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Objective assessment of cough

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ABSTRACT: Cough is a primitive reflex typically consisting of an initiating deep inspiration, glottal closure, and an explosive expiration accompanied by a sound. The flow characteristics of cough have been shown to differ between different pulmonary diseases. Cough sounds are generated at the larynx and in the lungs.

Modern analysing techniques have also been applied in cough sound studies, and differences in cough sound duration and spectra have been found in pulmonary diseases with different bronchopulmonary pathophysiology. Since the objective assessment of cough is clinically important, automatic cough detectors and counters have been constructed, *e.g.* to assess the efficacy of antitussive drugs. Also, ambulatory methods for assessment of cough have been reported.

This review includes a brief history of cough research and present methods available for objective assessment of cough.
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Once triggered, the cough reflex can be described as a sudden rapid air expulsion, with a forceful expiratory effort accompanied by an explosive transient sound. The main purpose of the cough reflex is to clear the airways from inhaled foreign bodies and to enhance mucociliary clearance in cases of impaired ciliary function and excessive mucus production. Cough often reflects respiratory illness or irritation, and it can also be an early symptom of asthma [1]. The physical character of cough depends on the underlying disease; it has been described as, *e.g.* dry, loose, or whooping, depending on the amount of expectoration and sound quality. In chronic obstruction and inflammatory diseases of the airways, the clearing of excess phlegm is highly dependent on the effectiveness of cough.

One of the first attempts to scientifically study the mechanics of cough reflex was made by CORYLLOS [2], as early as 1937, who measured the movements of the diaphragm, using manometric recording of intrapleural pressure *via* an inserted pneumothorax catheter during cough. Since then, several attempts have been made to record cough, based on the movement of the chest [3], airflow measurement at the mouth [4–8], and sound measurement of cough [9–12]. In cough experiments, cough has been triggered with inhalant irritants, such as citric acid [7, 13–16] or capsaicin, an important C-fibre stimulating agent [17, 18]. Attempts to study the spectral character of cough sound have been undertaken [9–11]. Also, the dynamics of the cough airflow curve [4, 5, 19, 20] have been recorded.

Cough can be a sign of the severity of a disease. The assessment of the frequency of cough events is important in pharmacological studies, where the clinical efficacy of antitussive medicines has to be evaluated. Therefore, methods using cough sounds for counting the cough events have also been developed. This review focuses on the historical background of cough research, as well as on modern methods for analysis and measurement of cough.

The cough reflex

Irritation of afferent cough receptors in the airways initiates the cough reflex. The vagus nerve conducts the afferent signal to the cough centre in the brainstem. As a response, efferent nerve impulses stimulate the diaphragm, intercostal muscles and larynx to produce the forceful explosive expiration of cough.

A deep inspiration usually starts a single cough (the inspiratory phase). During the subsequent compressive phase the glottis is temporarily narrowed and closed. During the last, expulsive phase, the sudden opening of the glottis occurs with transient and fast expiratory airflows [21–23]. A phonopneumogram of one cough is presented in figure 1. As indicated in the figure, glottal closure and the expulsive phase can be repeated several times without any inspiratory phase. Cough in which one single inspiration is followed by successive expiratory flow spikes of cough, not separated by inspiratory phases, is sometimes called a cough sequence [26]. Glottal closure does not seem to be absolutely necessary for coughing; patients with tracheostomy or laryngectomy are able to cough [21, 27, 28].

The pattern of cough possibly depends on the different sites of the airways and different stimuli causing the
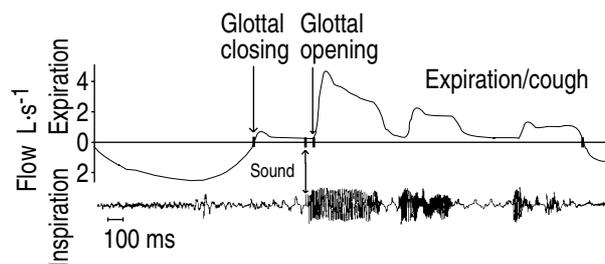
Fig. 1. – A phonopneumogram of cough. The airflow has been measured at the mouth and the cough sound at the sternal manubrium of the patient. A deep inspiration precedes the rapid expiration of cough and the cough sound begins before the CPEF. This cough sequence contains three cough flow phases [24, 25]. CPEF: cough peak expiratory flow.

cough reflex. Mechanical stimulation of the larynx can cause more prominent expiratory efforts than does mechanical stimulation of the lower airways [27]. Cough induced by a chemical stimulus in the lower respiratory tract tends to have stronger inspiratory components than cough caused by mechanical stimuli [29].

