Respiratory Medicine 132 (2017) 95–101

Contents lists available at ScienceDirect

Respiratory Medicine

journal homepage: www.elsevier.com/locate/rmed

Measuring voluntary and reflexive cough strength in healthy individuals

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ARTICLE INFO

Article history:
Received 5 April 2017
Received in revised form
4 September 2017
Accepted 25 September 2017
Available online 27 September 2017

Keywords:
Reflexive cough
Voluntary cough
Cough strength
Pressure
Airflow
Acoustic

ABSTRACT

Background: Cough reflex testing is a validated tool for identifying patients at risk of silent aspiration. However, inter- and intra-rater reliabilities of perceptual judgements of cough strength are sub-optimal. Although there are clinically established methods for measuring volitional cough strength, no similar methods are identified for reflexive cough strength. This study evaluated three measurement methods of voluntary and suppressed reflexive cough strength.

Methods: Fifty-three healthy subjects (≥50 years) participated in this study. Participants produced 'strong' and 'weak' voluntary coughs and suppressed reflexive coughs to incremental doses of citric acid. Peak and area under the curve (AUC) measurements were taken of pressure, airflow, and acoustics.

Results: There was no dose effect of citric acid on measures of reflexive cough strength. Strong voluntary coughs were stronger than reflexive coughs for all measures ($p < 0.001$) and weak voluntary coughs were stronger than reflexive coughs for two measures (AUC pressure: $p < 0.020$; peak flow: $p < 0.004$). AUC pressure and peak flow had the highest correlations and effect sizes. Correlations were low between voluntary and reflexive cough strength for all measures ($r \leq 0.46$).

Conclusion: Assessing strength of reflexive cough, rather than voluntary cough, is highly desirable in the dysphagic population. Pressure and flow provide the most useful objective measurements.

1. Introduction

Coughing plays a vital role in airway protection and clearance [1,2]. A voluntary cough is cortically controlled and includes an inspiratory phase, a compressive phase, and an expulsive phase; the inspiratory phase acts to provide a greater lung volume to enable more effective lung clearance [3,4]. Conversely, reflexive coughing is primarily mediated by the brainstem [5] and usually comprises a mixture of two different types of reflexive coughs: the cough reflex and the laryngeal expiratory reflex (LER) [6]. The cough reflex has an inspiratory phase, in contrast to the LER which does not have an inspiratory phase [6–10]. Reflexive coughing acts primarily to protect the airway from threat and clear the upper airway of aspirated material [2]. Reflexive coughing, therefore, is of particular importance for individuals with dysphagia, in which food, drink, and/or saliva can enter the airway, potentially resulting in aspiration pneumonia. Dysphagic patients frequently have dystussia (disordered cough response) which has been shown to be associated with increased risk of aspiration pneumonia [11–14]. Voluntary cough and reflexive cough are physiologically different [1,15,16] and, as such, are affected differently in neurological disorders [17–19].

Cough reflex testing (CRT) in neurologically-impaired patients, particularly those who have had a stroke, has been shown to be effective in identifying individuals with impaired cough sensitivity who are at risk of silent aspiration (aspiration without cough) and development of pneumonia [12]. Historically, CRT has examined natural cough, in which individuals are instructed to 'cough if they feel the need to'. However, research has shown that reflexive cough to capsaicin can be voluntarily suppressed [20]. This indicates that either cortical inhibition of reflexive cough is possible or, alternatively, that a true reflexive cough has not been initiated. Indeed,

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https://doi.org/10.1016/j.rmed.2017.09.013
0954-6111/

Abbreviations

AUC	area-under-the-curve
C2	two consecutive coughs without intervening inspiration
C5	five consecutive coughs without intervening inspiration
CRT	cough reflex testing
LER	laryngeal expiratory reflex

coughing behaviour is highly suggestive and the potential exists for patients undergoing natural CRT to unwittingly cough voluntarily – rather than reflexively – during the assessment, because they are aware they are undergoing CRT [21]. In order to offset this 'placebo effect', CRT can incorporate the assessment of suppressed cough, in which individuals are instructed to 'try not to cough'. This methodology helps to maximize the likelihood that resultant coughing is truly reflexive [21].

