The Diagnostic Accuracy of the Pitch Glide to Identify Aspiration in Patients with Respiratory Diseases: A Pilot Study

Mavrea Sofia^{1*}, MSc. Regan Julie¹, PhD

¹Department of Clinical Speech and Language Studies, Trinity College Dublin, Dublin, Ireland

Short Title: Pitch Glide to Identify Aspiration in Adults with Respiratory Diseases

*Corresponding Author

Full name: Sofia Mavrea

Institute: Pyksida – Speech and Language Therapy Center

Department: Speech and Language Therapy

Street Name & Number: Aristotelous 32

City, State, Postal code, Country: Kalamata, 24100, Greece

Tel: 00306986280199

E-mail: mavreas@tcd.ie

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ABSTRACT

Introduction: Initial research has been conducted to determine the diagnostic accuracy of the pitch glide during the clinical swallow evaluation to identify aspiration in adults post stroke. Findings suggest that reduced pitch glide can predict aspiration in patients with dysphagia post stroke. This study aimed to identify the diagnostic accuracy of the pitch glide in detecting aspiration, pharyngeal residue and hyolaryngeal excursion during swallowing in adults with respiratory diseases.

Material & Methods: 17 adults (9 males, mean= 75.2, SD= 8.98, and 8 females, mean age=73.5, SD= 8.17) with dysphagia who had a background of respiratory diseases (Chronic Obstructive Pulmonary Disease=11; Lower Respiratory Tract Infection= 6) were consecutively recruited in an acute hospital setting. Participants completed two pitch glide tasks (/a/ and /i/) immediately before a videofluoroscopic swallowing study (VFSS). Pitch glide recordings were analysed by blinded researchers both acoustically (Praat software) to obtain maximum F_0 , pitch range and auditory-perceptually using a binary scale (“normal” or “abnormal”). Clinicians blinded to pitch glide ratings rated 5ml, 10ml and a sip of liquid swallows during VFSS using the Penetration-Aspiration Scale, Bolus Residue Scale and hyolaryngeal component of the MBSImP. Receiving Operator Curve, Pearson correlations and independent sample t-tests were used to address the research questions.

Results: Maximum F_0 of sound /a/ had high sensitivity and specificity in identifying aspiration on 10ml of liquids during VFSS. Both pitch glides (/a/ and /i/) had moderate sensitivity and specificity in predicting aspiration on a sip of liquids. However, auditory-perceptual measures of pitch glide had weak accuracy in identifying people who were aspirating during VFSS. Finally, all pitch glide measures (acoustic and auditory-perceptual) had low accuracy in predicting pharyngeal residue and hyolaryngeal excursion.

Conclusion: Based on this initial pilot study, acoustic pitch glide of sound /a/ is an accurate way to predict aspiration on 10ml of liquids in patients with respiratory diseases. Based on findings from this study, both auditory-perceptual and acoustic analysis of pitch glide could not identify residue and hyolaryngeal excursion.

1. INTRODUCTION

Respiratory diseases are conditions of the airways and other structures of the lung. Some of the most common respiratory conditions are chronic obstructive pulmonary disease (COPD), asthma, occupational lung diseases, lung cancer and pulmonary hypertension. Risk factors include tobacco use, air pollution and occupational chemical use and dust. Respiratory disease poses a significant burden on society and this burden is worsening internationally due to tobacco use and ageing population. COPD, the most prevalent respiratory disease, is projected to be the third biggest cause of death by 2020 [1].

Oropharyngeal dysphagia is frequently present in adults with respiratory diseases and it can cause complications such as aspiration pneumonia, weight loss and malnutrition [2]. It can also have a marked impact on individuals quality of life (QOL) [3,4]. Most research in this area focuses on dysphagia in COPD, perhaps due to its prevalence. Approximately 15% - 20% of patients with COPD report difficulty in swallowing [5]. Silent aspiration is often observed in people with respiratory diseases due to impaired laryngeal sensitivity [6]. This can be difficult to identify based on the clinical swallow evaluation (CSE) [6]. Other features of dysphagia in adults with COPD include reduced anterior and superior hyolaryngeal excursion during swallowing. This can lead to poor airway protection and reduced upper oesophageal sphincter opening during swallowing, potentially impacting on safety and efficiency of swallowing respectively. Another important cause of dysphagia in patients with COPD is the difficulty coordinating the exhale-swallow-exhale respiratory cycle during deglutition [7,8]. Other dysphagia features include ineffective bolus preparation and reduced tongue base control, delayed pharyngeal swallow and delayed swallow response time [9–14]. Of note, it has been reported that tracheobronchial aspiration may result in pneumonia in 50% of cases when a decrease in deglutition safety occurs [15].

