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A new use for an old Holter monitor: an ambulatory cough meter

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A new use for an old Holter monitor: an ambulatory cough meter. A.B. Chang, R.G. Newman, P.D. Phelan, C.F. Robertson. ©ERS Journals Ltd 1997.
ABSTRACT: Cough is commonly used as an outcome measure in clinical studies, although the subjective reporting of cough is unreliable when compared to objective measures. We describe an inexpensive new ambulatory cough meter that is based on a disused Holter monitor.

The cough meter consists of a Holter monitor and a cough processor, designed on a computer to select the most appropriate filters. The cough meter was then validated against the overnight tape recorder on 21 occasions in 18 children (aged 6–15 yrs).

The agreement between the cough meter and the tape recorder was good (mean difference of -0.3 coughs·h^{-1}; limits of agreement -2.2 to 1.7 coughs·h^{-1}).

We conclude that our newly described ambulatory cough meter provides a valid and inexpensive method of objectively monitoring cough for up to 24 h.
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Cough is a common problem in childhood and, in epidemiological studies; the prevalence of cough without wheeze ranges 9–17% [1, 2]. However, cough as a symptom is poorly reproducible [3]. Moreover, the reporting of nocturnal cough has been shown to be unreliable [4, 5], and can be significantly influenced by psychological status [6]. Currently, no validated scoring system of cough is available. Studies on the severity of cough have used various subjective scoring systems, including the visual analogue score [7], and a variety of verbal category scores [4, 8].

In recent years, an innovative ambulatory cough meter has been described [8, 9]. The authors raised the standard of assessing cough and re-emphasized the need for objective monitoring of cough. However, their equipment was expensive, costing approximately (UK) £10,000. Using similar preprocessing of signals as described by Hsu *et al*. [8] we have recently developed an inexpensive cough meter by adapting a disused Holter monitor. The aim of the present paper was to describe and validate this device.

Materials and methods

Subjects

Eighteen children with nonspecific recurrent cough (≥2 episodes of nonproductive cough lasting for ≥2 weeks in the last 12 months) were recruited from the outpatients department. Children without a history of recurrent cough were enrolled as controls. Formal consent was obtained, and the study was approved by the hospital's Ethics Committee on Human Research.

Study design

The ambulatory cough meter was designed and validated as described below. The children used the cough meter for a 24 h period.

The cough meter

The input signals to the cough meter consist of electromyogram (EMG) and audio signals. The three attachment points of the EMG electrodes (paediatric pregelled silver chloride, Red Dot; 3M, Ontario, Canada) were the xiphisternum and both costal margins at the midclavicular line. The unidirectional Piezo-Ceramic microphone (BL 1670; Knowles Electronics, IL, USA) is most sensitive between 100 and 9,000 Hz, and is attached to the subject (inferior to the sternal notch) by double-sided adhesive rings (Hellige, Germany).

The cough meter consists of a cough processor and a Holter monitor. The cough processor (prototype designed on Amlab® operating system, Sydney, Australia) filters the input signals before recording. The selection of the most appropriate filters for preprocessing of the EMG and audio signals minimizes unwanted signals (those from other activities). The filters selected for the audio signal consisted of: a four pole high-pass (HP) Butterworth filter, with a -3 dB point at 1,200 Hz and a roll-off of 24 dB·octave^{-1}; and a two pole low-pass (LP) filter, with the -3 dB point at 5,000 Hz and the roll-off of 12 dB·octave^{-1}. For the EMG signal, the LP filter was the same as the audio system but the HP filter had a -3 dB point at 200 Hz.

Amplification of the signal gains were 11–38 (adjustable) for the audio signal and 981 for the EMG signal. Both the EMG and the audio signals were then full wave

