



COUGH: ASSESSMENT AND EQUIPMENT

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Cough is consistently the commonest symptom for which patients seek medical advice [1–3]. In the UK in 2005, £96.7 million was spent on over-the-counter cough liquids [4], for which there is little evidence of efficacy [5]. The European Respiratory Health Survey suggested that in young adults the median prevalences of nocturnal, nonproductive and productive cough are 30.7%, 10.2% and 10.2%, respectively [6].

Coughing is an unpleasant and distressing symptom and hence chronic coughing is associated with significant effects on quality of life [7]. Apart from physical complications such as chest wall pain, retching and vomiting, incontinence and syncope, significant psychological effects occur. Studies in patients attending specialist chronic cough clinics suggest significant rates of anxiety

and depression [8, 9]. Specific tools to measure cough-related quality of life have been developed and validated [10, 11].

The European Respiratory Society (ERS) has recently published guidelines to assist the diagnosis and management of cough [12]. The importance of cough has been further acknowledged by the addition of guidelines from organisations around the world, including the American College of Chest Physicians [13], the British Thoracic Society [14], the French Society for Oto-Rhino-Laryngology [15] and the Japanese Respiratory Society [16]. One of the main factors limiting our understanding and treatment of this common and distressing symptom has been the lack of well-validated tools to measure cough accurately. Until recently, the measurement of cough remained remarkably primitive.

The ideal measure of cough is a system to quantify coughing objectively. Only one system for making objective measurements of cough is currently available commercially, although several academic groups are making significant progress in developing accurate automated systems. It seems likely that clinically useful systems will be available in the near future. This guide aims to provide an overview of the techniques being developed in this field.

Methods for assessing cough

A variety of methods are available for the assessment of cough; subjective assessments are the easiest methods to employ and hence are in widespread use. Subjective scores using 0–5 scales for day and night or visual analogue scales can be completed rapidly and give an estimate of the patient's perception of the severity of their cough. The main limitation of these measures is that they are related only loosely to objective cough counts [17–19]; they are likely to be confounded by factors such as mood, vigilance and patients' expectations.

Cough challenge testing can be used to measure the sensitivity of the cough reflex by inhalation of irritants, *e.g.* capsaicin or citric acid [20]. However, there is considerable

overlap between cough thresholds in health and disease [21] and an abnormal cough challenge threshold is not present in all conditions where coughing is a feature [22]. A detailed description of the techniques involved in cough challenge testing and the equipment required has been recently documented [23].

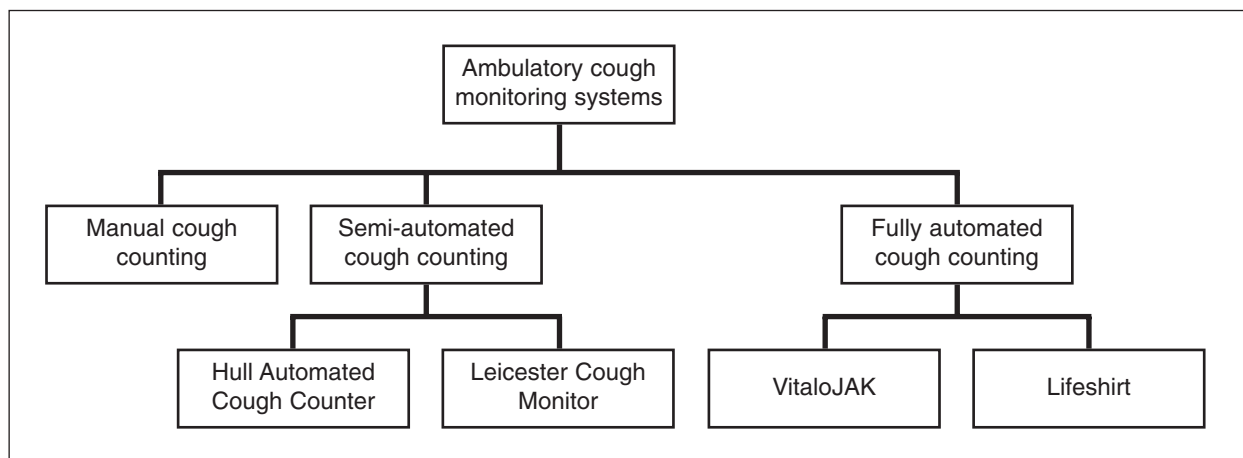
This review will focus on systems for direct measurement of coughing. Cough monitoring systems have been reported for over 40 years, the earliest system using nonambulatory analogue equipment [24]. Recent developments in digital sound recording and increases in the storage capacity of electronic devices have facilitated the development of automated devices for monitoring cough.