As dysphagia can have multiple clinical and QOL complications in people with respiratory disease, prompt and accurate identification of those with dysphagia and aspiration is imperative in clinical practice. Dysphagia evaluation can be divided into interdisciplinary swallow screening, the CSE and instrumental swallow evaluation. The CSE is a critical component to dysphagia evaluation and is typically conducted by the speech and language therapist (SLT) [16,17]. A CSE is completed to determine the presence and severity of dysphagia and to decide if further instrumental examination is needed in order to minimise risk of clinical or QOL complications [18,19]. It is not possible, based on the CSE, to identify the underlying pathophysiology causing of dysphagia. Additionally, many components of the CSE have poor intra-rater and inter-rater reliability [20]. It is also challenging to establish from the CSE if a person is aspirating or not. Several studies have investigated the diagnostic accuracy of components of the CSE to identify dysphagia and aspiration [20–22]. Based on these studies, most of which

focused on stroke populations, many CSE components including wet voice and cough post swallow do not have very good sensitivity and specificity [18,22–25]. As a result, clinicians are often unsure what components to include in a CSE in order to accurately and reliably identify those who are at risk of aspiration. Perhaps as a result, CSE practices vary widely internationally [16,17,26–29]. In order to advance the CSE, we need to identify and incorporate components that are both reliable and have adequate diagnostic accuracy to identify dysphagia and aspiration.

It is well recognised that there is a strong anatomical and physiological overlap between pitch elevation and swallowing. Reduced pitch elevation may be caused by pathological conditions such as superior laryngeal nerve injuries, generalised neurological damage that affects the superior laryngeal nerve or other nerves and muscles that take part in swallow [30,31]. Researchers have investigated the relationship between pitch elevation and hyolaryngeal excursion. Logemann initially developed the falsetto as an exercise to target laryngeal elevation as it helps elevate the larynx the same way as it does during swallowing [32]. The exercise consisted of gliding up pitch to a high voice and holding it for a set time. Dynamic magnetic resonance imaging (MRI) studies have demonstrated that the larynx elevates during pitch glide tasks [33]. When the F_0 increases, the laryngeal muscles activity increases, too [34]. This happens because the cricothyroid and vocalis muscles' activity increases significantly at higher frequencies [35,36].

Preliminary studies have been conducted to explore the link between pitch glide and aspiration in people with dysphagia [37,38]. Malandraki et al. (2011) examined the correlations between the pitch glide and aspiration on VFSS in forty adults with different aetiologies of dysphagia [37]. In this study, high maximum F_0 of the sound /a/ measured both auditory-perceptually and acoustically is associated with lower penetration-aspiration scores [37]. Additionally, pitch glide was found to have adequate correlations with residue scores. More recently, Rajappa et al., examined the diagnostic accuracy of the pitch glides /a/ and /i/ in identifying people who aspirated post-stroke [38]. The results of this study suggested that pitch elevation can predict silent aspiration in small liquid boluses with high sensitivity and moderate specificity. However, there were no correlations observed between pitch glide and residue and hyolaryngeal excursion [38].

No research has been conducted to investigate the diagnostic accuracy of the pitch glide to identify aspiration in adults with respiratory diseases. Based on the fact that silent aspiration and reduced hyolaryngeal excursion is common in people with respiratory diseases, and given varying diagnostic accuracy and reliability of the components of the CSE, this pilot study aims to investigate the diagnostic accuracy of the pitch glide to identify aspiration, pharyngeal residue and hyolaryngeal excursion in a population of adults with respiratory diseases.

