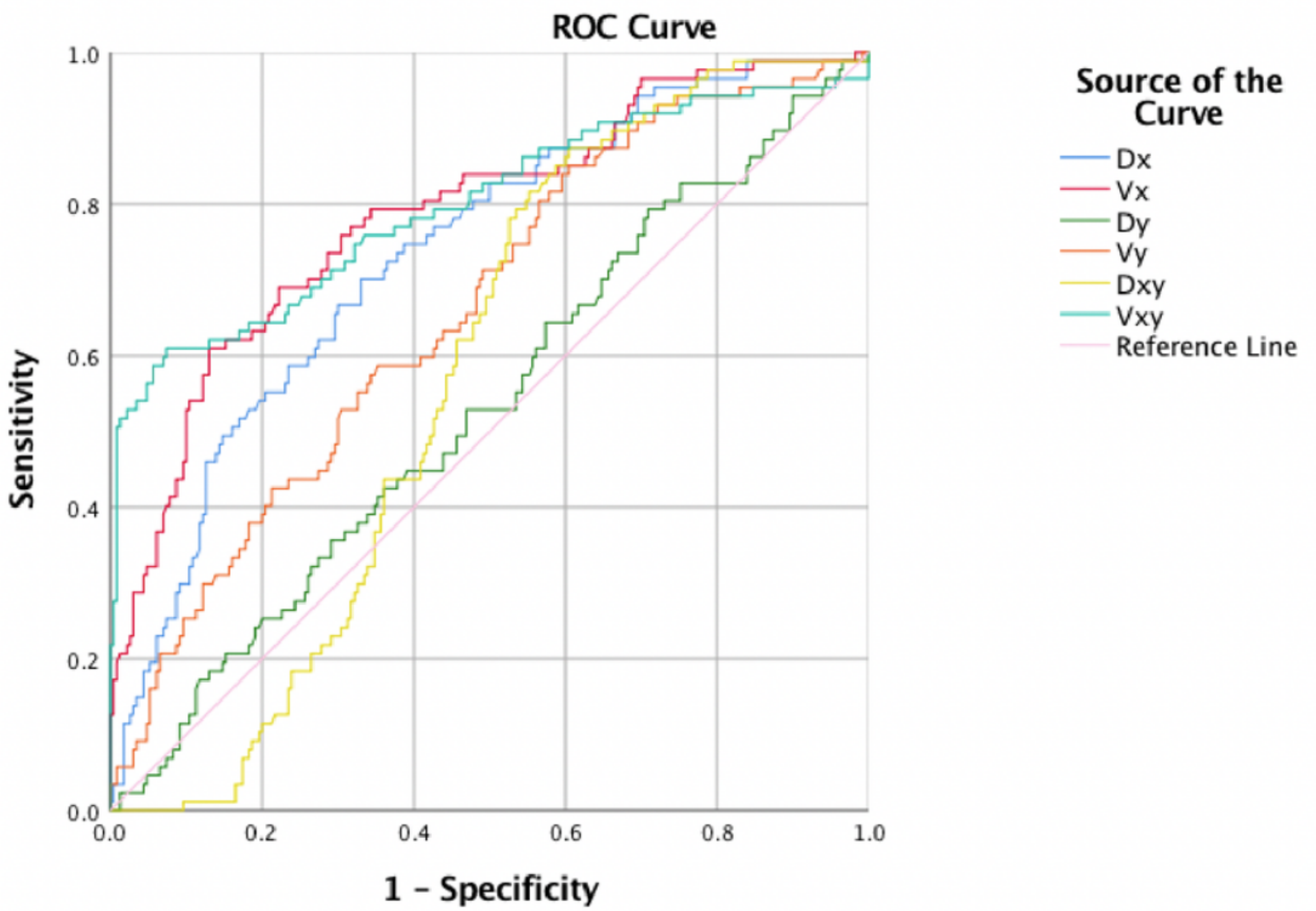

Figure 2

ROC curve of parameters of hyoid movement kinematic analyses for predicting aspiration Abbreviations : Dx, Anterior Hyoid Displacement; Vx, Velocity of Anterior Hyoid Displacement; Dy, Superior Hyoid Displacement; Vy, Velocity of Superior Hyoid Displacement; Dxy, Maximal Hyoid Displacement; Vxy, Average Velocity of Maximal Hyoid Displacement