Cough monitoring systems

The ideal cough monitor

The ideal cough monitoring system would be small, robust and unintrusive for the subject. As discussed in detail in the recent ERS guidelines on cough assessment, the way in which coughing is quantified must be defined [23]. Individual explosive cough sounds, epochs (*i.e.* bursts of cough sounds) or the time spent coughing can be counted. Currently there is no data to suggest one method of cough

Figure 1. Categories of cough monitoring devices.



quantification is any more valid than any other.

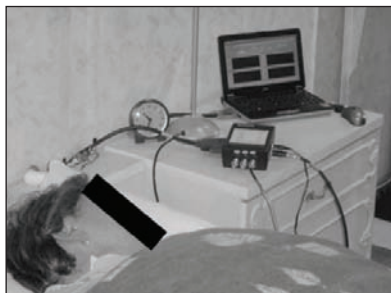
It is possible to make sound recordings of cough and to count the cough sounds manually; several groups have shown excellent agreement between trained cough counters [19, 25, 26]. This process is extremely time consuming, however, and therefore limits the duration of monitoring and the number of subjects that can be studied. The ideal cough monitoring system therefore needs to be able to detect and count cough automatically and with high sensitivity and specificity. The simplest way of classifying cough monitoring devices is by the degree of user input required (fig. 1).

Manual cough-counting devices

1) The Overnight Cough Monitoring System

Recently, two systems have been reported based on the manual counting of cough signal recordings. The first, the Overnight Cough Monitoring System, is an overnight respiratory sound monitoring system (6–8 h) for recording and quantifying cough and wheezing *via* air-coupled microphones on the chest wall or over the trachea (fig. 2) [27]. The system is nonambulatory but is reported to have been used successfully in the domestic environment as well in hospital in-patients, in 133 adults and children. The results of the recordings have not been published in detail. An

Figure 2. Nocturnal respiratory sound monitoring system.



algorithm is under development to categorise sounds automatically as wheeze or cough, but its performance is not yet published.

2) The Accelerometer Cough Monitoring System

The second system is the Accelerometer Cough Monitoring System. Accelerometers are frequently used for monitoring breath sounds (fig. 3) [28]. A system has been developed for recording cough sounds *via* an accelerometer placed at the supra-sternal notch [29]. Signals are recorded digitally onto a compact flash card in a portable device. Software assists manual review of the recording to identify cough sounds both visually and audibly. The device has been tested in 15 individuals but only over very short time periods (15–60 min). Most subjects had upper respiratory tract infections. The agreement between manual cough counting from these recordings and simultaneous video recordings was good. There is currently no automated detection of coughs in this system and so analysis would be extremely time-consuming for longer monitoring periods.

Semi-automated cough counting devices

3) The Hull Automated Cough Counter

The Hull Automated Cough Counter (HACC) consists of a lapel microphone and ambulatory recording device [26]. Sound recordings have been made for 1 h in 33 smokers with chronic cough. A probabilistic neural network is applied to acoustic features developed for speech recognition (cepstral coefficients) and used to classify extracted sound events as cough or non-cough (fig. 4). Reference cough and non-cough signals are required for detection and currently the system labels but does not count coughs, *i.e.* the system is not yet fully automated.

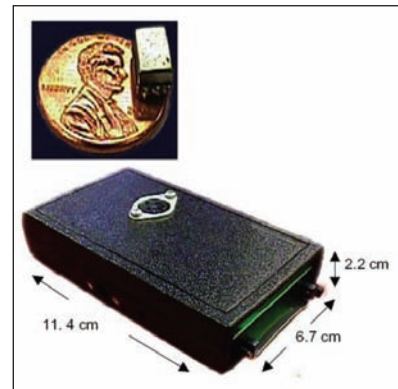


Figure 3. Accelerometer and recording device for cough monitoring.

With the assistance of the HACC, a 1-h cough recording can be counted in 1 min 35 s. The average sensitivity and specificity for cough detection are 80% (range 55–100%) and 96% (range 92–98%), respectively. The HACC has a tendency to overestimate cough counts at higher rates, and the average false-positive rate is 20%. Currently, extended recordings using the HACC are being performed in the context of a clinical trial of a novel antitussive agent (personal communication, A.H. Morice).

4) The Leicester Cough Monitor

The Leicester Cough Monitor (LCM) applies a keyword-spotting approach, based on hidden Markov models (statistical models that have been applied most commonly to temporal pattern recognition, *e.g.* speech and handwriting recognition) and the extraction of cepstral coefficients, to cough sound detection [30]. This algorithm produces a file of candidate cough sounds, which require manual counting by a trained observer. Cough sounds are collected using an ambulatory MP3 digital recording device from a free-field microphone, in patients with a variety of underlying diagnoses attending a specialist chronic cough clinic.