Based on previous research and the pathophysiology of dysphagia in COPD, it is hypothesised that a simple pitch glide task as part of the CSE may present with adequate diagnostic accuracy in identifying people who are aspirating. This pilot study also aims to investigate the association between acoustically and auditory-perceptually measured pitch glides. Finally, authors hypothesise that there are correlations between acoustic and auditory-perceptual pitch glide ratings and aspiration, pharyngeal residue and hyolaryngeal excursion.

2. MATERIALS AND METHODS

2.1 Participants

Ethical approval was granted by the research ethics committee of Tallaght University Hospital (SJH/AMNCH Research Ethics Committee, Tallaght University Hospital, Dublin). Participants were recruited consecutively over a 3-month period (January 2017 to March 2017) within the speech and language therapy department in an acute hospital setting. Seventeen adults (9 males, mean age= 75 years, SD= 8.98; 8 females, mean age=74 years, SD= 8.17) with a diagnosis of COPD (N= 11) and LRTI (N= 6) who presented with dysphagia based on CSE were included in the study (Table 1). All adult patients with a diagnosis of respiratory disease (COPD, asthma, LRTI) who had a scheduled appointment for VFSS met inclusion criteria for the study. Similar to previous studies, exclusion criteria were acute pneumonia, a tracheostomy tube, patients with cognitive impairment and professional voice users.

2.2 Pitch Glide Task

The first researcher measured pitch glide in a nearby quiet room within the x-ray department before the VFSS examination. The researcher initially demonstrated the pitch glide twice and participants were subsequently instructed to complete a pitch glide. The instruction provided was to “start saying vowel /a/ at your normal voice and slowly raise your voice as high as you can” [37]. Participants were requested to practice the pitch glide until the researcher was satisfied that the pitch glide was being carried out appropriately. Of note, the researcher did not try to train participants to produce a normal pitch glide, but instead encouraged them to raise the pitch of their voice instead of raising volume. Once the pitch glide had been practiced adequately, the participant was brought to the videofluoroscopy suite. Participants were positioned in a lateral view on a chair in the fluoroscopy suite. A “Logitech H110 3.5mm Connector Stereo” headset with noise-cancelling microphone connected to an “Olympus VN-731PC” voice recording device was placed on the participants’ head in order to standardise the distance between the mouth and the microphone for each participant during the recording of pitch glide. Voice recording device were set up at 44.1 kHz/16 bits, and input level was at 60 dB for all recordings [37]. Once the equipment was set to record, participants were asked to produce two pitch glide tasks using the instructions provided above

[37]. Both pitch glide attempts were recorded, but only the second one was analysed. It was decided to use only the second voice sample of each sound because some participants could not adequately complete the task on their first attempt and required feedback before their second attempt. As a result, the second pitch glide was a more accurate representation of their pitch glide. Once the pitch glides were completed, the headset microphone was removed and the VFSS protocol began. The time between the pitch glide recordings and the VFSS was a maximum of five minutes.

2.3 Videofluoroscopy

The VFSS procedure was video recorded at 25 frames per second with participants seated in a lateral upright position. Audio recordings were included as part of the VFSS. As per the local departmental VFSS protocol which was based on international best practice guidelines, all participants were given 5ml liquid barium (barium weight/volume 40%), 10ml liquid barium and a sip of liquids from a cup, a spoon of puree and a biscuit. All liquid volumes were measured by a 20ml syringe. In the current study, 5ml and 10ml liquid volumes were selected for analysis due to standardized bolus volumes and because people with respiratory disease often aspirate on liquid consistencies [39]. Where participants were provided with more than one 5ml, 10ml or a sip of liquid bolus, the first bolus of that volume was selected for analysis.

