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Detection of voice changes due to aspiration via acoustic voice analysis

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ABSTRACT

Objective: Aspiration can occur during swallowing. The present study investigated the feasibility of identifying aspiration risk (AR) via acoustic voice parameters.
Materials and methods: In total, 165 patients scheduled for a videofluoroscopic swallowing study (VFSS) were included. The patients were divided into two groups (AR and non-AR) based on their VFSS results. The AR group, which had ingested materials on or below the vocal folds, included 59 patients (42 males and 17 females). The non-AR group, which showed normal swallowing, included 106 patients (49 males and 57 females). The major cause of swallowing disorders was a stroke. A sustained vowel/a/for at least 3 s was recorded before and after swallowing. Eight acoustic voice parameters were measured using PRAAT, including fundamental frequency, standard deviation of F0, jitter, relative average perturbation (RAP), shimmer, amplitude perturbation quotient (APQ), harmonic-to-noise ratio (HNR), and noise-to-harmonic ratio (NHR). Changes in each acoustic voice parameter before and after the VFSS were compared between the two groups with a repeated-measures mixed analysis of variance.
Results: Only RAP showed a statistically significant interaction between group (non-AR and AR) and time (pre- and post-swallowing; $p = 0.030$). RAP decreased after swallowing in the AR group; however, it increased in the non-AR group. Jitter and NHR increased in the non-AR group but decreased in the AR group after swallowing, but the difference was not statistically significant.
Conclusions: Our results suggest that the accumulation of pasty food in the vocal folds may modify vocal fold vibration and change voice quality in patients with penetration/aspiration. Several acoustic voice parameters, especially jitter, RAP, and NHR, were affected by AR. Thus, acoustic voice analysis may be helpful in making a diagnosis of AR as a supplementary tool for standard swallowing study including VFSS or fiberoptic examination.

1. Introduction

Effective swallowing involves a complex mechanism that requires the coordination of multiple structures [1]. Specifically, airway protection during swallowing is accomplished through contraction of the laryngeal sphincter, epiglottal coverage of the

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laryngeal opening, and anterosuperior elevation of the larynx [2]. Swallowing disorders, or dysphagia, develop when the coordination of swallowing mechanisms breaks down. A slow swallowing speed, coughing/choking during swallowing, and a wet-hoarse voice quality after swallowing are common symptoms of dysphagia [3]. Dysphagia may also trigger penetration or aspiration (P/A), increasing the risk of pneumonia. Penetration is defined as residual ingested material in the laryngeal vestibule but above the true vocal folds. Aspiration is the unintentional movement of food or liquid into the trachea below the true vocal folds. P/A may increase the level of food residue in the vocal folds, increasing fold mass and viscosity. Thus, the vocal fold vibration will change, in turn affecting voice quality. One clinical sign of abnormal swallowing is a "wet voice" quality, also termed "wet phonation," "a gurgly voice," "impaired vocal quality," and "voice changes with swallowing" [4–6]. The wet voice is well-known to clinicians and is frequently used to rank the risk for P/A at the bedside [6–12].

However, some authors have indicated that a wet voice is not a good clinical predictor of aspiration risk during swallowing. Warms and Richards [5] found no relationship between a wet voice and the level of prandial materials in the larynx during swallowing. Groves-Wright et al. [4] reported that a wet voice was not a reliable predictor of material in the larynx. Waito et al. [13] concluded that neither perceptual judgments of voice abnormalities using the GRBAS scale [14] nor wetness after swallowing afforded reliable evidence of P/A or dysphagia. In addition, wet voice assessment is subjective and thus is associated with reliability and reproducibility concerns. Therefore, it remains unclear whether a wet voice can be used as a noninvasive method of assessing risk for aspiration or dysphagia.

