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Review Article

Respiratory Sounds Analysis in the World of Health 2.0 and Medicine 2.0

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Abstract

Objective: This paper is an update of the literature and ongoing researches related to the methods of analysis of respiratory sounds.

Methods and Material: The study includes a description of the various techniques that are being used to collect auscultation sounds, a physical description of known pathologic sounds for which automatic detection tools were developed.

Results: Respiratory sounds analyses are mainly based on respiratory phase detection, spectral analysis, wavelet, respiratory phase classification and signal processing. Current technologies are particularly based on new adapted innovative techniques such as artificial neural networks, fuzzy systems and genetic algorithms. Ongoing researches consist in finding of new markers of respiratory sounds, in the idea to increase the efficiency of decision aid algorithms and tools.

Conclusion: These techniques are part of the medicine 2.0 or health 2.0 tools developed in this field of medicine, as sciences of information and communication technologies (ICT), artificial intelligence (IA) and Web technologies.

Keywords: *Respiratory Sounds; Auscultation; Medicine 2.0; Health 2.0; Crackles; Wheezes; Rhonchus; Snoring; Squawk; Stridor; Respiratory Phase Detection; Spectral Analysis; Wavelet; Respiratory Phase Classification; Signal Processing; Artificial Intelligence; Artificial Neural Networks; Genetic Algorithm; Multilayer Perceptron; Fuzzy Rule Base Identification System*

Introduction

Respiratory sounds include information concerning the physiologies and pathologies of lungs and airways [1]. In practice, distinction between normal and abnormal respiratory sounds, e.g. vesicular sounds and crackles, is crucial for an accurate medical diagnosis. In this setting, Dr René Laënnec creates in 1817 the first treatise of respiratory or lung semiology and the technic of auscultation through a media, called "auscultation mediate" (from the Thesis: "De l'auscultation", Paris, 1819) (Figure 1a) [1]. For the latter, Dr Laënnec built the first paper-based (a cone with 24 paper sheets) and wooden-based stethoscope (Figure 1b). Since 1800', the stethoscope has become increasingly popular and has become the physician's basic medical tool. Before the end of the last century, the stethoscope had begun to appear much the same as it does today, with a binaural design, flexible tubing, and a combination of bell and diaphragm [1,2]. During the last decade, many progresses have been made to improve the stethoscope (Figure 1c) [3,4]. In this setting, the development of electronic auscultation and automated classification of recorded lung sounds are probably the most significant progress. Innovative technologies have been added to project the stethoscope and the auscultation into the era of evidence-based medicine and the world of medicine 2.0 [3].

The present paper describes state of the art, scientific publications and ongoing research related to the methods of analysis of respiratory sounds.

Figure 1: *1a: Doctor René-Théophile-Hyacinthe Laënnec, inventor of the stethoscope. 1b: The stethoscope is a system of transmission and amplification of sound by resonance. Its principle is rather simple. Using a specific interface (diaphragm or bell), a sound is picked up, and then transmitted over a small distance to the user's ears. Traditionally, the sound is transmitted in an aerial way via a conduit. 1c: The latest generation of stethoscopes is electronic and uses a microphone system and speakers to restore sounds.*

References search

Our team conducted independent literature searches using Medline and Google Scholar until January 31, 2018. We searched for studies relating to respiratory sounds analysis. Keywords included "respiratory sounds", "breath sounds", "lung sounds", "lung auscultation", "electronic auscultation", "acoustic signal processing", "computerized respiratory sound analysis", "computerized lung sounds analysis", "automated classification of respiratory sounds", "automated classification of lung sounds", "crackle detection", "wheeze detection", "evidence-based medicine", "health 2.0" and "telemedicine 2.0". Additional studies were obtained from references of identified studies, the Cochrane Library and the ISI Web of Knowledge. We restricted our search to English and French because these were the two languages for which both investigators were fluent. Two members of our team (EA, RG) independently reviewed and compared the resulting list of relevant articles and determined the eligibility of the full report. We evaluated each of the included studies for the analysis of respiratory sounds. All the studies were analyzed by all the authors of the present paper.