The rapidly adapting receptors stimulated by light touch and irritants are concentrated in the region of the carina, but they can also exist more proximally and peripherally in the airways [29, 30]. Pulmonary stretch receptors are located in the airway smooth muscle surrounding the trachea and bronchi [31], and are stimulated by stretching of the smooth muscle. The C-fibres in the bronchial walls, which are also known to be associated with bronchoconstriction [32], are possibly also receptors involved in the cough reflex. The oeosphageal-tracheobronchial cough reflex triggered by gastro-oesophageal reflux has also been shown to be a usual cause of cough [33].

Bronchial dynamics during cough

High airflow in the bronchi and the small cross-sectional area of the bronchi during coughing are important in clearing the airways from excess mucus. During the compressive phase of cough, the intrathoracic pressure increases to exceed the intrabronchial pressure, and the calibre of the bronchi diminishes [8, 34]. Reduction of the cross-sections of the bronchi to 50% of the normal calibre is usually considered to be the limit of normal airway narrowing during cough [35], although diminution to less than 40% of their normal calibre has also been reported in normal subjects [36, 37]. Simultaneously with the airway narrowing, the airflow velocity increases, enhancing the effectiveness of cough to remove secretions from the bronchi [26, 34].

The alveolar end of the bronchial tree remains open during the dynamic compression of cough, because the alveolar pressure is greater than the pleural pressure. The reverse occurs at the mouth end, beginning at the volume point when the pleural pressure and intrabronchial pressure are equal (equal pressure point, EPP). It is well-known that the site of EPP depends on the actual lung volume, but is independent of the subject's effort [36, 38, 39]. Therefore, in the airways proximally to EPP the only way to increase the pressure is to increase

the compression of the bronchi, which causes further narrowing of the cross-sectional area and increases the velocity [34].

In cough sequences, the actual volume of the lungs decreases flow spike by flow spike, and the EPP moves more peripherally. Thus, more and more of the smaller airways will be compressed and their lumens narrowed [34]. For the same oral flow rate, thoracic pressure has been found to fall only slightly with each cough spike, and it remains high during the whole cough sequence [40]. Therefore, the mean linear velocity in the intrathoracic airways may be greater in a cough sequence than in a single cough [40]. During a cough sequence, secretions are first removed from the large airways at high lung volumes; when the EPP moves peripherally, the secretions are removed from the smaller towards the larger airways. Especially in irreversible airway obstruction, *e.g.* chronic bronchitis and emphysema, the obstruction tends to displace the EPP towards the alveoli, and the length of the compressed segment increases [38]. The cough reflex is probably more effective in terms of foreign body or mucus expectoration when EPP is in the peripheral airways and *vice versa* [34]; the length of the compressed segment determines in which airways the cough is an effective means of eliminating secretions.

The flow dynamics of cough

The dynamics of cough can easily be visualized in a flow *versus* time presentation of the cough signal. Some studies using the flow curve of cough have been published [4–8]. In the flow recording of cough, pneumotachographs are needed which are sensitive enough to enable recording of the rapid flow changes occurring during a cough sequence. The durations of the flow phases of the cough reflex can easily be measured in the flow *versus* time presentation of cough.

Data on the duration of the glottal closure during the compressive phase of cough vary in the literature: about 0.2 s [8]; 0.09–0.34 s [41]; about 0.042 s [42]; and 0.040–1.010 s [25]. During the glottal closure, the subglottic pressure rises before the expiratory phase, and the duration of the glottal closure can be thought to reflect the effectiveness of the compressive phase of cough. Therefore, the duration of glottal closure possibly shows substantial variation, depending on the disease stage which causes different cough mechanisms [25].