Strength of coughing is an important factor in identifying risk of aspiration pneumonia [22]. However, there is no established method of objectively assessing reflexive cough strength, and clinical CRT often incorporates a binary 'weak' or 'strong' perceptual judgement of cough strength. Inter- and intra-rater reliability of perceptual judgement of cough strength has been shown to be low [23]. In the absence of CRT, clinicians often rely on volitional cough to assess ability to protect the airway in the event of aspiration. This assessment may not be directly applicable to the process of clearing aspiration. Developing a method to objectively measure the strength of reflexive cough is crucial to identify patients at risk of aspiration pneumonia with greater specificity.

This study investigated the strength of voluntary and suppressed reflexive cough, elicited by inhalation of incremental doses of nebulized citric acid, using outcome measures of pressure, airflow, and acoustics. We hypothesized that there would be a dose-response effect, with greater cough strength with higher doses of citric acid. Voluntary cough was also postulated to be stronger than suppressed reflexive cough. Finally, we hypothesized that pressure measures would be more accurate than airflow or acoustics.

2. Material and methods

2.1. Study subjects

Fifty-three healthy individuals (33 females) were recruited for this study. Exclusion criteria included: age <50 years, history of gastro-oesophageal reflux, respiratory conditions, neurological conditions, dysphagia, smoking, and taking steroids, opiates, or codeine-based analgesia in the 24 h prior to assessment. All subjects provided informed written consent. Ethical approval was granted by an appropriate regional Human Ethics Committee.

3. Materials

A within-subject design was utilized to investigate strength of reflexive and voluntary cough using measures of pressure, airflow and acoustics. For analysis of reflexive cough, CRT was carried out using citric acid solutions at concentrations of 0.4 Mol/L, 0.8 Mol/L, 1.2 Mol/L and 1.8 Mol/L, as well as 0.9% saline. A PulmoMate® Compressor Nebulizer (model 4650I, DeVilbiss Healthcare LLC, Pennsylvania, US) was used to deliver the stimulus to participants using a pre-determined free-flow output of 8 L/min and a restricted flow output of 6.6 L/min. This same flow output was also used to apply air only during voluntary cough testing to ensure identical airflow, pressure and acoustic conditions.

A physiological pressure transducer (Model MLT844) was connected to a bridge amp (Model ML110) and a respiratory flow head 1000 L (MLT1000L) was connected to a spirometer pod (Model ML311) (all ADInstruments, Dunedin, New Zealand). These were utilized to collect information on cough pressure and flow rate, respectively. A Littmann stethoscope was attached to an Optimus omnidirectional impedance microphone (1 KΩ Model 33-3003) to obtain acoustic measures of cough. All instruments were connected to an AD PowerLab 26T-3819 (model ML856, ADInstruments, Dunedin, New Zealand) and LabChart Version 7.3.7 was utilized to collect and analyse data. A disposable Hudson RCI MICRO MIST® adult, elongated aerosol nebulizer mask and 7-foot Start Lumen® Tubing (Teleflex, Morrisville, USA) were used for each participant. This face mask had detachable tubing attached to each port: one connected to the pressure transducer, and one connected to the spirometer flow head.

The sampling rate was set at 10 kHz and anti-aliasing low-pass filters were on for all measures. The spirometer was zeroed and calibrated using set parameters (0 mV = 0.0 L/s and 1.0 V = 40.1 L/s). The pressure transducer was manually calibrated using a sphygmomanometer. The recording range was set for each measure (flow: 500 mV; pressure: 2 mV, acoustic: 2 V). A low-pass filter was set for flow (30 Hz) and pressure (2 kHz) and turned off for acoustic.

3.1. Procedures

The face mask was securely placed, using elastic straps, to reduce mask movement and minimize air escape. The stethoscope was positioned centrally over the participant's central thyroid cartilage using a neck strap. This central position reduced artefact of detection of carotid pulse. The nebulizer was placed approximately 1 m from the recording equipment and the participant to prevent artefacts in sound and pressure recordings.

