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Digital detecting signs of bronchial asthma *

Cyfrowe poszukiwanie oznak astmy oskrzelowej

INTRODUCTION

In the diagnosis of bronchial disease — as in other domains of medicine — an integral approach to patients' complaints is essential [1]. Careful observation and evaluation of his personality during medical history taking as well as an optimal clinical examination by palpation and auscultation of the heart, great vessels and lungs may lead to a semi-quantitative diagnosis specially in valvular and congenital heart disease [6, 11]. The results of select imaging techniques may therefore be anticipated in these conditions by skilled clinical judgement alone [17].

Wheeze during auscultation are a prominent clinical feature of atopic bronchial asthma and may be an early sign of the condition [7, 16]. Auscultation, however, is subjective and inter-examiner disagreement is a problem [4, 10]. Computerised lung sound analyser can visualise, store, and analyse lung sounds and disagreement on the presence of crackles or wheezes is minimal [7].

AIM

The aim of this study was to compare clinical auscultation with classical (acoustic) phonendoscope or analogue/digital stethoscope. Respiratory sounds diagnosis was performed by computer-assisted signal processing i.e. amplification, Fourier, and frequency/time spectral analysis in detecting signs of bronchial asthma.

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METHODS

A. Medical auscultation procedure

We assessed the performance under standardised conditions of lung sound recording according to Pasterkamp [15]. Breath sounds were recorded on at fixed locations over the chest wall. Each subject was studied twice with a time interval of 1 hour. On each occasion, measurements were done in duplicate, with a 3-min. interval between recordings. Recordings were obtained from the investigators at the best site on the posterior lower chest as determined by classical auscultation. Chest radiography and spirometry were assessed earlier for excluding of interstitial opacities and/or detection of bronchial hyperreactivity (beta-2-mimetic's dilatation test) [16]. Spirometry was performed by Flowscreen Jaeger (Germany). Auscultation for wheezes, crackles or other lung sounds was performed by two independent examiners unacquainted with the diagnosis.

B. Biomedical engineering — digital auscultation

The algorithm was as follows:

Registration of crude normal breathing sounds and wheezes collected by analogue (Promed) and digital stethoscope (Welch Allyn) parallel with classic auscultation (Litmann) and doctors description's; Lung sounds were sampled and simultaneously amplified and digitised into a computer, and the average spectra of the inspiratory, expiratory, and background sounds were calculated like in Mahagan proposal [12]. Fourier techniques were used for power spectral analysis [15]. Mathematical analysis of inspiration/expiration and wheezing episodes duration in milliseconds and power spectral analysis was obtained from a recording of lung sounds over the lung bases.

In the next step classical Fourier analysis is performed using different time windows. As a default option, the square window with varying duration in time is used. Fourier analysis can give frequency components with required resolution depending on the duration of the time window [14]. Time window (observation time) can be chosen from few hundreds of ms up to 10s. Duration of 5 seconds is the default value. The longer time results in higher resolution, but the spectrum ends at lower frequency while the number of samples is constant. In the described system, 1024-point Fourier analysis is implemented. In order to avoid leakage of the spectrum, different time windows can be applied. Leakage exists when relation between sample rate and maximum frequency of the spectrum component in the investigated lung signal is violated. Additionally, the processed signed is highly non-stationary, what makes difficulties to chose proper sampling frequency. It is almost impossible to ensure integer ratio between sampling and observation periods. It causes that the signal under the investigation has artificially introduced high-frequency components, and in consequence, the leakage phenomenon disturbs the spectrum in high-frequency region. To reduce the undesired effects of the spectrum leakage, we propose to use Hamming (acc. 14) window implemented in the system in time domain.

In the system, 3 sampling frequency are possible: 11,025 Hz, 22,050 Hz and 44,100 Hz, however the highest one is recommended. It additionally reduces the leakage effects as we work with signals of breathing with highest frequency components at 2,000 Hz only. Frequency/time analysis is the main step of the implemented algorithm. Time window containing 1,024 16-bit sound's samples is shifted over the chosen observation period. The colourful image displays frequency variation in time of non-stationary signal. Bright-colour image's segments present the frequency components. They are located in different image's points, and the y-value (height on the diagrams) corresponds to the frequency value.

If the spectrum is uniformly distributed, plenty of spectrum components are generated during breathing (Fig. 1). Asthmatic wheezing is presented when single or a few spectral components are clearly higher than the rest of the spectrum (Fig. 2).

