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Original Article

Reliability of voluntary cough assessments using respiratory flow waveform

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Abstract. [Purpose] Voluntary cough can be assessed by recording flow waves. The purpose of this study was to examine the reliability of the measurements of respiratory flow waveforms, using equipment that recorded flow waves during cough. [Participants and Methods] Twenty healthy participants were recruited for this study. They underwent spirometry on them and, subsequently, their flow waves during single and consecutive voluntary cough tasks in the sitting position were recorded. The intra-class correlation coefficient was used to assess the intra-rater and inter-rater reliabilities for the voluntary cough data. [Results] The intra-class correlation coefficients were 0.6 to 0.8 for 'intra-rater reliability' and higher than 0.9 for 'inter-rater reliability', for single and consecutive cough tasks. The first assessment of cough peak flow was significantly higher than the second, during consecutive cough tasks. Similarly, the first assessment of cough volume acceleration was significantly higher than the second. [Conclusion] Our results demonstrated high intra-rater and inter-rater reliabilities for single and consecutive cough tasks. Following additional procedures and valuations, including the storage of data and standard range decisions, this method of cough assessment will be applied to patients with reduced cough function.

Key words: Voluntary cough, Respiratory flow waveform, Reliability

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INTRODUCTION

Cough is a physiological protective mechanism indispensable for clearing secretions in the airway.

Voluntary cough has three phases. During the inspiratory phase, deep inspiration begins. During the compression phase, the thoracic and abdominal cavities increases rapidly. During the expiratory phase, the glottis opens quickly and the expiratory muscles force expiration.[1)]. Many factors can reduce cough function, including aging[2)], neuromuscular diseases[3–5)], Parkinson's disease[6)], and more. Reduction of cough function may lead to secretion retention, which can increase the risk of respiratory complications. Therefore, it is important to assess cough function to prevent these complications.

Cough function can be assessed in a number of ways, including respiratory flow[7–13)], noises during cough[14)], pleural pressures[15)], and electromyography of abdominal muscles[7)]. Respiratory flow, in particular, is widely used and the measurement of peak cough flow (CPF)[16, 17)] is convenient and easy to use. However, its assessment is unsuitable in patients who need more detailed evaluations of their cough ability. Because this method is unable to measure conditions at each of the cough phases. If it's clear which parameters of cough has abnormality, it's possible to perform an efficient rehabilitation program.

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Furthermore, there are times when patients have to cough continuously for clearing secretions. However, it is not clear about the character of consecutive cough.

In this study, we utilized the measurement technique developed by Pitts T et al[18]. This technique evaluates each cough parameter by recording the flow waves during cough. This method can analyze airflow precisely, and it can be measured not only in single coughs but also in consecutive ones. Therefore, cough ability can be analyzed in greater detail. There are two reports[13, 18] about consideration of the reliability of the flow waves during cough. Singh[13] reports the reliability of only CPF and PVT (peak velocity time). Pitts[18] reports that of all cough parameters for the patients with Parkinson's disease. Therefore, there are no reports of the reliability of all cough parameters for normal people.

The purpose of this study was to examine the reliability of the measured value respiratory flow waveforms as assessed by pneumotachograph.

PARTICIPANTS AND METHODS

Twenty healthy participants were recruited for this study. They had no history of smoking or any cardiac or pulmonary disease. All participants provided written informed consent. All procedures adhered to the Declaration of Helsinki and were approved by the Ibaraki Prefectural University of Health Sciences Ethics Committee (Approval number 601). First, measurement of spirometry and respiratory muscle strength were performed with a multi-function spirometer (HI-801, Chest M.I, Inc. Tokyo, Japan) (Table 1). Parameters of lung functions included vital capacity (VC), predicted forced vital capacity (%VC), forced vital capacity (FVC), forced expiratory volume in 1 second (FEV1), and proportion of FEV1 and FVC (FEV1/FVC). Parameters of respiratory muscle power included maximum inspiratory mouth pressure (PImax) and maximum expiratory mouth pressure (PEmax).

Three raters accustomed to using the equipment measured the waveforms in this study. Participants were tried to cough three times after watching a demonstration and practicing three times. In the single voluntary cough task, a rater said, "Please cough hard after you take a deep breath" to the participant. In the consecutive cough task, the rater said, "Please cough twice after you take a deep breath". In both tasks, coughs were performed in a free timing. Participants performed the single and consecutive cough tasks for all three raters. The sequence of the three raters was randomly determined and a 1-min interval was set between each task. Each raters measured each participant twice at an interval of 1 week.