A counterbalanced design determined if a participant commenced with voluntary or reflexive coughs. In addition, execution of the type of voluntary cough – two strong coughs or two weak coughs – were varied randomly across participants. Participants were given instructions to 'take a breath in and produce two strong coughs on one breath', or 'take a breath in and produce two weak coughs on one breath'. Coughs were also modelled for participants.

A counterbalanced approach to the order of doses of citric acid was not possible due to the tendency for higher concentrations of citric acid to cause tachyphylaxis, thus influencing subsequently-administered lower concentrations. Therefore, the citric acid doses were administered incrementally, adhering to the European Respiratory Society guidelines [3]. Citric acid was administered for $\leq$15 s, as continual inhalation over a period of $\geq$1 min has been shown to result in tachyphylaxis [3]. Participants were instructed to 'Breathe in and out through your mouth. If you feel the need to cough, try to suppress it'. The European Respiratory Society Task Force recommend recording either a C2 or a C5 response (two or five consecutive coughs in response to application of a tussive agent) [3]. In this study participants were observed for the production of a C2 response, as this has been found to be more reproducible [24]. A C2 response was defined in this study as two consecutive coughs without intervening inspiration [21]. Each dose of citric acid was administered once only and when a C2 response was observed the nebulizer was turned off. After a C2 response was observed on three consecutive doses of citric acid, no further doses were presented. To prevent tachyphylaxis, a 60 s rest period was

given between each cough task, and saline was administered prior to, and in between, each citric acid stimulus.

3.2. Analysis

Pressure and acoustic signals were digitally manipulated with application of a high-pass filter (pressure: 2 Hz; acoustic: 20 Hz) to reduce baseline drift. C2 responses were identified using the airflow waveform to ensure that no inspiration between the first and second cough occurred. C2 responses were recorded for each of three consecutive doses and labelled as 'dose 1', 'dose 2', and 'dose 3'. Therefore, for some participants threshold dose – or dose 1 – was 0.4 Mol/L, and for others it was 0.8 Mol/L, depending on their individual responses. For each cough, peak and area under the curve (AUC) of pressure, airflow, and acoustics were identified and extracted. AUC was calculated from the rectified waveform for pressure and acoustics. Digital markers were manually placed in the files up to 1 s before ('s') and after ('e') the beginning and end of cough activity (Fig. 1). A macro was then run to place more systematic 'start' and 'end' markers automatically across all waveforms. This macro calculated a 'baseline' from 3 s of the acoustic waveform during a placebo trial. A threshold was then calculated from this baseline plus seven times the standard deviation of the baseline. The macro placed a 'start' marker as soon as the rectified acoustic waveform rose above the threshold after the manually placed 's' marker. Likewise, an 'end' marker was placed where the waveform rose above the threshold before the 'e' marker (Fig. 1).

Data analysis was completed using the IBM SPSS Statistics software (version 22). Repeated-measures analysis of variance (ANOVA) tests were used to compare the peak values and the AUC for reflexive and voluntary cough for pressure, airflow, and acoustics. Analysis of sphericity was evaluated using Mauchly's test of sphericity; when sphericity was violated the Huynh-Feldt estimate of sphericity was used to correct the degrees of freedom.

Paired t-tests were utilized to compare the third dose of citric acid to strong and weak voluntary coughs. Bivariate correlation analyses were conducted to compare the six outcome measures. A p-value of <0.05 was considered to be significant with a 95% confidence interval.

4. Results

Of the 53 recruited subjects, 29 (20 females, 9 males; mean age 61.0, age range 50–84) were considered suitable for inclusion for data analysis. Participants who did not produce a C2 response on three consecutive incremental doses of citric acid were excluded from data analysis. Of the 24 sets of data excluded from analysis, 2 were due to equipment failure, 6 were due to human error, and 16 (32% of participants) were due to absent C2 response.

4.1. Reflexive coughs

Citric acid dose had no significant effect on coughing strength as measured by peak or AUC of pressure, airflow, or acoustics (Tables 1 and 2). However, there was a significant effect of cough position in the C2 response, with the first cough being stronger than the second (Table 2).