In cases of the tracheobronchial collapse syndrome [43–45], cough is associated with only slight expectorations. According to our previous studies [25], high inspiratory and expiratory cough peak flow values, long duration of glottal closure and few flow peaks in the cough sequences were typical for cough caused by the tracheobronchial collapse syndrome of the proximal airways. In this kind of cough, the compressive phase and high flows in the central airways are possibly more important in the cough mechanism than, for example, in chronic obstruction. We have also observed that the duration of glottal closure increased towards the end of the cough bursts (consecutive coughs separated from each

other by inspirations). This indicates that the compressive phase of cough may play a more important role at the end than at the beginning of a cough burst.

Patients with diseases with copious sputum and chronic bronchial obstruction show multiple flow spikes and long cough sequences. Marked collapse of peripheral airways and high intrathoracic pressure during the flow peaks in the cough sequences are essential for the cough mechanism, particularly in asthma and chronic bronchitis [5, 34, 40].

In obstruction, the cough peak expiratory flow rate (CPEF) in voluntary cough has been documented to be lower than in normal subjects [5, 19], and it has been reported to increase after bronchodilation [5, 6]. In patients with restrictive pulmonary disease, the CPEF has been shown to be slightly lowered, but higher than in obstructive patients. The lowest CPEF has been demonstrated in patients with combined ventilatory impairment [5]. In normal subjects, and in patients with airway obstruction, voluntary CPEF has been reported to be somewhat higher than PEF measured in forced expiration [19].

The characteristics of spontaneous cough may differ widely from those of voluntary cough. The authors have studied spontaneous cough in cases of airway obstruction, and CPEF was far lower than the maximal voluntary PEF measured with a Wright peak flow meter. YOUNG and ABDUL-SATTAR [40] published phonopneumograms of involuntary cough in patients with obstructive airways disease, and found very low CPEF values. LANGLANDS [4] reported stimulated (spontaneous) cough flow patterns with great variation of cough peak flow characteristics. We have previously found end-expiratory cough, in which the cough interrupts an initially normal expiration with a rapid cough flow burst (fig. 2), to be a typical feature of obstruction and spontaneous cough [25]. The possible mechanism of end-expiratory cough is that in airway obstruction, the narrowed vibrating airways collapse for a moment during expiration and, therefore, cough interrupts the expiration.

The flow dynamics of cough can also be presented in a flow-volume display, in which the cough curve resembles the characteristics of a maximum expiratory flow volume curve. However, its transient flow spikes in normal persons have supramaximal flow [46], interrupted by short periods of zero flow when the glottis is closed. In the flow-volume curve of cough, a slope presentation has also been used, when the slope is drawn through the peak flows of one cough sequence; the voluntary cough

slope of normal persons has been shown to be reproducible with a normal individual day-to-day variation, and also to be independent of the volume at which coughing occurs [26]. The flow-volume curve of cough may offer a new way to study cough dynamics, but this method has not yet been widely applied.

Cough sounds

The origin of cough sounds is still poorly defined. All the structures of the larynx are involved in cough, and together with the resonance of the nasal and thoracic cavity cough gets its personal tone. It is possible that sound in voluntary cough is influenced more by laryngeal structures than the sound in involuntary cough.

The glottis is maximally open during the inspiratory phase of cough. During the expiratory phase of cough, a transient dilatation of the larynx has been reported, far smaller than during the inspiratory phase; the vocal chords do not approach each other as they do in phonation [47–50]. At the beginning of the expiratory phase, there is a sudden increase of vibration of vocal chords followed by sudden decrease in the vibration, coinciding with a movement of the vocal processes of the arytenoid cartilages forward and medially [49, 50]. Vibratory movements of the laryngeal structures, including the vocal folds, mucous membrane of the posterior laryngeal wall, and the ary-epiglottic folds and the epiglottis have been found during the whole expiratory phase of cough [49–51]. The epiglottis has been observed to be pulled backward and to partly cover the larynx, decreasing the diameter of the glottal part of the airways and simultaneously increasing the airflow velocity. During a strong cough, the epiglottis has been found to strike the posterior pharyngeal wall with a vigorous swing backward, in a way not found in phonation [49, 50].