We assembled the following equipment. Respiratory flow was measured by Respiratory Flow Heads (MLT300L, ADInstruments, Sydney, Australia) with facemask, and the analog signal was amplified via a respirable amplifier (AR-601G, NIHON KOHDEN, Tokyo, Japan). The analog signal was then converted into a digital one via an analog-to-digital converter (PowerLab/16SP, ADInstruments, Sydney, Australia). The flow signal was digitized at 1 kHz using the application program of time series analysis (LabChart, ADInstruments, Sydney, Australia).

A reprehensive wave pattern of the single cough is shown in Fig. 1. In the single voluntary cough task, the three cough phases (inspiratory, compression, expiratory) were determined from the respiratory flow waveforms. This waveform determined the following parameters: 1. inspiratory phase duration (IPD) [sec] as the length of the inspiratory phase, 2. inspiratory peak flow (IPPF) [L/sec] as the bottom absolute value in the inspiratory phase, 3. compression phase duration (CPD) [sec] as the length of the compression phase, 4. cough peak flow (CPF) [L/sec] as the top value in the expiratory phase, 5. expiratory rise time (EPRT) [sec] as determined from the point where the upward curve begin to the top value in the expiratory phase, 6. cough volume acceleration (CVA) [L/sec^2] as the CPF divided by the ERPT (Fig. 1).

In the consecutive voluntary cough tasks, the same method was used as for single coughs about 2 times of coughs (Fig. 2). In consecutive coughs, CPF_{1st} and CVA_{1st} were defined as CPF and CVA in the first cough, and CPF_{2nd} and CVA_{2nd} were defined as CPF and CVA in the second cough.

The results are shown with mean values and standard deviations (SD). Intra-class correlation coefficient (ICC) was evaluate intra- and inter-rater reliability for voluntary cough data. For the intra-rater reliability, ICC (1.3), data at the first and 1

Table 1. Charactristics, plumonaly function, and cough capacity parameters

Parameter	Data
Male/Female (n)	10/10
Age (years)	20.5 ± 0.6
Height (cm)	164.9 ± 7.8
Weight (kg)	55.2 ± 7.9
%VC (%)	103.1 ± 10.9
FEV1/FVC (%)	91.3 ± 5.5
PImax (cmH_2O)	66.8 ± 22.3
PEmax (cmH_2O)	73.9 ± 32.4

Data are numbers or means ± SD for all participants.
%VC: predicted forced vital capacity; FEV1/FVC: proportion of forced expiratory volume in 1 second and forced vital capacity; PImax: maximal inspiratory pressure; PEmax: maximal expiratory pressure.

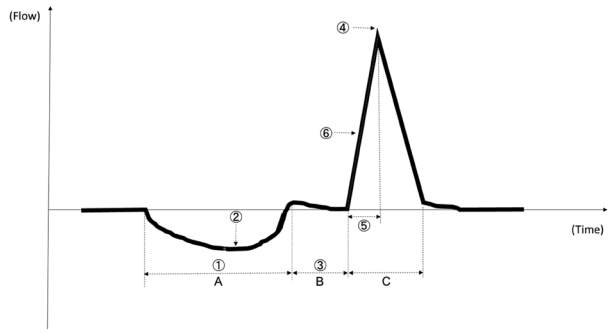

Fig. 1. Sample respiratory flow waveform.
A: inspiratory phase; B: compression phase; C: expiratory phase. 1. IPD: inspiratory phase duration (sec); 2. IPPF: inspiratory peak flow (L/sec); 3. CPD: compression phase duration (sec); 4. CPF: cough peak flow (L/sec); 5. EPRT: expiratory rise time (sec); 6. CVA: cough volume acceleration (L/sec^2).

