Review

Respiration

Respiration 2011;81:161–174
DOI: 10.1159/000321231

Received: May 31, 2010
Accepted after revision: August 29, 2010
Published online: November 13, 2010

Validated Methods of Cough Assessment: A Systematic Review of the Literature

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Key Words
Cough, assessment, monitoring, measurement · Quality of life · Systematic review · Visual analogue scales

Abstract
Background: Cough is a common symptom for which patients often seek medical advice and consume vast amounts of drugs. It is a real challenge for both the physician and the clinical researcher to evaluate a cough's clinical importance and its precise response to treatment. ***Objectives:*** This systematic literature review has the following objectives: first, to make an inventory of the validated tools for assessing cough, and second, to investigate the extent to which the results of various assessment methods can be correlated. ***Methods:*** Two independent investigators searched the Medline, Embase, and Cochrane databases for validation studies on cough assessment tools. ***Results:*** Thirty-four studies were included. Several ambulatory cough monitors automatically identify cough and have been validated in a limited number of patients. Three cough-specific quality-of-life scales (Leicester Cough Questionnaire, Cough Quality of Life Questionnaire, and Burden of Cough Questionnaire) have been validated. No validation studies of descriptive scores or visual analogue scales were found. The correlations between quality-of-life scores and cough frequency were good. The correlations between descriptive scores or visual analogue scales and more objective methods, such as cough frequency monitoring or quality-of-life scores, were inconsistent. ***Conclusion:*** Cough-specific quality-of-life questionnaires can provide valid outcomes for research into cough. Although the current developments in cough monitoring devices are promising, further studies on a larger scale, under more realistic conditions, and for different patterns of cough are required before they can be recommended for widespread use.
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Background

Acute cough is the commonest reason for consultation in general practice [1], and persistent cough is the commonest reason for consulting a respiratory specialist [2]. Therefore, cough is undoubtedly a part of many clinicians' daily practice. Evaluating the severity of the cough and its impact on the patient's life is a key step in the clinical work-up of cough. This initial assessment is likely to influence the clinician's decision to prescribe cough suppressants. Cough suppressants are widely used for both acute and chronic cough despite a lack of evidence of their effectiveness [3]. In clinical trials, the effects of various cough suppressants have usually been no better than that of the placebo [4–8]. However, the outcome

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0025–7931/11/0812–0161$38.00/0

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measures in these studies have frequently been based on patients' subjective evaluations of their cough using descriptive questionnaires or visual scales. The validity of these measures is unknown. Therefore, the evaluation of cough by validated methods is a challenge for researchers and clinicians alike.

The validity of a measurement instrument is the extent to which it measures what it intends to measure [9]. Therefore, the first issue in cough assessment is to clarify what precisely should be measured. Indeed, the assessment of cough severity can involve several different aspects: (1) the importance of the cough, objectively measured in terms of the frequency or intensity of the expulsive effort; (2) the impact of the cough on the patient's quality of life, and (3) the importance of the cough, as perceived by the patient. The following assessment tools are currently available: cough monitors used to objectively measure cough frequency, and quality-of-life questionnaires, verbal descriptive scores (VDS), and visual analogue scales (VAS) used to subjectively measure cough severity. In this paper, we consider these 3 facets of cough assessment (fig. 1).

The main objective of this systematic review of the literature was to identify the existing validated cough evaluation methods. The second objective was to assess their concurrent validity by investigating the ways in which the results of various cough evaluation methods correlate with one another.

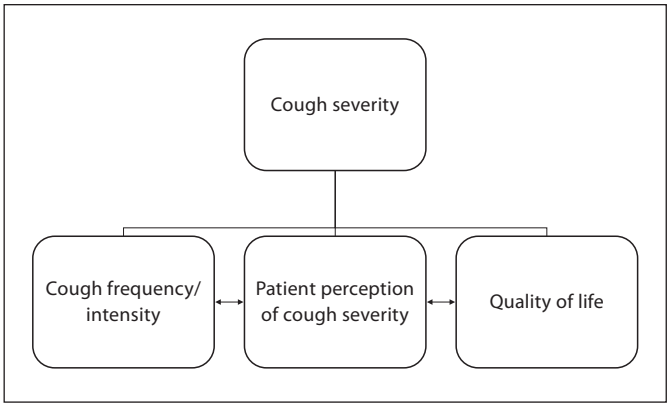

Fig. 1. Cough assessment. There are different cough assessment tools designed to measure different aspects of cough severity, cough frequency or intensity, the repercussions of cough on the daily life of the patients, and the patients' perception of their cough severity.

Methods

Search Strategy

In accordance with our search strategy (online suppl. material, www.karger.com/doi/10.1159/000321231), we searched the entries in the Medline, Embase, and Cochrane Central Register of Controlled Trials databases up until January 26, 2009. The search queries included the MeSH (Medical Subject Headings of the United States National Library of Medicine) term 'cough' as the conditional term, together with all the MeSH terms covering the various cough outcomes encountered during an initial nonsystematic literature search.

Study Selection

Inclusion Criteria

The criteria were developed according to the objectives of the review.