To compare the different spectrums and their uniformity in order to extract the asthmatic cases, the spectrum uniformity measure is proposed. It can be defined e.g. as number of highest spectral components, which appear in the spectrum above certain threshold level. The classification can be performed as follows: if the number of such components in the spectrum is lower than 3–5, we have the asthmatic case in the investigations. Other measures are actually under consideration, and this one, which is the most significant statistically will be recommended for practical use.

All the above-mentioned results were compared with the control group.

MATERIALS

The group of investigated patients with different stage of bronchial asthma consisted of 90 persons aged 4.5–63 years. Digital and classical auscultation were performed parallel in a control group consisted of 30 healthy persons (aged 4–76 years) who had a normal chest radiograph, normal spirometric data and any complaints concerning asthmatic wheezes. There were four current smokers and three previous smokers.

RESULTS

Part 1. Comparison between classical and digital auscultation by physician

Among 34 patients with an episodic bronchial asthma inspiratory (more often on the peak of inspiration phase) or expiratory wheezes were detected by classical auscultation in seven (20.5%) persons and by digital one in 14 (41.2%). In the moderate bronchial asthma group consisting of 46 patients we detected definite clear wheezes in 38 (82.6%) and additional crackles or rhonchi with longer expiration than inspiration period in 5 (10.9%) patients. Normal pictures of breathing were among 3 (the rest of them — 6.5%), because intensive medication, between them inhaled glycocorticoid and long acting beta-2-mimetic. All but two patients without evidence of disease on moderate gravity had wheezes detected by digital manner, especially in Fourier based spectral analysis. In the group with severe asthma, consisting of 10 persons, both classical and digital auscultation revealed wheezes in all patients, whereas spirometry data were below 50% for FEV1 or PEF and below 30% of MEF25-50. In normal subjects lung sounds were different from those in asthma when detected by both methods of auscultation. These were early, slight inspiratory rhonchi or wheezes only in two heavy smokers (Smoke check; 55 and 48 PPM CO).

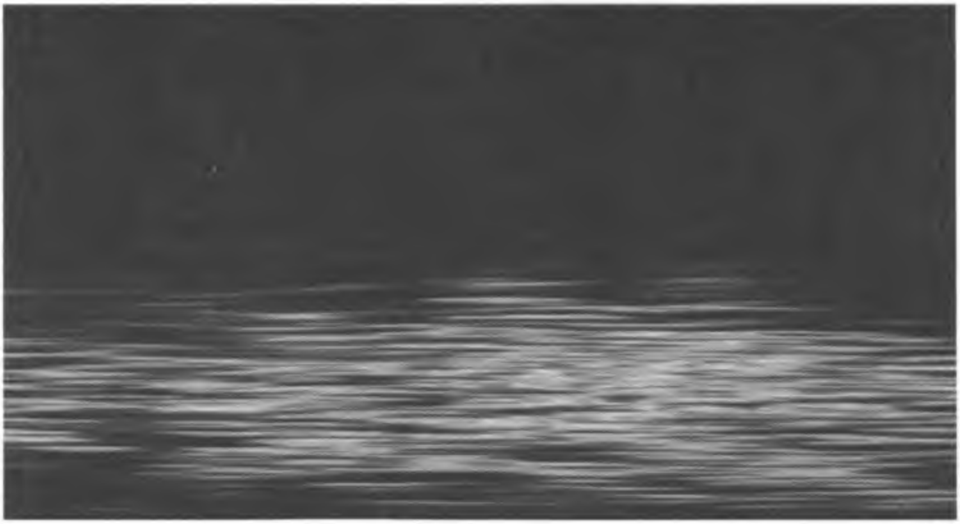

Fig. 1 a.

Fig. 1 b.

Fig. 1. Digital auscultation with time-frequency analysis of lung sounds. Part 1.a. Single normal breath sounds picture during 2 seconds, healthy volunteer, 25 years old, non smoker. Part 1.b. Single pathological wheeze imaging during 2 seconds. Patient AP, 25 years old, moderate phase of bronchial asthma (Fast Fourier analysis of frequency/time)