In addition to the laryngeal and nasopharyngeal structures, cough sounds are influenced by the expiratory air coming from the lungs. KORPAS and co-workers [27, 47] have studied the origin of cough sounds; they suggest that the pathological processes in the lungs determine the character of cough sounds. They explain the cough sound to be produced through the vibration of airway and lung structures in turbulent airflow. The altered character of cough sound seen in pathological conditions depends on the changed speed of airflow in the airways, and on the changed resonance of the airways and the surrounding lung tissue [27, 52]. In addition, the secretions in the airways influence the character of cough sounds [53]. Compliance of the airways is possibly important in the character of cough sound. With increased compliance, a greater volume of the conducting airways can be attained during the inspiratory phase, and during expiration the airway compression is increased.

FORGACS [54] has described the sound of "loose cough" as resembling the sound of sputum in the airways. Inflammation or hypersecretion has been shown to cause splitting of cough sounds and several cough flow peaks in one cough sequence [25, 47]. FORGACS [54] also noted that similar sounds are heard in some conditions without sputum. We have found a great number of cough
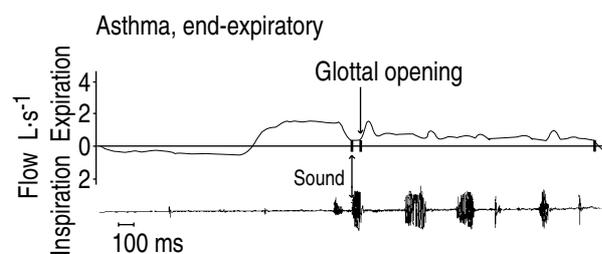

Fig. 2. – An end-expiratory cough of a patient with asthma. The expiration begins normally, but it is interrupted by cough with four flow phases. Deep inspiration, therefore, does not immediately precede these coughs [24].

flow phases in cough sequences and the discontinuity of the cough sounds also to be characteristic of pulmonary fibrosis [25]. In pulmonary fibrosis, the discontinuity of cough sounds was even higher than in chronic airway obstruction with copious expectorations. Pulmonary crackles heard at the chest are thought to be caused by the abnormal closing of airways in expiration and their sudden opening in inspiration [54–56]. This raises the question of whether, in fibrosis, the closing sounds from small airways, *i.e.* expiratory crackles [57], could cause the discontinuous character of the cough sounds. Further research, however, is needed.

Wheezing sounds are important signs of obstruction, and they are also a component of cough sounds. Wheezing can possibly also be generated without obstruction in forced expiration, as happens during cough. The forced expiratory wheezes of normal subjects have been shown to be related to the presence of flow limitation [58, 59]. In this situation, the wheezes have been seen representing an airway choke-point, possibly near the EPP, when the forced breathing occurs between total lung capacity and residual volume [60].

Phonographic recording of cough

Modern interest in respiratory sounds began in the 1950s [61]. At the turn of the 1970s and 1980s, some reports were also published on cough sound analysis [10, 20, 62]. Since then, cough sounds have been analysed, based on methods used in lung sound analysis [11, 40, 42, 47]. The basic method used to analyse respiratory sounds is phonography, *i.e.* the sound intensity signal is displayed in the time domain, often simultaneously with the airflow signal (phonopneumography) [63]. The phonographic recording of cough is sometimes also called tussiphonography [20].

In phonographic studies, one cough (during one expiratory flow peak in a cough sequence) has sometimes been described to be a double sound; the first cough sound at the beginning (during the fast flow phase) of the expiratory phase, and the second cough sound at the end (during the slower flow phase before the glottal closure). Between them is a noisy phase [62]. This is illustrated in figure 3. The second sound has been reported to be lacking in paralysis of the vocal folds [47]. However, the second sound has often also been documented to be lacking in asthmatic cough [64].

Previous studies on cough sounds have usually concentrated on the study of the initial burst of the cough sound (the first cough sound). In phonographic studies, the duration of the first cough sound in voluntary cough has been shown to be longer in patients with pulmonary diseases than in normal persons [10]. However, according to our previous studies, it seems worthwhile to study the sounds during the whole cough sequence [25]. The wheezing sounds, for example, often occur during the whole cough sequence.