2.4 Data analysis

2.4.1 Pitch Glide

The second of two pitch glide recordings for each participant was analysed both acoustically and auditory-perceptually after being re-identified using Audacity Software (Version 2.0.3) [40]. The initial files were on WMA form and were converted to WAV form using Audacity Software (Version 2.0.3) [40], in order to be analysed acoustically using Praat Software (Version 5.3.53) [41]. The acoustic analysis using Praat Software (Version 5.3.53) was performed by the first researcher who had under five years clinical experience working as a SLT [41]. This researcher completing the acoustic analysis was blinded to age, diagnosis and dysphagia severity of each participant. Measures obtained for the pitch glide were (i) maximum F_0 and (ii) pitch range, considering that in adults F_0 typically ranges between 80 and 175 Hz among men, and 160 and 270 Hz among women [42]. Pitch range is defined as the range between modal pitch and falsetto and was calculated by extracting the modal pitch value from the falsetto value. During the acoustic analysis with Praat Software (Version 5.3.53) [41], the floor for men, who are low pitched, was set to 75Hz and the ceiling to 400Hz, while for women, who are high pitched, the floor was set to 75Hz and the ceiling to 500Hz. Additionally, the researcher took a 40-millisecond midportion

because the pitch floor was 75 Hz for both men and women. Using Praat Software (Version 5.3.53) [41], the first researcher put the left vertical cursor over the onset waveform and the right vertical cursor over the offset of the waveform of sound /a/ and requested to be provided with the maximum and the minimum pitch from the pitch options menu of the software. The minimum pitch of the voice samples was got in order to be extracted from the maximum pitch to obtain the pitch range. The distance between the two cursors was proportional to the time that elapsed between the start and the end of each patients' pitch glide task.

Auditory-perceptual analysis was conducted by the second researcher who was blinded to the acoustic analysis and was not presented for the VFSS. The second researcher had eighteen years clinical experience with dysphagia. The second researcher was provided with pitch glide recordings but was also blinded to the age, diagnosis and dysphagia severity of each participant. The researcher rated each pitch glide using a binary scale (rating 0 for patients who were unable to pitch glide from a low frequency to a high frequency and rating of 1 for those who could pitch glide from a low frequency to a high one). The researcher was instructed not to rate any other voice components such as voice quality, voice volume or hoarseness. Furthermore, 20% of pitch glide recordings were reanalysed auditory-perceptually by another SLT, who had limited experience in voice disorders, for inter-rater reliability.

2.4.2 Videofluoroscopy

Data obtained from the VFSS recordings were analysed by clinicians based in the university hospital, who were certified to use MBS Measurement Tool for Swallow Impairment (MBSImP) and had extended experience in dysphagia [43]. These SLTs were asked to analyse each VFSS recording frame by frame and they were aware of patients age and diagnoses, but they were blinded to all pitch glide analyses. Bolus volumes that were collected and analysed were 5ml, 10ml and a sip of liquids. The Penetration-Aspiration Scale was used to rate aspiration on 5ml, 10ml and the sip of liquids from 1 (material does not enter the airway) to 8 (material enters the airway; passes below the vocal folds, no effort made to eject) [44]. Pharyngeal residue and hyolaryngeal excursion were rated using Bolus Residue Scale and the hyolaryngeal excursion component of the MBSImP respectively [43,45]. Residue was rated on a scale from 1 (no residue) to 6 (residue in valleculae and posterior pharyngeal wall and piriform sinus) [45]. On the other hand, hyolaryngeal excursion was rated using a scale from 0 (complete superior movement of thyroid cartilage with complete approximation of arytenoids to epiglottic petiole) to 3 (no superior movement of thyroid cartilage) [43].

2.5 Statistical analysis

Statistical analysis was conducted using IBM SPSS software (Version 25.0) and MedCalc software (Version 17.8) [46,47]. Cohen's kappa was used to examine the inter-rater reliability for auditory-perceptual analysis. Receiver operating characteristics (ROC) curves were used to find out the sensitivity and specificity of auditory-perceptual ("normal" and "abnormal") and acoustic (maximum F_0 , pitch range) pitch glide measurement in the prediction of aspiration, pharyngeal residue and hyolaryngeal excursion. A p-value of 0.05 was regarded as statistically significant. Correlations were used between acoustic and auditory-perceptual pitch glide and aspiration, pharyngeal residue and hyolaryngeal excursion. Finally, Pearson correlations were used to examine correlations between sounds /a/ and /i/ and independent t-tests were used to compare mean max F_0 values between patients with normal and abnormal maximum pitch perception ratings, as a measure of reliability between the two voice evaluation methods.