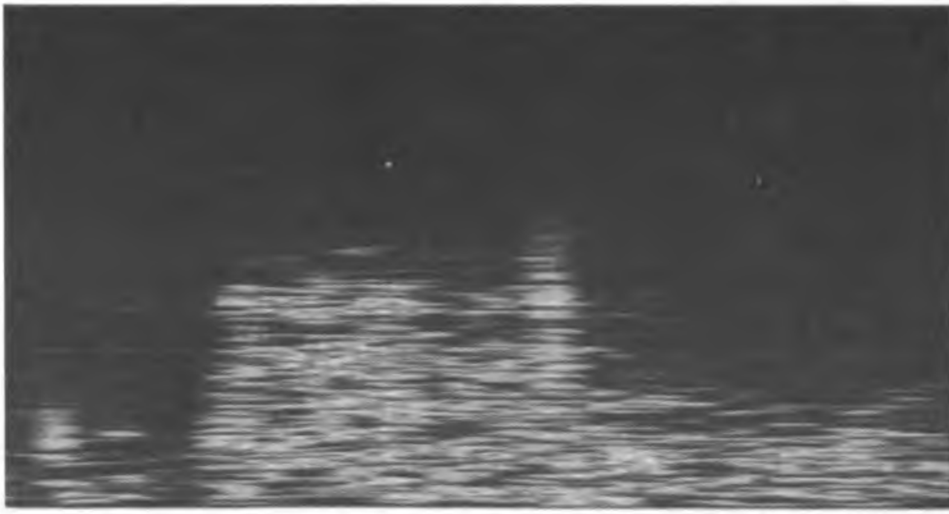

Fig. 2 b.

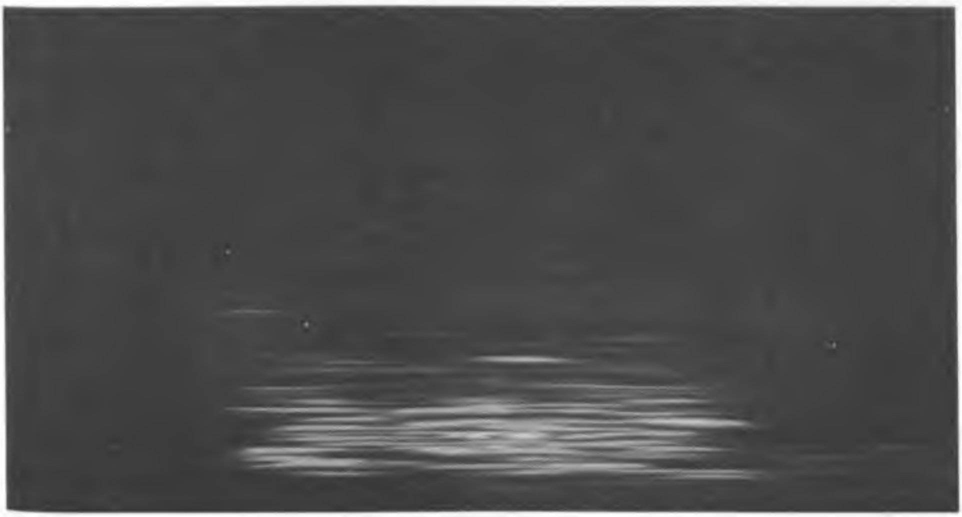

Fig. 2 b.

Fig. 2. Digital auscultation with time-frequency analysis of lung sounds. Part 2.a. Healthy person, PS-I., 23 years old, non smoker without atopy, single normal breath sample 5 seconds, Part 2.b "Healthy" patient AJ, 23 years old, heavy smoker, "coughs sometimes", not curable till now. Clasic acoustic auscultation: "exacerbated vesicular noise".

Part 2. Duration of inspiration and expiration during breathing

Average time of expiration among 90 asthmatic patients was 1544.82 ms (min. 463, max. 3000 ms) in comparison to 1437.18 ± 1079.6 ms (min. 1000, max. 2693 ms) in group of 30 healthy persons (no significant difference). Time of inspiration among asthmatic patients was on the average 1075.09 ms (minimum— 00 ms, maximum — 2222 ms), and in healthy persons the average was 1352.18 ± 519.9 ms (min. 1118, max. 1929 ms) (minimal difference).

Part 3. Digital imaging of lung sounds

Real difference concerning pictures of breathing were clearly visible on the monitor immediately after crude breathing sounds recording, especially of type whizzing or whistling. Different shapes of such sounds are presented in Figures 1 and 2, in correlation with normal lung sounds.

