Dysphagia
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REVIEW

Accuracy of Acoustic Evaluation of Swallowing as a Diagnostic Method of Dysphagia in Individuals Affected by Stroke: Preliminary Analysis

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Abstract
After a stroke, more than half of the patients have some kind of disability, and dysphagia is frequently found. Cervical auscultation by Doppler sonar is an innovative technique with gain of credibility in the clinical evaluation of swallowing. To verify the diagnostic accuracy of Doppler sonar along with the *DeglutiSom® software* as an auxiliary method in the evaluation of oropharyngeal dysphagia in patients after stroke. The research is a cross-sectional, uncontrolled, blind, quantitative study with systematic random sampling. Patients from inpatient and outpatient units of a reference hospital with a stroke care unit were concomitantly submitted to both Doppler sonar and Fiberoptic Endoscopic Evaluation of Swallowing (*FEES*®). Seventy-three audio files collected from 26 patients through Doppler sonar were analyzed using *DeglutiSom® software* and confronted with the *FEES*® report, regarding three food consistencies offered to them during the exam. The study showed that the Doppler sonar correctly identified, among all the analyzed files, those that actually presented tracheal aspiration as well as it effectively identified patients who did not aspirate. The Youden index of 0.91 corroborates this information, showing a promising accuracy in detecting tracheal aspiration in the studied sample. The study evaluates the diagnostic accuracy of Doppler sonar, showing that it can be used as a valuable tool in the diagnosis of tracheal aspiration in patients after stroke. It is important to emphasize that the identification of residue by this method requires further studies. Also, larger sample size and more than one blind evaluator should be considered in future researches to increase the reliability of the proposed method.

Keywords Acoustics · Data Reliability · Dysphagia · Doppler Effect · Stroke · Swallowing Disorders

Introduction

Stroke is a second major cause of mortality around the world [1]. According to the World Stroke Organization, for every four people over the age of 25, one will suffer from the symptoms of stroke throughout life. Estimates point to 13.7 million new cases and 5.5 million deaths every year, in addition to 116 million years of healthy lives interrupted by this disease, worldwide [2].

After a stroke, most patients have some form of disability. The most prevalent is the motor one, followed by communication and language disorders [3], in addition to dysphagia, a common alteration in strokes, with an incidence ranging from 37 to 78% [4, 5].

Oropharyngeal dysphagia is a symptom characterized by the association of signs that put the patient at nutritional, dehydration, and lung risks [6]. After stroke-related dysphagia, there is an increased risk of developing stroke-associated pneumonia (SAP), a pathology diagnosed in 14% of patients [7, 8]. The approach of a multidisciplinary team combined with the screening for dysphagia and the prophylactic and therapeutic measures resulting from its early diagnosis in patients with acute stroke are able to reduce the rates of clinical complications related to the dysfunction, including the imminent risk of pneumonia associated with the pathology [9–14].

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Early diagnosis of dysphagia in stroke patients is fundamental [14]. The screening method for dysphagia should be fast, minimally invasive, easy to use [15], capable of selecting individuals who present signs suggestive of dysphagia, leading to a more complex evaluation of the swallowing mechanisms. The assessment itself needs a broader analysis, specific procedures, and complementary tests to define a diagnosis in the sample selected by the screening [16]. Also, it should be implemented in services that regularly attend such a patient. There are multiple methods for assessing dysphagia in the acute phase of stroke; yet, there is no consensus on the best form of non-invasive clinical investigation [17, 18].

The acoustic analysis of swallowing has stood out among the auxiliary methods in the assessment of dysphagia [19]. Swallowing sounds contain numerical characteristics that should enable a reliable classification of these changes, making cervical auscultation an auxiliary method in the identification of patients with a potential risk of tracheal aspiration [20].

A great effort was made to develop more sensitive and clinically viable methods to characterize the data obtained from swallowing sounds [21]. Currently, the technique has been actively researched and used to estimate dysphagic conditions in various clinical contexts [22].

Cervical auscultation by Doppler sonar is a recent technique, which has gained credibility in the clinical evaluation of swallowing [19], it presents itself as a promising diagnostic method in different age groups, it is fast, painless, does not require sedation, does not expose the patient to radiation, simple, and inexpensive [19, 23, 24]. When using acoustic and visual perceptions in the sound detection of swallowing, it offers objective information [23], quantifies the time used in each swallowing [19, 25, 26], in addition to showing excellent diagnostic precision in the discrimination of these sounds [25].