This approach achieved a mean sensitivity of 71% (range 50–99%) when compared with manual

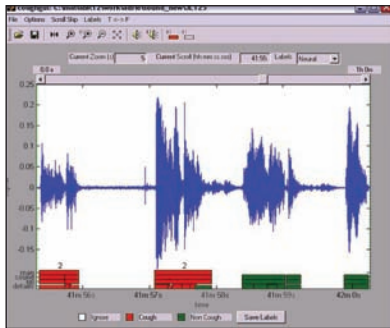


Figure 4. Graphical User Interface from the Hull Automated Cough Counter showing sound waveforms, cough sounds labelled in red, non-cough sounds in green.

counting from the sound recordings. The performance is reported to be improved by the addition of a 95% energy threshold; sensitivity 82% (53–99%). This improvement is at the expense of discounting all coughs that fall below this energy level: an average of 29% (range 6–72%) of the original manually counted cough sounds.

A recent abstract suggests the latest iteration of this algorithm has a sensitivity of 91% and specificity of 99% in the same data set, with a false-positive rate of 2.5 events·h⁻¹ [31]. It is not clear whether energy thresholding is still employed.

Fully automated cough-counting devices

5) Lifeshirt® System

The Lifeshirt® system is a wearable, ambulatory system incorporating respiratory inductance plethysmography (RIP). It measures respiratory parameters, electrocardiograph and activity with an accelerometer (fig. 5) [32]. With the addition of a unidirectional throat microphone the system is commercially available for objective cough monitoring. An algorithm has been developed to detect cough using a combination of sound and RIP. The details of the techniques used have not been published but have recently been awarded a US patent.

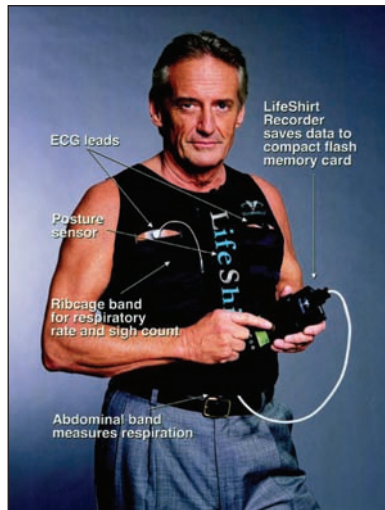


Figure 5. Lifeshirt® system, throat microphone not shown.

The Lifeshirt performance has been tested in eight subjects with chronic obstructive pulmonary disease (who complained of cough) by comparison with manual cough counting from video. In this relatively nonambulatory setting the sensitivity was 78.1% (95% confidence interval (CI) 75.1–78.2%) and specificity 99.6% (95% CI 99.6–99.6%). The false-positive rate is not reported but the positive predictive value is 84.6%. Further validation studies in collaboration with the pharmaceutical industry

are under way and a measure of cough intensity is being developed (personal communication, A. Derchek).

6) VitaloJAK

The VitaloJAK system (fig. 6) is the product of a collaboration between industry (Vitalograph Ltd, Buckinghamshire, UK) and a multidisciplinary academic research team (Respiratory Research Group, University of Manchester, University Hospital Manchester NHS Foundation Trust, UK). The device and software are not yet commercially available. The device uses a contact microphone placed on the chest wall and a custom-made digital recording device to detect cough from sound. A lapel microphone is also attached to make simultaneous free-field recordings for validation purposes (manual cough counting).

This system uses a physiological approach to cough detection. Subjects perform voluntary coughs, which are recorded, from set lung volumes. Much of the variability in cough sounds within an individual can be explained by the lung volume from which the cough occurs [33]. Acoustic parameters extracted from these



Figure 6: VitaloJAK cough monitoring device.

voluntary coughs can be then used to interrogate a 24-h sound recording and pick out spontaneous cough sounds. Pilot work in 10 subjects (n=5 chronic cough, n=5 asthma) suggests this is a sensitive technique for cough detection; sensitivity 97.5% (91.3–99.5%) and specificity 97.7% (93.1–99.5) [34]. A larger validation study is under way to examine the performance of this method in cough caused by a wide range of conditions. In addition, the ability to categorise spontaneous cough sounds by volume coughed from is being explored. This may give a surrogate measure for cough intensity.

