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Review Article

A Scoping Review on the Intersection Between Voice and Swallowing Measures in Healthy and Disordered Populations

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ABSTRACT

Purpose: Voice and swallowing are distinct functions that share anatomical and physiological properties; however, research investigating their intersection is limited. The purpose of this scoping review was to explore the literature surrounding the relationship between voice and swallowing measures in healthy adults and those with non-degenerative disorders. Specifically, we aimed to elucidate whether objective voice measures could be used as correlates of swallowing function.
Method: We systematically searched four databases (Embase, PubMed, CINAHL, and Web of Science) for relevant literature using a combination of key words and controlled vocabulary generated from the Yale Mesh Analyzer. The inclusion criteria consisted of peer-reviewed studies in the English language that reported on healthy adults and/or patients with non-degenerative neurological disorders and pulmonary diseases and contained instrumental and/or objective voice and swallowing measures. Two raters completed the abstract screening process followed by independent full-text reviews. Case studies, review studies, gray literature, or abstract-only studies were excluded.
Results: Among 5,485 screened studies, 182 were fully reviewed, with only 11 studies meeting the inclusion criteria. Eight studies found an association between voice and swallowing objective measures, whereas the other three did not. Significant voice measures that were related to swallowing safety and/or physiology included maximum fundamental frequency ($F0$), $F0$ range, maximum phonation time, biomechanics of effortful pitch glides, and voice onset time.
Conclusions: Although there was heterogeneity in the measures used, specific objective voice measures showed promise in clinical practice as a screening tool for dysphagia. Further investigations are needed to validate the clinical utility of these measures across diverse patient populations.

Voice and swallowing are two distinct functions that share anatomical and physiological properties. Both processes involve the coordinated function of intricate sensory and motor systems, including the upper aerodigestive tract, cranial nerves, and musculature (Li-Jessen & Ridgway, 2020). The larynx plays a central role in voice production (Khambata, 1977) and serves a crucial function in swallowing by protecting the airway during the pharyngeal phase of swallowing (Matsuo & Palmer, 2008). Furthermore, the neuromuscular control required for phonation and swallowing involves overlapping neural pathways and structures, such as intrinsic/extrinsic laryngeal muscles (Li-Jessen & Ridgway, 2020) and the brainstem nuclei responsible for coordinating phonation, swallowing, and breathing (Avivi-Arber et al., 2011; Dutschmann, 2022).

Correspondence to Amna S. Mira: amnasmira@gmail.com. Portions of this work have been presented as poster presentations at the Fall Voice Conference (October 2023) and the Voice, Speech, & Technology Symposium (December 2023). ***Disclosure:*** *The authors have declared that no competing financial or nonfinancial interests existed at the time of publication.*

Hence, there has been a long-standing clinical assumption of a relationship between voice and swallowing functions, although empirical research elucidating this connection remains limited.

As speech-language pathologists (SLPs), we observe that neurological and pulmonary diseases and disorders often manifest with concurrent deficits in both voice and swallowing abilities. This observation is supported by literature that indicates shared neural pathways and physiological mechanisms underlying voice and swallowing in these populations. Neurological conditions such as cerebrovascular accidents (CVAs; Smithard et al., 1997; Venketasubramanian et al., 1999), traumatic brain injury (TBI; Lee et al., 2016; McHenry, 2000), and vocal fold paralysis (VFP; Arens & Voigt-Zimmermann, 2018) can lead to impairments in both laryngeal control and respiratory coordination, impacting both voice production and swallowing safety. Similarly, pulmonary diseases such as chronic obstructive pulmonary disease (COPD; Gonzalez Lindh et al., 2017; Mohamed & El Maghraby, 2014) may result in compromised respiratory function, impacting laryngeal valving and airway protection during swallowing. Thus, objective voice measures may be useful as biomarkers or clinical correlates for swallowing dysfunction in neurological and pulmonary-based disorders.

Clinical Objective Measures of Voice and Swallowing

The standard protocols for instrumental and objective evaluation of voice include laryngoscopic imaging, acoustics, and aerodynamics (Patel et al., 2018). Acoustic measures are often an affordable option for obtaining objective voice data, requiring only a microphone, acoustic analysis software, and trained personnel to acquire and interpret the signals. Similarly, the aerodynamic measure of maximum phonation time (MPT) is affordable, is easy to capture, and requires only a stopwatch or timer. Such objective measures (with minimal required equipment) can be performed at the bedside and are noninvasive, making them a viable option for a wide range of health care facilities worldwide, including locations with underserved populations.

There are also several bedside dysphagia screening tools to help identify individuals at risk for aspiration and abnormal swallowing physiology. The Swallowing Quality of Life Questionnaire (SWAL-QOL) is a 44-item tool that offers a self-reported measure of 10 concepts of swallowing-related quality of life. Although the SWAL-QOL provides valuable insights to clinicians and researchers, it is time-consuming, does not elucidate specific physiological reasons underlying dysphagia, and could be influenced by a patient's cognitive impairment or language barrier (McHorney et al., 2002). The water swallow test (WST), on the other hand, is a simple bedside screening method, where the patient is instructed to drink 3 oz of water as fast as they can without interruptions. This tool is often used by SLPs and other medical staff (e.g., nurses), wherein medical personnel are advised to look for overt signs of aspiration (e.g., cough) at the time of the test. However, the WST may not detect subtle or silent aspiration events, with sensitivity documented at 40.5% and specificity at 82.1%, especially in patients with intermittent symptoms (Kuuskoski et al., 2024). Moreover, this bedside screener does not provide specific information on the physiological basis for dysphagia in those screened (Kuuskoski et al., 2024). The Yale Swallow Protocol presents a comprehensive approach to evaluating swallowing safety, performing with higher sensitivity (100%) and specificity (64%), compared to the WST. The Yale Swallow Protocol involves the administration of the WST, a cognitive assessment, and an oral mechanism examination (Suiter et al., 2014), which may improve screening accuracy but requires training and may be time-consuming to administer. Subsequently, there is no universally accepted dysphagia screener used across SLPs or medical personnel, and concerns remain about the potential for underdetection of silent aspiration while using these tools (Brodsky et al., 2016; Smithard et al., 1997).

The inability to consistently detect aspiration at bedside has led to reliance on instrumental assessments to determine aspiration risk. Specifically, the fiberoptic endoscopic evaluation of swallowing (FEES) and the modified barium swallow study (MBSS) are deemed the gold standards for comprehensively evaluating penetration/aspiration and swallowing function (Brady & Donzelli, 2013; Pisegna & Langmore, 2016). Despite their diagnostic efficacies, both FEES and MBSS are resource-intensive, with FEES requiring endoscopic systems and MBSS requiring coordination with radiology services and equipment. Moreover, the use of FEES and MBSS necessitates specific SLP training and expertise that is not universally attainable. These limitations are particularly pronounced in underresourced settings, such as nursing homes, certain global regions, and underserved communities, where access to FEES and MBSS is often difficult or even nonexistent (Birchall et al., 2023).