(1) Validation studies of the objective measurements of cough intensity and/or frequency: any study that compared a specific cough frequency monitoring method with a cough frequency measurement using either video or audio recordings of coughing human beings, with no restrictions in terms of etiology, age of the patient, setting, or treatment of the cough. Randomized controlled trials using several outcome measures, 1 of which was an objective measure of cough intensity and another a previously validated test or scale (e.g. Smith et al. [10] studied the effects of codeine with VAS, VDS, and cough frequency monitoring), were also included because they allowed a comparison to be made between the 2 outcome measures.
(2) Quality-of-life scores or scales: studies that reported their item generation methodology, internal consistency, reproducibility, concurrent validity compared with validated generic quality-of-life scales, and/or responsiveness to change.
(3) Studies pertaining to the reproducibility of descriptive scores or scales assessing cough severity.
(4) Studies that compared the different measurements with validated measurements: studies which used different methods of cough assessment and evaluated correlations between the results of each measurement. We elected to include studies that used objective cough frequency measurements that had only been validated for nighttime use even though we felt that a 24-hour validation would have been preferable.

Exclusion Criteria

(1) Coughing was evaluated over a short period of time, e.g. immediately after a provocation test or linked to anesthesia induction or anesthesia withdrawal.
(2) Cough was assessed by an external observer without audio/video recording.
(3) Papers describing the development of a new cough monitor with no comparison to a reference standard such as video recording.
(4) Invasive methods, which we deemed inappropriate to quantify an uncomplicated cough.
(5) Questionnaires linked to a specific cough etiology that aimed to assess the burden of the pathology [such as lung cancer and chronic obstructive pulmonary disease (COPD), among others] rather than the burden of the cough.
(6) Studies in languages other than French, English, or Dutch.
(7) Studies not conducted in humans.

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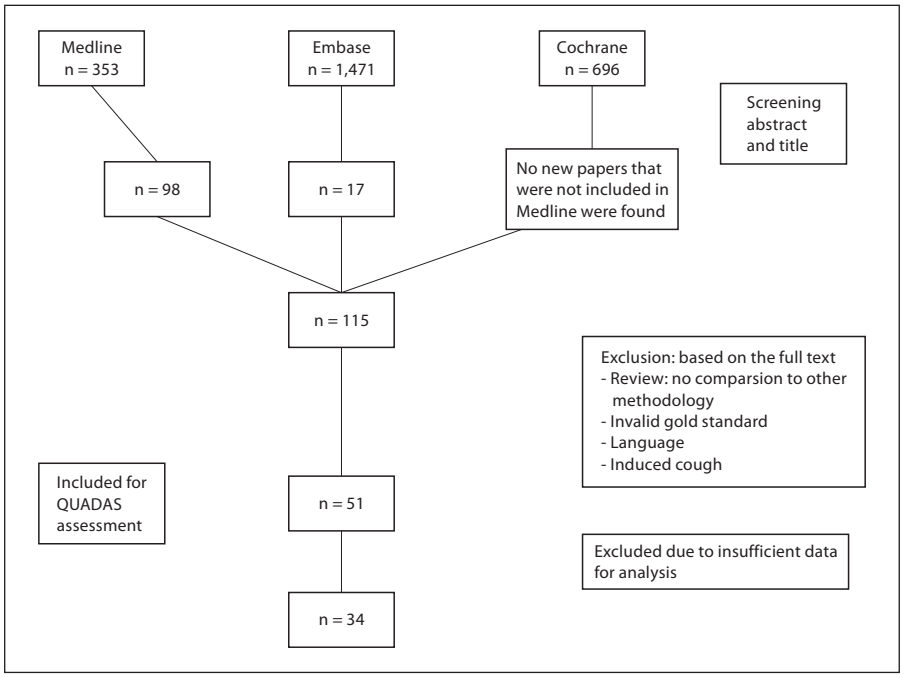

Fig. 2. Flow chart. Results of the literature search.

Selection Procedure

Two researchers (S.L. and D.F.) independently selected studies based on the afore mentioned inclusion and exclusion criteria. The relevance of these studies was assessed in 2 successive steps. First, the title and abstract were reviewed and a number of studies excluded. If the researchers were unable to come to a clear conclusion based on the title and abstract, the study was provisionally included. The full texts of the remaining studies were then retrieved and examined against the inclusion/exclusion criteria. Disagreements between the 2 researchers were resolved by consensus. For cases in which no consensus was reached, the third researcher (J.D.) made the final call. Figure 2 depicts the selection procedure.

Evaluation of the Validity of the Included Studies

Those studies that fulfilled the inclusion criteria were then independently evaluated for their methodological quality by 2 researchers (S.L. and D.F.) using the QUADAS grid [11]. No meta-analysis was possible because of the heterogeneity of the inclusion criteria and the outcomes compared in the different studies.

Results

Thirty-four articles were retained on the basis of the inclusion criteria. Ten of them were validation studies concerning cough frequency monitoring in children and/or adults [12–21]. Seven studies validating cough-specific quality-of-life scores were included [22–29].

Fifteen studies compared instruments used to measure the perceived severity of the cough (i.e. VDS or VAS) with objective cough frequency measurements or quality-of-life scores. These comparative studies were the only source of evidence we found of attempts to validate these subjective measurements. Twelve of these studies, i.e. 6 in adults [10, 30–34] and 6 in children [19, 35–39], compared subjective measurements with objective cough frequency measurements. Three studies compared subjective methods with a quality-of-life score [28, 40, 41]. Finally, 6 studies compared quality-of-life scores with objective measurements of cough [30, 31, 33, 42–44].