Future developments in cough monitoring

This review has focused on the simple quantification of coughing. The intensity with which a subject coughs is also likely to be an important end-point and to have an independent impact on patients’ quality of life. It has been well described that coughing has a diurnal pattern, with more coughing

during the day than at night. The examination of the temporal patterns of cough over 24 h or even several days may be different in different conditions. Furthermore, the detailed study of cough acoustics may be able to provide other useful additional endpoints in cough monitoring, such as the proportion of coughs with mucus in the airway (*i.e.* ‘wet’ cough sounds) [35, 36] or even wheezing within cough sounds [37]. Whether cough acoustics and temporal distributions will ever be able to predict diagnosis remains to be fully explored [38].

Conclusions

Objective measurement of cough is currently possible using digital recording devices and manual cough counting. The laborious nature of manual counting limits the size and scope of studies that can be performed in this way. A variety of semi-automated and automated cough monitoring systems are under development. It seems likely that in the near future accurate, validated,

automated systems will be available for use in clinical practice, clinical research and testing of antitussive agents. ■

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First author [ref]	Device name	Signal and sensor	Recording duration h	Ambulatory	Subjects	Automated detection	Sensitivity %	Specificity %
GROSS [27]	–	Sound Air coupled microphones	6–8 overnight	No	n=133 Adults and children	No	n/a	n/a
PAUL [29]	–	Sound Accelerometer	0.25–1	Yes	n=15 Adults and children	No	n/a	n/a
BARRY [26]	HACC	Sound Lapel microphone	1	Yes	n=15 Smokers with chronic cough	Semi	80	96%
MATOS [30]	LCM	Sound Free field microphone	6	Yes	n=19 Chronic cough patients	Semi	71–82	Not reported
BIRRING [31]	LCM	Sound Free field microphone	6	Yes	n=19 Chronic cough patients	Not reported	91	99
COYLE [32]	Lifeshirt	Sound Throat microphone	24	Yes	n=8 COPD patients	Yes	78	99
MCGUINNESS [33]	VitaloJAK	Sound Contact sensor	24	Yes	n=10 Chronic cough and asthma patients	Yes	97.5	97.7

Table 1. Summary of features of cough monitoring systems.