Thus, reliable and objective screening tools that correlate to abnormal swallowing physiology and/or safety would be a benefit to those working with dysphagic patients. More information in an initial dysphagia screening can prompt the necessary referrals for advanced diagnostic procedures (i.e., FEES, MBSS), supporting clinicians in decision-making processes and determining when more resource-intensive tests may be needed. Improved screening capabilities may also assist in identifying patients at higher aspiration risk and prioritizing timely referrals for these more in-depth assessments.

Given the shared anatomical and physiological underpinnings of voice and swallowing functions, acoustic and aerodynamic measures present a theoretical approach for initial dysphagia screening. For example, changes in vocal fold vibration patterns, which can be detected through acoustic analysis (Li et al., 2021), may be correlated with laryngeal dysfunction during swallowing (Murugappan et al., 2010). Furthermore, aerodynamic measures may not only reflect the respiratory strength necessary for voice production but also, potentially, the ability to sustain breath control during the swallowing process (Troche et al., 2014). Acoustic and aerodynamic measures could enable a non-invasive, low-cost screener that may provide specific information about the integrity of the sensorimotor laryngeal function for voice and swallowing. Voice-based screeners have the potential to fill a critical gap in current screening methods because acoustics and aerodynamic measures provide objective results and could potentially lead to more consistent referrals for further swallow assessment (e.g., FEES, MBSS). Thus, a critical appraisal of the current evidence is needed to determine the next steps in voice-swallowing research.

Purpose of this Scoping Review

To our knowledge, no review to date has systematically explored the intersection between objective voice and swallowing measures. Recognizing the importance of guiding future research and informing clinical practice, this scoping review aimed to

- Identify and describe current objective voice and swallowing measures used to detect aspiration risk and abnormal swallowing physiology and
- Describe the relationships between objective voice and swallowing measures in healthy adults and those with non-degenerative neurological and pulmonary diseases and disorders.

Method

We conducted a scoping review following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) 20-item checklist (Tricco et al., 2018). A scoping review is a systematic way to search for literature that provides an overview of existing information on a particular topic. A scoping review was chosen as it was an appropriate way to explore the literature around the intersection between voice and swallowing objective measures in people with and without disorders, with no limitations on specific measures, study design, or methodological approaches. This approach served as a foundational analysis aimed at establishing a broad understanding prior to undertaking the validation of specific measures or the completion of detailed systematic reviews focused on specific metrics.

Literature Search

Embase, PubMed, CINAHL, and Web of Science were systematically searched from their dates of inception to the search date of March 21, 2023. A health sciences librarian (M.P.) created all database-specific searches using a combination of key words and controlled vocabulary generated from the Yale Mesh Analyzer (https://mesh.med.yale.edu/). Key word alternatives and variations were developed from the terms *dysphagia* and *voice measures*. Please see the Appendix for an example of the search strings. Records were added to and deduplicated through EndNote, and a secondary deduplication was completed using the free software program Rayyan (https://www.rayyan.ai/; Ouzzani et al., 2016).

Literature Review

Study Inclusion and Exclusion Criteria

Inclusion and exclusion criteria were set by the coauthors before the screening and review processes. The inclusion criteria were as follows: (a) enrollment of adult (≥ 18 years old) human subjects, (b) studies reported in the English language, (c) studies that included healthy subjects and/or people with neuro/nerve-based or pulmonary disorders of any cause (e.g., CVA, VFP, TBI, COPD), and (d) studies that included at least one objective measure of swallowing (e.g., MBSS, FEES, electromyography [EMG], magnetic resonance imaging [MRI]) and one objective measure of voice (e.g., acoustics, aerodynamics, EMG, laryngoscopy, MRI).

The exclusion criteria were as follows: (a) previous scoping reviews, systematic reviews, meta-analyses, or literature reviews; (b) gray literature (e.g., abstracts, posters, dissertations); (c) case studies or single-case designs; (d) studies that only included people with degenerative neurological diseases (e.g., amyotrophic lateral sclerosis [ALS], Parkinson's disease, dementia); (e) studies that only included people with head and neck cancer (HNC), autoimmune diseases, or dysphonia due to non-neurogenic causes (e.g., benign lesions, muscle tension dysphonia, hyperfunctional voice disorders, functional dysphonia, psychogenic, papilloma); and (f) studies that did not investigate an association between voice and swallowing measures. The hierarchy used for the screening and evaluation processes was as follows: (a) language, (b) study design,

(c) population, (d) outcome measures, and then (e) statistical analyses.

Review Procedures and Data Extraction

Before completing the official screening and review processes, two authors (A.M. and L.G.) independently reviewed a random selection of 200 titles and abstracts from the literature search. This reliability review yielded excellent reliability, with 93.5% absolute agreement. The authors discussed their differences and reached a consensus of 100% with a third author (V.M.). The two authors then divided the title/abstract screenings, wherein each author completed 50% of the identified studies. Subsequently, three authors (A.M., L.G., and A.S.) completed the full-text review process (41%, 41%, and 18%, respectively) to determine final inclusion eligibility. These processes were completed using Rayyan (Ouzzani et al., 2016).

Once the included studies were identified, authors independently extracted information and placed all data into an Excel document. Author A.M. led the data extraction, reviewing 100% of the included studies, while authors L.G., A.S., and V.M. independently extracted data from distinct subsets, ensuring no overlap and maintaining the blinding protocol. Discrepancies were collaboratively resolved to reach a consensus of 100% for all the data extracted. The information of interest for this review was as follows:

1. Study information: author(s), year published, aim, and location;
2. Population characteristic: sample size, age, sex, and diagnosic distribution;
3. Methods: list of obtained objective voice and swallowing measures;
4. Statistical analyses and conclusions.

A quality assessment was not undertaken in this scoping review because it falls outside the scoping review methodology according to PRISMA-ScR guidelines (Tricco et al., 2018). Moreover, the heterogeneity observed in study designs, patient populations, and outcome measures across the included studies further complicated the feasibility and interpretation of a quality assessment. Lastly, as our primary objective was to explore the breadth of literature surrounding the relationship between voice and swallowing measures, conducting a quality appraisal did not align with the objectives of our scoping review. There is a value of quality assessment in identifying gaps in the literature and guiding future research directions, which can be considered in a subsequent systematic review focused on specific measures and populations.

Results

Study Selection

Our literature search yielded 8,832 studies for review. However, once duplicated records were removed (n = 3,347), only 5,485 studies were screened by title and abstract. After screening, 182 studies were read in full for inclusion assessment, of which 171 studies were excluded due to foreign language (n = 13), study design (n = 10), publication type (n = 42), wrong population (n = 6), wrong measures (n = 59), did not include statistical analyses (n = 35), or included the target population as well as excluded populations within one analysis (n = 6). Please refer to Figure 1 for the workflow of the review process. A total of 11 studies met our inclusion criteria and were analyzed in this scoping review (Lim et al., 2020; Malandraki et al., 2011; Mavrea & Regan, 2020; McCulloch et al., 1996; Miloro et al., 2014; Rajappa et al., 2017; Ryalls et al., 1999; Sayaca et al., 2020; Shaker et al., 2002; Song et al., 2023; Venkatraman et al., 2020).