Validation of Tools Used to Measure Cough Frequency or Intensity

Table 1 shows the cough monitoring validation studies. Four types of technology have been developed to identify coughs and to measure cough frequency. The first type of device is based on audio-recognition alone [7, 13, 15]; the second type of technology is based on audio signals plus electromyography (EMG; by identifying intercostal and/or abdominal muscle contractions, a cough is identified when the audio and EMG signals occur simultaneously) [17, 18]; the third type is based on an accelerometer which measures the vibration at the suprasternal notch alone [16], and the fourth type is a multiparametric device based on plethysmography, electro-

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Table 1. Cough monitoring validation studies

First author	Patients n	Patients included	Recording conditions	Test description/ automated detection	Standard reference	Results
Smith, 2006 [10]	8	Subjects with chronic cough	Overnight in laboratory	Digital audio recording Manual counting of period of interest with sound activity	Manual count on video	Mean difference: 0.3 coughs/h (95% CI –1.5 to 0.9). Analysis time: 8 h (video) versus 2–4 h (digital sound recordings)
Paul, 2004 [7]	15	Subjects with frequent coughing	Home, outpatient, inpatient for 15–60 min	Accelerometer Portable device with no automated analysis software to assist manual review of recording	Video	Good interobserver agreement Correlation coefficient between video and audio: investigator 1: 0.96 (95% CI 0.918–1.00) investigator 2: 0.97 (95% CI 0.93–1.00)
Coyle, 2005 [21]	8	Subjects with COPD and more than 10 coughs/day	24-hour recording in video room	LifeShirt: combination of plethysmography, ECG, and EMG Automated analysis	Video	Sensitivity: 78.1%; specificity: 99.6% Positive predictive value: 84.6% Negative predictive value: 99.4% Kappa: very good (0.80)
Barry, 2006 [15]	10	Smokers with chronic cough	1-hour recording at hospital	Hull Automatic Cough Counter: digital audio recording Semiautomated detection, i.e. cough recognition according to sound spectrum (probabilistic neural network) followed by manual review	Signal visualization on graphical user interface and listening to periods of interest in real time by 2 independent listeners	Sensitivity: 80% (range 0.55–1) Specificity: 96% (range 0.92–0.98)
Munyard, 1994 [18]	20	4 healthy adults, 1 healthy child, 1 child with asthma, and 14 children with cystic fibrosis	Short duration (1–8 h), working adult	EMG + microphone + ECG Manual review of graphical interface	Tape recording	Correlation coefficient: 0.99 (95% CI 0.96–0.99)
Matos, 2006 [12]	19	Patients with cough recruited from a specialized cough clinic	Usual daily routine recording, mean recording 6 h, starting in the morning	LCM digital audio recording Semiautomatic analysis: identifying and then listening to the recognized signals	Manual counting of recordings	Mean detection rate: 71% False-positives: 13/h
Birring, 2008 [13]	23	15 adults suffering from chronic cough and 8 volunteers	6-hour recording	LCM Semiautomated analysis, operator must classify a small fraction of the sound detected	Manual counting of audio recordings on LCM	Mean difference: –4 coughs/h/patient (95% CI –6 to 13 coughs/h; p = 0.4) Sensitivity: 91%; specificity: 99%
Corrigan, 2003 [20]	28	Healthy newborns and children under 1 year of age admitted for cough (main symptom)	Ambulatory or hospitalized recumbent babies; crying was excluded from the analysis	LR100 = EMG + audio signal Automated tagging followed by manual review	Audio counting of periods with visualized activity	Mean sensitivity: 81% PPV: 0.81 Mean difference: 0.36 coughs/h (95% CI –0.53 to 0.63 coughs/h)
Chang, 1997 [17]	18	Healthy children and children suffering from nonspecific recurrent cough	Overnight, 8–10 h	EMG and audio signal; visual reading of recording No automated analysis	Tape recording	Mean difference: –0.3 coughs/h (–0.7 to 0.2) Limits of agreement: –2.2 to 1.7 coughs/h
Hamutcu, 2002 [19]	14	Patients hospitalized for exacerbation of cystic fibrosis	Count during chest physiotherapy	Modified LR100: cough defined as a rapid phasic burst in audio and EMG signals Semiautomated analysis	Audio count during chest physiotherapy	r^2 = 0.96 (95% CI 0.89–0.98) Difference: 0.5 episodes/session

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cardiography, and an accelerometer (LifeShirt; VivoMetrics) [21]. All of these can potentially be used in an ambulatory setting. Only 1, the LR102 (Logan Sinclair) (a type 2 device), has been validated for use in children [19]. The following 3 devices provide partially or completely automated analyses: the LifeShirt, the Leicester Cough Monitor (LCM), and the LR102. The automated analysis of the LifeShirt has been validated under controlled conditions in COPD patients, although its sensitivity (79%) could be improved. The LCM provides a partially automated analysis. The LR102 provides a completely automated analysis of cough episodes, but it has only been validated in its manual counting mode and measurements of numbers of single cough or cough seconds require manual reading of the indentified cough epoch.

Measurement units are the explosive sound each time the patient coughs [13, 15, 21, 32] or the coughing episode [18] occurs, and the events are defined as separate from one another by a free interval of a determined duration. Cough frequency can also be expressed in units of time spent coughing (e.g. the number of seconds per hour, including a minimum of 1 explosive coughing sound) [16].

