# COMPUTER AIDED LUNG SOUND ANALYSIS
## *A Preliminary Study to Assess its Potential as a New Outcome Measure for Respiratory Therapy*

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Abstract: A barrier to assess the relative effectiveness of respiratory therapies has been insufficient accurate, reliable, and sensitive outcome measures. Lung sounds provide useful information for assessing and monitoring respiratory patients. However, standard auscultation is too subjective to allow them to be used as an outcome measure. In this paper, Computer Aided Lung Sound Analysis (CALSA) characterising crackles' Initial Deflection Width (IDW) and Two Cycle Deflection (2CD) is proposed as a potential objective, non-invasive, bedside outcome measure to assess the response to alveolar recruitment and airway clearance interventions. A preliminary 'repeated measures' experimental study was conducted. Seventeen participants with cystic fibrosis were recruited from out-patient clinics. Demographic, anthropometric and lung sound data were collected. The intra-subject reliability of crackles' IDW and 2CD was found to be 'good' to 'excellent', estimated by the Analysis of Variance, Intraclass Correlation Coefficient, Bland and Altman 95% limits of agreement and Smallest Real Difference. It is concluded that crackle IDW and 2CD detected by CALSA are reliable and stable measures. In future, CALSA may be useful for assessing and monitoring respiratory interventions in clinical settings.

## 1 INTRODUCTION

The lack of reliable outcome measure has been an obstacle to providing evidence about the relative effectiveness of respiratory therapy interventions. The main aims of respiratory physiotherapy include: increasing alveolar recruitment, thereby improving ventilation; increasing secretion removal and therefore airway clearance; decreasing work of breathing and consequently dyspnoea; increasing muscle strength and endurance to increase exercise capacity and independence in daily functioning and increasing patients' understanding of their lung condition to promote self-management. Research into airway clearance techniques has been one of the priorities identified for research (CSP, 2002). In this paper we explore the potential for computer aided lung sound analysis (CALSA) to be used as an outcome measure for respiratory therapy interventions.

Respiratory physiotherapists currently use the following outcome measures to monitor their interventions and evaluate their practice: sputum quantity, respiratory function tests, tests of gas exchange, imaging evidence and standard auscultation techniques. Most of these are not specifically related to the physiotherapy intervention employed and may be affected by other factors (Marques et al., 2006). There is no gold standard outcome measure that is specifically related to respiratory physiotherapy interventions. Most of the published respiratory physiotherapy research compares two or more active interventions rather than an active intervention versus an inactive control. In such studies it is never clear if differences are not detected because the outcome measures are not appropriate, or because the treatments being compared are equally effective/ ineffective. Although there are other more invasive or laboratory-based outcome measures available, these are generally only applicable to a research setting.



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## 1.1 Lung Sounds

Normal lungs generate breath sounds as a result of turbulent airflow in the trachea and proximal bronchi. The airflow in the small airways and alveoli has a very low velocity and is laminar, and therefore silent. Turbulent flow characteristics are influenced by airway dimensions, which are a function of body height, body size, age, gender and airflow will all affect breath sounds (Pasterkamp et al., 1997). Sounds heard or recorded at the chest differ according to the location at which they are heard or recorded, and vary with the respiratory cycle (Sovijarvi et al., 2000). The geometry of the bronchi also contributes to the complexity of the thoracic acoustics (Kompis et al., 2001) because it affects flow, and consequently breath sounds.

Normal breath sounds can be classified as ‘abnormal’ if heard at inappropriate locations. There are also added sounds (known as adventitious sounds) which can be continuous (wheezes) or discontinuous (crackles). Their presence usually indicates a pulmonary disorder.

Wheezes are continuous adventitious lung sounds. The mechanisms underlying their production appear to involve an interaction between the airway wall and the gas moving through the airway (Meslier et al., 1995), producing continuous undulating sinusoidal deflections by fluttering of the airway walls. Wheezes are clinically defined as musical sounds and can be characterised by their location, intensity, pitch, duration in the respiratory cycle, and relationship to the phase of respiration (Meslier et al., 1995).