3. RESULTS

3.1 Reliability

To examine intra-rater reliability of pitch glide recordings, voice samples were re-analysed acoustically using Praat software and 100% agreement was obtained (41). Moreover, 20% of the 17 voice samples were reanalysed auditory-perceptually for inter-rater reliability by a clinician blinded to VFSS findings and there was 92% agreement with very good inter-rater reliability for both sounds /a/ and /i/ (Cohen's $\kappa = 0.871$, $p = 0.001$; and Cohen's $\kappa = 0.842$, $p = 0.010$, respectively). Finally, there were good correlations between the maximum F_0 two sounds (/a/ and /i/) ($r = 0.891$, $p < 0.001$) and excellent correlation between the perceptual ratings of sounds /a/ and /i/ ($r = 0.934$, $p < 0.001$). Finally, Participants who were rated as having abnormal pitch glide had not decreased max F_0 (mean = 375.06 Hz, SD = 573.98, SE = 17.36) compared to participants who were rated as having normal pitch glide (mean = 229.88 Hz, SD = 83.98, SE = 20.36, $p < 0.001$).

3.2 Pitch Glide and Aspiration

On 5ml of liquids, pitch range and auditory perceptual analysis of sounds /a/ and /i/ had moderate sensitivity and specificity in the prediction of aspiration. Maximum F_0 and pitch range of sound /a/ had high sensitivity and specificity (sensitivity 83%, specificity 81%, AUC = 0.864, $p = 0.001$) on 10ml of liquids (Figure 1 and Table 2) with a cutoff point of 361.453Hz. Additionally, there were adequate correlations observed between these variables (Figure 2 and Table 3). On the other hand, auditory-perceptual analysis had inadequate sensitivity and specificity in the prediction of aspiration. It was also discovered that maximum F_0 of both sounds /a/ and /i/ had moderate sensitivity and specificity (sensitivity 80%, specificity, 75%, AUC = 0.767, $p = 0.055$) in the prediction of

aspiration on a sip of liquids. Finally, silent aspiration could not be calculated as there the was no episode of silent aspiration presented.

3.3 Pitch Glide and Pharyngeal Residue

As it is shown in Table 4, there were no strong correlations between pharyngeal residue and pitch glide. Maximum F_0 of sound /a/ had high sensitivity but inadequate specificity in predicting pharyngeal residue on 10ml of liquids (sensitivity 93%, specificity 50%, AUC = 0.633, $p = 0.667$) (Table 5). However, the other voice measures (pitch range and auditory-perceptual analysis) had sensitivity lower than 66% and specificity lower than 54% in the prediction of pharyngeal residue across the three liquid volumes.

3.4 Pitch Glide and Hyolaryngeal Excursion

Maximum F_0 of sound /a/ had moderate sensitivity and specificity in predicting hyolaryngeal excursion (sensitivity 66%, specificity 78%, AUC = 0.714, $p = 0.287$) on 10ml of liquids. However, as it is shown in Table 6 both sounds /a/ and /i/ had low sensitivity and specificity in predicting hyolaryngeal excursion. Additionally, as it is shown in Table 7, there were no correlations between hyolaryngeal excursion rates and pitch glide.

4. DISCUSSION

The current study aimed to investigate the diagnostic accuracy of the pitch glide in identifying aspiration in a clinical population with respiratory diseases. Findings suggest that maximum F_0 of sound /a/ can accurately identify those who are aspirating on 10ml of liquids in adults with respiratory diseases. Moreover, maximum F_0 of both sounds /a/ and /i/ had moderate sensitivity and specificity in identifying aspiration in this population group. According to these preliminary findings, patients who cannot glide their pitch high enough may be in significant risk of aspiration. Additionally, it was discovered that lower maximum F_0 was associated with higher penetration-aspiration scores. These results support the findings of the two previous studies which reported that reduced pitch elevation can accurately predict aspiration on small liquid boluses [37,38]. However, the sample size of our study was small, and results should be validated in a future study including a bigger sample size.