The Doppler effect is described as the physical principle that modifies the frequency of sound waves that return when hitting a moving object in relation to a sound source [27]. The equipment's transducer, using piezoelectric elements, can function as an emitter when it converts an electrical signal into an acoustic signal or as a receiver when it does the reverse function, transforming an acoustic signal into an electrical signal [28]. When the emitted acoustic signals encounter a static surface, the reflected signal has the same frequency, but when it encounters a moving structure, such as the structures involved in swallowing, the signal is reflected at a different frequency. In this way, the same piezoelectric ceramic disk that emits the acoustic signal, captures the movements produced by the patient in the act of swallowing and transforms them. If the surface moves in the opposite direction to that of the emitted signal, the frequency of the reflected signal is greater than the frequency of the emitted signal, if the surface moves in the direction of the emitted signal, the frequency is less than that of the emitted signal.

After the capture, the sound signals obtained by Doppler are analyzed with the help of *DeglutiSom® software* that uses artificial intelligence through computational algorithms to recognize and classify each swallow [29]. Recent studies reveal the importance of artificial intelligence in the diagnosis and treatment of dysphagia, with the purpose of bringing tools that help clinical decision making, thus offering a simpler and more reliable path to patients who need care in this area [30].

Previous studies have already shown the importance of using validated methods to identify dysphagia in care units for patients after stroke [17, 31, 32].

Given the importance of the topic addressed and the need to incorporate a validated and effective auxiliary method in the evaluation of swallowing in this population, this study proposes to verify the diagnostic accuracy of Doppler sonar along with the *DeglutiSom® software* in the assessment of oropharyngeal dysphagia in patients after stroke, particularly focusing on its ability to identify tracheal aspiration and residues of the ingested bolus.

Method

This research is a cross-sectional, uncontrolled, blind, quantitative performed study with systematic random sampling. Patients were referred from the inpatient units: neurology, medical clinic, and ICUs, in addition to the outpatient clinics of a university hospital.

This study was approved by the Research Ethics Committee of the XXXXXX under number 3,066, XXX and by the Research Ethics Committee of XXXXXX under number 3,350, XXX.

The selection of patients followed the flowchart of the hospital unit, with clinical evaluation and analysis of medical records carried out by a multidisciplinary team composed of doctors, nutritionists, and speech therapists. Patients identified as at risk of deglutition disorders were referred to the peroral endoscopy service for both otorhinolaryngological and phonoaudiological evaluations, and submitted to tests in order to confirm their swallowing conditions. Among these patients, those with the pre-defined criteria were included in the sample.

This study included 26 patients affected by stroke, 13 (50.0%) were male and 13 (50.0%) were female, ranging from 18 to 93 years old (64.9 ± 15.6 years), admitted to the hospital for specialized treatment, from February to September 2019.

The time interval between the medical diagnosis of stroke (carried out by means of specific clinical procedures, diagnostic exams such as MRI, and neurologist evaluation) and the swallowing examinations of this study ranged from 2 to 76 days (10.8 ± 14.6 days).

Regarding swallowing complaints, 80.8% reported these symptoms and 61.5% of them presented significant weight loss after the onset of dysphagia signs. The most common pre-existing diseases were hypertension and diabetes, found in 69.6% and 23.1% of the cases.

As inclusion criteria, the following aspects were observed: patients affected by stroke, both genders, age ≥ 18 years, responsiveness to perform the instrumental examinations (*FEES*®, or Fiberoptic endoscopic evaluation of swallowing [33] and acoustic evaluation using Doppler sonar), who signed the Free Informed Term of Consent, and who did not participate in any swallowing therapy.

Individuals with a level of consciousness on Glasgow Coma Scale [34] ≤ 12, previous history of head and neck surgery, previous structural anomalies of oropharyngolarynx, such as tracheomalacia, laryngomalacia, and hemodynamic instability were excluded from the study.

After requesting the examination, as a routine of the inpatient and outpatient units responsible for the follow-up, the selection of the subjects and the agreement to participate in the study, the patients were concomitantly submitted to both Doppler sonar/*DeglutiSom*® *software* and the reference examination to assess swallowing, *FEES*®.

The equipment to perform the acoustic evaluation was a portable ultrasonic Doppler sonar detector, Model JPD – 100 s (mini), Jumper brand, with emission frequency of 3 MHz, emitter power of 10 MW / cm^3, peak acoustic pressure ≤ 1MP, output power less than 20mW, and continuous Doppler work mode with gel contact in the transducer. The Doppler sonar was connected to a standard Sony microcomputer with AMD E-2 1.7 GHz processor and 4 GB DDR RAM memory, installed with Microsoft Windows 10 and the *DeglutiSom*® *software*.