Except for the expiratory flow phases, during very low airflows sound has also been reported to occur, sometimes during the whole cough sequence [40, 25]. In the
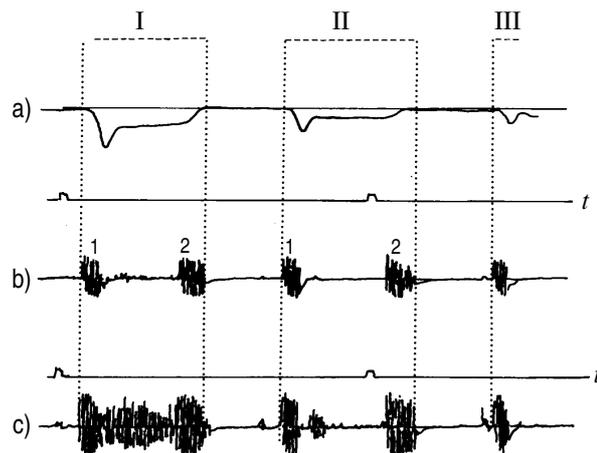

Fig. 3. – One voluntary cough with three expiratory flow phases (I, II, III). a) The cough flow curve. b and c) the cough sound signal is presented with different sound filtrations. The time scale (*t*) displays a time expansion of 100 mm·s⁻¹. In b), with increased sound filtration, the cough sound signal during one cough expiratory phase is visualized as a double sound, 1st and 2nd cough sounds. (Modified according to KELEMEN and CSERI [62], by permission of *Atemw-Lungenkr*).

work of YOUNG and ABDUL-SATTAR [40], patients with bronchitis had involuntary coughs with low flows. Sound occurred on several occasions during the whole period of low airflow preceding the coughs. This might be caused by incomplete closure of the glottis during the flow peaks of cough sequences.

Cough sounds are quite easily caught because of their loud intensity and high frequency content. One of the greatest problems in cough recording is the recording site. When the pneumotachograph is at the mouth, it is understandable that some distortion of the cough sound is inevitable. Some authors have recorded the sounds in the free field in front of the mouth [10], on the throat [65], in front of the mouth when the patient was breathing through a Bennet's mask [14], on the sternal manubrium [25], and on the jugular fossa [62]. Every one of the recording sites listed above causes some changes in the cough sound signal. In addition, the use of the nose-clip reduces the influence of the upper airways on the cough sound signal [11].

Phonocardiographic microphones were used in the first lung sound recording systems [63, 66, 67]. Their low intensity levels and frequency response characteristics limit their application to respiratory sound analysis, although they may be suitable in the detection of cough sounds in cough counting. DRUZGALSKI *et al.* [68] compared the use of different microphones in the recording of respiratory sounds, and found air-coupled condenser microphones suitable for recording respiratory sounds. Piezoelectric microphones used in lung sound analysis [59, 69–71] also offer methods for cough sound analysis, although, as far as we know, no studies on cough sound have been performed using them.

Studies on the frequency of cough sounds

One way to study sounds is to assess intensity bands at several frequency levels. KORPAS and SADLONOVA-KORPASOVA [10] have found that the frequency bands in

cough cover 50–3,000 Hz; they have also found different frequency characteristics for normal persons compared with patients with chronic obstruction or asthma. Frequencies of 300, 400 and 500 Hz have been reported to be accentuated in the voluntary cough of normal persons, whereas frequencies of 500, 700 and 1,200 Hz have been reported in the cough of patients with chronic bronchitis [10]. DEBREZENI *et al.* [11] noted that cough sounds displayed a basic sound component in normal subjects at 350 Hz and in asthma at 500 Hz.

In sound spectrography (sonogram), the sound frequency is presented as a function of time, and the sound phenomena during a whole cough sequence can be visualized. In particular, wheezing sounds between the cough peak flows are easily distinguished with sound spectrography. Figure 4 presents a sonogram of cough. Several reports on cough measurements with a sound spectrograph have been published [9, 12, 25, 72]. PELTOLA and co-workers [12, 72] have published sonograms of cough sounds in whooping cough. Whooping was clearly visualized as continuous sounds in the sonogram, and salbutamol seemed to shorten the duration and to lower the frequency of the whooping sounds. HIRSCHBERG and SZENDE [9] have published sonogram displays of cough in case reports of children with different pulmonary diseases, and found different profiles of cough sound. In the sonogram display of cough sounds, the duration of the sounds and especially their wheezing components can be measured during the whole cough. The discontinuity of cough can easily be estimated, *e.g.* by measuring the number of sound fragments of cough sounds [25]. In sound spectrography, however, the analogue equipment is cumbersome to use. The device consists of a drawing drum, and the spectrum is burned on special paper. This may be the reason why sound spectrography has so far not been extensively used in respiratory

sound analysis. Computerized sonogram analyses, thus, offer a way to expand the possibilities of this method in analysing cough sounds.