4.2. Voluntary coughs

There was a significant effect for type of voluntary cough, 'strong' or 'weak' ($p < 0.01$ for all measures). There was also a significant effect for cough number, with the first cough being stronger than the second, for four measures (peak pressure: $p < 0.01$; AUC pressure: $p < 0.01$; peak flow: $p < 0.01$; AUC acoustic: $p < 0.01$) (Table 2).

4.3. Reflexive coughs versus voluntary coughs

On average, participants' strong voluntary coughs were significantly stronger than dose 3 of citric acid (Table 3). In contrast, there was no significant difference in strength between weak voluntary coughs versus reflexive coughs at dose 3 of citric acid on peak pressure, peak acoustic, and AUC acoustic. There was a significant

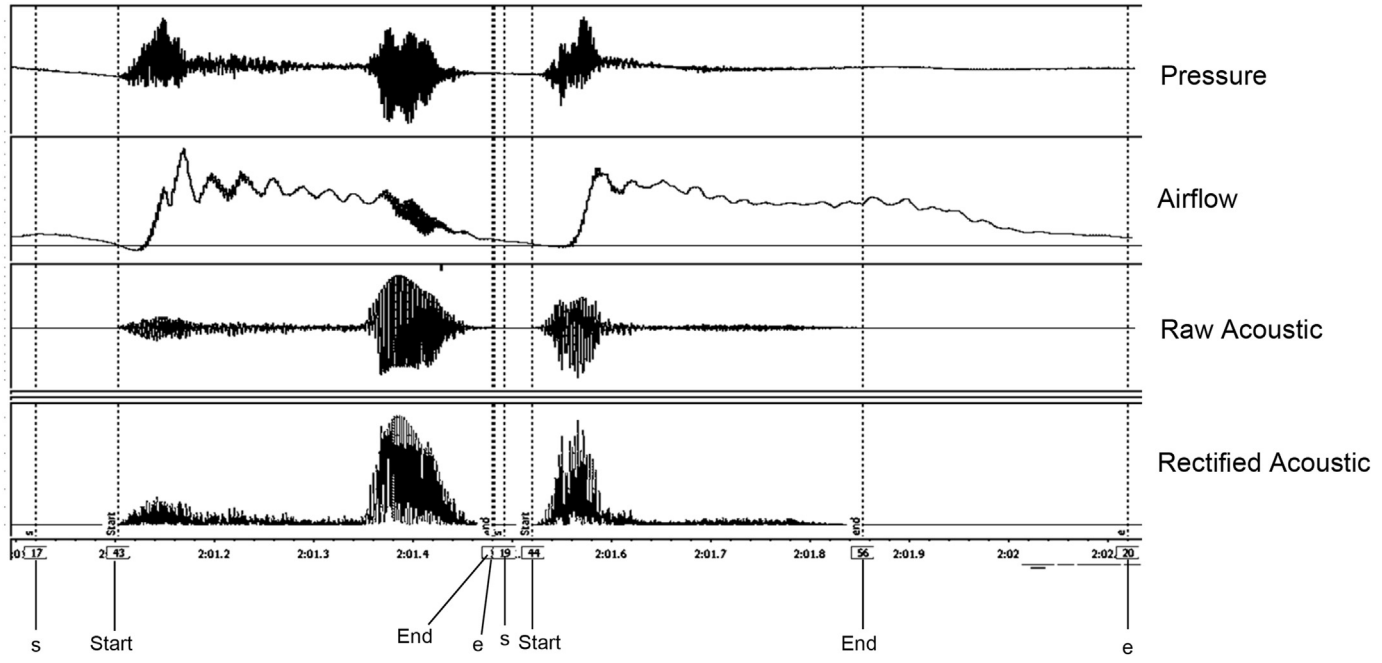

Fig. 1. Automatic marker placement for two strong voluntary coughs from participant 14 B. 'Start' and 'End' markers have been automatically placed within the manually placed 's' and 'e' markers. The top waveform is pressure, the 2nd waveform is airflow, 3rd waveform is raw acoustic, and 4th waveform is rectified acoustic.