The equipment used to perform *FEES*® was the nasofiberscope Karl Storz Laryngostrobe model 8020, a digital camera Telecam model DX NTSC 20,232,120, a light source Xenon Nova model 201,315 20-Endoskope, and a Sony video recorder, in addition to the safety protocol for nasofiberscopic assessment of swallowing [35] and the penetration-aspiration scale by Rosenbek et al. [36]. The presence of traces of the content ingested in the region of valleculae and/or pyriform sinuses, after swallowing (residues) were also evaluated. Therefore, it was determined the presence or absence of residues (regardless the patient has or has not any dysphagia) and if a dysphagic patient aspired portions or all the offered bolus [37, 38]. Considering the idea of having a simple acoustic screening method for dysphagia (regardless its nature), it was determined if a patient with stroke had dysphagia or not as well.

The studies of swallowing through *FEES*® and the referred reports were prepared by the otolaryngologist and the speech therapist responsible for the peroral endoscopy sector in the same hospital. The acoustic evaluations were performed by a speech therapist with more than 5 years of experience in swallowing acoustic analysis and who was not present at the time the acoustic signals by the Doppler sonar. The research speech therapists received previous training of 8 h in acoustic assessment of swallowing.

During the swallowing assessment, each participant remained in the sitting position. After applying the contact gel to the transducer of the ultrasonic detector, it was positioned in the lateral region of the trachea, below the cricoid cartilage, either on the right or left side of the larynx, a location that is described in the literature as the best place to detect swallowing sounds [22, 39], as shown in Fig. 1.

For the evaluation by *FEES*®, the fiberscope was introduced into one of the nasal cavities and led to the "velopharyngeal sphincter" during the spontaneous swallowing of saliva, using a topical anesthetic xylocaine gel applied directly to the fiberscope with the intention of reducing the discomfort caused by *FEES*®.

During the capture of swallowing sounds by Doppler sonar and the evaluation by *FEES*®, by means of a spoon or a glass, 10 ml of the following textures were offered to the subjects: extremely thickened, moderately thickened and thin liquid ones, prepared with water and thickener, at the time of the examination, and following the standard of ©*The International Dysphagia Diet Standardization Initiative (IDDSI)* [40]. In addition, blue aniline inorganic dye was incorporated to contrast with the pink coloration of the mucosa of the anatomical region evaluated.

All the audio recordings with the acoustic signals collected by Doppler Sonar obtained from the offer of each consistency were recorded independently, generating individual files in the *DeglutiSom*® *software*, which, after randomization with the assistance of the website "random.org" [41], were analyzed by the blind evaluator, who gave his opinion on dysphagia, residue, and aspiration – the same classification labels used in *FEES*®, i.e., "dysphagia" as any alteration in the transport of the bolus from the mouth to the