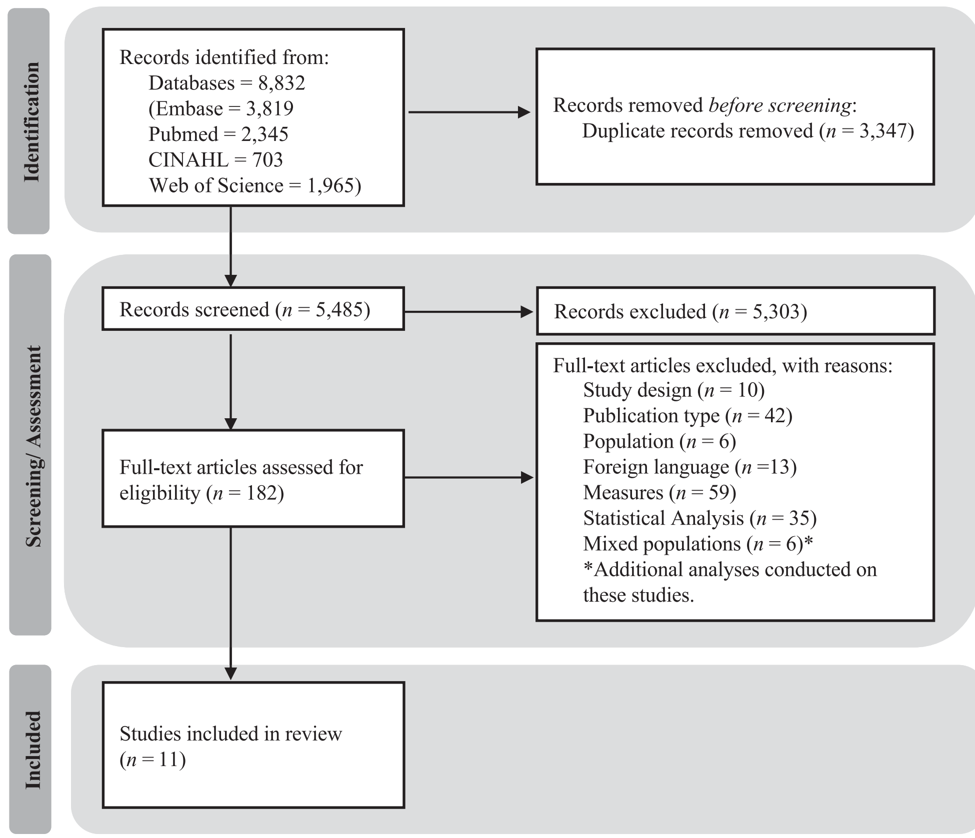
Summary of Studies

The 11 included studies were published between the years 1996 and 2023. Studies were conducted in diverse geographical locations, including the United States, South Korea, Taiwan, Turkey, Ireland, and China. Four studies (36%) exclusively enrolled healthy participants aged between 19 and 43 years. One study (9%) enrolled a combination of healthy and dysphagic participants aged between 65 and 93 years. The remaining six studies (55%) enrolled disordered populations with heterogeneous diagnoses and ages ranging from 31 to 94 years. Among these disordered populations, CVA emerged as the most common diagnosis, as represented in six studies. The sample sizes across the studies varied greatly, ranging from as few as six to as many as 106 participants. A detailed breakdown of population characteristics and distributions can be found in Table 1.

Objective Measures

In our review, we explored which objective measures have been used in the literature to investigate the relationship between voice and swallowing in people with and without neurological disorders or pulmonary disease (Aim 1). To do so, we compiled objective measures used across the 11 studies that met our inclusion criteria. Acoustic measures were most frequently employed for voice analysis, present in 45.5% (n = 5) of studies. These included assessments such as maximum fundamental frequency ($F0$) and $F0$ range, which were documented in three studies (Malandraki et al., 2011; Mavrea & Regan, 2020;

Figure 1. Flowchart of identified, screened, assessed, and included studies.



Rajappa et al., 2017). Additional acoustic measures such as voice onset time (VOT; Ryalls et al., 1999) were also reported. Aerodynamic evaluations, particularly MPT, were noted in 27.3% (n = 3) of the studies (Lim et al., 2020; Sayaca et al., 2020; Song et al., 2023).

MBSS was the most commonly used tool (63.6% of the studies, n = 7) for swallowing evaluation and was scored using the 8-point Penetration Aspiration Scale (PAS; Rosenbek et al., 1996) in six studies (Lim et al., 2020; Malandraki et al., 2011; Mavrea & Regan, 2020; Rajappa et al., 2017; Ryalls et al., 1999; Song et al., 2023). Additional biomechanical outcomes were determined from MBSS images using ImageJ software by Venkatraman et al. (2020), who assessed hyolaryngeal excursion while swallowing thin liquids and pudding. Laryngeal biomechanics were also measured during sequential swallowing movements using dynamic MRI (Miloro et al., 2014). That is, Miloro et al. (2014) measured anterior and superior hyoid movements, hyolaryngeal excursion, laryngeal elevation, pharyngeal shortening, and lateral pharyngeal wall approximation during sequential swallows of a magnesium-infused liquid as well as during effortful pitch glide task. Finally, hooked-wire electroglottography (EMG) was used in one study to capture the magnitude and timing of the thyroarytenoid (TA) and interarytenoid (IA) muscle activities during swallowing of saliva, 5 and 10 ml of thin liquids, and during phonation at low, comfortable, and high pitch levels (McCulloch et al., 1996).

Statistical Associations

To determine whether objective voice measures could detect swallowing safety and/or physiology, we summarized the statistical outcomes from the 11 included studies (Aim 2). Eight (73%) of the 11 studies found a significant association between voice and swallow measures (Lim et al., 2020; Malandraki et al., 2011; Mavrea & Regan, 2020; Miloro et al., 2014; Rajappa et al., 2017; Ryalls et al., 1999; Song et al., 2023; Venkatraman et al., 2020), whereas three (27%) did not (McCulloch et al., 1996; Sayaca et al., 2020; Shaker et al., 2002).

The most common acoustic measure that was correlated with swallowing safety (assessed under MBSS) was maximum $F0$. Maximum $F0$ of /ɑ/ identified aspiration and predicted hyolaryngeal excursion biomechanics in people with respiratory diseases (Mavrea & Regan, 2020).

Table 1. Included studies that investigated the associations between voice and swallowing measures.