The intensity of the signal can potentially be captured in several devices and 1 group of authors mentions they did so [16]. However, they did not report on this. Furthermore, none of the monitors provide an automated analyses of such signals.

According to the QUADAS tool, the quality of the studies varied (fig. 3). The conditions under which the instruments were validated ranged from highly controlled conditions, such as a video room, to actual ambulatory conditions. Some of the cough frequency meters were only validated during the night. The conditions of validation are important because the likelihood of environmental noise and the degree of patient mobility are likely to affect the accuracy of such devices.

Validation of Quality-of-Life Scores

The validation of quality-of-life scores is shown in table 2. Three scales have been validated but only for subjects with chronic cough. The Leicester Cough Questionnaire (LCQ) was developed and validated in English [25]. A Dutch translation has also been validated [22]. The Cough Quality of Life Questionnaire (CQLQ) was developed and validated in English [26, 28, 29]. One scale has been validated in the parents of children suffering from chronic cough in Australia [27], and 1 scale was developed and validated in Italian [23, 24].

All 4 of these studies used internal consistency as an indicator of reliability. The Italian scale also examined the scale's reproducibility and responsiveness to change. Except for the CQLQ, the scores for these instruments were compared with the scores obtained with a generic quality-of-life tool.

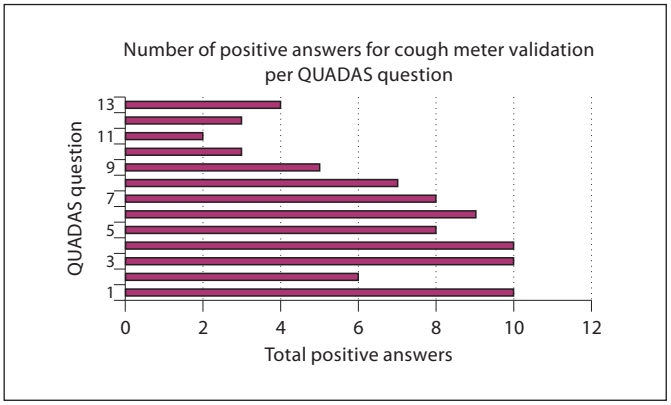

Fig. 3. Global quality of the included studies on cough meter validation. For each study, 13 questions from the QUADAS tools were assessed and 1 point was given if the study fulfilled this criteria. The figure represents the number of studies including each QUADAS criteria.

Comparisons of VDS and/or VAS and Other Measurements

The correlations between VDS or VAS and objective cough measurements or quality-of-life scores are inconsistent. This is true when they are used in both adults and children. The correlations vary not only according to the precise instrument, but even for the same instrument according to the time the measurement is made. For example, the correlation between VDS and/or VAS and a cough frequency measurement ranged from 0.07 [95% confidence interval (CI) –0.33 to 0.448] to 0.81 (95% CI –0.614 to 0.912), depending on the setting of the study and the period evaluated (day or night analysis) [10, 30–34]. The same lack of a consistent correlation was found in children [19, 35–39] and for comparisons with quality-of-life tools [28, 40, 41]. Various descriptive scores and quality-of-life tools were used in different studies. The diseases that were investigated were asthma, cystic fibrosis, COPD, seasonal rhinitis, and primitive ciliary dyskinesia, all of which are associated with chronic or recurrent coughing. We found no studies that examined the perceived severity of an acute cough. Tables 3–5 present comparisons between VDS and/or VAS and other measurements.

The quality of the studies in this section was rather good and homogeneous (fig. 4).

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Table 2. Validation of quality-of-life scores

First author	Patients, n	Population included	Scale	Creation of scale; internal validity
Birring, 2003 [13]	104 for generation items 56 for comparison to other scales 24 for reproducibility 9 for responsiveness	Adults (mean age 57 years) with unexplained aspecific chronic cough	LCQ	(1) Generation of items following interviews of patients and professionals (2) Reduction of items (3) Allocation into domains Cronbach's α: total 0.92 physical 0.79 psychological 0.89 social 0.85
French, 2002 [26]	215	Adults with a chronic cough of more than 8 weeks in duration Adults suffering from acute cough Smokers with cough but no complaints	CQLQ	Factor analysis Cronbach's α: total 0.92 physical 0.85 psychosocial 0.83 functional 0.86 emotional 0.7 extreme physical 0.7 personal safety 0.63
Huisman, 2007 [22]	152	Patients with chronic cough (mean age 59 years) hospitalized – third line	Translated LCQ	Cronbach's α: 0.77–0.91
Baiardini, 2005 [23]	170 for the item reduction question 95 for validation	Patients with chronic cough (mean age 57 years)	Italian scale	Literature review, experts' and pulmonologists' unstructured interviews with patients Item reduction by patients, degree of importance, internal consistency (Cronbach's α between 65 and 86)
Braido, 2006 [24]	95	Adults with chronic cough	Italian score of quality of life	
Kalpaklioglu, 2005 [28]	40	Patients aged 10–69 years referred third line for chronic cough	CQLQ and LCQ	
Newcombe, 2008 [27]	170	Children referred for chronic cough	Burden of cough questionnaire	Items generated from informal discussions with patients following the Juniper asthma questionnaire Reduction according to 2 methods: *Clinical impact:* 27 items internal consistency: 0.94 interitem correlation: rs = 0.12–0.87 *Psychometric method:* full scale Cronbach's α: 0.92 internal consistency: moderate to strong interitem correlation: rs = 0.39–0.57
Polley, 2008 [29]	147	Patients referred for chronic cough Stable patients suffering from asthma COPD patients Patients with bronchiectasis	European QoL	LCQ CQLQ