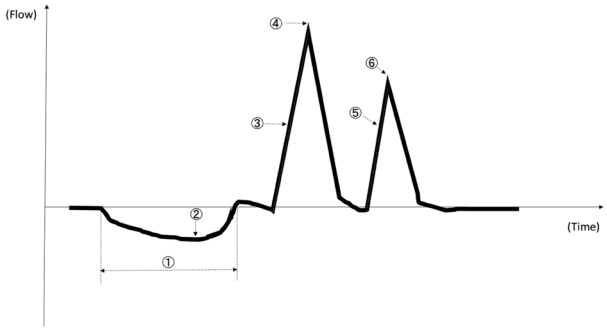

Fig. 2. Respiratory flow waveforms of consecutive voluntary coughs. 1. IPD: inspiratory phase duration (sec); 2. IPPF:inspiratory peak flow (L/sec); 3. CVA1st: first time of cough volume acceleration (L/sec^2); 4. CPF_{1st}: first time of cough peak flow (L/sec); 5. CVA_{2nd}: second time of cough volume acceleration (L/sec^2); 6. CPF_{2nd}: second time of cough peak flow (L/sec).

week later were compared. For the inter-rater reliability, ICC (2.3) measuring data on the same day were used. In consecutive coughs, two kinds of CPF and CVA were compared using Wilcoxon signed rank test. All data were analyzed using SPSS 22.0 (SPSS, Inc; Chicago, IL, USA) and a p-value less than 0.05 was considered statistically significant.

RESULTS

Table 1 lists the participants' characteristics. All participants demonstrated normal pulmonary function (%VC ≥80 and FEV1/FVC ≥70). Table 2 shows intra-rater reliability in the voluntary single cough and consecutive cough tasks, respectively, with ICCs of 0.6 to 0.8. IPPF showed the lowest value with 0.615 at single cough task. IPPF and CPF_{2nd} indicated low value ICC with 0.649 and 0.616 at consecutive cough tasks. Similarly, Table 3 shows inter-rater reliability. These ICC values were all more than 0.9. The first time of CPF was significantly greater than the second time of that at consecutive cough tasks. Similarly, the first time of CVA was significantly greater than the second time of that (Table2).

DISCUSSION

We assembled the equipment in order to assess wave forms during cough in detail. And this research considered whether the intra-and inter-rater reliability of was obtained in measurement of respiratory flow waveforms with our equipment. First, we will consider the validity of our single voluntary cough task results using our equipment. While McCool[1)] reported that CPF in a single cough is approximately 6 L/sec, the CPF was 7.49–8.13 L/sec in our study. We suspect that our CPF values were slightly higher because the participants were younger and their %VC was beyond 100%. Therefore, they had normal respiratory function. While it has been reported that the glottis closes at approximately 0.2 sec[1)], the average CPD in our study was 0.25–0.28 sec. Voluntary factors may influence CPD, with participants purposely lengthening their CPD in order to cough harder. Based on these results, we believe our equipment can reliably assess a single cough. Standard values for IPD and IPPF have only infrequently been reported in the literature and we therefore suspect that our study data may actually become reference data because voluntary action strongly influences IPD and IPPF and therefore predictably may occur in these measurements.

Landis et al.[19)] categorized the value of ICC, which is 0.61–0.80 was substantial and 0.81–1.00 was almost perfect. The ICCs of inter rater reliability was more than 0.9 for all parameters of both the single and the ICC was cough tasks and all parameters were relevant to almost perfect. This finding suggests that our equipment has a high reliability and may be useful in the assessment of cough function, especially with the previously mentioned validity. For intra-rater reliability, the ICCs were 0.615–0.829 at single cough task and they were 0.616–0.890 at consecutive cough task. Inter-rater reliability has two parts that we must consider, the rater's measurement skill and the participant's reappearance skill. The rater's measurement skill almost depends on control of the equipment in terms of the character of this study, therefore, it is hardly influenced by the elements of the raters were good or bad at the measurement. The participant's reappearance, skill means that he or she can perform the same task in the same way. Participants may not have had enough time to acquire the necessary skills for this study, particularly the voluntary consecutive cough. Further studies should determine how to assess if participants have had enough practice time to acquire the necessary skills.

Historically, the peak flow meter has been used mainly for the assessment of cough. However, the peak flow meter can only assess one point, the CPF, in the expiratory phase. In comparison, our setup for measurement can assess not only expira-