Part 4. Frequency/time spectral analysis of asthmatic wheeze

The peak frequency (Hz) was significantly higher in the wheeze recordings than in the normal breathing samples (598 ± 90 vs 181 ± 30, $p<0.0001$). In the adult population digital stethoscopes yield higher frequencies and greater amplitude than analogue stethoscopes. Quantification of lung sounds may provide for improved monitoring and diagnostic capability during diagnostics of early asthma and — for example — bronchial asthma specific immunotherapy.

DISCUSSION

The stability of lung sounds measurements over time may influence their clinical usefulness [12, 19]. In the present study we investigated the temporal variability of the spectral pattern of normal and pathological lung sounds.

Described above, modern methods of auscultation give us (medical authors — KB and ZS) new objectives and very useful information concerning especially so-called "exacerbated noise". Probably this is, additionally, the first description concerning clearly clinical appearance (with acoustic data collection and picture presentation) of so-called "minimal persisted inflammation" of bronchial wall or cough organic causes without clear changes in spirometric measurements (syndrome Corrao) [4].

This modern demonstration of breathing sounds was enthusiastically accepted by patients, which made educational procedures and PEF rate introduction much easier. On the other hand, senior doctors with traditional education were more sceptical about this method, because it was viewed as "too modern, too biophysical, not known at all". Young interns accepted it carefully. Spontaneous wheeze varied from solitary rhonchus to prolonged rhythms of loud stridor, and resembled the "induced" wheezes recorded previously by Rietveld et al. [16]. Power spectra showed that the spectral contents (frequency distribution) were comparable, although the *in vivo* patterns were more prolonged in duration. The diagnostic sensitivity and specificity of wheezing for a reduction in PEF of >20% were 88% and 92%, respectively [16].

Korenbaum and co-workers [8] designed several devices for acoustic examination and evaluation of components of human respiratory sounds. These devices analyse forced expiratory sounds, distinguish between air-borne and structure-borne sounds, and distinguish abnormalities in voice transmission to the chest wall. Tests of the devices on human subjects confirmed the validity of Korenbaum's [8] theoretical models, which offer promise for the development of a new class of medical diagnostic instruments. Our own model of lung function is still in preparation. Describing the digital auscultation method — according to our own experience with children below 4 years of life — is the best method of registration and analysis of wheezing episodes, despite expensive and difficult to perform bodypletysmography.

Digital imaging concerns not only pneumonology but also a lot of other medical disciplines. For example, although auscultation is commonly used as a continuous monitoring tool during anaesthesia, the breath sounds of anaesthetized patients have never been systematically studied (al-Jarad, 1993) [7]. Manecke et al. [9] used digital audio technology to record and analyse the breath sounds of 14 healthy adult patients receiving general anaesthesia with positive pressure ventilation. Sounds recorded from inside the oesophagus were compared to those recorded from the surface of the chest, and corresponding airflow was measured with a pneumotachograph. The sound samples associated with inspiratory and expiratory phases were analysed in the time domain (amplitude) and frequency domain (peak frequency, spectral edge, and power ratios). There was a positive linear correlation ($R2 > 0.9$) between inspiratory flow and sound amplitude in the precordial and oesophageal samples of all patients. The amplitude of the inspiratory and expiratory sounds was approximately 13 times greater when recorded from inside the oesophagus than from the surface of the chest in all patients at all flows ($p<0.001$) [9].

This interesting but invasive investigation was different from our quite non-invasive approach. In another presentation [5], similar to our own one, 55 children with bronchial asthma were tested using three exercise provocation tests: a treadmill, stairways running and cycloergometer. The results were evaluated on the basis of the lung function tests, auscultation and airways resistance measurement with occlusion method. Of these three tests the treadmill test seemed to be the most useful to prove bronchial hyperreactivity towards exercise. Stairways running occurred to be very congenial. The study also proved the usefulness of auscultation in evaluating bronchial constriction after exercise [5]. Of course, it was only classical application with acoustic — non digital — phonendoscope.

Recently, wheeze detection by tracheal auscultation has been proposed as an indicator of bronchial responsiveness during bronchial provocation test in children [3]. Three cumulative doses of a methacholine solution were inhaled by 45 workers with occupational exposure to flour dust [3]. Spirometry was done using an electronic spirometer. Tracheal sounds were recorded with an electronic stethoscope placed over the anterior cervical triangle, 2 cm above the sternal notch. The amplified sounds were stored on magnetic tape, band-pass filtered (50–2000 Hz), and digitised at a sampling rate of 4096 Hz into a GenRad Vibration Control System. Wheezes were detected by fast Fourier transform (FFT) analysis and their presence compared to a 20% fall in FEV1. A positive MAC test by spirometry was found in 12 subjects whereas wheezes were identified in 14 subjects. Among the wheezing subjects, nine had a positive MAC test (range of fall in FEV1 = 20.6 to 42.3%) and five had a negative one (range of fall in FEV1 = 3.6 to 16.9%). Moreover, no wheezes were found in the remaining three subjects with a positive MAC test (range of fall in FEV1 = 20.7 to

27.4%). Taking a 20% fall in FEV1 as a reference, wheezes were 75% sensitive and 84.8% specific to detect airflow obstruction (Bohadana et al. [3]).

