Annals of Otology, Rhinology & Laryngology
2017, Vol. 126(5) 396–400

DOI: 10.1177/0003489417694912
journals.sagepub.com/home/aor
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Measurement of Cough Aerodynamics in Healthy Adults

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Abstract

Importance: Cough is a critical human reflex and also among the most frequent symptoms in medicine. Despite the prevalence of disordered cough in laryngeal pathologies, comprehensive and quantitative evaluation of cough in these patients is lacking.

Objective: Herein we seek to establish normative values for cough aerodynamics to provide a population standard for reference in future studies.

Design, Setting, and Participants: Healthy subjects were recruited from an outpatient clinic to perform voluntary cough. Subjects were instructed on the technique for maximal voluntary cough production with measurements recorded on pneumotachograph. Fifty-two subjects were studied, including 29 women and 23 men with a mean age of 51.6 and 52.3 years, respectively.

Main Outcomes and Measures: Cough peak airflow, peak pressure, and expiratory rise time. Results were stratified by age, gender, and height.

Results: Peak airflow demonstrated significant differences across age, gender, and height, with flow increasing according to increasing height. Peak cough pressure also increased with height and was significantly greater in males versus females. Expiratory rise time, the time from glottal opening to peak airflow, did not vary with age or height but was statistically significantly longer in women.

Conclusions: Cough aerodynamics can be readily measured objectively in the outpatient setting. Expiratory rise time, peak flow, and peak pressure are important aspects of each cough epoch. Normative data provided herein can be used for future studies of patients with laryngotracheal disorders, and these cough parameters may prove to be simple, accessible, and repeatable outcome measures.

Keywords

cough, respiratory function tests, laryngology, respiratory tract diseases, laryngeal diseases, aspiration pneumonia

Introduction

Cough is a critical human reflex that prevents aspiration of foreign materials into the airway, responds to aerodigestive irritants, and expectorates mucus and foreign materials from the tracheobronchial airway and lungs.[1,2] Cough is the most common chief complaint among all patients evaluated by primary care physicians in the United States, and chronic cough is among the most frequent reasons for referral to a pulmonologist and an otolaryngologist.[3]

The majority of patients with disordered cough suffer from the common cold or other acute infections of the respiratory tract.[1,4] Other etiologies include asthma, bronchitis, gastroesophageal reflux disease, chronic obstructive pulmonary disease, upper airway cough syndrome, and neurogenic cough (the latter of which is variably referred to as neuropathic cough, cough hypersensitivity syndrome, or postviral-vagal neuropathy).[5] Thus, cough onset, quality, frequency and severity represent a diverse range of underlying pathologies. Otolaryngologists can play an important role in diagnosis and treatment of disordered cough.

Although disordered cough is among the most frequently encountered symptom in all of medicine, assessment of cough strength and quality is not presently a routine aspect of care because basic cough mechanisms remain poorly understood. Distinguishing a normal, healthy cough from a

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pathologic cough may not be obvious to clinicians based solely on their acoustic perception.[6] Furthermore, studies linking the acoustic or aerodynamic features of cough with underlying pathophysiology are limited to a few disease processes.[6,7]

The normal cough sequence consists of glottal opening during a slow inspiratory phase, a compression phase with closed glottis, and rapid glottal opening during the expiratory phase.[8] The inspiratory phase is associated with great variability, while the compressive phase is consistently brief.[9] The slow inspiratory phase may also be absent in subsequent coughs during a single cough epoch.[8] The compressive phase requires vocal fold adduction via the intrinsic laryngeal muscles to allow the buildup of subglottic air pressure. The rapid expiratory phase is associated with an initial vocal fold abduction via activation of the posterior cricoarytenoid muscle,[10,11] which is closely followed by glottal narrowing due to the Bernoulli phenomenon before returning to the normal inspiratory position.[9]

Prior cough research has focused primarily on pulmonary physiologic parameters, such as the typical cough pattern associated with specific underlying pulmonary pathologies, the relation between cough volume and pulmonary function measures, and peripheral and central neurologic mechanisms of cough reflex and suppression.[12,13] It has been hypothesized that laryngotracheal pathologies may reduce effectiveness or intensity of cough peak airflow due to their glottic or subglottic constriction or reduced glottal resistance. However, no prior study has collected normative data for cough peak airflow in a healthy adult population. We therefore recruited healthy adults to measure aerodynamic parameters of cough. The goal of this study was to develop normative data for use as a benchmark for future research in patients with laryngotracheal pathology.

Materials and Methods

Healthy individuals over age 18 without laryngotracheal, pulmonary, or neurodegenerative pathology or current respiratory infection were recruited from the head and neck surgery clinic. Persons with current or past tobacco use were excluded. Informed consent was obtained from all subjects prior to participating in the study. This study was approved by the local Institutional Review Board.