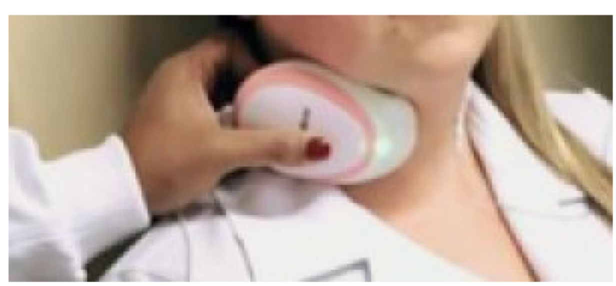


Fig. 1 Position used to capture acoustic signals

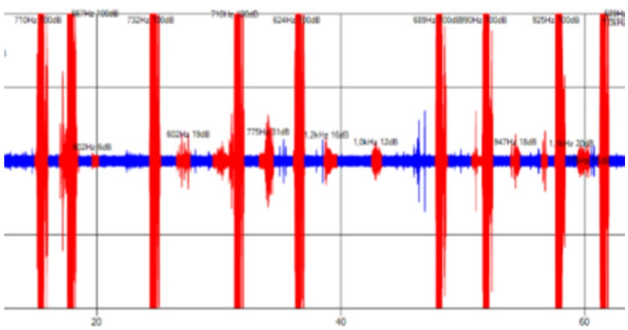


Fig. 2 Example—normal swallowing

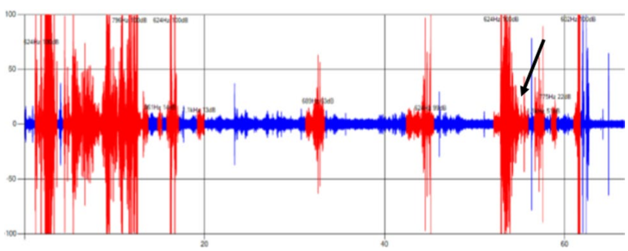


Fig. 3 Example—tracheal aspiration

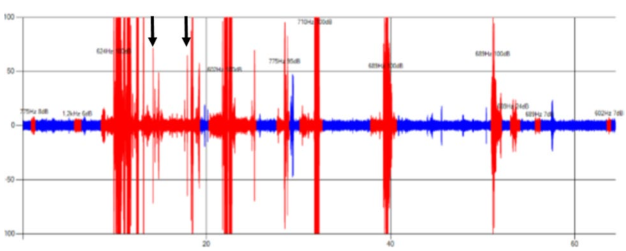
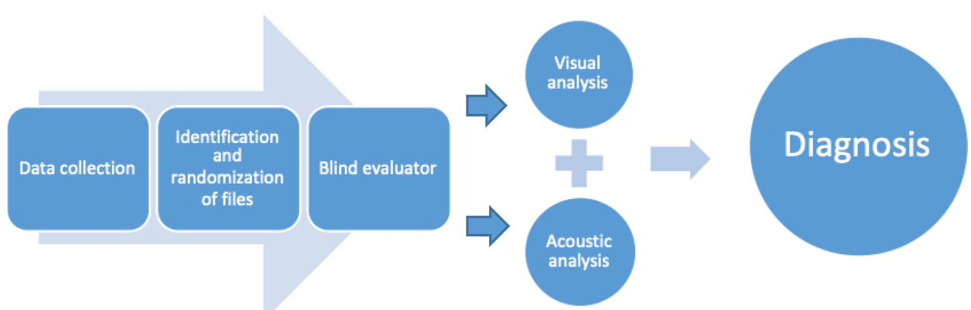


Fig. 4 Example—residue

Fig. 5 Flowchart of Acoustic Evaluation



stomach, "residue" as the presence of traces of the content ingested in the region of valleculae and/or pyriform sinuses, after swallowing, and "aspiration" when the content ingested exceeds the glottal level [36, 42, 43]. Figures 2, 3, and 4 show examples of acoustic signals from normal swallowing, and swallows containing tracheal aspiration and residue, respectively, that were analyzed by the blind evaluator.

The evaluator used the acoustic analysis evaluation system based on the visual and acoustic characteristic of the received file (Fig. 5) and the recognition of the swallowing sound by visual scale of the Acoustic Assessment of Swallowing Protocol—AASP (Fig. 6) [44] in the *DeglutiSom® Software*, which signals through algorithms and artificial intelligence what swallowing is. At least 3 swallows per food consistency were indicated for evaluation.

To avoid an inspection bias and ensure only the diagnostic contribution of the examination, the evaluator was not aware of the previous assessments or clinical characteristics of the patient. Thus, the study became blind [45].

After this step, the results of the blind evaluation were compared with the *FEES®* report and statistically analyzed.

The samples were gathered by a systematic random method, with the sample size corresponding to a confidence level of 95.0%, and a sampling error of ± 11.0%, since it is a preliminary study. The analyses were performed using descriptive methods (frequency tables, comparative graphs, average, minimum, maximum, and standard deviation values).

For the validity analysis, the following indicators were estimated: sensitivity, specificity, actual prevalence, estimated prevalence, correct and incorrect classification, Youden index, likelihood ratios (LR + and LR-), and odds ratio of diagnosis. Reliability was analyzed using the Kappa index.

Results

A total of 78 audio files were expected; however, 5 files were discarded because they did not present adequate quality for acoustic analysis, leaving the total of 73 files in the three tested food consistencies.

Table 1 presents a comparison between both the blind evaluator responses and the acoustic evaluation of

ACOUSTIC ASSESSMENT OF SWALLOWING PROTOCOL (AASP)

Name					
Ager		Gender		Date	

GUIDELINES FOR USING THE PROTOCOL

1) Check your equipament;

2) When using the Deglutisom Software; connect the Software and observe the ambient sound capture. Adjust the sound input and volume (computer and/or Doppler), if necessary;

3) Arrange the sound capture device appropriately;

4) Start the procedure;

5) Guide the individuals to avoid talking and make head movements so that no interference occurs during the capture of sounds;

6) At the end, evaluate the visual acoustic representations of the sound wave for reporting.