Crackles are discontinuous adventitious sounds and their presence may be an early sign of respiratory disease. They are intermittent, non-musical, brief sounds thought to be caused by the acoustic energy generated by pressure equalization or change in elastic stress after a sudden opening or closing of airways (Forgacs, 1978, Nath and Capel, 1974). Their character is explosive and transient and depends on the diameter of the airways. Their short duration and often low intensity, makes their discrimination and characterisation by normal auscultation very difficult (Kiyokawa et al., 2001). Crackles are generally characterised by the Initial Deflection Width (IDW), i.e. the duration of the first deflection of the crackle and the Two Cycle Deflection (2CD), i.e. the duration of the first two cycles of the crackle. The mean values of IDW and 2CD durations for fine and coarse crackles are defined (ATS, 1977, Sovijarvi et al., 2000). During respiratory disease, the involvement of different airways is associated with the crackle frequency, i.e., high frequency crackles are associated with peripheral airways and lower frequency crackles with upper airways (Fredberg and Holford, 1983). These measurements therefore have the potential to be useful as an outcome measure for respiratory therapy.

## 1.2 Standard Auscultation

Standard auscultation via a stethoscope is an assessment tool used by many health professionals during chest examination in their clinical practice, and is often used by physiotherapists to monitor patients’ response to respiratory interventions. However, the literature has contradictory reports about its value in routine current practice. Some authors argue that auscultation is an inappropriate outcome measure because of the differences in health professionals’ hearing acuity as well as in the properties of stethoscopes. There can also be different approaches to the description of auscultatory findings, nomenclature difficulties, and inter- and intra-observer variability (Welsby et al., 2003) Others have argued that auscultation is an easy, rapid, effective, non-invasive, and cost-effective way of assessing the condition of the airway and breathing (Chen et al., 1998). However, agreement between observers during standard stethoscope examination for the presence of normal or adventitious lung sounds was found to be only ‘poor to moderate’, and clinical experience was not found to have any clear effect on accuracy or reliability (Brooks et al., 1993). Elphick et al. (2004) found that using computerised acoustic analysis of recorded lung sounds improved the reliability of detection for all sounds when compared to listening through a stethoscope. Therefore, although the use of a standard stethoscope may be too subjective to provide a useful outcome measure, the sounds generated from the lungs provide useful information, and relate directly to movement of air and secretions.

## 1.3 Computer Aided Lung Sound Analysis

There is a great deal of information derivable from lung sounds, that is not normally readily accessible even to experienced clinicians and exceeds the memory capacity of most people. Lung sounds interpretation is enhanced using CALSA through the efficient objective data collection, generation of permanent records of the measurements made with easy retrievability and through graphical representations that help with diagnosis and management of patients' suffering from chest diseases (Earis and Cheetham, 2000). Digital recordings of normal lung sounds have shown high inter- and intra-subject repeatability with the inter-individual variability explained by height, gender and anatomic characteristics (Sanchez and Vizcaya, 2003).

There is some evidence in the literature to support the hypothesis that CALSA characterising adventitious lung sounds may be a useful outcome measure. The number and distribution (per breath) of adventitious sounds has been associated with severity of disease and crackles characteristics have been found to differ in different diseases, allowing differentiation between conditions (Piirila, 1992). Furthermore, the number of wheezes per respiratory cycle has been reported as a good indicator for airway obstruction (Baughman and Loudon, 1984). CALSA has already been used to assess the airways' response to bronchodilators and bronchoconstrictors in children and in adults. Malmberg et al. (1994) studied 11 asthmatic children (aged 10 to 14 years) and found that spectral analysis of lung sounds can be used to detect airways obstruction during bronchial challenge tests. When combined with spirometry, CALSA increased the sensitivity of detection of pulmonary disease and was able to provide early signs of lung disease that was not detected by spirometry alone (Gavriely et al., 1994).

The use of CALSA has been found to be specific, reliable, and sensitive within the limited use to which it has been put to date but has not yet been evaluated as an outcome measure for physiotherapy. Although it is known that normal lung sounds are reliable and that adventitious lung sounds have some clinical meaning, the reliability of the specific parameters of adventitious lung sounds (e.g. crackles' IDW and 2CD) has not been adequately explored. In order for CALSA to be used as a valid outcome measure its reliability amongst patient populations in clinical settings must be demonstrated. Therefore, the inter- and intra-subject reliability of CALSA to measure crackles over short time-periods in adult patients with cystic fibrosis were explored.