Study measurements were obtained with the subjects in the standard seated position as recommended by the American Thoracic Society spirometry guidelines.[14] Subjects were asked to perform a maximal voluntary cough following demonstration of the same by a member of the research team. The subject was instructed to inspire deeply, then cough as forcefully as possible. Two practice attempts were performed prior to undertaking recordings, and 3 consecutive attempts were thereafter recorded. The maximal cough epoch was selected for analysis, which is the usual analytic method within the literature.[15,16] The cough was measured with a pneumotachograph, which is a noninvasive device for measurement of aerodynamic parameters such as airflow and pressure and is considered the "gold standard." The measurement system consisted of a pneumotachograph with dual respiratory flow heads and 2-chamber adult face mask (Glottal Enterprises, Syracuse, New York, USA), dynamic cardioid microphone (Shure SM58, Niles, Michigan, USA), multichannel data acquisition system (National Instruments Corporation NI 9215, Austin, Texas, USA), and analytic software (LabVIEW SignalExpress 2012 Version 6.0.0, National Instruments Corporation). After collecting aerodynamic data with the pneumotachograph, airflow measures were extracted utilizing Matlab (R2015a, Mathworks, Natick, Massachusetts, USA). The peak expiratory flow and peak expiratory pressure were measured directly (Figure 1). The expiratory rise time was calculated as the time from the beginning of the expiratory phase to the peak expiratory flow, which represents the time from glottal opening to achievement of maximal air flow.[17,18]

Descriptive statistics were used to compare demographic characteristics. Frequency histograms and scatter plots with linear regression were generated for visual inspection of healthy population data. The 1-way analysis of variance test was utilized to compare means for the aerodynamic parameters among patients in different age, gender, and height groups; these factors are known to impact pulmonary function and are the recommended parameters for adjustment of spirometry tests.[19] Statistical analyses were performed using Stata/MP Version 13.0 (StataCorp, College Station, Texas, USA).

Results

Healthy subjects recruited for analysis included 29 women and 23 men with a mean age of 51.6 and 52.3 years, respectively. There were 23 subjects within the age range of 20-49 and 29 subjects within the age range of 50-80. Fifty years was selected as an age division point to produce 2 groups each with a 30-year span of ages. All patients had a maximum phonation time of greater than 10 seconds.

Peak flow was significantly different according to age, gender, and height. The peak flow was 803.8 L/min among subjects in the younger age group (20-49) as compared to 604.5 L/min among subjects in the older age group (50-80) (P = .008; Table 1). Peak flow was also different between men and women, with mean flows of 828.2 versus 585.1 L/min, respectively (P = .0009; Table 2). Peak flow increased as height increased, with mean flow of 577.1 L/min in the lowest height group and increasing to 1116.0 L/min in the highest height group (P = .002; Table 3).

Peak pressure was significantly different by gender and height but not by age. Male subjects had higher peak pressures than female subjects, with a mean pressure of 1.63 Pa

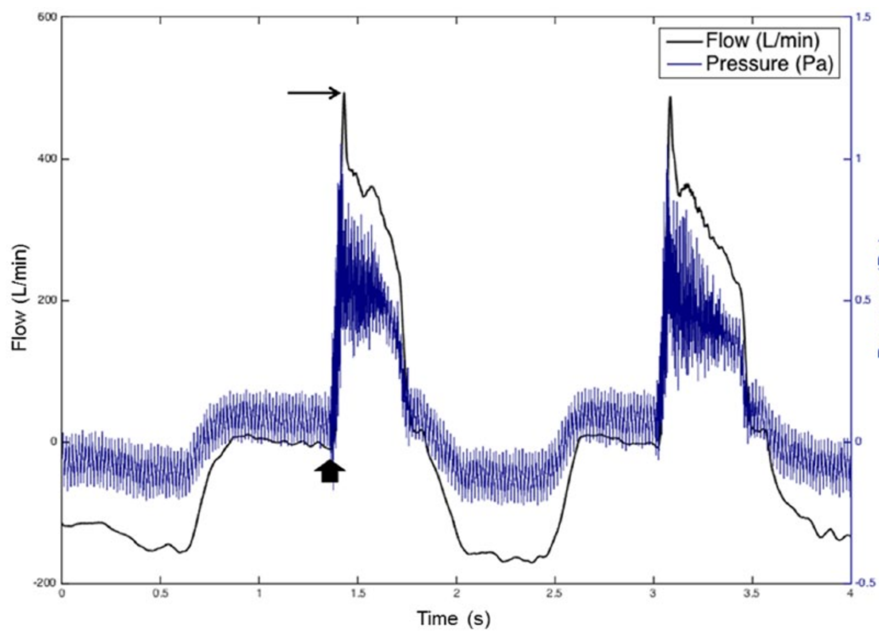

Figure 1. Airflow and pressure measurements of a normal human cough as measured by the pneumotachograph. Thin arrow indicates the cough expiratory peak time point, where peak flow and peak pressure are measured. Thick arrowhead indicates the onset of cough at the moment of transition from the compressive phase to the expiratory phase, indicating sudden glottal opening. The expiratory rise time is the duration from onset of cough to peak flow (between the 2 arrows).