ACOUSTIC ANALYSIS OF SWALLOWING

1- ACOUSTIC METHOD OF CAPTURE

Accelerometer		Digital stethoscope		Doppler Sonar		Other	
Model							

2- LOCATION OF SOUND CAPTURE

- (1) Lateral region of the trachea, immediately below the cricoid cartilage, on the right side;
- (2) Lateral region of the trachea, immediately below the cricoid cartilage, on the left side;
- (3) Center of the cricoid cartilage.

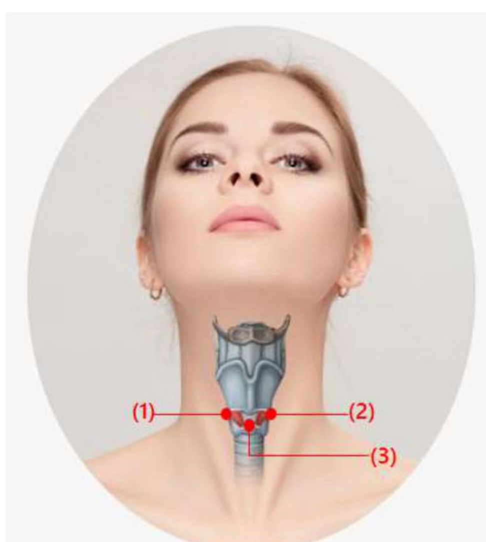


Fig. 6 Acoustic Assessment of Swallowing Protocol (AASP)

3- FOOD CONSISTENCIES USED

Thin liquid		Very slightly thickened		Slightly thickened	
Moderately thickened		Extremely thickened		Solid	

Ref. International Dysphagia Diet Standardisation Initiative (IDSSI), 2019.

Other

Food thickener (brand)

Number of repetitions of the consistency offered during the procedure (no.)

Thin liquid		Very slightly thickened		Slightly thickened	
Moderately thickened		Extremely thickened		Solid	

Other

Utensil used

Spoon		Cup		Straw	

Other/type

4- ACOUSTIC FINDINGS

Acoustic signals of the sound wave	Free sip	TL		VST		ST		ME		ET		Solid
		5ml	10ml	5ml	10ml	5ml	10ml	5ml	10ml	5ml	10ml	
Peak frequency (Hz)												
Average Intensity (dB)												
Average Wave Time (s)												
Number of swallows												

**** The filling will be according to the values provided by the method or software used.

Legend: TL= Thin Liquid; VST= Very slightly thickened; ST= Slightly thickened; MT= Moderately thickened e ET= Extremely thickened.

Acoustic signals of swallowing change | Yes (Y) No (N)	Free sip	TL		VST		ST		MT		ET		Solid
		5ml	10ml	5ml	10ml	5ml	10ml	5ml	10ml	5ml	10ml	
Presence of noise between swallows												
Acoustic signal suggestive of residues												
Acoustic signal suggestive of aspiration												
Cough												

Legend: TL= Thin Liquid; VST= Very slightly thickened; ST= Slightly thickened; MT= Moderately thickened e ET= Extremely thickened.

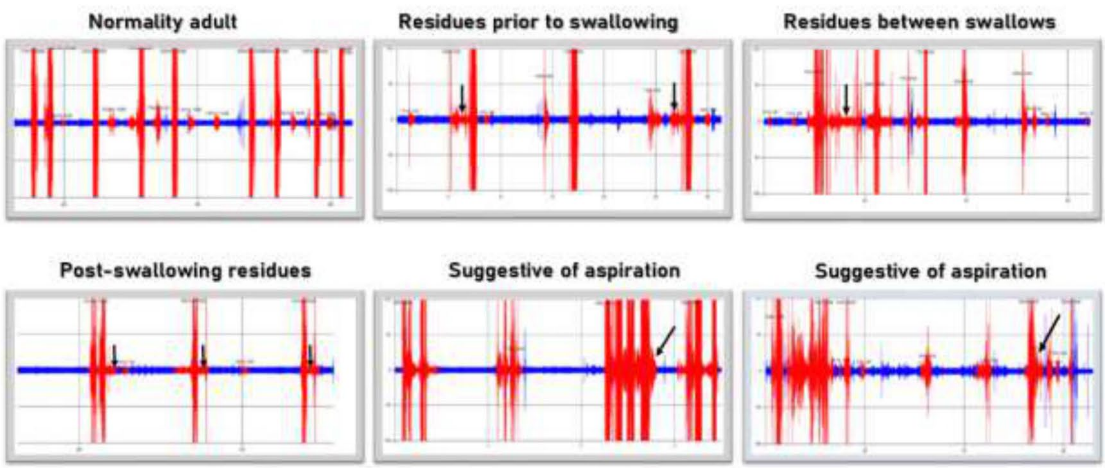
Fig. 6 (continued)