REFERENCES

1. Burt CW, Schappert SM. Ambulatory care visits to physician offices, hospital outpatient departments, and emergency departments: United States, 1999–2000. *Vital Health Stat 13* 2004; 157: 1–70.
2. Schappert SM, Burt CW. Ambulatory care visits to physician offices, hospital outpatient departments, and emergency departments: United States, 2001–02. *Vital Health Stat 13* 2006; 159: 1–66.
3. Schappert SM, Nelson C. National Ambulatory Medical Care Survey: 1995–96 summary. *Vital Health Stat 13* 1999; 142: i–vi, 1–122.
4. IRI 2005 OTC Market Size statistics: Proprietary Association of Great Britain, 2005.
5. Schroeder K, Fahey T. Systematic review of randomised controlled trials of over the counter cough medicines for acute cough in adults. *BMJ* 2002; 324: 329–331.
6. Janson C, Chinn S, Jarvis D, Burney P. Determinants of cough in young adults participating in the European Community Respiratory Health Survey. *Eur Respir J* 2001; 18: 647–654.
7. French CL, Irwin RS, Curley FJ, Krikorian CJ. Impact of chronic cough on quality of life. *Arch Intern Med* 1998; 158: 1657–1661.
8. Dicipinigaitis PV, Tso R, Banauch G. Prevalence of depressive symptoms among patients with chronic cough. *Chest* 2006; 130: 1839–1843.
9. McGarvey LP, Carton C, Gamble LA, et al. Prevalence of psychomorbidity among patients with chronic cough. *Cough* 2006; 2: 4.
10. Biring SS, Prudon B, Carr AJ, Singh SJ, Morgan MD, Pavord ID. Development of a symptom specific health status measure for patients with chronic cough: Leicester Cough Questionnaire (LCQ). *Thorax* 2003; 58: 339–343.
11. French CT, Irwin RS, Fletcher KE, Adams TM. Evaluation of a cough-specific quality-of-life questionnaire. *Chest* 2002; 121: 1123–1131.
12. Morice AH, Fontana GA, Sovijarvi AR, et al. The diagnosis and management of chronic cough. *Eur Respir J* 2004; 24: 481–492.
13. Irwin RS, Baumann MH, Bolser DC, et al. Diagnosis and management of cough executive summary: ACCP evidence-based clinical practice guidelines. *Chest* 2006; 129: Suppl., 1S–23S.
14. Morice AH, McGarvey L, Pavord I. Recommendations for the management of cough in adults. *Thorax* 2006; 61: Suppl 1: i1–i24.
15. Mayaud C. [Pneumology, chronic cough and the “Recommendations”]. *Rev Pneumol Clin* 2006; 62: 269.
16. Kohno S, Ishida T, Uchida Y, Kishimoto H, Sasaki H, Shioya T, et al. The Japanese Respiratory Society guidelines for management of cough. *Respirology* 2006; 11: Suppl. 4, S135–S186.
17. Hsu JY, Stone RA, Logan-Sinclair RB, Worsdell M, Busst CM, Chung KF. Coughing frequency in patients with persistent cough: assessment using a 24 hour ambulatory recorder. *Eur Respir J* 1994; 7: 1246–1253.
18. Smith J, Owen E, Earis J, Woodcock A. Cough in COPD: correlation of objective monitoring with cough challenge and subjective assessments. *Chest* 2006; 130: 379–385.
19. Decalmer S, Webster D, Kelsall A, McGuinness K, Woodcock A, Smith JA. Chronic cough: how do cough reflex sensitivity and subjective assessments correlate with objective cough counts during ambulatory monitoring? *Thorax* 2007; 62: 329–334.
20. Morice AH. Inhalation cough challenge in the investigation of the cough reflex and antitussives. *Pulm Pharmacol* 1996; 9: 281–284.
21. Prudon B, Biring SS, Vara DD, Hall AP, Thompson JP, Pavord ID. Cough and glottic-stop reflex sensitivity in health and disease. *Chest* 2005; 127: 550–557.
22. Choudry NB, Fuller RW. Sensitivity of the cough reflex in patients with chronic cough. *Eur Respir J* 1992; 5: 296–300.
23. Morice AH, Fontana GA, Belvisi MG, et al. ERS guidelines on the assessment of cough. *Eur Respir J* 2007; 29: 1256–1276.
24. Woolf CR, Rosenberg A. Objective assessment of cough suppressants under clinical conditions using a tape recorder system. *Thorax* 1964; 19: 125–130.
25. Corrigan DL, Paton JY. Pilot study of objective cough monitoring in infants. *Pediatr Pulmonol* 2003; 35: 350–357.
26. Barry SJ, Dane AD, Morice AH, Walmsley AD. The automatic recognition and counting of cough. *Cough* 2006; 2: 8.
27. Gross V, Reinke C, Dette F, Koch R, et al. Mobile nocturnal long-term monitoring of wheezing and cough. *Biomed Tech (Berl)* 2007; 52: 73–76.
28. Kraman SS, Wodicka GR, Pressler GA, Pasterkamp H. Comparison of lung sound transducers using a bioacoustic transducer testing system. *J Appl Physiol* 2006; 101: 469–476.
29. Paul IM, Wai K, Jewell SJ, Shaffer ML, Varadan VV. Evaluation of a new self-contained, ambulatory, objective cough monitor. *Cough* 2006; 2: 7.
30. Matos S, Biring SS, Pavord ID, Evans DH. Detection of cough signals in continuous audio recordings using hidden Markov models. *IEEE Trans Biomed Eng* 2006; 53: 1078–1083.
31. Biring SS, Matos S, Evans DH, Pavord I. Leicester Cough Monitor: a novel automated cough detection system. *Am J Resp Crit Care Med* 2007; 175: A379.
32. Coyle MA, Keenan DB, Henderson LS, et al. Evaluation of an ambulatory system for the quantification of cough frequency in patients with chronic obstructive pulmonary disease. *Cough* 2005; 1: 3.
33. McGuinness K, Kelsall A, Lowe J, Woodcock A, Smith JA. Automated cough detection: a novel approach. *Am J Resp Crit Care Med* 2007; 175: A381.
34. McGuinness K, Morris J, Kelsall A, Woodcock A, Smith JA. The relationship between cough acoustics and the volume inspired prior to coughing. *Am J Resp Crit Care Med* 2007; 175: A381.
35. Murata A, Taniguchi Y, Hashimoto Y, Kaneko Y, Takasaki Y, Kudoh S. Discrimination of productive and non-productive cough by sound analysis. *Intern Med* 1998; 37: 732.
36. Hashimoto Y, Murata A, Mikami M, Nakamura S, Yamanaka E, Kudoh S. Influence of the rheological properties of airway mucus on cough sound generation. *Respirology* 2003; 8: 45.
37. Smith JA, Ashurst HL, Jack S, Woodcock AA, Earis JE. The description of cough sounds by healthcare professionals. *Cough* 2006; 2: 1.
38. Korpas J, Sadlonova J, Vrabec M. Analysis of the cough sound: an overview. *Pulm Pharmacol* 1996; 9: 261–268.