Study	Sample size/ages	Diagnoses distributions	Voice measures	Swallowing measures	Major findings
Lim et al. (2020)	*n* = 106 M = 44, F = 62 Age: *M* = 68.43 ± 13.26 years	106 stroke patients: No aspiration or penetration (*n* = 49) Penetration (*n* = 31) Aspiration (*n* = 26)	Aerodynamics: MPT of /ɑ/	MBSS was completed and evaluated using the 8-point PAS, ASHA-NOMS, and the FDS.	1. MPT values differed significantly between normal, penetration, and aspiration groups (as determined by PAS) and were moderately correlated with ASHA-NOMS. 2. MPT was more reliable and valid in detecting aspiration (81% sensitivity and 82.5 specificity) when compared to the 3-oz water swallow test (76% and 59%), and the Burke dysphagia screening test (100% and 10%).
Malandraki et al. (2011)	*n* = 40 M = 16, F = 24 Age: 31–92 years *M* = 68	40 patients: Esophageal (*n* = 6) Neuro-other (*n* = 6) Dementia/Parkinson's (*n* = 7)[a] Neuro-stroke (*n* = 6) Other medical (*n* = 10) HNC or trauma (*n* = 5)[a]	Acoustics: maximum *F*0 and *F*0 range extracted from pitch raising task of /ɑ/ during MBSS image acquisition	MBSS videos were analyzed using a 3-point residue scoring system (0 = *no residue*, 1 = *coating*, and 2 = *pooling*), and the 8-point PAS.	1. Reduced ability to raise pitch (measured acoustically by maximum *F*0) can significantly predict PAS scores for thin liquid swallows. 2. Reduced maximum *F*0 was significantly associated with higher mean residue scores.
Mavrea & Regan (2020)	*n* = 17 M = 9 Age: *M* = 75 ± 8.98 years F = 8 Age: *M* = 74 ± 8.17 years	17 patients COPD (*n* = 11) Lower respiratory tract infection (*n* = 6)	Acoustics: maximum *F*0 and *F*0 range extracted from pitch glide task of /ɑ/ and /i/ immediately before completing the MBSS	MBSS was completed, and swallows were analyzed using the MBSImP, 8-point PAS, the bolus residue scale, and hyolaryngeal excursion of the modified barium swallow measurement tool for swallow impairment.	1. Maximum *F*0 of /ɑ/ had high sensitivity and specificity in identifying aspiration on 10 ml of liquids, while /i/ had moderate sensitivity and specificity in predicting aspiration of thin liquids. 2. Maximum *F*0 is an inadequate means to predict pharyngeal residue in patients with respiratory diseases.

(*table continues*)

Table 1. *(Continued).*

Study	Sample size/ages	Diagnoses distributions	Voice measures	Swallowing measures	Major findings
McCulloch et al. (1996)	*n* = 7 M = 6, F = 1 Age: 23–25 years	7 healthy participants	Hooked-wire EMG to measure the activity of the thyroarytenoid and interarytenoid muscles during various tasks including voicing at different pitch levels and swallowing.		1. The activity of these muscles during swallowing was significantly higher compared to voicing tasks. This indicates that while there is muscle activity during both voicing and swallowing, the extent and nature of this activity differ between the two functions, reflecting their specific roles in voice production and airway protection.
Miloro et al. (2014)	*n* = 11 M = 6, F = 5 Age: 22–30 years *M* = 25	11 healthy participants	Two-planar dynamic MRI to measure laryngeal and pharyngeal biomechanics of effortful pitch glide (a pitch glide and a pharyngeal squeeze maneuver) and swallowing.		1. There were no significant differences in biomechanics between effortful pitch glide and swallowing for most measures except for superior hyoid movement, which was greater in swallowing. 2. Effortful pitch glide and swallowing had partially similar biomechanics.
Rajappa et al. (2017)	*n* = 45 M = 22, F = 23 Age: 43–94 years *M* = 71.5	45 stroke patients (< 1 month poststroke)	Acoustics: maximum *F*0 extracted from pitch glide task of /ɑ/ and/or /i/	MBSS was completed, and swallows were analyzed using MBSImP and PAS.	1. Reduced maximum pitch elevation predicted silent aspiration of small liquid volumes in stroke patients. This was indicated by high sensitivity and moderate specificity.
Ryalls et al. (1999)	*n* = 6 M = 6 Age: 65–93 years *M* = 80.6	5 patients with dysphagia 1 healthy participant	Acoustics: VOT extracted from 18 isolated monosyllabic consonant–vowel–consonant words	MBSS was completed, and swallows were analyzed by a clinician who classified the type and severity of dysphagia.	1. Dysphagic speakers produced shorter voiceless VOT, indicating potential impairments in laryngeal motor control.

(*table continues*)

Table 1. *(Continued).*

Study	Sample size/ages	Diagnoses distributions	Voice measures	Swallowing measures	Major findings
Sayaca et al. (2020)	*n* = 57 M = 29, F = 28 Right hem Age: *M* = 73.54 ± 7.28 years Left hem Age: *M* = 73.15 ± 6.94 years	57 patients with unilateral strokes Right hem (*n* = 37) Left hem (*n* = 20)	Aerodynamics: MPT of /ɑ/	Water swallowing performance evaluated by the swallow volume, capacity, and speed.	1. There were no differences in MPT, water swallowing performance (swallow volume, capacity, and speed), and swallowing difficulty ($p > .05$). 2. MPT test cannot detect swallowing speed, performance, and capacity in patients with hemiplegia.
Shaker et al. (2002)	*n* = 11 Sex distribution (unclear) Age: *M* = 41 ± 2 years	11 healthy participants	Videoendoscopy synchronized with manometry to measure vocal fold closure during various voluntary tasks including swallowing and phonating.		1. The vocal fold closure pressures varied depending on the task performed, indicating that the magnitude of muscle contractions involved in vocal fold closure differs with each function. 2. Vocal fold closure pressure was significantly higher when swallowing than during voicing.
Song et al. (2023)	*n* = 32 M = 22, F = 10 Age: Low-risk group *M* = 57.94 ± 10.10 years High-risk group *M* = 57.31 ± 9.82 years	32 poststroke patients (model training group) 8 poststroke patients with dysphagia (model testing group)	Acoustics: F2 of vowel /i/ and /u/, maximum *F*0, F1 of /ɑ/, CQ, CQP, CI, CIP, NNE, LI, *F*0, *F*0 SD, jitter, shimmer, APQ, RAP, NHR Aerodynamics: MPT of /ɑ/ Electrograms: during speech tasks, electroglottogram electrodes were used to capture vocal fold vibration	MBSS was completed, and swallows were analyzed using PAS to group patients (low risk and high risk).	1. The best predictive model identified by the study included MPT, F2 of the /u/, and *F*0 difference before and after swallowing ($\Delta F0$), demonstrating an accuracy of 87.5% for identifying the risk of aspiration in the testing group. 2. The model that was suggested: $\text{logit}(P) = -3.824 - 0.504 \times \text{MPT} + 0.008 \times \text{F2 /u/} - 0.085 \times \Delta F0$, where the cut-off value is 0.500; when the score is > 0.500, the patient is at high risk for penetration/aspiration.