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Reproducibility	Comparison	Responsiveness
Intraclass correlation (total scale): 0.96	Spearman's correlation of LCQ with VAS: rs = 0.72 St George's Respiratory Questionnaire: rs = 0.54 Short-form 36-item (SF36) health status questionnaire: rs = 0.46	After treatment, effect size: physical 1 psychological 1.75 social 0.84 LCQ total 1.68
Test-retest: paired t test = difference not significant r (total scale) = 0.89	Not with other scales but comparison between groups of patients (complaining and noncomplaining coughing patients) ANOVA followed by Tukey HSD: significant difference between groups of patients	Measured in chronic cough: $p < 0.01$ (statistically significant) for total scale and subscales
Intraclass correlation: 0.86–0.93	Comparison scale with: SF36 (r = 0.41) Borg cough scale (r = –0.41) HADS (hospital anxiety and depression scale) (r = –0.46)	Improvement score: 5.28 (4.41–6.15)
Readministered after 1 week to 22 untreated stable patients: good reliability (range 0.67–0.88)	SF36: low correlation for most items	15 days, posttreatment group of 25 asthmatic patients: statistically significant difference for 16 out of 21 items
	Significant correlation between SF36 and CCIQ for daily life impact, but not for other domains	
	Significant correlation between specific and generic QoL except between CQLQ and mental for SF36 Correlation between component HADS and LCQ: r = –0.48 for anxiety (95% CI –0.66 to –0.24) r = –0.69 for depression (95% CI –0.8 to –0.52) Correlation between CQLQ and LCQ: *Pretreatment:* r = –0.42. (95% CI –0.61 to 0.17) *Posttreatment:* r = –0.60 (95% CI –0.74 to –0.39) Correlation between CQLQ and baseline anxiety: r = 0.34 (95% CI 0.08–0.55)	Effect size 1 or greater
	Comparison with Pediatric Quality of Life Inventory, version 4.0 (PedsQL4.0); 12-item Short Form Health Survey, version 2 (SF-12v2) Cronbach (between 0.56 and 0.91) Spearman's correlation: 0.01 and –0.69	Response following treatment was significant for the 2 scales
	Different associations between LCQ and CQLQ according to pathology: *Chronic cough:* r = –0.56 (95% CI –0.647 to 0.458) *COPD:* r = 0.49 (95% CI 0.379–0.587) Asthma: r = –0.94 (95% CI –0.954 to –0.922) *Bronchiectasis:* r = –0.88 (95% CI –0.908 to 0.845) Euro QoL and LCQ: r = 0.48 (95% CI 0.367–0.579) Euro Qol and CQLQ: r = –0.53 (95% CI –0.622 to 0.424)	

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Table 3. Comparison of descriptive scores of cough impact or visual analogue scales versus validated cough frequency counting in adults

First author	Patients n	Mean cough frequency	Population included	Validation conditions	Test description
Smith, 2006 [30]	19	Median: 8.27 (IQR 5.94–11.67)	COPD patients with cough score greater than 2	Home: day (10 h) and night (10 h)	EVA and descriptive scores
Declamer, 2007 [31]	62	Median (day): 15.59 coughs/h (IQR 1.06–46) Median (night): 2.94 coughs/h (IQR 0–26)	Patients with chronic cough more than 8 weeks in duration	Normal routine: daily ambulatory analysis (night and day)	EVA and score
Smith, 2006 [30]	19	Median on admission (coughs/h): day: 21.2 (IQR 14–34.9) night: 4.8 (IQR 1–6.8)	Adult patients hospitalized for exacerbation of cystic fibrosis	Starting at 10:00 a.m. and at 10:00 p.m. for a duration of 10 h	VAS score (0–100) Descriptive score
Smith, 2006 [30]	26	Median: 7.51 coughs/h (range 2.67–23.11)	Patients with COPD and chronic cough	Ambulatory: night (10 h) and day (10 h) Patient walking at home	VAS and score
Krahnke, 2004 [34]	28	Mean ± SD: 197 ± 157 bouts per baseline session (24 h)	Patients older than 12 years with seasonal allergic rhinitis	Ambulatory: 24-hour recording but patients must stay within a certain range of monitoring	Diary card semi-quantitative scale
Kelsall, 2008 [33]	70	Median: 12.2 coughs/h (IQR 6.8–18.1)	Patients with unexplained chronic cough recruited in third line	24-hour recording: normal daily routine	VAS
Marsden, 2008 [44]	56	Median: 2.6 cough seconds/h	56 asthma patients	Ambulatory: recording for 24 h	Numeric cough scores VAS

Comparison of Cough Frequency and Quality-of-Life Scores

The LCQ correlated well with objective cough frequency measurements in 4 studies (r values ranged between –0.53 and –0.60) [31, 33, 43, 44]. The CQLQ correlated moderately well with objective measures in 2 studies (r = 0.30) [30]. Another study reported a good correlation but did not provide an exact value for the correlation coefficient [42]. A comparison between cough frequency and quality-of-life scores is displayed in table 6.