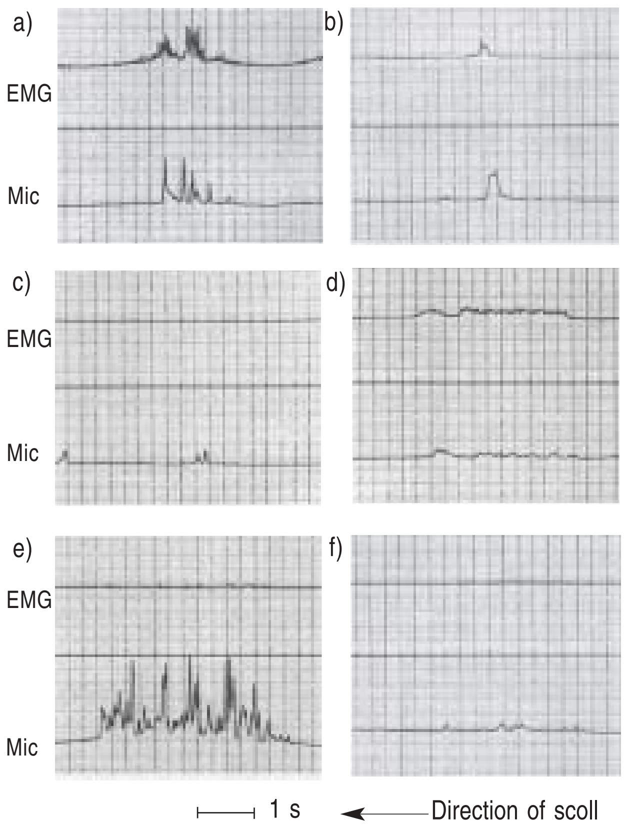

Fig. 1. – Cough and various other signals generated from the cough meter: a) cough; b) sneeze; c) throat clearing; d) blowing nose; e) simultaneous jump and shout; f) loud speech. EMG: electromyogram; Mic: microphone.

rectified and further filtered with a LP Butterworth filter (55 Hz) to give a time constant of 3 ms. The signals were then attenuated to enable recording onto the Holter monitor (Diagnostic Medical Instruments Inc., New York, USA), which has a recording speed of 1 $mm \cdot s^{-1}$ and allows continuous recording for up to 24 h. The recorded tape was replayed on the cardioview monitor (DMI, New York, USA) and the coughs counted. The time of the recording was displayed on the screen and the tapes were processed in a blinded manner. The signals generated from the cough meter were easily distinguished from other signals (fig. 1).

Validation of the cough meter

A scientific recorder (Racal Store 4D Recorder; Racal Thermionic, UK) was used to record overnight, simultaneously with the cough meter. The Racal system which permitted recording of signals of 100–5,000 Hz for up to 17 h, was positioned next to the child's bed. The parent(s) were instructed to turn on the tape recorder before going to sleep. The recorder was then played back at 2–4 times the recording speed and the signal viewed on a cathode ray oscilloscope (5223 digitalizing oscilloscope; Tektronix, OR, USA). This allowed audio replay with simultaneous visualization of any audio signal on the monitor. When a signal was detected, the tape recorder was played at the speed it was recorded, to verify the presence of the cough.

Statistical analysis

The time recorded on the tape-recorder was synchronized with the corresponding time on the cough meter. As a measure of agreement between the two methods, limits of agreement were calculated using the formula: $\Delta \pm 2\text{SD}$ (Δ = mean difference, SD = standard deviation of the differences) [10].

Table 1. – Comparison of the number of coughs counted by the overnight tape-recorder and the cough meter

Sex	Age	Recorded time	Coughs recorded by the two methods				δ
			Tape recorder		Cough meter		
	yrs	h	Total	coughs·h^{-1}	Total	coughs·h^{-1}	coughs·h^{-1}
F	11	8.0	100	12.5	131	16.4	-3.9
F	11	8.5	43	5.1	49	5.8	-0.7
F	11	7.5	0	0.0	0	0.0	0.0
M	10	8.0	47	5.9	46	5.8	0.1
M	10	7.4	0	0.0	2	0.3	-0.3
M	15	9.0	37	4.1	43	4.8	-0.7
F	9	10.0	38	3.8	40	4.0	-0.2
F	11	8.2	0	0.0	1	0.1	-0.1
F	12	10.0	3	0.3	15	1.5	-1.2
M	12	7.0	27	3.9	21	3.0	0.9
F	11	8.8	24	2.7	31	3.5	-0.8
M	7	11.0	320	29.1	305	27.7	1.4
M	8	8.7	93	10.7	95	10.9	-0.2
F	11	8.0	20	2.5	21	2.6	-0.1
F	11	10.0	29	2.9	27	2.7	0.2
F	11	2.0	6	3.0	6	3.0	0.0
F	10	9.0	11	1.2	13	1.4	-0.2
F	15	8.0	5	0.6	6	0.8	-0.1
F	12	11.0	25	2.3	22	2.0	0.3
M	12	8.0	21	2.6	22	2.8	-0.1
F	12	10.0	3	0.3	3	0.3	0.0
Median	11	8.5	24.0	2.7	22.0	2.8	-0.1
Mean	11	8.5	40.6	4.5	42.8	4.7	-0.28

δ: difference, *i.e.* coughs counted by tape recorder - cough meter. M: male; F: female.