(*table continues*)

Table 1. *(Continued).*

Study	Sample size/ages	Diagnoses distributions	Voice measures	Swallowing measures	Major findings
Venkatraman et al. (2020)	*n* = 18 M = 5 young and 4 older, F = 5 young and 4 older Age: Young 19–23 years *M* = 21 ± 1.33 Older 65–79 years *M* = 72.85 ± 5.59	18 healthy participants	MBSS was completed to investigate hyoid biomechanics during swallowing and vocal pitch elevation of the vowels /ɑ/ and /i/. Superior elevation and anterior hyoid excursion were obtained using kinematic analysis through ImageJ software.		1. Superior hyoid elevation was greater for swallowing than for vocal pitch elevation task in both young and older groups. 2. Anterior hyoid excursion was not significantly different across both tasks in both groups, although was overall reduced in the older group. 3. Superior hyoid excursion was moderately positively correlated between swallows and pitch raising in the young group. 4. Anterior hyoid excursion was moderately positively correlated between swallows and pitch raising in the older group.

Note. M = male; F = female; MBSS = modified barium swallow study; PAS = Penetration Aspiration Scale; ASHA-NOMS = American Speech-Language-Hearing Association National Outcome Measurement System Swallowing Scale; FDS = functional dysphagia scale; MPT = maximum phonation time; HNC = head and neck cancer; *F*0 = fundamental frequency; COPD = chronic obstructive pulmonary disease; MBSImP = modified barium swallow impairment profile; EMG = electromyography; MRI = magnetic resonance imaging; VOT = voice onset time; hem = hemisphere; F2 = Formant 2; F1 = Formant 1; CQ = contact quotient; CQP = contact quotient perturbation; CI = contact index; CIP = contact index perturbation; NNE = normalized noise energy; LI = low intense; APQ = amplitude perturbation quotient; RAP = relative average perturbation; NHR = noise-to-harmonic ratio.

[a]Diagnoses were factored into the statistical analyses.

A lower maximum $F0$ of /ɑ/ was associated with higher PAS and residue scores in patients with heterogeneous neurological diagnoses (Malandraki et al., 2011). Similarly for stroke patients, a reduced maximum $F0$ predicted silent aspiration as seen on MBSS (Rajappa et al., 2017).

Anterior hyoid excursion during pitch glides shared the same excursion trajectory (measured in pixels) during swallowing in young and older healthy adults. Additionally, maximum $F0$ of /ɑ/ and /i/ was moderately and positively correlated with superior hyoid elevation observed under MBSS in younger adults and with anterior hyoid excursion in older adults (Venkatraman et al., 2020). Another significant result was reported by Miloro et al. (2014), who discovered comparable laryngeal and pharyngeal biomechanics (i.e., anterior hyoid movement, hyolaryngeal approximations, laryngeal elevation, pharyngeal shortening, and lateral pharyngeal wall medialization) between effortful pitch glide (a task that combines a pitch glide and pharyngeal squeeze) of /i/ and swallowing thin liquid under dynamic MRI in healthy adults.

The aerodynamic measure, MPT of /ɑ/, had a strong inverse correlation with PAS score; as MPT increased, indicating longer phonation capability, PAS scores tended to decrease, suggesting improved airway protection during swallowing in CVA patients (Lim et al., 2020). MPT exhibited promising sensitivity and specificity for predicting penetration and aspiration, with a cut-off value of 7.98 s for aspiration (sensitivity = 91.3%, specificity = 96.2%) and 9.08 s for penetration (sensitivity = 91.8%, specificity = 73.7%; Lim et al., 2020).

Patients with dysphagia produced shorter VOT for voiceless stops and larger degrees of prevoicing (quantified as negative VOT) for voiced stops during single-word utterances compared to adults without dysphagia, suggesting impacted laryngeal motor control and timing of adductory movements (Ryalls et al., 1999). Finally, Song et al. (2023) proposed a predictive model for aspiration risk defined by PAS scores (low risk vs. high risk) in stroke patients that incorporated MPT, the second formant frequency (F2) of /u/, and $F0$ difference before and after swallowing ($\Delta F0$). The formula used for the prediction was $\text{logit}(P) = -3.824 - 0.504 \times \text{MPT} + 0.008 \times \text{F2 /u/} - 0.085 \times \Delta F0$, with a cut-off value of 0.500. Coefficients in the formula indicated the influence of each factor on the risk of penetration/aspiration. That is, lower MPT, higher F2 of /u/, and a smaller change of $F0$ before and after swallowing were all associated with a higher risk of penetration/aspiration. This model demonstrated a high sensitivity of 87.5% and a high specificity of 87.5% (Song et al., 2023).

A total of 27% of the studies that reported non-significant associations with objective swallow measures; all of these studies employed alternative measures that were not utilized in the studies that did find significant associations. One study that used hooked-wire EMG to measure intrinsic laryngeal muscle activity in healthy adults found significantly greater muscle activity for thin liquid swallows than during voicing at a comfortable pitch and loudness (McCulloch et al., 1996). Another study used manometry to measure vocal fold adduction pressure and intratracheal pressure in healthy adults, in which vocal fold pressure was higher in dry swallows than in continuous voicing of /ɑ/ and /i/ (Shaker et al., 2002). The last study compared MPT to swallowing performance with 100 ml of water, measured by volume, speed, and capacity in stroke patients. The authors found no significant correlation between MPT and swallowing performance (Sayaca et al., 2020).

Discussion

This scoping review aimed to elucidate the association between objective voice and swallowing measures in people with and without non-degenerative neurological disorders and pulmonary diseases. We did this by documenting the objective measures described in the literature to investigate this intersection and by exploring which objective voice measures were significantly associated with swallowing safety and/or function. Our search yielded 5,485 studies, with only 47 studies investigating both voice and swallowing objective and/or instrumental measures in our target populations and only 17 studies exploring their intersection. However, six studies were excluded because they had a heterogeneous group of diagnoses (including excluded patient populations), which did not account for diagnoses in their analyses. Thus, 11 studies that met the inclusion criteria were included in this review.

Results of our review revealed that a variety of objective measures have been employed across these studies to explore the intersection of voice and swallowing functions such as $F0$, $F0$ range, hyolaryngeal biomechanics, VOT, intrinsic laryngeal muscle activity amplitude, and PAS scores, among others. Although a wide range of measures were analyzed, only specific measures showed significance consistently across studies. For example, maximum $F0$ showed promise in identifying aspiration and predicting hyolaryngeal excursion biomechanics in those with respiratory diseases (Mavrea & Regan, 2020), as well as superior hyoid elevation in young healthy adults and anterior hyoid excursion in older adults (Venkatraman et al., 2020). Furthermore, a lower maximum $F0$ predicted silent aspiration on small volumes of liquids in stroke patients (Rajappa et al., 2017), highlighting its potential as a valuable screening tool for swallowing safety.