Interests of new developments in this field of medicine

Our understanding of the mechanisms linked to the creation of respiratory sounds is for the moment imperfect. In this setting, the recording and analysis of respiratory sounds allow improving our understanding [3]. It may also permit an objective relationship between abnormal respiratory sounds with respiratory pathology. Besides, this objective analysis allows developing classification systems that make it possible to precisely qualify normal and adventitious respiratory sounds using information and communication technology sciences (ICT), Web tools and artificial intelligence (AI) [1,4]. These elements are the pillars of "health 2.0" or "medicine 2.0". In this setting, whilst conventional stethoscope auscultation is subjective and hardly sharable, electronic stethoscope with the addition of these tools should provide an objective and early diagnostic help, with a better sensitivity and reproducibility of the results [5]. Thus, these elements also bring respiratory auscultation into the era of "evidence-based medicine" (EBM). Applications, including diagnosis evaluation, monitoring and data exchange through Web are obvious complementary tools to objective and automatic auscultation sounds analysis. Sensors devices will allow long duration monitoring for patient at home or at hospital. It could also be a useful solution for less-developed countries and remote communities [6]. In addition, this type of system has the great advantage to keep the non-invasive and less expensive characteristics of auscultation. Sestini and coll.'s studies [7] indicate that an association between acoustical signal and image is benefit for breath sounds' learning and understanding for students in medical science.

Physiological data of respiratory sounds

Mechanisms of breath sounds production

The origin of respiratory sounds is not yet completely clear. Sarkar gives a complete and useful description of respiratory and breath sounds production [8]. Normal respiratory sound is produced by the air flow along the trachea-bronchial tree. However, not all types of airflow produce breath sound. Only turbulent and vorticose airflow will generate breath sound. The streams of airflow are parallel to the walls. It is parabolic in shape as air in the central layers moves faster than air in the peripheral layers, with little or no transverse flow. Therefore, there is little mixing or collision between layers of gas. Laminar flow pattern follows the Poiseuille equation [1,8].

Propagation of respiratory sounds

The propagation and deformation of respiratory and breath sounds are linked to several factors [9]. In fact, the acoustical response of the stethoscope, the asymmetry of the sounds (that can indicate the presence of a pathology), the heterogeneous composition of the body surface (bones, muscles, skin…) have been documented as interference factors or like as filters [1,9]. Thus, sound is filtered by the lung and the chest wall (low-pass filter). In this context, the analysis point is crucial factors. Respiratory sounds have different characteristics depending on the location of recording and ventilation cycle (expiration or inspiration). The locations of recording can be divided into two classes: the trachea and the chest (front and back). Moreover, measurements indicate that lung sounds are lower in amplitude than tracheal sounds [10].

Experimental conditions for recovery of respiratory sounds

Rossi and coll.'s article [10] gives recommendations concerning the experimental conditions required for recording respiratory sounds. It describes the optimal experimental conditions, especially concerning background noise, including sounds other than respiratory such as vocal sounds. In this paper, Rossi., *et al.* also give: the specific procedures to follow according to the type of sounds we wanted to record (breath, cough, and snores); information for the recording (diagnosis, evaluation of a therapy, monitoring); the age of subject (baby, infant, child, adult), and the recording method (free field, endobronchial microphone) [10]. In this setting, Sarkar recommends a "sitting position" for short recordings and a "lay position" for long recordings [8]. Several factors disturb the auscultation signal analysis [3,5]. These factors modify results and make comparison between research centers more difficult, even with the same protocol and equipment [71]. These factors include: age and corpulence of the patient; volume air changing in the lungs; location of sound capturing; breathing flow; position of the patient; and characteristics of the measurement equipment. As evocated below, they have significant influence on the results, since they may generate minor or major artefacts and bias and that whatever the quality of the stethoscope used [5].