Results

Validation of the cough meter

The median age of the 21 children (17 subjects and 4 controls) was 11 yrs (range 6–15 yrs). Three were excluded for the following reasons: dislodgment of microphone (one subject); intolerance of itch at the site of the EMG electrodes (one control, aged 6 yrs); and the overnight tape recorder did not work (one subject). The coughs counted on the cough meter were compared to those obtained from the tape recorder on 21 occasions in 18 children (15 subjects and 3 controls) (table 1). The number of coughs recorded on the tape recorder tended to be lower than that of the cough meter. The mean difference (tape recorder-cough meter) was -0.3 coughs·h^{-1} (95% confidence interval (95%CI) -0.7 to 0.2). The limits of agreement between the two methods were -2.2 to 1.7 coughs·h^{-1}.

Discussion

We have shown that a relatively simple and inexpensive ambulatory cough meter can be built by adapting a Holter monitor. We have also validated this new device.

Cough has previously been quantified using EMG [11] or spectral analysis of the sound [12]. Cox *et al.* [11] used nonportable abdominal EMG as a measurement of cough intensity, which correlated well to the airflow and volume produced in cough. Piirila *et al.* [12] spectrographically analysed the acoustic and dynamic characteristics of coughs in various pulmonary disorders. Using their sound spectrograph, which had a broad band filter of 300 Hz, they found that during a cough there is an average of 2.6±0.8 expiratory flow phases and that the sound always occurred simultaneously with the expiratory flow phase [12]. The observation of multiple peaks in the cough signal generated by our cough meter is similar because we used a very short time constant, which averaged the signal over 3 ms rather than the 30 ms used by Hsu *et al.* [8].

The establishment of the ambulatory cough meter [8], first described by the Brompton group, raised the standard in the assessment of cough both in adults and children. However, the cost of the Brompton group's cough meter is high, and thus limits its availability. The cough processor described here costs less than £400 to design and build. The Holter monitor that was used was one of the two monitors that were no longer in use by the cardiology department. However, an existing Holter monitor can be utilized and the cost of a new Holter monitor (tape system) is approximately £1,400. The cough meter described here also differs from the Brompton cough meter in the frequency band of the filters and the time constant. The filters chosen in this cough processor were based on the preliminary studies using the Amlab® Operating System, which provided instantaneous signals of the activity studied. A short time constant of 3 ms was chosen for the averaging circuit because it was found that the cough signals were more easily distinguished from other signals, although this cannot be quantified.

The attachment points of the EMG were chosen from trial and error. When the electrodes were placed higher (4–5th intercostal space), the signals were less distinct. EMG activity from the region chosen for the attachment of the electrodes includes activity from the anterolateral abdominal muscles, the diaphragm [13] and the intercostal muscles. These muscles are involved in the generation of cough [14, 15].

The agreement value between the cough meter and the overnight tape recorder validated this cough meter. In all but three subjects, the cough meter recorded more coughs, probably because cough sounds can be muffled if the child coughs into a pillow. Also, if the child walked away from the tape recorder (*e.g.* to go to the toilet), the tape recorder would be unable to pick up the sound of the cough, whereas the cough would be recorded on the cough meter. The previously described cough meter [8] was not validated against any other objective method of recording cough.

The limitations of the cough meter described are that the recorded tapes are manually read and, therefore, time-consuming and that a trained investigator is required. However, this is not unlike the system described by Munyard *et al.* [9].

We conclude that our newly described ambulatory cough meter, which consists of a cough processor adapted to a Holter monitor, provides a valid and inexpensive method of objectively monitoring cough for up to 24 h.

Note: a diagram of the circuit of the cough processor, designed on the Amlab® operating system, can be obtained from the authors.

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