Since the 1970s, computer-aided systems have been used for lung sound analysis using Fast Fourier Transform (FFT) spectrum analysis. The FFT analysis is a mathematical algorithm that permits the division of a signal into its component frequencies [73]. In FFT spectrum analysis, the sound signal is presented in the frequency-intensity scale. FFT analysis of normal breath sounds [70], crackles [25, 74] and wheezing sounds has been performed [68, 75]. The FFT spectra of the voluntary cough of patients with asthma, chronic bronchitis, bronchial carcinoma and laryngeal nerve paralysis showed higher frequencies than cough from healthy volunteers [76]. THORPE *et al.* [64] have studied the FFT spectra of the first cough sound of normal and asthmatic children, and have found that they showed higher frequencies in asthmatics. The FFT spectra of the spontaneous cough of patients with asthma have been shown to be lower in frequency than those of patients with chronic bronchitis or tracheobronchial collapse syndrome [25].

Cough counters

Automatic counting methods are desirable in order to make the cough counts more reliable and objective in pharmacological studies. In addition, the degree and diurnal variation of coughing can be different in different pulmonary diseases [77, 78]. Patient diaries [79], observers' notations [80], and scoring of cough intensity and frequency [81] have been used in assessing the severity of cough. Several attempts to count coughs objectively have been made, using either the rapid movement, flow or sound phenomena during cough. In the 1950s, pneumographic belt recording of thoracic pressure changes during cough was used by some researchers to study the number of coughs, cough intensity and duration of coughing [3]. Methods using the measurements of airflow during coughing were also used in cough counting in the 1950s [6, 7, 82]. Unfiltered recording of cough sounds with a free-field microphone and cassette recorder was described in the 1960s [78, 83]: the number of cough events was counted off-line by a listener. Some other researchers have performed sound recording of coughs with a contact microphone [13, 65, 84], others have measured both airflow and sound pressure in front of the mouth during coughing [6, 14, 15].

THOMAS *et al.* [85] recorded cough sounds with a microphone placed on the throat; the signal was transmitted to a receiver and recorded with a tape recorder. An automatic counter recorded the number of coughs from the recorded signal. This recording equipment allowed the patient to move about within a diameter of about 15 m. In some studies, a pressure transducer was attached to the trachea and connected to a single channel recorder. The cough frequency and intensity were evaluated afterwards from the analogue recordings [83, 86]. POWER *et al.* [87] developed a system consisting of a
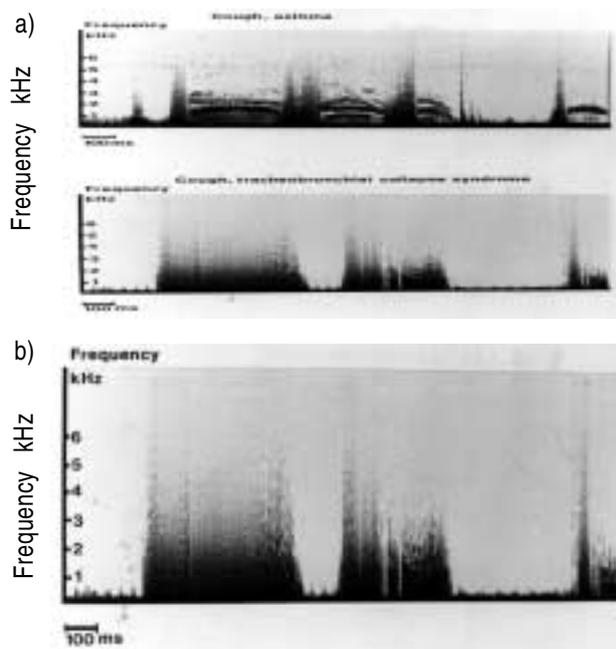

Fig. 4. – Sonogram spectrograms of cough: a) in asthma; and b) in tracheobronchial collapse syndrome [24].

directional microphone situated at the bedside of the patient and connected with an auto-editing tape recorder. Also abdominal electromyographic activity (EMG) has been recorded with surface electrodes to detect cough efforts [88]. Movements of the thyroid cartilage have been detected with a strain gauge [89] to count coughs. Toop *et al*. [90] presented a portable system for cough sound spectral analysis. This method did not make ambulatory cough recording possible, because the equipment was moved on a trolley.