Definition of terms used to qualify a sound

To date, there are several definitions of common markers' characteristics such as e.g. wheezes and crackles [1,5]. Thus, a universal semantic has to be created. Several works tried to collect terms' definitions in relation with to lung and respiratory sounds and has concluded to a collection of 162 terms commonly utilized in the project: "Computer Respiratory Sound Analysis" (CORSA) [11]. In this setting, several authors or learned societies have proposed a universal nomenclature or classification of respiratory sounds [5,9,11]. Nevertheless, it still doesn't allow physician to have a common definition of terms that are used. Consequently, the descriptions of the sounds characteristics are still based on imaged illustrations. For example, a wheeze is currently associated to a "whistling sound", and a crackle to "a sound of rice in a frying pan". Sovijarvi and coll.'s articles [11] provide accurate definitions of currently used terms in pulmonary auscultation domain and sound analysis. The more pertinent are recalled here.

Respiratory sounds

Characteristically, normal respiratory sounds are heard clearly during inspiration but only in the early phase of expiration. In sound analysis, the frequency range of normal lung sounds appears to be narrower than that of tracheal sounds, extending from below 100 Hz to 1,000 Hz, with a sharp drop at approximately 100 to 200 Hz [9,11].

Breath sound: They include normal and adventitious sounds recorded over the chest wall, the trachea or at the mouth [5,11]. Their generation is related to airflow in the respiratory tract. Acoustically, these sounds are characterized by broad-spectrum noise with a frequency range depending on the pick-up location.

Lung sound: It concerns all respiratory sounds heard or detected over the chest wall or within the chest including breath sounds and adventitious sounds detected at this location [1,9,11]. This sound is soft, nonmusical, heard only on inspiration and on early expiration. For clinician, lung sound is diminished by factors affecting sound generation (e.g. hypoventilation, airway narrowing) or sound transmission (e.g. lung destruction, pleural effusion, pneumothorax); assessed as an aggregate score with normal breath sound; rules out clinically significant airway obstruction. Normal breath sound: On the chest wall, breath sound is characterized by a low noise during inspiration and hardly audible during expiration [5,11]. On trachea, normal respiratory sound is characterized by a broader spectrum of noise (for example containing higher-frequency components), audible both during inspiratory and expiratory phase. Normal breath sounds include vesicular sounds, broncho-vesicular sounds, bronchial and tracheal sounds, together with mouth sounds.

Adventitious sound: It related to additional respiratory sounds superimposed on normal breath sounds [1,11]. They can be continuous (like wheezes) or discontinuous (such as crackles). Some of them (like squawks) have both characteristics. The presence of such sounds usually indicates pulmonary disorders.

Abnormal sounds: As opposed to the former ones, abnormal sounds are those which may indicate a lung problem, the absence of sound, or the presence of sound where it should normally not have heard [1,9,11]. It usually reflects a lung problem, such as obstruction, inflammation, or obstruction

Known trackers

Crackles: These adventitious explosive and discontinuous sounds appear generally during inspiratory phase [5,9,11]. Crackles are characterized by their specific waveform, their duration, and their location in the respiratory cycle. A crackle can be characterized by its total duration, as fine (short duration) or coarse (long duration). Occurrences of crackles in lung sounds usually reflect a pathological process in pulmonary tissue or airways. "Coarse" crackles are nonmusical, short, explosive sounds. They are heard on early inspiration and throughout expiration, affected by cough and transmitted to mouth. This sound is accurate during the beginning of the breathing-in phase, they reflect chronic bronchi diseases. In the middle of breath-in phase, crackles reflect bronchiectasis. When crackles occur at the end of breath-in phase, they are generated by the peripheral bronchi, and might be the sign of pneumonia. "Fine" crackles are generated by the peripheral bronchi. This sound is nonmusical, short, explosive; heard on mid-to-late inspiration and occasionally on expiration; unaffected by cough, gravity-dependent, not transmitted to mouth. "Fine" crackles are the sign of an infection or a pulmonary edema. "Coarse" crackles sound like "salt on a pan" whilst "fine" crackles sound more like "slow opening of Velcro's strips" or "a bottle of sparkling water that you open".