Discussion

This systematic review has identified several cough frequency meters that are accurate, require little time for analysis, and are suitable for use in an ambulatory setting. Automated analyses (totally automated or quasi-totally automated) are available for 3 devices: the LR102, the LifeShirt, and the LCM. However, the automated analysis of the LR102 has yet to be validated. Access to these devices is currently limited, and none of them measures

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Measurement unit	Comparison	Results
Cough seconds: number of seconds with at least 1 cough event	Digital recording, manual count listening to nonsilent episodes	No significant correlation between the objective count and the subjective score – r (day) = 0.07 (95% CI –0.33 to 0.448) – r (night) = 0.17 (95% CI –0.236 to 0.526) No significant correlation between the objective count and EVA – r (day) = –0.07 (95% CI –0.448 to 0.330) – r (night) = 0.30 (95% CI –0.103 to 0.618)
Cough seconds	Digital sound recording	– Score (day) vs. log (day) time spent coughing: r = 0.50 (95% CI 0.323–0.643) – Score (night) vs. log (night) time spent coughing: r = 0.55 (95% CI 0.383–0.682) – VAS (day) vs. log cough count: r = 0.46 (95% CI 0.275–0.612) – VAS night: r = 0.61 (95% CI 0.457–0.728)
Cough seconds	Digital recording device	Correlation between subjective change and the number of seconds spent coughing – score (day): r = 0.34 (95% CI –0.058 to 0.645) – score (night): r = 0.19 (95% CI –0.217 to 0.540) – VAS (day): r = 0.47 (95% CI 0.097–0.727) – VAS (night): r = 0.81 (95% CI 0.614–0.912)
Cough seconds: number of seconds per hour with at least 1 explosive sound	Digital recording device Cough counted manually in cough seconds	– Cough score (day) and cough seconds: r = 0.37 (95% CI 0.044–0.625) – Cough score (night) and cough seconds: r = 0.48 (95% CI 0.177–0.700) – VAS (day) and cough seconds: r = 0.41 (95% CI 0.091–0.653) – VAS (night) and cough seconds: r = 0.50 (95% CI 0.202–0.713)
Coughing bouts per hour	Home-based validated telemetry	– Good correlation between subjective and objective assessment for 1, 2, and 3 (Spearman's correlation 0.51 for 24 h, $p < 0.001$) – Daytime s = 0.54 ($p < 0.001$) – Nighttime s = 0.39 ($p < 0.001$)
Cough explosive phase Cough seconds Cough episodes	Sound recording the cough wave on PC quantified by observer using audiovisual display	– Daytime EVA and objective count: r between 0.4 (95% CI 0.218–0.555) and 0.45 (95% CI 0.276–0 0.596) according to cough unit – Nighttime EVA and objective count: r between 0.6 (95% CI 0.455–0.714) and 0.67 (95% CI 0.544–0.767)
Numbers of seconds containing 1 or more explosive cough sound	Cough sound recording manually counted	– r (daytime; score and frequency) = 0.32 (95% CI 0.062–0.538) – r (nighttime; score and frequency) = 0.44 (95% CI 0.2–0.63) – r (daytime; VAS and frequency) = 0.45 (95% CI 0.212–0.637) – r (nighttime; VAS and frequency) = 0.43 (95% CI 0.188–0.623)

cough intensity in an automated mode. The cough's intensity, which can be measured by several monitors, is related to the intensities of the measured signal (loudness, intensity muscular contraction, and intensity of thoracic amplitude). It remains to be shown how the intensity of these signals is nearest to the intensity of the expulsive efforts. It also remains to be proven whether cough intensity correlates better than cough frequency with the impact of cough on quality of life.

There are several limitations to the studies examined. The numbers of participants were limited. The recording conditions were not always similar to real-life situations. Validations under laboratory conditions could overestimate the specificity of the monitor and reduce the number of false-positive counts because of the interference caused by patient movements and background noise. Furthermore, comprehensive validation of the automatic analyses of the devices requires that they be tested across wide ranges of cough frequencies, cough loudness, and

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Table 4. Comparison of score or visual analogue scale to an objective cough count in children

First author	Patients n	Cough frequency	Population included	Validation condition	Measurement description by score or scale	Definition of cough unit
Hoskyns, 1991 [39]	16	Median coughing episodes: 14.5 (with controlled release salbutamol) and 12 (with placebo)	Asthmatic children aged 6–14 years and children with persistent cough	Nighttime recording	Daytime and nighttime scoring	Number of 10-second cough episodes
Chang, 1998 [36]	84	Median daytime cough frequency in coughing patients: 61 coughs/24 h (IQR 159); in noncoughers: 10 coughs/24 h (IQR –15) Nighttime cough frequency in coughing patients: 2.5 (IQR 20); in noncoughers: 0 (IQR 2.7)	Children aged 6–17 years with recurrent non-specific cough in the respiratory outpatient department	24 h, normal activity	EVA (1–10)	Undefined
Hamutcu, 2002 [19]	10	Mean ± SD on admission: 18.2 ± 8.4 episodes/h during the day and 5.8 ± 2.9 at night	Patients hospitalized for exacerbation of cystic fibrosis	17 h, recording in hospital	VAS, descriptive score for daytime and nighttime	Cough episodes with a minimum interval of 2 s free between them
Chang, 2003 [37]	40	Median: Day 1: 75 coughs/h (9–719) Day 7: 44 coughs/h (0–500)	Children aged 6–17 years with recurrent cough	24 h	VAS, descriptive score	
Li, 2006 [35]	36	Median number of episodes per day: 25.5 (IQR 6–43)	Subjects aged 7–18 years with stable moderate asthma – outpatient clinic	Ambulatory	VAS day- and nighttime	Combination of rapid phasic burst in both signals, counted as individual spikes and as bouts
Zilhif, 2005 [38]	30	Median: 19 coughs/h (IQR 11–22.5)	20 children with primitive ciliary dyskinesia and 10 healthy children Mean age 10.8 years	Ambulatory recording for 17 h and 40 min	Clinical score for day- and nighttime VAS	Cough episodes (2 s between 2 spikes)