The authors have described a cough recording system in which a paraboloid acoustic fibreglass mirror was placed at the foot of the bed 40 cm above the level of the mattress and directed toward the face of the patient [91]. The sound signal was high-pass filtered at 3.6 kHz (-3 dB) and 1.7 kHz (-20 dB). Body movements were simultaneously recorded with a static-charge-sensitive bed. The signals were recorded in a frequency modulated (FM) recorder and simultaneously fed, after analogue-to-digital conversion, to automatic on-line analysis. The method was validated by a trained observer. The method was found to be highly sensitive in detecting cough (99%), and displayed high positive predictivity (98%). The method makes the long-term recording of cough possible. The restriction of this method was that the patient had to remain in bed during the entire recording.

Hsu *et al*. [77] have developed a portable method for cough counting. It consists of a portable tape recorder, a unidirectional microphone for cough sound recording attached onto the chest, and EMG surface electrodes for recording the activity of the lower respiratory muscles, including diaphragmatic activity. The analysis of the signal is accomplished with a computer; the signal is regarded as cough when a rapid expiratory effort indicated by EMG recording, simultaneously with a transient sound signal, is detected. In cough induced by low-chloride or capsaicin, there was a strong correlation between the number of coughs obtained with the cough counter and by an observer. In a patient study, there was a high correlation of the spontaneous cough count by the counter and the subjective cough symptom score in patients with chronic cough during day time, but not during the night. In asthmatics, the correlation of the subjective symptom scores and the cough count by the counter was not significant.

Cough sound is easy to record but in long-term recording ambient noise may cause problems. When free ambulation is allowed during the recording of cough sounds, speech in particular may complicate cough counting when cough sound signal only is used, because it contains frequencies which occur also in human speech [10]. Therefore, a sufficient level of high-pass filtering and some simultaneous movement or EMG signals are possibly worth connecting to the sound measurement.

Future possibilities of cough sound study

Though cough sound is partly due to the function and vibration of laryngeal structures, an important part of the cough sound signal also comes from the lungs. This makes cough an interesting target for diagnostic purposes. The frequency and flow dynamics of cough mesured in phonopneumographic methods have been deduced to be different in different diagnoses [25], *i.e*. in different bronchial dynamics and secretional conditions. The studies on cough sounds deal mostly with voluntary cough. More studies on spontaneous cough sounds are needed, and new attempts to study cough sound spectra and other sound characteristics will employ modern techniques. Studying the airflow and sound characteristics of cough are possibly still the basic means for analysis of the cough signal.

The genesis of cough sounds is still unclear. Studies on the function of the larynx during cough would elucidate the role of the structures of the larynx in the cough reflex, and especially in the genesis of cough sound. Simultaneous study of lung and cough sounds would possibly also augment the information on the genesis of cough sound.

Cough counters are important in assessing the efficacy of antitussive medicines. The methods used in cough counting are still mostly restricted to counting of coughs only in the vicinity of the detector equipment. This often means that cough is counted only during the night. When the cough does not prevent the patient from falling asleep, spontaneous cough is known to be suppressed during sleep, and therefore the number of coughs usually diminishes during undisturbed sleep [87, 92, 93]. Ambulatory cough recording equipment should be developed in order to count coughs during the daytime as well.

In conclusion, cough is one of the old primitive human reflexes. However, cough research has not yet received sufficient attention. Because the disease processes triggering the cough reflex cause different flow and sound patterns, the analysis of cough may benefit diagnostics. Counting of cough events is important in assessing the effect of cough medicines and, therefore, the development of on-line ambulatory cough counters is awaited with enthusiasm.

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