Table 1
Means and standard deviations for reflexive and voluntary coughs.

Stimulus	Cough Number	Peak Pressure mmHg	AUC Pressure mmHg.s	Peak Flow L/s	AUC Flow L	Peak Acoustic V	AUC Acoustic V.s
		Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Dose 1 Citric acid	1st	2.10 ± 1.17	0.072 ± 0.046	0.905 ± 0.555	0.133 ± 0.090	0.391 ± 0.248	0.015 ± 0.012
	2nd	1.68 ± 0.93	0.047 ± 0.028	0.570 ± 0.371	0.085 ± 0.062	0.357 ± 0.264	0.012 ± 0.011
Dose 2 Citric acid	1st	2.30 ± 1.52	0.077 ± 0.048	0.869 ± 0.546	0.132 ± 0.077	0.381 ± 0.269	0.017 ± 0.019
	2nd	1.77 ± 1.08	0.042 ± 0.021	0.631 ± 0.445	0.086 ± 0.059	0.339 ± 0.248	0.010 ± 0.009
Dose 3 Citric acid	1st	2.25 ± 0.99	0.080 ± 0.051	0.920 ± 0.575	0.158 ± 0.124	0.400 ± 0.292	0.017 ± 0.017
	2nd	1.94 ± 1.30	0.048 ± 0.028	0.664 ± 0.519	0.106 ± 0.089	0.311 ± 0.273	0.011 ± 0.012
2 weak Voluntary coughs	1st	1.85 ± 1.18	0.119 ± 0.068	1.347 ± 0.661	0.176 ± 0.091	0.369 ± 0.279	0.013 ± 0.015
	2nd	1.67 ± 1.11	0.085 ± 0.056	1.089 ± 0.603	0.172 ± 0.118	0.362 ± 0.275	0.017 ± 0.018
2 strong Voluntary coughs	1st	7.35 ± 3.80	0.349 ± 0.132	2.020 ± 0.734	0.334 ± 0.133	0.654 ± 0.129	0.057 ± 0.035
	2nd	5.98 ± 2.89	0.194 ± 0.097	1.508 ± 0.568	0.292 ± 0.108	0.616 ± 0.172	0.040 ± 0.027

Table 2
Repeated-measures ANOVA results for voluntary and reflexive coughs.

Effect		Cough Number		Dose	Type of cough
		Reflexive cough	Voluntary cough	Reflexive cough	Voluntary cough
Peak Pressure	F	11.9	16.5	0.43	57.7
	P	0.002	<0.001	0.650	<0.001
	1 − β	0.913	0.975	0.117	1.000
AUC Pressure	F	30.8	59.5	0.12	54.9
	P	<0.001	<0.001	0.862	<0.001
	1 − β	1.000	1.000	0.067	1.000
Peak Flow	F	33.2	66.8	0.05	20.5
	P	<0.001	<0.001	0.952	<0.001
	1 − β	1.000	1.000	0.057	0.992
AUC Flow	F	10.6	0.05	2.37	44.4
	P	0.003	0.827	0.103	<0.001
	1 − β	0.882	0.055	0.459	1.000
Peak Acoustic	F	4.51	1.04	0.56	41.6
	P	0.043	0.316	0.925	<0.001
	1 − β	0.535	0.167	0.058	1.000
AUC Acoustic	F	10.9	8.77	0.56	59.0
	P	0.003	0.006	0.926	<0.001
	1 − β	0.890	0.815	0.058	1.000

Table 3
Comparison of C1 and C2 reflexive coughs at citric acid dose 3 with C1 and C2 'strong' voluntary coughs for each outcome measure.