cough patterns, and during both day- and nighttime. Some of these devices (LCM) still produce false-positive results when subjects clear their throats or when nearby individuals cough. Finally, the review process was limited to validation studies published in English, French, or Dutch. Other validation studies may have been published in other languages. Papers reporting the development of cough monitors were excluded.

Quality-of-life scales have been validated in adults with chronic cough and in the close relatives of children suffering from chronic cough and can thus be usefully applied in this context [25–27]. Further studies could evaluate the impact of cough under acute conditions.

This literature review did not identify any validation studies of VDS or VAS. However, these are very widely used as outcome measures in intervention studies and are promoted in guidelines for cough assessment [45]. The cor-

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Description of cough frequency measure	Results
Microphone with vocal activator and manual control	Correlation between log of nocturnal cough frequency and parental nocturnal score: r = 0.588 (95% CI 0.214–0.812) during CRS week but no significant correlation with placebo
EMG and microphone (22)	Daytime cough: – subjects: 100% – controls: k = 0.61 for child-completed chart; k = 0.44 for parent-completed chart Nighttime cough: – subjects: k = 0.11 (parents); k = 0.22 (child) – controls: k = 0.16 (parents); k= 0.24 (child) – correlation between cough frequency count and VAS completed by parents: rs = 0.6 (95% CI 0.42–0.73) – correlation between cough frequency count and VCD: rs = 0.65 (95% CI 0.5–0.77)
LR100	No significant correlation between VAS or score and objective count (data not given)
EMG and microphone (22)	Day 1: log cough frequency per 24 h and log cough score – child: r = 0.32 (95% CI 0.01–0.57) – parent: r = 0.32 (95% CI 0.01–0.58) Day 7: – child: r = 0.44 (95% CI 0.13–0.67) – parent: r =0.42 (95% CI 0.11–0.65)
LR102	No significant correlation between daytime cough (p = 0.63) and nighttime cough (p = 0.717) and the recorded frequency (data not given)
LR100, automatic analysis with manual revision	– r (daytime; score and frequency) = 0.93 (95% CI 0.872–0.962) – r (nighttime; score and frequency) = 0.71.(95% CI 0.515–0.835) – VAS and frequency: r = 0.906 (95% CI 0.830–0.949)

relations of these scores and scales with quality-of-life scores or with measures of cough frequency vary considerably. VDS are often based on a mixture of items related to the perception of cough frequency and the perception of its impact on the patient's life. Therefore, it is very difficult to interpret precisely what the scores represent. Patients' perceptions of the importance of their cough when measured by VAS or VDS may be influenced by elements other than cough frequency or its repercussions on the patient's quality of life. It is likely that factors such as disease, duration of illness, patient mood, cough intensity, and global context play roles in these perceptions. Despite having good face validity, these scores and scales cannot be regarded as validated tools indicative of cough frequency or the repercussions of the cough on the patient's quality of life.

The correlation between the total quality-of-life score measured with the LCQ and the cough frequency count is quite good. This suggests that cough frequency has an

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Table 5. Comparison between the validated quality of life score and the descriptive score or visual scale

First author	Patients n	Population included	Validation conditions	Descriptive score or EVA	Scale used for quality of life	Results
Torrego, 2006 [41]	42	Stable patients with bronchectasis vs. healthy patients	Unspecified	Night- and daytime score: 0–5	LCQ	Strong negative relationship between score and LCQ r = –0.9 (95% CI –0.940 to 0.836)
Kalpaklioglu, 2005 [28]	40	Third-line referred patients with chronic cough	Ambulatory	Score: 1–5	LCQ-CQLQ	Significant correlation before treatment b = 0.415 (score-CQLQ), B = –0.272 (LCQ); p = 0.008 No significant correlation after treatment Note: neither symptoms nor cough duration appeared to play a role in patients' pretreatment anxiety or depression
Marchant, 2008 [40]	190	Newly referred children suffering from chronic cough	Ambulatory	Score: 1–5	Burden cough score: Clinical impact: 27 items Psychometric: 26 items	rs = –0.17; p = 0.042 for clinical impact scale rs = –0.23; p = 0.005 for psychometric scale