Reference scale of normality standards values

Average	Frequency	Intensity	Time
Adult	900Hz a 2200Hz	30dB a 91dB	0,4s a 1,9s
Elderly	800Hz a 2300Hz	30dB a 90dB	1,4s a 2,0s

Ref . CICHEROJA e MURDOCH BE, 2002; YOUMANS SR e STIERTWALT JA, 2005; SANTOS RS e MACEDO EDF, 2006; SÓRIA FS., et al, 2015.

Visual Scale



Results

	No signs of altered swallowing.
	Signs of altered swallowing.

Consistencies and volumes

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Speech therapist's signature/stamp

Fig. 6 (continued)

swallowing by Doppler sonar (along with the *DeglutiSom® software*) and *FEES®* evaluation method.

The intra-rater reliability of the Doppler sonar evaluation with the *FEES®* is shown through the Kappa index [46], which varies from 0 to 1, and the closer to 1, the more

Table 1 Classification of dysphagia, residue, and tracheal aspiration through the evaluation of Doppler sonar in comparison with *FEES*®, for the three food consistencies

Doppler sonar	*FEES*® (Standard)		Total	Kappa
	Yes	No		
Dysphagia				
Yes	44	3	47	0.5144 Moderate
No	12	14	26	
Total	56	17	73	
Residue				
Yes	29	8	37	0.3404 Fair
No	16	20	36	
Total	45	28	73	
Tracheal aspiration				
Yes	15	5	20	0.8133 Almost Perfect
No	0	53	53	
Total	15	58	73	

Table 2 Doppler Sonar validity indicators in relation to the *FEES*® standard for dysphagia, residue, and tracheal aspiration in the three tested food consistencies

Indicators	Dysphagia	Residue	Tracheal aspiration
Sensitivity	79%	64%	100%
Specificity	82%	71%	91%
Actual prevalence	77%	62%	21%
Estimated prevalence	64%	51%	27%
Positive predictive value	94%	78%	75%
Negative predictive value	54%	56%	100%
Correct classification	79%	67%	93%
Incorrect classification	21%	33%	7%
Youden Index	0.61	0.36	0.91
Likelihood ratio RV +	4.4	2.2	11.1
Likelihood ratio RV-	0.3	0.5	0.0
Diagnosis chances ratio	17	4.5	-

reliable the evaluation method is. As shown in Table 1, for tracheal aspiration, the Kappa index of 0.8133 shows a significant agreement regarding the degree of reliability. In comparison to tracheal aspiration, the identification of residue resulted in the lowest intra-rater reliability (Kappa = 0.3404).

Table 2 shows the validity indicators for the acoustic assessment of swallowing when compared to the standard method, *FEES*®. From all the analyzed audio files, the evaluator has correctly identified those that actually presented tracheal aspiration using Doppler sonar. Therefore, a sensitivity of 100.0% is observed. Regarding specificity, the results show that in 91.0% of the analyzed audio files,

Table 3 95.0% confidence intervals for sensitivity, specificity, positive predictive value, and negative predictive value, respectively in the three tested food consistencies

Indicators	Dysphagia	Residue	Tracheal aspiration
Sensitivity	[70%; 88%]	[53%; 75%]	[91%;100%]
Specificity	[73%; 91%]	[61%; 81%]	[84%; 98%]
Positive predictive value	[89%; 99%]	[69%; 88%]	[65%; 85%]
Negative predictive value	[43%; 65%]	[45%; 67%]	[91%;100%]