Cough sound: Transient sound induced by the cough reflex with a frequency range between 50 and 3,000 Hz [5,11]. The characteristics of cough sounds are different depending upon pulmonary diseases. Cough sounds containing wheezes are typical in asthma.

Rhonchus: Rhonchus is a low-pitched wheeze containing rapidly damping periodic waveforms, with duration greater than 100 ms and a frequency range below 300 Hz [1,5,11]. It is a musical, low-pitched, similar to snoring; lower in pitch than wheeze. Rhonchus may be heard on inspiration, expiration, or both. Rhonchus can be found, for example, with patients having secretions or narrowing in central large airways and with abnormal airway collapsibility, or chronic bronchitis.

Snoring sound: It is a respiratory low-frequency noisy sound with periodic components (fundamental frequency 30 - 250 Hz) detected usually during sleep induced by abnormal vibrations in the walls of the oropharynx [1,9,11]. It is typical breathing in sound but a small breathing out component may appear, especially for patients with obstructive sleep apnea.

Squawk: It deals with relatively short breathing-in adventitious sound having a musical character, occasionally found in patients with interstitial lung disorders [1,11]. Squawk is mixed sound with short musical component (short wheeze) accompanied or proceeded by crackles. Acoustically, these waveforms may sound like that of short wheezes, but they are often preceded by a crackle. The duration of squawks may vary between 50 and 400 ms. The basic mechanisms of their origin probably differ from those of wheezes in obstructive lung diseases. Squawks usually occur from the middle to the end of the breath in cycle in hyper responsiveness pneumonia and infectious pneumonia.

Stridor: It is a very low-frequency wheeze originating in the larynx or trachea [5,9,11]. It is musical, high-pitched. Stridor may be heard over the upper airways or at a distance without a stethoscope. Stridor appears most frequently during inspiration. It can be audible at the level of the mouth, of the trachea and over the chest wall, without the help from a stethoscope. Stridor can appear, for example, in whooping cough, and in laryngeal or tracheal stenosis.

Wheeze: This adventitious and continuous sound has a musical characteristic [1,9,11]. It is musical, high-pitched. Wheeze is heard on inspiration, expiration, or both. Acoustically, wheeze is characterized by periodic waveforms with a dominant frequency usually over 100 Hz and with duration of more than 100 ms; hence, the sound must include at least 10 successive vibrations. Wheezes are usually associated with airways obstruction due to various causes. If the wheeze contains essentially a single frequency, the wheeze is called monophonic. If it contains several frequencies, then it is obviously called a polyphonic wheeze. Wheeze might be localized when it is due to an anatomic obstruction. Or it might be diffuse in the presence of asthma. Shaharum., et al. [12] recommend placing the stethoscope on the trachea to characterize wheezes. This avoids the signal to cross the chest which acts as a low pass filter, and thus preserve more signal bandwidth.

Pleural friction rub, or simply plural rub: Is an audible signal present in case of pleurisy or other diseases affecting the chest cavity [1,9,11]. Pleural rub is a non-polyphonic sound which can be characterized by its duration, which is around 15 ms. Pleural rub is nonmusical, explosive, usually biphasic sounds. Pleural rub is typically heard over basal regions. This sound is caused by the rubbing of pleural membranes when breathing. It can be heard during inspiration and or expiration. It has a low pitch (below 350 Hz) and can be caused by inflammation of the pleural membrane, or by a pleural tumor. It sounds like feet in the snow [5].

Visualization methods

Auscultation which is based on the doctor's hearing presents various limitations such as deficiencies present on the auscultation device like an acoustic stethoscope [1]. Recently, various researches have implemented a variety of lung sound image representation method in identifying a range of respiratory sounds [1,5,9]. Several techniques are used in detecting the different types of respiratory, as pneumophonogram (or periodogram) and pneumo-spectrogram [9,11].