Table 6. Comparison of quality-of-life scores with cough frequency

First author	Patients n	Cough frequency	Inclusion	Validation conditions	Count	Scale	Results
Jeyakumar, 2006 [42]	28	Not specified	Patients with chronic cough for more than 6 months	Ambulatory	Estimated reduction in cough frequency (100%, 75% …)	CQLQ	Strong correlation (data not given)
Birring, 2006 [13]	29	Mean: 43 (8) coughs/h for chronic cough and 2 (1) coughs/h in healthy controls	20 patients suffering from chronic cough and 9 healthy subjects	Ambulatory	Digital ambulatory cough monitoring	LCQ	Correlation between cough frequency and LCQ: total r = –0.6 (95% CI –0.769 to 0.354)
Smith, 2006 [14]	26	Median: 7.51 coughs/h (range 2.67–23.11)	COPD and chronic cough patients	Ambulatory (night and day)	Digital recording device: cough counted manually in cough seconds	EVA and CQLQ	Total r = 0.36 (95% CI 0.33–0.617) Nighttime r = 0.05 (95% CI –0.286 to 0.375) Daytime r = 0.29 (95% CI –0.045 to 0.567)
Declamer, 2007 [31]	62	Median (day): 15.59 (range 1.06–46) Median (night): 2.94 (range 0–26)	Patients with chronic cough for more than 8 weeks (median = 5.5 years)	Normal routine ambulatory analysis (night and day)	Digital sound recording	LCQ	Correlation between LCQ total and log count total: r = –0.55 (95% CI 0.383–0.682) Daytime r = –0.54 (95% CI –0.67 to –0.371) Nighttime r = –0.39 (95% CI –0.55 to –0.19)
Kelsall, 2008 [33]	70	Median (24 h): 12.2 coughs/h (IQR 6.8–18.1)	Patients with unexplained chronic cough	24-hour recording	Digital sound recording: Cough explosive phase Cough seconds Cough episodes	LCQ	Correlation between LCQ total and explosive phase: r = –0.53 (95% CI –0.370 to –0.659) Correlation between LCQ total and cough seconds: r = – 0.53 (95% CI –0.69 to –0.37) Correlation between LCQ total and cough episode: r = –0.46 (95% CI –0.287 to –0.604)
Marsden, 2008 [44]	53	Median: 2.6 coughs/h	Asthmatic patients	Ambulatory recording for 24 h	Numbers of seconds with 1 or more explosive cough sounds	LCQ	Correlation between LCQ total and cough seconds: r = –0.54 (95% CI –0.707 to –0.316)

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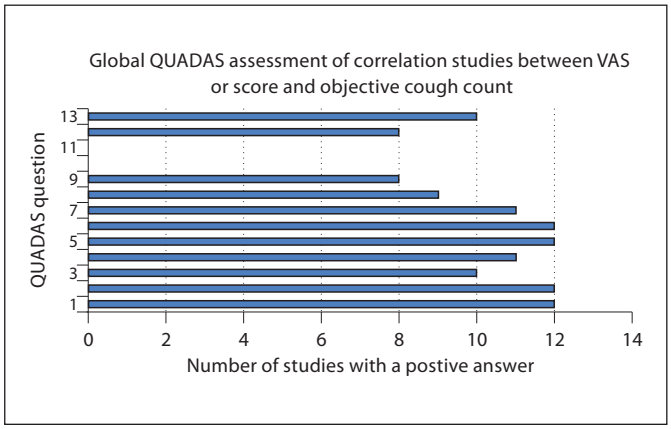

Fig. 4. Global quality of included studies on the comparison between subjective scoring and objective cough count. Number of studies fulfilling each QUADAS criteria.

impact on the patient's quality of life even though other elements are also likely to influence the quality-of-life scores. Further studies could usefully explore the weights of different factors.

Recommendations for the Researcher

Few studies assessing the effects of cough treatments have objectively measured cough frequency or its repercussions on the quality of life of patients. Clinical trials using validated cough evaluation criteria are required. Different types of measurements could reflect different aspects of cough severity, although the close correlation found between cough frequency and scores on the LCQ suggest that the different aspects may be linked (e.g. cough frequency may influence quality of life). Outcomes should be chosen to be congruent with the objective of the study. Aiming to improve the patients' quality of life is presumably the main objective of symptomatic prescriptions. Quality-of-life questionnaires should probably be used as primary outcome measures in trials of cough suppressants. There are 2 validated instruments for use in adults (LCQ [25] and CQLQ [26]) and 1 for use in children [27]. If cough frequency can be considered an indicator of disease severity, it can be used to monitor the evolution of the disease in terms of the treatment. The LifeShirt, the LCM, and the LR102 seem promising in this respect but require broader validation before their widespread use in clinical trials can be recommended.

Recommendations for the Clinician

The diagnostic significance of cough rhythm, as well as its nature, frequency, and intensity, is still unclear, and further research on this matter is necessary to determine whether cough pattern monitoring (e.g. characteristic of cough or time occurrence) has a place in clinical practice. Cough frequency monitoring may help to identify predisposing environmental factors [46, 47]. It could also help to objectively evaluate response to treatment, which is an element in the diagnostic work-up of certain cases of cough.

Quality-of-life scores may be useful in the evaluation of chronic cough and may thus direct therapeutic decisions and help the clinician to monitor the evolution of the cough. These questionnaires could also be useful in directing clinicians to particular areas in the patient's quality of life that are affected by the cough (i.e. physical, psychological, or social domains) and thus allow them to provide more appropriate care. Although not currently validated, VDS and VAS may be valuable precisely because they do not correlate with more objective measurements. This may encourage clinicians to investigate the factors that influence the patient's perception of his/her symptoms, disentangling the factors that are directly linked to the objective severity of the cough from other factors, such as mood and anxiety, that should be addressed accordingly. This, in turn, may lead to a reduction in the inappropriate use of cough suppressants.

Acknowledgements

The authors would like to thank the members of Sophie Leconte's PhD supervising committee for their insightful comments and suggestions regarding cough outcomes.

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