# 2 METHODOLOGY

A single group repeated measures design was employed in which triplicate recordings were made from the same patients over a short time period. The study received full approval from Southampton & South West Hampshire Research Ethics Committees (A).

Since this was a reliability study, power calculations were not appropriate. Potential participants were identified via the respiratory out-patient clinics held at two hospitals on the south coast of the UK. Participants were included in the study if they were 1) able to give and sign informed consent; 2) formally diagnosed with cystic fibrosis (CF); 3) 18 years of age or older and 4) clinically stable for one month prior to the study (no hospital admissions, exacerbations/ infections or change in medication). Participants were excluded from the study if they had co-existing lung pathologies.

Anthropometric data such as height and weight were measured using calibrated digital scales. The lung sound recordings were performed with a digital stethoscope (WelchAllyn Meditron, 5079-402). The input from the microphone was connected via an amplifier to a laptop with customised software, suitable for data acquisition, written in Matlab (version 7.1).

## 2.1 Protocol

All participants provided informed consent prior to data collection. Demographic and basic anthropometric data were recorded first. The lung sound recordings followed the guidelines defined by Computerized Respiratory Sound Analysis for short term acquisition (Sovijarvi et al., 2000). Participants' skin was marked with a pen in seven different places to ensure consistency of stethoscope placement: one centrally over the trachea (sternal notch); two on the back of the chest (right and left bases: at 5 cm from the paravertebral line and 7 cm below the scapular angle); two on the front of the chest (right and left: in the second intercostal space, mid-clavicular line); two on the side of the chest (right and left: in the fourth to fifth intercostal space, mid axillary line). Lung sound recordings were then performed with the digital stethoscope held by hand over each location. Participants were asked to breathe through the mouth during recordings. Three sets of recordings were made for 25 seconds at each marked location.

## 2.2 Analysis

Gender, date of birth, height and weight data were entered into SPSS version 14. Body mass index (BMI) in (kg/m$^2$) was calculated using the formula

BMI = weight/(height)$^2$. Descriptive statistics were used to describe the sample.

The lung sounds were recorded with a sampling frequency of 44.1 KHz. All files from the seven anatomical sites were processed to detect crackles using algorithms written in Matlab based on Vannuccini et al.'s algorithm (1998). The data from all files with the duration in milliseconds of the crackles variables (IDW and 2CD) were imported to SPSS version 14 for statistical analysis.

### 2.2.1 Relative Reliability

Inter-subject reliability was analysed using analysis of variance (ANOVA). All recordings were performed by the same researcher. The inter- and intra-subject reliability was examined in each recording position in each session. Therefore, the ICC was calculated using the equation (1,k) which uses the one-way ANOVA table: ICC (1,K) = (BMS-WMS)/BMS, where ICC is the Intraclass Correlation Coefficient, BMS = between subjects mean squares; WMS = within subjects mean squares; k = number of observers or measures. The ICC results were analysed according to Fleiss (1986) criteria i.e. values above 0.75 represent excellent reliability; between 0.4 and 0.75 represent moderate to good reliability and below 0.4 represent poor reliability.

### 2.2.2 Absolute Reliability

Bland-Altman plots were performed to provide visual information about systematic bias and random error by examining the direction and magnitude of the scatter around the mean difference (Bland and Altman, 1986). The standard error of measurement (SEM) was obtained by calculating the square root of the within subject mean square (WMS) values obtained in the ANOVA table performed for each recording position for each session. These values were then used to calculate the Smallest Real Difference (SRD), which represents the smallest change that can be interpreted as a real difference.

## 3 RESULTS

Seventeen CF participants, age range of 18 to 67 years old (8 female and 9 male) and average BMI of 20.6±3.3 kg/m$^2$, were recruited. The inter-subject reliability analysis confirmed the expected variability between subjects. It has been suggested that to assess intra-rater (or test-retest) or inter-rater reliability in reliability studies, a measure of relative reliability, the ICC, and a measure of absolute reliability, Bland & Altman 95% limits of agreement, should both be reported (Rankin and Stokes, 1998).