Acoustic analysis can be employed to objectively evaluate dysphagic patients at the bedside. Certain acoustic parameters very effectively detect possible P/A [2,15]. Ryu et al. [2] and Groves-Wright [16] measured jitter, shimmer, the noise-to-harmonic ratio (NHR), and the relative average perturbation (RAP) in patients with dysphagia to identify the presence of P/A. Significant increases in phonation measures were evident when foreign materials were directly visible in the larynx after swallowing. Also, the mean duration of swallowing differed in patients with and without dysphagia [15]. In an in vivo laryngeal study, vocal fold vibration was irregular and aperiodic when the fold was under a liquid load, reflected in both nonlinear and perturbation parameters (e.g., jitter and shimmer) during phonation. Such studies strongly indicate that foreign materials in the larynx change acoustic measures during phonation. Thus, acoustic analysis may reliably detect aspiration. However, it has recently been claimed that acoustic analysis does not reliably detect dysphagia or P/A. Waito et al. [13] found that acoustic measures of voice quality were not adequately sensitive or specific when used to detect aspiration in patients with dysphagia. Bruijn et al. [17] found no association between voice acoustic parameters and swallowing function. Chang et al. [18] also reported no changes in the acoustic variables evaluated by Ryu et al. [2] before and after swallowing in patients with and without P/A.

Intuitively, prandial materials in the larynx would be expected to change vocal fold vibration and reduce voice quality during phonation. Thus, it would be expected that acoustic analysis would detect such changes. As mentioned above, some studies found that certain acoustic measures were significantly affected by laryngeal P/A, but other studies did not. The differences may be attributable to the amount or consistency of the boluses used in the various studies. Ryu et al. [2] did not report either the type or volume of bolus given. Waito et al. [13] and Chang et al. [18] gave only 5 mL amounts of a thin barium suspension. Chang et al. [18] considered that a small bolus might not remain in the vocal folds during swallowing. Thus, even if P/A had been present, the vocal fold mass may not have changed to an extent that affected voice quality.

We investigated voice changes associated with P/A using objective acoustic analysis employing the parameters selected by Ryu et al. [2] and Chang et al. [18] We sought to confirm that acoustic analysis reliably detects P/A at the bedside. We varied our boluses in terms of both consistency and volume to explore whether the contradictory results in the literature are attributable to differences in these parameters. We hypothesized that voice analysis can detect swallowing disorders, especially P/A. The purpose of this study was to investigate whether acoustic measures reflect voice changes in P/A.

2. Materials and methods

2.1. Participants

This study was conducted at 000 000 000 Hospital from September, 2015, to November, 2016, with approval from our institutional review board (IRB no. 000 2016-05-020-001). All participants were scheduled for a videofluoroscopic swallowing study (VFSS) to evaluate swallowing difficulties. The exclusion criteria were aphonia due to tracheostomy or vocal palsy, any mass in the vocal folds, profound hearing loss, and an inability to follow one-step commands (e.g., oral apraxia). The subjects were categorized into two groups, aspiration risk (AR) and non-AR, according to the finding of the VFSS and a fiberoptic endoscopic evaluation (FEE).

Based on the five-point modified penetration aspiration scale (MPAS), the degree of swallowing disorder was determined for each participant and used to allocate him/her into one of the groups. The MPAS is a 5-point scale, ranging from 1 to 5 as follows: 1, ingested material does not enter the airway; 2, ingested material enters the airway and remains above the vocal folds; 3, ingested material enters the airway and contacts the vocal folds; 4, ingested materials enters the airway, passes below the vocal folds, and effort is made to eject; and 5, ingested material enters the airway, passes below the vocal folds, and no effort is made to eject. Patients rated from 1 to 2 were placed in the non-AR group, while patients rated from 3 to 5 were placed in the AR group.

Initially, 185 patients were recruited; of these, 20 were diagnosed with vocal palsy with FEE and were excluded. Finally, 165 subjects (91 males and 64 females) were selected. There were 59 patients (42 males and 17 females) in the AR

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