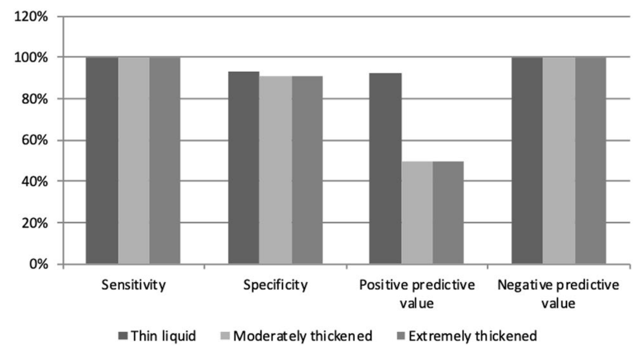

Fig. 7 Comparison of the main indicators in the three food consistencies-Tracheal aspiration

Doppler sonar was effective in identifying patients who did not present tracheal aspiration. The presence of residue presented the lowest sensitivity (64.0%) and sensibility (71.0%), while the identification of dysphagia using the acoustic method presented intermediate results (respectively 79.0% and 82.0% for sensibility and specificity).

The presented data also show a positive predictive value for dysphagia of 94.0% and a correct classification of 93.0% for tracheal aspiration. A previous study [47] defines the Youden index as one of the oldest measures to assess the accuracy of a diagnosis test, with values varying from 0 to 1 and the higher the result, the better the diagnostic capacity of the evaluated test. In this case, the value of 0.91 corroborates the above information, showing a significant accuracy of the Doppler sonar in the diagnosis of tracheal aspiration in the sample studied.

Table 3 shows the validity indicators within the studied audio files, in the three food consistencies offered to the patient, within a 95.0% confidence interval. With the obtained results, it is possible to highlight the superior diagnostic accuracy of Doppler sonar regarding tracheal aspiration in comparison to the detection of residue. The acoustic screening of dysphagia presented intermediate accuracy.

Finally, Fig. 7 shows the comparison between the main indicators of diagnostic validity, in the three food consistencies offered to the patient during the evaluations. As it can be seen, the sensitivity and negative predictive value denote a promising diagnostic capacity in the three consistencies.

In relation to specificity and positive predictive value, there is a higher efficiency when using "thin liquid" food consistency, that is, among all the analyzed files, the Doppler sonar was able to correctly exclude individuals who did not present tracheal aspiration. In addition, it presents prominence in adequately diagnosing the individuals actually positive for tracheal aspiration.

Table 4 Divergence cases in dysphagia results between Doppler and *FEES*® sonar, classified with the Rosenbek scale ($n = 15$)

Rosenbek scale	Dysphagia		Proportion In %
	Sonar doppler	*FEES*®	
1	3	–	20
2	–	3	20
3	–	6	40
5	–	3	20

Discussion

Given the diversity of methods used to assess the swallowing changes in patients after stroke, it is essential to conduct research in order to demonstrate the effectiveness of the support tools used by these professionals.

The acoustic analysis of swallowing using Doppler sonar has shown to be a promising technique in this area as it combines speed, agility, low cost while, it is painless, without exposing the patient to radiation, totally non-invasive, and avoids unnecessary displacements in the cases of patients with any type of restriction.

There are several difficulties encountered when the proposal is to study a population as complex as that from patients after stroke. Research shows clinical characteristics found in this pathology: facial weakness, asphyxia, hemiplegia, drowsiness, dyspraxia, dysarthria, loss of consciousness, among others [48]. During data collection the difficulties encountered coincide with ones detailed in this study, due to the clinical condition and hemodynamic instability: often these patients were not able to leave the inpatient sector to have the evaluations done, which reduced the sample.

Regarding the quality of the audio files for the acoustic analysis, the factors involved in the disposal of 5 files were: excessive noises and movements during the examination, inadequate location to capture the swallowing signals, poor adhesion of the ultrasonic detector to the surface of the skin, interruption of the examination due to severe dysphagia, or even technical problems in the equipment. Previous studies involving acoustic analysis of swallowing have already demonstrated these types of setback and the need to exclude inappropriate signals for analysis due to the presence of strong disorders, such as speech sounds, coughs, and excessive head and neck movements [49]. Given the difficulties encountered during data collection, we suggest continuing the study for a larger sample with results of greater foundation and scientific proof.

It is important to emphasize that despite this study used *FEES*® as the reference method, since it is considered an accurate and valuable technique for determining oropharyngeal dysphagia [50], other studies point to videofluoroscopy (VFS) as the reference tool to in this evaluation [51, 52], because it presents high sensitivity and specificity in the diagnosis [53]. Thus, it is suggested that new studies be carried out using VFS as a comparative method, since it is an objective method that does not require invasive maneuvers to observe the swallowing process in real time (at the expense of X-ray), allowing to be used in patients with some changes in their neurological conditions, although it is known that the cognitive deficits can impair the patient's understanding during the clinical evaluation [54]. In clinical practice, during data collection, it was possible to observe that *FEES*® requires greater cooperation from the patient regarding the insertion of the nasofibroscope into the nasal cavity and the permanence in the appropriate posture for the evaluation. This requirement of *FEES*® led to the small size of the study sample.