Measure		Mean Difference	Standard Deviation	Standard Error	t (28)	Sig.	Cohen's d
Peak Pressure	1st cough	−5.106	3.846	0.714	−7.1	<0.001	1.33
	2nd cough	−4.034	3.097	0.575	−7.0	<0.001	1.30
AUC Pressure	1st cough	−0.269	0.135	0.025	−10.7	<0.001	1.99
	2nd cough	−0.146	0.103	0.019	−7.6	<0.001	1.42
Peak Flow	1st cough	−1.100	0.780	0.145	−7.6	<0.001	1.41
	2nd cough	−0.844	0.638	0.118	−7.1	<0.001	1.32
AUC Flow	1st cough	−0.176	0.149	0.028	−6.3	<0.001	1.18
	2nd cough	−0.186	0.142	0.026	−7.1	<0.001	1.31
Peak Acoustic	1st cough	−0.254	0.300	0.056	−4.5	<0.001	0.85
	2nd cough	−0.305	0.247	0.046	−6.6	<0.001	1.23
AUC Acoustic	1st cough	−0.041	0.034	0.006	−6.5	<0.001	1.21
	2nd cough	−0.028	0.028	0.005	−5.5	<0.001	1.00

difference in cough strength for AUC pressure and peak flow, and for the second coughs of AUC flow, with reflexive coughs being weaker than weak voluntary coughs (Table 4).

4.4. Within-cough-type correlations

Bivariate correlations between voluntary and reflexive cough revealed low correlations for all measures (Table 5). Bivariate correlations of the different outcome measures for reflexive cough and voluntary cough found highest correlations between peak and AUC of the same measures (Table 6). On different measures, the highest correlations for voluntary cough and reflexive cough were between AUC pressure and peak flow, and AUC pressure and AUC flow. Acoustic measures correlated poorly with all other measures for reflexive and voluntary cough.

Table 4
Comparison of C1 and C2 reflexive coughs at citric acid dose 3 with C1 and C2 'weak' voluntary coughs for each outcome measure.

Measure		Mean Difference	Standard Deviation	Standard Error	t (28)	Sig.	Cohen's d
Peak Pressure	1st cough	0.397	1.454	0.270	1.5	0.153	0.273
	2nd cough	0.270	1.838	0.341	0.8	0.436	0.147
AUC Pressure	1st cough	−0.039	0.085	0.016	−2.5	0.020	−0.459
	2nd cough	−0.037	0.064	0.012	−3.1	0.004	−0.578
Peak Flow	1st cough	−0.427	0.727	0.135	−3.2	0.004	−0.587
	2nd cough	−0.425	0.709	0.132	−3.2	0.003	−0.599
AUC Flow	1st cough	−0.018	0.125	0.023	−0.8	0.444	−0.144
	2nd cough	−0.066	0.128	0.024	−2.8	0.010	−0.516
Peak Acoustic	1st cough	0.032	0.292	0.054	0.6	0.562	0.110
	2nd cough	−0.051	0.329	0.061	−0.8	0.410	−0.155
AUC Acoustic	1st cough	0.003	0.017	0.003	1.0	0.316	0.176
	2nd cough	−0.006	0.020	0.004	−1.6	0.123	−0.300

Table 5
Correlations between reflexive cough (RC) at citric acid dose 3 and strong voluntary cough (VC) measures of the first cough and second cough.

	First Cough		Second Cough	
	Pearson's Correlation (r)	Significance	Pearson's Correlation (r)	Significance
Peak pressure RC vs Peak pressure VC	0.082	$p = 0.674$	0.055	$p = 0.776$
AUC pressure RC vs AUC pressure VC	0.144	$p = 0.457$	-0.065	$p = 0.739$
Peak flow RC vs Peak flow VC	0.309	$p = 0.103$	0.314	$p = 0.097$
AUC flow RC vs AUC flow VC	0.328	$p = 0.083$	−0.38	$p = 0.843$
Peak acoustic RC vs Peak acoustic VC	0.155	$p = 0.422$	0.459	$p = 0.012$
AUC acoustic RC vs AUC acoustic VC	0.316	$p = 0.095$	0.191	$p = 0.321$

Table 6
Correlations between measures for reflexive cough at all doses of citric acid and weak and strong voluntary cough.