Additionally, maximum *F*0 in conjunction with other measures such as MPT, F2 of /u/, and *F*0 difference before and after swallowing ($\Delta F0$) showed promise in predicting low-risk versus high-risk groups of penetration/aspiration via MBSS in patients post-CVA (Song et al., 2023). MPT itself exhibited better sensitivity and specificity in detecting PAS scores than other dysphagia screening tests in patients with CVA (Lim et al., 2020). These findings imply that combining multiple objective acoustic and aerodynamic measures can enhance the accuracy of dysphagia screening, with lower MPT values being a marker for penetration/aspiration (Song et al., 2023) and PAS scores (Lim et al., 2020). The study by Song et al. (2023) is of particular interest to patient care, as their combination of acoustic and aerodynamic measures yielded greater sensitivity than other swallow screeners. That is, their accuracy was approximately 87% for both sensitivity and specificity, whereas the WST has only shown 40.5% and 82.1%, respectively (Kuuskoski et al., 2024).

It is unsurprising that maximum *F*0 was one of the most promising measures across studies. It may be that maximum and range of *F*0 are important screeners because they push the system to its greatest capacity, representing a challenging phonatory task. Previous research has shown that individuals with vocal fatigue have reduced maximum *F*0 and/or reductions in their overall *F*0 range (Kitch & Oates, 1994), while *F*0 measures at typical pitch and volume remains unaffected (Neils & Yairi, 1987). Similarly, other conditions, such as vocal fold edema, can lead to reduced maximum *F*0 (Bastian et al., 1990), indicating its ability to detect subtle changes in the laryngeal system.

The intriguing intersection between voice measures and swallowing safety suggests deeper physiological interconnections. These associations were likely due to similarities between hyolaryngeal movements and muscle activation patterns present when increasing vocal pitch and ensuring safe and effective swallowing. To effectively raise pitch, intrinsic laryngeal adductor muscles coordinate with suprahyoid muscles to (a) approximate the vocal folds, (b) passively stretch and elongate the vocal folds, and (c) elevate and rock the larynx to a position that facilitates increases in maximum *F*0 (Honda et al., 1999; Ludlow, 2005; Shipp, 1975). Furthermore, sufficient subglottal pressure and respiratory control are needed to sustain phonation during this task (Titze, 1989).

Laryngeal and respiratory actions are shared with swallowing when (a) the intrinsic adductor muscles approximate the vocal folds to help guard the airway and (b) the suprahyoid muscles assist in the elevation and anterior excursion of the hyolaryngeal complex to, once again, help protect the airway and open the pharyngoesophageal segment for prandial material to pass into the esophagus (Kim & McCullough, 2008; Perera et al., 2008). During swallowing, respiration coordination manifests as a cessation of breathing—commonly referred to as swallow apnea—occurring at mid-to-low expiratory volumes, to ensure the airway is protected at a critical timepoint (Martin-Harris et al., 2005). Therefore, when reduced maximum *F*0 was associated with higher PAS scores and increased aspiration risk, the relationship could have been due to the underlying intrinsic and extrinsic laryngeal muscle movements shared by both functions as well as the stability/coordination of the respiratory–laryngeal subsystems. The study by McCulloch et al. (1996) further supports shared muscle engagement between phonation and swallowing when they found concurrent muscle activation in the TA and IA across both tasks in healthy adults.

However, it is essential to note that our analysis revealed marked differences in the degree of muscle activity between swallowing and voicing. McCulloch et al. (1996) measured the magnitude of intramuscular activity (i.e., root-mean-square) of the intrinsic laryngeal muscles (TA, IA) in healthy adults during voicing tasks (low, comfortable, and high pitch) and swallowing (saliva, 5 ml and 10 ml of water). Although they found that the magnitude of muscle activity increased as pitch increased, the magnitude was significantly higher, in general, for swallowing trials compared to voicing trials. The authors determined that these specific intrinsic muscles play a crucial role in pitch modulation during voicing and laryngeal closure to provide airway protection during swallowing; however, a greater degree of activation may be an important difference between voice and swallowing functions (McCulloch et al., 1996).

Likewise, analyses of biomechanical variables yielded similarities in some movements of the hyolaryngeal complex during voicing and swallowing in healthy adults; however, superior hyoid elevation had a significantly greater degree of movement during swallowing (Miloro et al., 2014; Venkatraman et al., 2020). This trend was further supported in healthy adults when vocal fold manometric pressures were significantly greater during swallowing than during voicing as well (Shaker et al., 2002). Taken together, these findings support the hypothesis that voicing may require lower degrees of muscular recruitment and reduced levels of hyolaryngeal biomechanical excursions, leading to discrepancies in the relationship or functional indications between voicing and swallowing. Moreover, voice and swallowing require coordination not only between the degree of muscle activation but also the precise timing and sequence of movements with respiration that may be different from one another. Timing and sequence of laryngeal and respiratory events were not assessed in many of these studies, providing a future direction for research to understand how voice and swallowing functions are related to one another. Further studies could employ additional analysis from MBSS images on temporal and sequencing of events and/or additional tools such as high-resolution manometry and respiratory plethysmography, which can provide further details to analyze the coordination of these events.

Finally, it must be noted that pitch glides are difficult for many patients to perform and that not all SLPs or medical personnel may be able to elicit maximum pitch height for patients. Medical personnel (specifically nurses) have been critical in screening patients for dysphagia at the bedside across many different settings (Robbins et al., 2007). Therefore, while the inclusion of pitch glides in screening protocols could potentially yield valuable information, practical considerations must be accounted for. Training medical personnel to accurately perform and interpret acoustic signals obtained from pitch glides would be essential, although not always feasible.

Secondary Analyses: Heterogeneous Population Studies

Only one study in our review included additional participants from various diagnoses outside the included populations (healthy, non-degenerative neurological, pulmonary disease); however, the authors of the study accounted for the participants' diagnoses in the statistical model. Specifically, Malandraki et al. (2011) enrolled 40 participants with our target diagnosis of stroke but also included those with dementia, Parkinson's disease, and HNC (see Table 1 for a complete list). Their mixed-model analysis included "diagnoses" as a factor, with no indication that the relationship between maximum *F*0 and PAS scores varied by diagnosis. With this information, we decided to take a second look at studies excluded due to heterogeneous participant groups that included both our target population and those that would have been otherwise excluded from this review.

Our original intent to focus on non-neurodegenerative and respiratory populations was based on the hypothesis that these conditions present a more uniform set of characteristics that are generally unimpacted by neural degeneration and iatrogenic effects, or treatments for the disease process (e.g., radiation, surgical excision, or resection). Therefore, we decided to exclude patients from other populations, such as neurodegenerative disorders (e.g., Alzheimer's disease, Parkinson's disease, ALS) and HNC due to their heterogeneity in clinical presentations and variability in sensorimotor aspects of swallowing. These populations have often been isolated in research studies due to the need to stage their disease processes to describe the population and to examine specific subgroups due to the natural progression of the disease (i.e., Alzheimer's vs. Parkinson's swallowing physiology). However, we acknowledge that patients with these diagnoses likely continue to have shared neurophysiology linking voice and swallowing together and wanted to provide more information on the remaining studies that met the majority of our inclusion criteria.