Although, previous evidence suggest that auditory-perceptual results of the pitch glide were accurate in predicting aspiration and there were adequate correlations between auditory-perceptual ratings and aspiration, in our study it was revealed that auditory-perceptual analysis of the pitch glide had inadequate sensitivity and specificity [37,38]. Correlations between auditory-perceptual results of the pitch glide and aspiration status were also weak, in the current study. In our case, the SLT who performed the auditory-perceptual analysis had an extensive experience in dysphagia and limited background in voice disorders. This outcome highlights the fact that auditory-

perceptual analysis is an easy and time saving way but may not always be reliable in predicting aspiration. It has been reported that correlations between auditory-perceptual and acoustic pitch glide may be weak or moderate and auditory-perceptual analysis requires a lot of training [48]. On the other hand, instrumental analysis does not require special training and it seems to be a reliable way to rate voice samples. Moreover, in the current study, unlike the previous studies that included standardised bolus volumes, we examined two standardised bolus volumes (5ml and 10ml) and an unstandardized one (a sip). This decision was made because patients do not measure bolus volumes when they have to swallow a drink and some of them have bigger sips of water, while others have smaller ones. For that reason, it was important to investigate if pitch glide can accurately predict swallow safety in a bolus volume that represents “real-life circumstances”. Regarding silent aspiration, previous studies suggest that reduced maximum F_0 can be a sign of silent aspiration in patients with a diagnosis of stroke, or patients with different aetiologies of dysphagia [37,38]. In our study, there were no patients with an episode of silent aspiration during the VFSS and as a result there are no results obtained.

In our study, participants were requested first to produce sound /a/ and then sound /i/. However, it was proved that sound /a/ was more accurate than sound /i/. According to previous findings sound /i/ requires more power to be produced and as a result it can increase the hyolaryngeal elevation [49,50]. Hence, it is conjectured that the production of sound /a/ that preceded the production of sound /i/, might have caused fatigue to participants, so, they were not able to glide their pitch high enough on sound /i/.

The current study concludes that pitch glide is an inadequate means to predict pharyngeal residue in patients with respiratory diseases and there were weak correlations between pitch glide and residue. These results concur with the results of Rajappa et al. [38], who used MBSImP [43] to identify the volume and the site of bolus in pharyngeal structures and suggested that there are no correlations between pitch glide and residue in patients with a diagnosis of stroke. However, Malandraki et al. [37], used a 3-point residue scoring system [51] to measure the volume of residue and examined the relationship between pitch glide and pharyngeal residue and concluded that maximum F_0 of sound /a/ was associated with residue in patients with different aetiologies of dysphagia. In the current study Bolus Residue Scale [45] was used in order to detect and classify residue in the valleculae, piriform sinuses, and/or posterior wall of the pharynx. It is important to highlight the fact that these three studies used three different scales and each one was focused on different diagnostic groups. As a result, the different scales and the diversity in populations could explain different findings. As this is the first study to examine the diagnostic accuracy of the pitch glide in the prediction of residue, more research is required in that field. Residue is the result of incomplete bolus clearance due to poor propulsion, weak pharyngeal vigor, and/or impaired upper esophageal sphincter (UES)

relaxation [52,53]. In patients with dysphagia, pharyngeal residue may be a predictor of aspiration because it can cause aspiration after swallow [53,54]. According to the literature, patients with COPD may have high incidence of pharyngeal residue on fiberoptic endoscopic evaluation of swallowing (FEES) because of the reduced laryngopharyngeal mechanosensitivity and impaired swallowing function, as well [14].

According to the results of the current pilot study, pitch glide (both acoustic and auditory-perceptual) low sensitivity and specificity in the prediction of hyolaryngeal excursion in adults with respiratory diseases and there were not strong correlations between pitch glide and hyolaryngeal excursion. Rajappa et al. used MBSImP [43] scale to examine the hyolaryngeal excursion in patients with stroke and concluded that auditory-perceptual and acoustic analysis of pitch glide did not correlate to hyolaryngeal excursion [38]. According to Mokhlesi et al., patients with COPD have reduced larynx elevation [5]. There have been recent studies that have revealed strong relationships between pitch glide and hyolaryngeal excursion, as pitch glide targets and activates the hyolaryngeal muscles that participate in the process of swallowing and it is able to elevate hyolaryngeal complex as much as it does during swallowing [55,56]. It is important to mention that these studies used functional magnetic resonance imaging (fMRI) as a reference standard in order to examine healthy adults, contrary to our study that examined patients with respiratory diseases. In clinical practice, pitch glide is commonly used by many clinicians as an exercise to target and strengthen the hyolaryngeal muscles. This exercise can help the patients elevate the larynx the same way as it does during swallowing [57].