The ICC values range between 0.57 to 0.85 for the crackles' IDW variable and between 0.75 and 0.96 for the crackles' 2CD. The ICC results were generally found to be excellent in both groups of participants. The crackles' IDW variable generally presented a lower ICC value when compared with the crackles' 2CD variable. Bland and Altman 95% limits of agreement were performed and the scatter plots were analysed in all recording positions for both groups of participants on the three different occasions. No systematic bias was present. The SRD ranged from 0.33 to 0.76 ms for the crackles' IDW and from 1.29 to 2.66 ms for the crackles' 2CD.

## 4 DISCUSSION

The inter- and intra-subject reliability of crackles' IDW and 2CD measured using CALSA has been rarely investigated. There is, however, a consensus that the inter and intra-observer reliability of the detection of added lung sounds among health professionals using tape-recorders, audio-files or standard auscultation is generally poor (Elphick et al., 2004). The inter-subject variability for both crackles' variables studied (IDW and 2CD) in this research was found to be high, as shown by the significant ANOVA. This high inter-subject variability for crackles' IDW and 2CD duration was expected due to differences in demographic and anthropometric characteristics (Sanchez and Vizcaya, 2003), and varying acuity of pathology.

The intra-subject reliability was found to be 'good' to 'excellent' with no systematic bias between the repeated measures. Previous studies have also reported high intra-subject reliability of lung sounds in healthy subjects (Mahagnah and Gavriely, 1994) and in healthy subjects and patients with fibrosing alveolitis (Sovijarvi et al., 1996). However, these studies have analysed lung sounds in the frequency domain, in small samples of mainly healthy subjects and have not included people with excessive secretions making comparisons difficult.

The ICC and Bland and Altman 95% limits of agreement have been recommended as the more adequate methods to assess reliability (Rankin and Stokes, 1998). The ICC for the crackles' IDW and 2CD suggested 'excellent' or 'good' reliability in almost all recording positions, in both groups of participants. However, the ICC should be interpreted with caution. Bland and Altman 95% limits of agreement are independent of the true variability in the observations and therefore, complement the ICC analysis and provide detail regarding the nature of the observed intra-subject variability (Rankin and Stokes, 1998). The reliability assessed from Bland and Altman techniques was found to be acceptable, and no consistent bias was detected in any recording position of the two crackles' variables studied. Therefore, crackle characterisation using CALSA was deemed reproducible over short time periods. The ICC has rarely been used when analysis lung sounds, but 'satisfactory' reproducibility of lung sounds based on ICC results have been reported (Schreur et al., 1994). However, this analysis was performed in the frequency domain where spectral characteristics were considered and the recordings were performed in a sound proofed room.

In this research, the SRD values, over short time periods, for both variables studied (crackles' IDW and 2CD) presented a similar range of values indicating the stability of the measure in CF participants. Smallest real difference calculations were not found in other published studies involving lung sound analysis and therefore, comparisons with the findings of this research were not possible.

As it has been demonstrated, the use of CALSA in terms of clinical properties shows potential to be use as an outcome measure for respiratory therapy but this has not been previously explored. At this point in time, the data related to lung sounds are complex and time consuming to analyse. To be clinically useful as an outcome measure it will be essential to simplify, and increase the speed of, the analytical process. Furthermore the cost-effectiveness of implementing this outcome measure is unknown. Validation of CALSA as a responsive outcome measure is challenging because of the lack of a gold standard respiratory therapy measure with which to compare it. Studies relating to responsiveness to change of lung sounds before and after an intervention of known effect e.g. bronchodilators, suction, would help in clarifying the responsiveness of the measure, and increasing understanding of the validity of CALSA in clinical settings. Nevertheless, the aims proposed at the outset for this research have been achieved.

# 5 CONCLUSIONS

This preliminary study suggests that the use of CALSA to characterise crackles is reproducible over short time periods in cystic fibrosis outpatients. This finding gives initial confidence that CALSA has potential as an outcome measure for respiratory therapy interventions (such as physiotherapy for airway clearance) but further evaluation is necessary.

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