	Reflexive Cough		Voluntary Cough	
	Pearson's Correlation (r)	Significance	Pearson's Correlation (r)	Significance
Peak pressure vs AUC pressure	0.628	$p < 0.01$	0.836	$p < 0.01$
Peak pressure vs Peak flow	0.571	$p < 0.01$	0.474	$p < 0.01$
Peak pressure vs AUC flow	0.377	$p < 0.01$	0.440	$p < 0.01$
Peak pressure vs Peak acoustic	0.334	$p < 0.01$	0.436	$p < 0.01$
Peak pressure vs AUC acoustic	0.313	$p < 0.01$	0.422	$p < 0.01$
AUC pressure vs Peak flow	0.757	$p < 0.01$	0.613	$p < 0.01$
AUC pressure vs AUC flow	0.756	$p < 0.01$	0.595	$p < 0.01$
AUC pressure vs peak acoustic	0.265	$p < 0.01$	0.420	$p < 0.01$
AUC pressure vs AUC acoustic	0.351	$p < 0.01$	0.559	$p < 0.01$
Peak flow vs AUC flow	0.802	$p < 0.01$	0.770	$p < 0.01$
Peak flow vs peak acoustic	0.001	$p = 0.99$	0.290	$p < 0.01$
Peak flow vs AUC acoustic	0.026	$p = 0.73$	0.288	$p < 0.01$
AUC flow vs peak acoustic	0.099	$p = 0.20$	0.447	$p < 0.01$
AUC flow vs AUC acoustic	0.112	$p = 0.14$	0.406	$p < 0.01$
Peak acoustic vs AUC acoustic	0.812	$p < 0.01$	0.694	$p < 0.01$

5. Discussion

This study evaluated pressure, airflow and acoustics measures of reflexive and voluntary cough to identify one salient objective measure of reflexive cough strength that could be easily implemented in clinical practice. It is the first step in establishing an objective threshold of effective reflexive cough strength to accurately identify patients at risk of aspiration pneumonia. Although there are methods available to clinically evaluate strength of voluntary cough, this research is unique in investigating reflexive cough strength in suppressed, rather than natural, reflexive cough. Based on effect sizes and correlation, peak flow and AUC pressure appear to provide optimal measurement and show the greatest potential for clinical application. In contrast, acoustic measures were found to be the least accurate and sensitive. A key finding of this study was the significant difference between strength of voluntary and reflexive cough in healthy individuals, and low correlations between voluntary and reflexive cough strength. This supports previous findings that assessment of voluntary cough does not provide accurate information on reflexive cough function [9,25,26]. Furthermore, increasing citric acid dose has no effect on suppressed reflexive cough strength. This finding is in contrast to other research which has reported a dose response effect with natural CRT [27–29] which highlights the need for further study into both suppressed and natural CRT using this methodology to enable more precise identification and management of patients at risk of aspiration pneumonia.

5.1. Reflexive and voluntary cough

It was hypothesized that as the dose of citric acid increased there would be a corresponding increase in magnitude of cough response. This was based on previous research that found positive dose-response relationships when investigating natural cough with increasing doses of tussigenic agent [27–29]. However, these results strongly indicate that there is no significant difference in

cough strength to different doses of citric acid. This outcome might be explained by the protocol of assessing suppressed, rather than natural cough. We postulate that suppressed cough is a closer approximation to true reflexive cough with no cortical involvement, as the individual can no longer voluntarily control their cough response [21]. This absence of a dose-response relationship in suppressed cough suggests that the strength elicited is an all-or-nothing response independent of stimulus dose. The dose-effect observed in natural reflexive cough could be explained by cortical augmentation of the all-or-nothing reflexive response. This suggests that any threat to the airway, whether a small amount of water or a large solid bolus, would result in the same strength of response to protect and clear the airway.

However, research in cats has demonstrated that coughing strength is greater when the risk of aspiration is larger [13]. Furthermore, research has concluded that a tussigenic agent does not identically replicate an aspiration event [15]. Therefore, cough responses in this study may not present the equivalent of a true reflexive cough response to aspiration and the existence of a dose effect with genuine aspiration is possible. Therefore, an alternative hypothesis for the absence of a dose-response relationship in suppressed cough is that although the sensitivity of suppressed cough is truly reflexive, the individual retains cortical control of coughing strength and that in trying not to cough, the cough strength is inhibited.