Mahagnan et al. [12] presented so-called same-day variability (SDV) of electronic auscultation data, i.e. the variability of corresponding spectra calculated between the daily duplicate and between the two recording sessions (between-day variability, BDV). SDV was 32.8 ± 12.0% during inspiration and 40.8 ± 12.6% during expiration (p=0.005). BDV was 36.9 ± 11.3% during inspiration and 42.7 ± 12.7% during expiration. These values were not significantly different from SDV except for sounds recorded from the interscapular region (SR). The increased BDV at SR was found to be a result of slight differences in microphone position from the first session to the next. Similar changes in microphone position at the other recording sites did not alter the variability of lung [12], like in our own investigation.

Nissan et al. [13] tested the sound signals from four custom-made piezoelectric transducers, affixed at specific locations on the chest wall, and the breathing flow signal produced by a pneumotachograph were amplified, filtered and digitised simultaneously at 4000 Hz per channel for 512 ms. The acoustic data were transformed to the frequency domain to enable the calculation of the power spectra [13]. Those were averaged over successive runs and displayed as log power vs. frequency. The operator could assess the convergence of the spectral pattern using the on-line graphics and calculated parameters, and store the data once the noise level had reached a pre-set level. This procedure was repeated during expiration, inspiration and on breath arrest [13]. In this investigation we applied improving techniques of lung sound mapping and time-expanded wave-form analysis to common diseases that involve the lung: bronchial asthma.

In similar investigations, Bettencourt et al. [2] presented data concerning interstitial pulmonary fibrosis (IPF), chronic obstructive pulmonary disease (COPD), congestive heart failure (CHF), and pneumonia (Pn). Twenty subjects were studied in each group and 15 subjects without evidence of lung disease. Differences in timing, character, and location were observed, which allowed separation among these groups. Multiple logistic regression models were created and tested by the bootstrap method [2]. Regression models correctly classified 68 and 79% of subjects. Area under the receiver operating curve ranged from 0.96 for IPF and CHF to 0.80 for COPD. We agreed with above mentioned data and concluded that auscultatory differences exist among common pulmonary conditions and that statistical models based on auscultatory data perform well in predicting diagnostic categories.

Respiratory sounds of pathological and healthy subjects were earlier analysed by Sankur et co-workers [18] via autoregressive (AR) models with a view to construct a diagnostic aid based on auscultation. Using the AR vectors, two reference libraries, pathological and healthy, were built [18]. Two classifiers, k-nearest neighbour (k-NN) classifier and a quadratic classifier, were designed and compared. Performances of the classifiers were tested for different model orders [18]. This excellent idea will be in the future in front of our scientific plans, too.

CONCLUSIONS

Digital auscultation changes the crude wheezes registration from ears to eyes, and changes qualitative interpretation of it into quantitative one. In other words, it brings the problem from the physician's mind to microprocessor sets for analysis, storage, patients and doctors education, which made, in this manner, real the revolutions of lung auscultation, especially in children with episodic bronchial asthma. Since it carries a significant although small false-negative rate versus spirometry, the acoustic technique based upon wheeze detection cannot, at the present time, fully replace spirometry during airway challenge testing in subjects with suspected asthma.

Signs of early asthma not apparent on the spirometry or even classical auscultation are detected by digital auscultation with higher frequency.

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STRESZCZENIE

Opisano zastosowanie mikrokomputera w analizie dźwięków płucnych. System był użyty eksperymentalnie do przeprowadzenia półautomatycznej auskultacji cyfrowej, w celu poprawy czułości przesiewu dla astmy oskrzelowej. Wyniki analizy dźwięków płucnych po ich zapisaniu, w połączeniu z testami czynnościowymi płuc oraz klasycznym osłuchiwaniem akustycznym, okazały się przydatne do identyfikowania patologii oskrzeli na porównywalnym poziomie.