Six additional studies met all the inclusion criteria, except for our target population. The secondary analyses of these six studies further supported our primary conclusions, with 67% of the additional studies also reporting a significant association between voice and swallowing measures. The use of acoustics was prominent in four of the six studies (67%), and the use of MBSS (PAS and laryngeal biomechanics) was evident in all six studies (Chang et al., 2012; Kang et al., 2018; Ryu et al., 2004; Waito et al., 2011; Yamaguchi et al., 2018; Yoon et al., 2019).

In the secondary analysis, studies that found significant associations supported the use of acoustic measures (e.g., relative average perturbation [RAP], average *F*0, noise-to-harmonic ratio), MPT, and laryngeal configuration during voicing as visualized via laryngoscopy (Kang et al., 2018; Ryu et al., 2004; Yamaguchi et al., 2018; Yoon et al., 2019). The studies found that acoustic measures of jitter, shimmer, RAP, noise-to-harmonic-ratio, and voice turbulence index were associated with PAS score (Kang et al., 2018; Ryu et al., 2004), reduced MPT was a risk factor for aspiration (Yamaguchi et al., 2018), and glottic gaps and hypomobility under laryngoscopy were correlated with a high rate of tracheal aspiration (Yoon et al., 2019). These results in broader populations reinforce the consistency and strength of using acoustics as correlates of swallowing function reported in the current review.

Studies that did not find associations also evaluated acoustic measures related to pitch and vocal quality (e.g., average *F*0, shimmer, jitter, noise-to-harmonic ratio). Importantly, data were extracted from vowels (i.e., sustained vowels and extracted vowels during utterances) that did not challenge the patients to perform hyolaryngeal elevation (as observed during maximum pitch glides) or test the stamina and coordination between respiration–phonation needed for MPT. Moreover, vocal quality parameters (shimmer, jitter, etc.) are often related to vibrational characteristics (Mehta & Hillman, 2008) and not necessarily the integrity of the hyolaryngeal complex. These may be some potential reasons for the lack of significant acoustic findings in these studies (Chang et al., 2012; Waito et al., 2011). Please refer to Table 2 for more information on the secondary analyses.

This additional evidence strengthens our confidence in the observed overlap between voice and swallowing

Table 2. Secondary analyses of excluded articles that had heterogeneous populations.

Study	Sample size/ages	Diagnoses distributions	Voice measures	Swallowing measures	Major findings
Chang et al. (2012)	*n* = 44 P/A group M = 18, F = 9 Non-P/A group M = 15, F = 2 Age: P/A group *M* = 61.8 ± 15.6 years Non-P/A group *M* = 66.1 ± 13.4 years	Stroke (*n* = 15) HNC (*n* = 12) Aging (*n* = 2) Degeneration (*n* = 3) Spinal cord injury (*n* = 2) Others (*n* = 10)	Acoustic: average *F*0, shimmer %, RAP, NHR, and voice turbulence index All measures were completed on a 2-s sustained phonation of /ɑ/.	MBSS was completed, and swallows were evaluated using the PAS to determine P/A vs. non-P/A.	1. No relationship between acoustic parameters and swallowing thin liquids, or P/A. 2. The authors explained their results by the possibility of their use of only thin barium, which could have passed the vocal folds to the trachea after collecting the post-MBSS acoustic measures.
Kang et al. (2018)	*n* = 165 M = 91, F = 74 Age: 30–98 years *M* = 70.8 ± 11.5	Stroke (*n* = 83) Medical disease (*n* = 10) HNC (*n* = 24) Aging (*n* = 35) Degeneration (*n* = 13)	Acoustic: *F*0, *F*0 *SD*, jitter, RAP, shimmer, APQ, HNR, and NHR All measures were completed on a 3-s sustained phonation of /ɑ/.	MBSS was completed, and swallows were evaluated using a modified 5-point scale to identify P/A.	1. Acoustic parameters of jitter, RAP, and NHR were affected by the aspiration risk, suggesting that the accumulation of pasty food in the vocal folds may impact the vibration of vocal folds and, hence, change the vocal parameters.
Ryu et al. (2004)	*n* = 93 M = 56, F = 37 Age: *M* = 64.8 ± 14.3 years	Stroke (*n* = 43) Medical disease (*n* = 20) ENT (*n* = 12) Parkinson's (*n* = 6) Meningioma (*n* = 4) Dermatomyositis (*n* = 3) Others (*n* = 5)	Acoustic: The /ɑ/ vowel sound was recorded for 3 s before and after MBSS; average *F*0, RAP, shimmer %, NHR, and voice turbulence index.	MBSS was completed, and swallows were evaluated using the modified Logemann's protocol to divide participants into groups: Low-risk group (*n* = 48) High-risk group (*n* = 45).	1. The variables of voice analysis, except average *F*0, changed significantly after swallowing, indicating that voice analysis can be used as an adjunct tool for silent aspiration at clinical bedside examination. 2. Each acoustic variable reflects different aspects of the voice; hence, a combination of two variables can increase the sensitivity in detecting P/A.

(*table continues*)

Table 2. *(Continued).*

Study	Sample size/ages	Diagnoses distributions	Voice measures	Swallowing measures	Major findings
Waito et al. (2011)	*n* = 40 M = 20 F = 20 (unspecified ages)	40 participants referred to MBSS (unspecified diagnoses)	Acoustic: jitter %, shimmer %, and SNR were calculated in time–frequency Analyses were conducted on voice sample consisted of the phrase “ha-ha-ha-ha,” using the /ɑ/ vowel segments spliced from the first two /ha/ syllables.	MBSS was completed, and swallows were evaluated using PAS scale, and other ordinal scales of swallowing impairment (i.e., distal bolus location at swallow onset, incomplete airway closure, vallecular residue, and pyriform sinus residue).	1. There were no significant changes for any acoustic measure across swallow samples, even when evaluating people with different swallowing severities and/or penetration–aspiration risk.
Yamaguchi et al. (2018)	*n* = 30 M = 22, F = 8 Age: *M* = 77.0 ± 14.6 years	30 participants referred to MBSS (unspecified diagnoses)[a]	Aerodynamics: MPT of /ɑ/, at a speaking level from the maximal inspiration position as long as possible, and the duration was measured.	Videoendoscopic swallowing evaluation to evaluate swallowing using a 4-step grading 0–3 and to group patients into aspiration and non-aspiration groups. MBSS was used to measure the distance of laryngeal elevation at rest and the maximal elevation.	1. MPT was significantly shortened in the group with aspiration 2. A significant positive correlation between the distance of laryngeal elevation and MPT. 3. MPT was significantly shortened in the group with aspiration.
Yoon et al. (2019)	*n* = 178 M = 123, F = 55 Age: *M* = 62.8 ± 14.1 years	178 participants referred for MBSS Stroke (*n* = 54) HNC (*n* = 38) Cervical cord injury (*n* = 36) VF injury (*n* = 8) Others (*n* = 43)	Videoendoscopy: to assess the presence/absence of glottic gap	FEES was completed, and swallows were assessed using PAS. MBSS was completed and swallows were evaluated using PAS. Postswallow residue was measured based on pixel-based circumscribed using the Yale Pharyngeal Residue Severity Scale.	1. Glottic gap and vocal folds hypomobility were correlated with a high rate of tracheal aspiration.