Table 2. Intra-rater reliability at cough tasks

Task	Parameter	First time	One week later	ICC	95%CI
Single cough					
	IPD (sec)	1.31 ± 0.32	1.26 ± 0.34	0.769	0.51–0.90
	IPPF (L/sec)	2.21 ± 0.82	2.61 ± 0.86	0.615	0.26–0.83
	CPD (sec)	0.28 ± 0.14	0.25 ± 0.12	0.829	0.62–0.93
	CPF (L/sec)	7.49 ± 2.31	8.13 ± 2.34	0.725	0.43–0.89
	CVA (L/sec^2)	142.58 ± 58.23	155.66 ± 59.71	0.858	0.68–0.94
Consective coughs					
	IPD (sec)	1.35 ± 0.28	1.26 ± 0.28	0.729	0.44–0.88
	IPPF (L/sec)	2.41 ± 0.77	2.74 ± 0.76	0.649	0.31–0.84
	CPD (sec)	0.30 ± 0.11	0.27 ± 0.12	0.731	0.44–0.88
	CPF_{1st} (L/sec)	8.07 ± 2.44*	8.28 ± 2.57*	0.778	0.53–0.91
	CPF_{2nd} (L/sec)	5.24 ± 1.24	5.36 ± 1.25	0.616	0.26–0.83
	CVA_{1st} (L/sec^2)	147.14 ± 62.99*	152.29 ± 62.21*	0.890	0.75–0.96
	CVA_{2nd} (L/sec^2)	121.89 ± 38.91	128.63 ± 45.00	0.835	0.63–0.93

*$p<0.05$.
Data are numbers or means ± SD for all participants.
IPD: inspiratory phase duration; IPPF: inspiratory peak flow; CPD: compression phase duration; CPF: cough peak flow; CVA: cough volume acceleration; ICC: intra-class correlation coefficient; CI: confidence interval.

Table 3. Inter-rater reliability at cough tasks

Task	Parameter	Rater			ICC	95%CI
		A	B	C		
Single cough						
	IPD (sec)	1.29 ± 0.32	1.34 ± 0.41	1.29 ± 0.29	0.90	0.79–0.96
	IPPF (L/sec)	2.41 ± 0.85	2.49 ± 0.85	2.37 ± 0.80	0.95	0.90–0.98
	CPD (sec)	0.26 ± 0.13	0.28 ± 0.13	0.27 ± 0.12	0.91	0.81–0.96
	CPF (L/sec)	7.67 ± 2.47	7.99 ± 2.82	7.82 ± 2.66	0.99	0.97–0.99
	CVA (L/sec^2)	155.66 ± 62.36	160.00 ± 67.30	152.57 ± 65.34	0.99	0.98–0.99
Consective coughs						
	IPD (sec)	1.25 ± 0.28	1.33 ± 0.32	1.28 ± 0.28	0.93	0.86–0.97
	IPPF (L/sec)	2.49 ± 0.79	2.59 ± 0.81	2.64 ± 0.87	0.93	0.85–0.97
	CPD (sec)	0.28 ± 0.12	0.30 ± 0.13	0.27 ± 0.12	0.93	0.85–0.97
	CPF_{1st} (L/sec)	7.96 ± 2.57	8.08 ± 2.65	8.03 ± 2.70	0.99	0.99–0.99
	CPF_{2nd} (L/sec)	5.13 ± 1.39	5.24 ± 1.40	5.23 ± 1.41	0.94	0.95–0.99
	CVA_{1st} (L/sec^2)	146.65 ± 64.87	158.02 ± 66.54	152.19 ± 65.38	0.99	0.98–0.99
	CVA_{2nd} (L/sec^2)	126.29 ± 46.19	127.77 ± 46.08	131.83 ± 46.31	0.98	0.95–0.99

Data are numbers or means ± SD for all participants.
IPD: inspiratory phase duration; IPPF: inspiratory peak flow; CPD: compression phase duration; CPF: cough peak flow; CVA: cough volume acceleration; ICC: intra-class correlation coefficient; CI: confidence interval.

tory phase function in three phases. Successfully evaluating the characteristics of the cough waveform may have real clinical benefit indicating underlying diseases or disorders.

Furthermore, our equipment can assess not only a single cough but also consecutive coughs. It is also necessary the ability to continue coughs hard for clearing secretions in the airway. In the consecutive cough task, CPF_{2nd} and CVA_{2nd} were smaller than CVA_{1st} and CVA_{2nd}. And voluntary elements in the inspiratory and compression phases were excluded for the second cough. Therefore, it resembles an involuntary cough, which can be hard to evaluate. Therefore, we think that making this method practicable is meaningless.

In the limit of this study, we didn't consider the validity of the assessment of cough function with our equipment. It's necessary to estimate the validity with the cough parameters and respiratory function and so on. And our setup is large-scale and therefore hard to transfer. However, it can be improved by miniaturization of the PC and other elements. we are planning to complete further studies on investigating optimal ways to educate participants regarding the cough task, storage of normal data, standard range decisions, and adjustment waveform characteristics by disease

Conflict of interest

The authors declare no conflicts of interest.

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