One point to discuss is the question of the subjectivity of the criteria used during the analysis of the audio files and the peculiarities of the standards used by the hospital service that classifies dysphagia based on the presence/absence of residue in the region of vocal fold and laryngotracheal aspiration. The blind evaluator conducted his evaluations of dysphagia, residue, and aspiration in an isolated and specific way for in each audio file, based on the acoustic aspiration signal and the principle that the ability to detect of residue may be influenced by several factors external to the pathology, such as color, opacity, coating, and consistency of the food offered during the evaluation [43, 55]. In addition, the patient's ability to eject food from the airways contributes to the classification of swallowing. Even elderly people, without changes in swallowing, may receive scores 2 and 3 on the penetration-aspiration scale by Rosenbek et al. [36].

Isolated residues were signaled in some cases, but not identified as dysphagia. Sixty percent of the divergences occurred on the 3 and 5 scales according to the Rosenbek classification, where there is the presence of residue, as shown in Table 4. This aspect highlights the need for the use of validated protocols and scales to assess dysphagia, in order to align the responses between the evaluators.

Studies show that cervical auscultation is influenced by the experience of the evaluator [56]. It is believed that the Kappa index of 0.5144, considered moderate for dysphagia, arose as a result of dysphagia associated with the residue, whose identification by both methods were not so good as the one verified for dysphagia associated with tracheal aspiration. Moreover, by means of acoustic analysis it is not feasible to delimit small quantities of residues, which may have significantly influenced these results.

The present study showed significant degree of reliability of acoustic analysis using Doppler sonar regarding tracheal aspiration, shown by the Kappa index of 0.8133. A sensitivity of 100.0% and a specificity of 91.0% were also observed. Another study using the acoustic assessment of swallowing through the microphone showed 66.0% for specificity and, 62.0% for sensitivity to detect normality, but the majority consensus among the evaluators showed 90.0% for specificity and, 80.0% for sensitivity to determine the normality of swallowing when compared to radiologically defined tracheal aspiration [57].

Patients with tracheal aspiration and/or residues are classified as having dysphagia. Therefore, the ability of the acoustic analysis using Doppler sonar, that shows intermediate results for dysphagia (Tables 2 and 3) in comparison to tracheal aspiration and residues, is directly influenced by the lower ability of this method to identify residues. The identification of dysphagia by Doppler sonar in patients with both tracheal aspiration and residue are mainly due to tracheal aspiration. Therefore, a dysphagic patient without tracheal aspiration may not be identified by the acoustic method. Consequently, a reliable acoustic screening method for dysphagia requires further studies to improve its ability to identify different phenomena found in all types of dysphagia.

The literature indicates that the procedures used in clinical examinations that assess swallowing function are not so sensitive and specific to define tracheal aspiration [58]. Thus, by combining functional assessment and acoustic analysis of swallowing, the speech therapist may have a safer diagnosis of aspiration in patients after stroke.

Finally, this study revealed that the acoustic evaluation of swallowing using Doppler sonar presents a promising diagnostic accuracy corroborating the referred information in a systematic review on acoustic evaluation methods in which the best results of diagnostic accuracy were attributed to Doppler sonar when compared to the microphone and the stethoscope. The Doppler showed a Youden index of 0.80 while the stethoscope was 0.28 and the microphone was 0.23. In addition, RV + and RV– values showed greater diagnostic accuracy for Doppler, thus showing excellent diagnostic accuracy in the discrimination of swallowing sounds [25].

Because it presents good sensitivity and specificity in capturing swallowing sounds, Doppler sonar can be used as a diagnostic method since it includes several requirements requested for an effective method of determining tracheal aspiration. Moreover, it is shown as a non-invasive method in relation to the reference standard currently used, the VFS [25].

Conclusion

Acoustic analysis using Doppler sonar demonstrates promising diagnostic accuracy and can be used as a valuable tool in the diagnosis of tracheal aspiration in patients after stroke. It is important to emphasize that the use of this method for identification of residue and/or screening of dysphagia requires further studies. Also, larger sample size and more than one blind evaluator should be considered in future researches to increase the reliability of the proposed method.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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