The cough sequence effect found in this study – with the first cough being stronger than the second – is consistent with other research showing that strength of coughing decreases over the course of a cough sequence [15,28,30]. This is likely due to decreasing lung volume as air is expelled during each cough, leading to less volume to contribute to subsequent coughs [28].

The finding that strong voluntary coughs were indeed stronger than weak voluntary coughs confirms that the outcome measures are sensitive to different levels of coughing strength, as hypothesized. As with reflexive cough, second coughs were found to be weaker than first coughs for measures of peak and AUC pressure, peak flow, and AUC acoustic.

The finding that strong voluntary coughs are stronger than reflexive coughs supports research that has shown that surface electromyography measures of respiratory muscle activity are greater for voluntary cough than for reflexive cough stimulated by a tussigenic agent [15]. Lasserson et al. [15] considered that this may be due to smaller lung volumes for reflexive cough compared to voluntary cough, in which there is usually inspiration before the cough. Our finding that weak voluntary coughs are not weaker, and are often stronger, than reflexive coughs was unexpected and suggests that, perceptually, suppressed cough will appear weak and subsequently be judged as ineffective in cough reflex testing. All of our findings are in agreement with previous research which contends that reflexive and voluntary coughs are physiologically different [7]. Furthermore, the differences in neurological control [31] signify that neurological disorders will impact reflexive and voluntary cough differently [19,26]. The first defence against aspiration is reflexive coughing. Voluntary coughing may facilitate clearance after an aspiration event, but does not inhibit aspiration [2]. Therefore, given the physiological and neurological differences between reflexive and voluntary cough the assessment of an individual's airway protection status should be assessed directly from assessment of reflexive cough, perhaps in conjuction with assessment of voluntary cough for aspiration clearance [9,25].

5.2. Clinical implications

This study suggests that many healthy individuals would perceptually present with a weak suppressed reflexive cough when compared to their voluntary cough and, thus, pass a CRT but be judged as weak. Subjective perceptual judgements of coughing strength should therefore be made with great caution as this could result in more conservative management than is indicated.

The relatively high number of healthy participants who failed to produce a suppressed reflexive cough response indicates that the use of suppressed reflexive cough testing alone in the clinical setting may result in a high proportion of patients being deemed to have an absent cough response. Previous research has revealed that some healthy individuals do not produce a cough response to citric acid (22% for suppressed and 5% for natural reflexive cough testing) [21]. It is unclear if this implies failure to cough to aspirate. However, it is hypothesized that a combination of natural and suppressed reflexive cough testing in the clinical setting would provide the best sensitivity and specificity to identify patients at risk of aspiration. Additionally, a combination approach would ensure that patients with cognitive or communication impairment who might struggle to follow instructions for the suppressed reflexive cough test are not disadvantaged.

Future research investigating the strength of both natural and suppressed reflexive cough would be useful to provide information about whether a dose-response effect exists in natural reflexive cough. It would also be of value to investigate strength of natural and suppressed reflexive cough to genuine aspiration to elucidate whether there is cortical inhibition of reflexive cough strength and whether there is a dose-effect with greater threat to the airway. Validation of our reflexive cough strength testing equipment, by comparison with videofluoroscopic swallowing study findings, would also be valuable to identify effective and ineffective cough strength thresholds as well as further evaluate the sensitivity of the different outcome measures.

6. Conclusions

This study supports research advocating the importance of assessing strength of reflexive cough, rather than voluntary cough, in the dysphagic population. Measures of pressure and airflow, in particular, show promise for such objective measurements. The absent citric acid dose-effect on suppressed reflexive cough strength highlights the need for further investigation of both suppressed and natural CRT using this methodology to enable more precise identification and management of patients at risk of aspiration pneumonia.

Declarations

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflicts of interest

None.

Acknowledgements

The authors gratefully acknowledge the technical assistance of Ester Guiu Hernandez in the development of the equipment utilised in this study and the programming for data extraction.

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