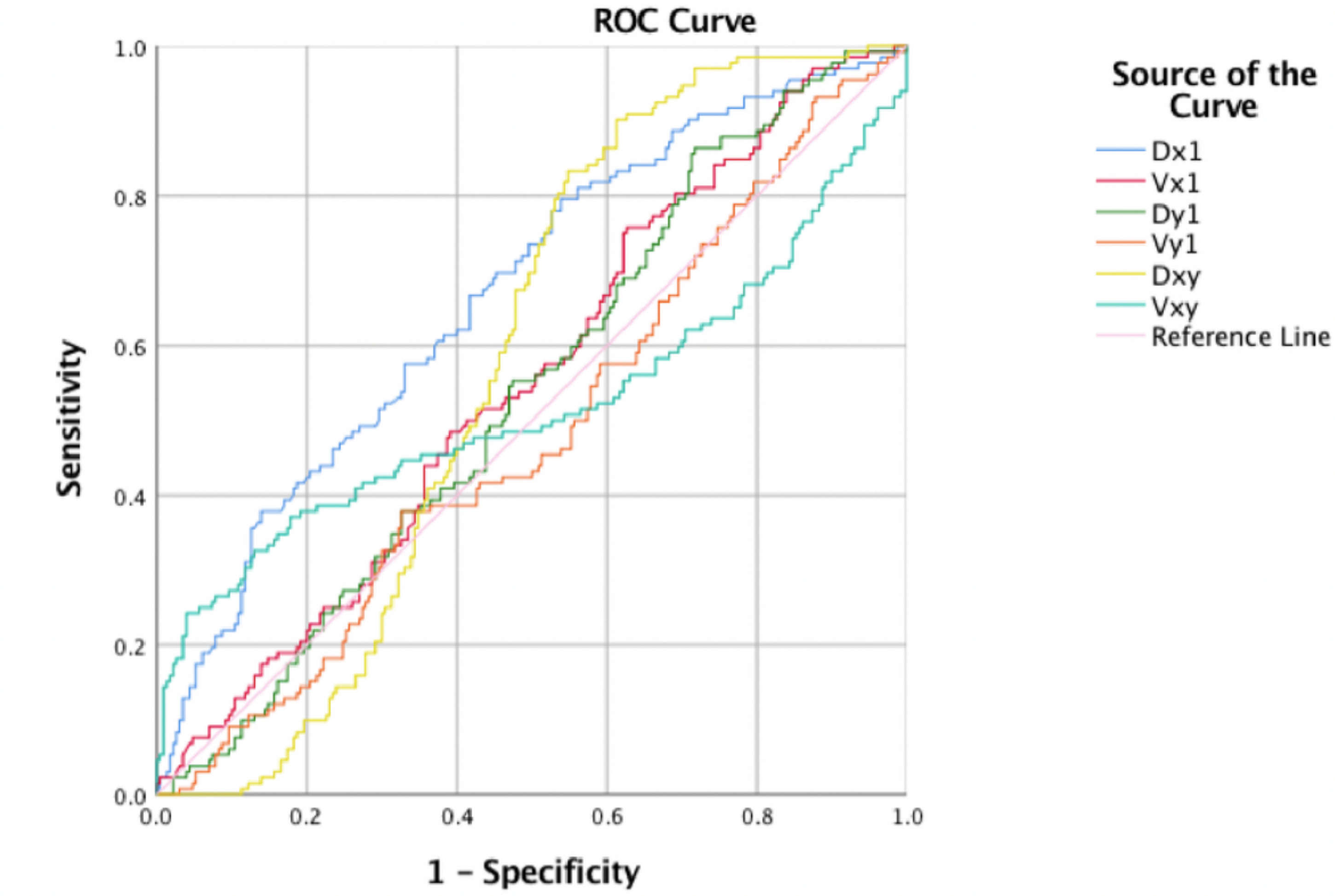

Figure 3

ROC curve of parameters of hyoid movement kinematic analyses for predicting pyriform sinus stasis Abbreviations : Dx, Anterior Hyoid Displacement; Vx, Velocity of Anterior Hyoid Displacement; Dy, Superior Hyoid Displacement; Vy, Velocity of Superior Hyoid Displacement; Dxy, Maximal Hyoid Displacement; Vxy, Average Velocity of Maximal Hyoid Displacement