Note. P/A = penetration/aspiration; M = male; F = female; HNC = head and neck cancer; *F*0 = fundamental frequency; RAP = relative average perturbation; NHR = noise-to-harmonic ratio; MBSS = modified barium swallow study; PAS = Penetration Aspiration Scale; APQ = amplitude perturbation quotient; HNR = harmonic-to-noise ratio; SNR = signal-to-noise ratio; MPT = maximum phonation time; VF = vocal fold; FEES = fiberoptic endoscopic evaluation of swallowing.

[a]Patients with organic disease, such as tumor, and functional disease, such as vocal cord paralysis, in the larynx were excluded.

objective measures and their relevance. Pitch glide tasks, which intrinsically require coordinated vocal fold adduction and laryngeal elevation with respiratory support, have shown promise in being able to detect variations in hyolaryngeal movement abilities during swallowing. Subsequently, the pitch glide task provides indirect insights into the level of swallowing function/safety (Mavrea & Regan, 2020; Rajappa et al., 2017; Song et al., 2023; Venkatraman et al., 2020). Such associations highlight the potential use of acoustic measures (e.g., maximum *F*0 captured during dynamic pitch glides) in reflecting functional aspects of swallowing. This evidence suggests that while pitch glides and swallowing are distinct functions, the mechanisms involved in pitch modulation are relevant to the movements necessary for safe swallowing. Future research should, therefore, include a larger synthesis of studies on other populations, such as HNC patients, to fully understand how voice measures may indicate dysphagia in specific patient groups.

Limitations and Future Directions

Although this scoping review serves as a foundational exploration of the interplay between objective voice measures and swallowing function, it is essential to recognize its limitations. A notable limitation is the exclusion of non-English language papers, which may have resulted in the omission of relevant studies. Additionally, by not including gray literature, we may have overlooked conference papers, theses, and reports that could contribute to a more comprehensive understanding of our topic. Our reliance on a limited number of databases has also potentially limited the breadth of our search, restricting the scope of our findings. Lastly, the lack of quality analysis prevented us from commenting on the strength of the evidence presented in the included studies, although it is a common limitation in scoping reviews.

For future directions, we recommend investigating the use of maximum *F*0 and MPT as dysphagia safety screeners in different populations, such as those mentioned in the present study, and expanding into individuals with HNC and neurodegenerative diseases. Extending the application of these measures to diverse patient groups will help confirm their validity and reliability. Also, in our review, few studies have sought to develop clinical criteria, cut-off scores, or acoustic screening tools for dysphagia. Song et al. (2023) developed an acoustic and aerodynamic formula to predict high- and low-aspiration risk. Future studies should focus on the full validation of tools like these for their clinical utility and should continue to evaluate the sensitivity and specificity of detecting dysphagia, aspiration risk, and swallowing safety at the bedside.

Conclusions

This scoping review emphasized the potential clinical utility of specific objective voice measures to be used in dysphagia screening, particularly *F*0 and MPT, while acknowledging the multifaceted nature of the relationship between voice and swallowing. By incorporating these measures into clinical practice, clinicians may enhance dysphagia screening practices and supplement traditional bedside evaluations and subjective self-reported measures. Ongoing research efforts should focus on validating these measures across various patient populations to advance the field of dysphagia screening.

Data Availability Statement

Data sharing is not applicable to this article as no data sets were generated or analyzed during the current study.

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Appendix

Search String Example: Embase

No.	Query
1	voice disorder'/exp/dm_di OR 'speech analysis'/exp
2	voice disorder*':ti,ab OR 'voice qualit*':ti,ab OR 'speech analys*':ti,ab
3	(laryngoscop*:ti,ab OR stroboscop*:ti,ab OR endoscop*:ti,ab OR 'laryngeal electromyogra*':ti,ab OR 'mri':ti,ab OR 'magnetic resonance imag*':ti,ab OR 'mr imag*':ti,ab OR videostroboscop*:ti,ab OR nasolaryngoscop*:ti,ab OR aerodynamic*:ti,ab OR 'glottal flow*':ti,ab OR PAS:ti,ab OR 'x-ray imag*':ti,ab OR 'hook wire EMG':ti,ab) AND (dysphonia:ti,ab OR phonation:ti,ab OR voice:ti,ab OR speak*:ti,ab OR vocal*:ti,ab)
4	((voice NEAR/3 acoustic*):ti,ab) OR 'pitch elevation*':ti,ab OR 'pitch glide*':ti,ab OR (((voice OR vocal) NEAR/3 pitch*):ti,ab)
5	((acoustic* OR spectroacoustic* OR 'auditory-perceptual' OR 'speech patholog*' OR vocal*) NEAR/5 (evaluat* OR analys* OR measure* OR parameter* OR assess*)):ti,ab
6	fundamental frequenc*':ti,ab OR 'jitter':ti,ab OR 'relative average perturbation':ti,ab OR 'shimmer':ti,ab OR 'amplitude perturbation quotient':ti,ab OR 'harmonic to noise ratio':ti,ab OR 'noise to harmonic ratio':ti,ab OR 'peak-to-peak amplitude variation*':ti,ab OR 'voice turbulence':ti,ab OR 'vocal qualit*':ti,ab OR 'phonation time*':ti,ab OR 'energy modulation depth':ti,ab OR 'voice efficiency coefficient*':ti,ab OR 'voice capacit*':ti,ab OR 's/z ratio*':ti,ab OR 'cepstral peak prominence':ti,ab
7	#1 OR #2 OR #3 OR #4 OR #5 OR #6
8	dysphagia'/exp
9	dysphagia*:ti,ab
10	swallow*:ti,ab OR deglutition:ti,ab
11	aspirat*:ti,ab
12	(hyolaryngeal:ti,ab OR hyoid:ti,ab) AND laryn*:ti,ab
13	pulmonary aspiration'/exp
14	#8 OR #9 OR #10 OR #11 OR #12 OR #13
15	#7 AND #14
16	('animal'/exp OR 'nonhuman'/exp) NOT 'human'/exp
17	#15 NOT #16
	juvenile'/exp NOT 'adult'/exp
	#17 NOT #18