Table 1. Aerodynamic Measures of Normal Adult Cough Stratified by Age.

	Age Group				
	20-49		50-80		
	n = 23		n = 29		
Characteristic	M	SD	M	Sd	*p* Value
Female (n, %)	7	46.7	11	68.8	.21
Height (in)	67.5	3.7	66.5	4.2	.36
Peak flow (L/min)	803.8	286.1	604.5	230.8	.008
Peak pressure (Pa)	1.42	0.52	1.30	0.47	.382
Expiratory rise time (ms)	65.4	12.7	65.1	20.0	.953

Table 2. Aerodynamic Measures of Normal Adult Cough Stratified by Gender.

	Gender				
	Male		Female		
	n = 23		n = 29		
Characteristic	M	SD	M	SD	*P* Value
Age (y)	51.6	19.0	52.3	15.2	.876
Height (in)	69.9	3.0	64.5	3.0	<.0001
Peak flow (L/min)	828.2	231.3	585.1	258.3	.0009
Peak pressure (Pa)	1.63	0.46	1.12	0.39	.0001
Expiratory rise time (ms)	58.9	16.9	70.3	15.5	.015

versus 1.12 Pa in women (P = .0009). Peak pressure also increased according to patient height group, with a mean value of 1.11 Pa in the lowest height group and increasing to 2.06 Pa in the highest height group (P < .0001).

The expiratory rise time was found to have the least variability of the aerodynamic measures among healthy patients. There was no significant difference in the expiratory rise time among patients in different age or height groups. The rise time was significantly different between genders, with a mean value in men of 58.9 milliseconds versus 70.3 milliseconds in women (P = .015).

Discussion

Measurement of respiratory parameters such as pulmonary function tests (PFT) for patients with COPD or expiratory peak flow for children with asthma is a routine aspect of patient care, but measurement of cough has not been widely applied in daily practice.[20] One of the major barriers to

Table 3. Aerodynamic Measures of Normal Adult Cough Stratified by Height.

	Height Group								
	60-64”		65-69”		70-74”		75-80”		
	n = 13		n = 29		n = 7		n = 3		
Characteristic	M	SD	M	SD	M	SD	M	SD	*P* Value
Female (n, %)	13	100.0	16	55.2	0	0.0	0	0.0	<.0001
Age (y)	52.9	16.3	49.1	18.0	62.4	11.1	50.7	14.7	.318
Peak flow (L/min)	577.1	186.5	653.9	271.5	886.3	190.1	1116.0	209.6	.002
Peak pressure (Pa)	1.11	0.39	1.25	0.39	1.91	0.43	2.06	0.31	<.0001
Expiratory rise time (ms)	73.4	12.2	63.6	16.1	62.7	25.9	51.8	8.5	0.151

incorporating measurements of cough aerodynamics in patient assessment and management is the lack of normative data for comparison. Here we provide normative data on cough peak expiratory flow, peak expiratory pressure, and expiratory rise time in a sample of 52 healthy adults. The data are stratified by age, gender, and height and allow for comparison in future studies of the impact of neurological and laryngotracheal disorders on cough and vice versa.

Significant gender differences in cough aerodynamics were noted in this study. The cough peak flow was lower in female subjects, along with the peak pressure. The expiratory rise time was longer for females, with a mean of 70.3 milliseconds relative to 58.9 milliseconds for males. These findings are consistent with pulmonary spirometric findings demonstrating lower peak expiratory flow for women as compared to men[21] as well as lower cough peak flow in female adolescents as compared to male adolescents.[16] These findings highlight the need for gender-specific normative data when studying pathophysiology.

Although this study included a large number of healthy adults and allowed for comparisons across age, gender, and height, we did not have a large enough sample for multivariate regression analysis. Some spirometers rely on regression equations to calculate predicted pulmonary function test results; however, use of normative data tables is also a common analytic method. We utilized a gold standard pneumotachograph that is known to correlate to direct measures such as the subglottal tap technique; however, improved precision of pressure measures may potentially have been obtained by employing direct subglottal manometry. We chose to not use this invasive technique for research in these healthy subjects.

Measurements of cough parameters into clinical practice may allow cough strength to become an indicator of functional status and perhaps a tool to help guide patient care. Objective measurement of cough strength could reveal this functional role of the larynx in a way that other currently available assessment tools for voice and deglutition do not.

Conclusion

Cough is an important human reflex, and disordered cough can have a significant impact on patients. Despite this, complete quantitative data on adult human cough have not been available. In this study, we employed pneumotachography as a tool for quantitative cough analysis. These data demonstrate the importance of stratifying by age, gender, and height in future research. Expiratory rise time is the most consistent cough parameter among healthy patients and may provide a novel measure of physiologic relevance for future studies of pathologic cough.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This study was supported by Grants R01DC011299 and R01DC011300 from the National Institutes of Health, and Department of Veteran Affairs, Veterans Health Administration, Office of Research and Development, Biomedical Laboratory Research and Development VA Career Development Award IK2BX001944.

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