Although the results of this pilot study are consistent with previous research, the sample size was small due to the limited time-frame of the study. A larger number of participants may have provided more valid and accurate results. Findings should inform a larger investigation focusing on a homogenous clinical group to determine if pitch glide can accurately identify people who are aspirating. The addition of pitch glide with good diagnostic accuracy into the CSE would greatly enhance the CSE in this population. Additionally, as only sounds /a/ and /i/ have been tested to date, it would be important to examine sounds /e/ and /o/, too, and to use different food consistencies. Finally, all studies used a binary scale to rate pitch glide auditory-perceptually. It is recommended that the use of a validated scale would provide more accurate results about auditory-perceptual analysis on further studies. Considering the limitations of the current study the results should be interpreted with caution.

5. CONCLUSION

There is still limited research on the diagnostic accuracy of the pitch glide in predicting swallow safety. To our knowledge, this is the first study that investigated the accuracy of the pitch glide in detecting aspiration, residue and impaired hyolaryngeal excursion in adults with respiratory diseases. For this reason, findings should inform

future research to establish whether pitch glide can be a reliable means to identify aspiration status in people with respiratory diseases. The diagnostic accuracy of the pitch glide at the bedside examination would be of major clinical value for people with respiratory disease in a community with limited access to FEES and VFSS.

6. STATEMENTS

6.1 ACKNOWLEDGMENT

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6.2 STATEMENT OF ETHICS

Ethical approval was granted by the research ethics committee of Tallaght University Hospital (SJH/AMNCH Research Ethics Committee, Tallaght University Hospital, Dublin).

6.3 STATEMENT OF WRITTEN INFORMED CONSENT

All participants were given a detailed informational leaflet describing the reasons of the study and the whole procedure. They were, also, able to ask further questions if needed and discuss more about the study. Patients who wanted to participate were asked to sign a consent form.

6.3 DISCLOSURE STATEMENT

The authors have no conflicts of interest to declare

6.4 AUTHOR CONTRIBUTIONS

SM contributed in voice data collection, acoustic analysis, statistical analysis, data interpretation, and manuscript preparation. JR contributed in participants' recruitment, VFSS data collection, auditory-analysis of voice data, supervision the findings of this work and manuscript review. All authors have provided final approval of the version submitted.

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FIGURE AND TABLE LEGENDS

Figure 1: Receiver operating characteristics (ROC) curve of Maximum F0 of sound /a/ as a predictor of aspiration in 10ml of liquids

Figure 2: Scatter plot of the Penetration-Aspiration Scores and Maximum F0 of sound /a/ on 10ml of liquids

Table 1: Demographics

Table 2: Sensitivity, specificity, diagnostic odds ratio (DOR), area under the curve (AUC), positive likelihood ratio (PLR), negative likelihood ratio (NLR), positive predictive value (PPV), negative predictive value (NPV) and accuracy of maximum F0 in the prediction of aspiration.

Table 3: Correlations between pitch glide variables and Penetration-Aspiration Scores across bolus volumes

Table 4: Sensitivity, specificity, diagnostic odds ratio (DOR), area under the curve (AUC), positive likelihood ratio (PLR), negative likelihood ratio (NLR), positive predictive value (PPV), negative predictive value (NPV) and accuracy of maximum F0 in the prediction of pharyngeal residue

Table 5: Correlations between pitch glide variables and Bolus Residue Scale scores across bolus volumes

Table 6: Sensitivity, specificity, diagnostic odds ratio (DOR), area under the curve (AUC), positive likelihood ratio (PLR), negative likelihood ratio (NLR), positive predictive value (PPV), negative predictive value (NPV) and accuracy of maximum F0 in the prediction of hyolaryngeal excursion

Table 7: Correlations between pitch glide variables and hyolaryngeal scores across bolus volumes