Pneumo-phonogram: It is a simultaneous and overlapped display of sound signal and airflow in time domain during breathing [1,5,11]. more signal bandwidth.

Pneumo-spectrogram: This is a representation in which time is represented in abscises, frequency in ordinate, and the intensity of the signal by a palette of colors [1,5,11]. The figure 2 is an example of a spectrogram, the intensity going from black then blue, yellow and red.

These visualization methods may be used in identifying the different types of respiratory sounds, however, most technique are sensitive to interfering signal and may display an incorrect representation results given the presence of obstructive noise such as mechanical or ambient noise. Nevertheless, the presented visualization aims to produce images that would aid clinicians in identifying various breath sounds [11].

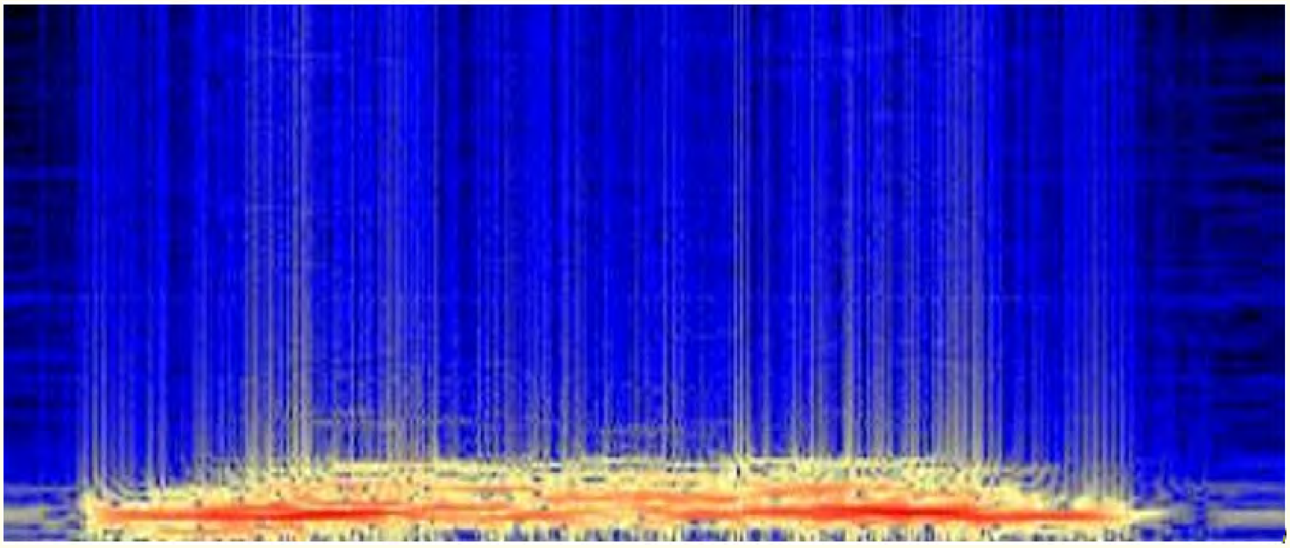

Figure 2: Example of pneumo-spectrogram of normal breath sound (data collected in the ASAP project [Analysis of Auscultatory and Pathological Sounds] developed by the French national agency for research [ANR 2006 - TLOG 21 04]).

Capture techniques

The stethoscope is used by clinicians to aid in the diagnosis of respiratory disorders. However, application of the stethoscope in research studies has been limited due to the inherent inter-observer variability and subjectivity in the interpretation of respiratory sounds [1,5,12]. Thus, the diagnostic value of auscultation in detecting abnormal respiratory sounds in clinical research could be improved if implemented using an objective and standardized approach to interpretation. Moreover as we see bellow, acoustical stethoscope has several limitation [11]. In this setting, the development of robust acoustic devices for use at the bedside, e.g. electronic stethoscopes paired with small convenient recorders as smartphone, may provide the long-awaited portable objective means to record, analyze, and store lung sounds just as any other clinical information is measured and stored. Computerized analysis of recorded respiratory sounds may offer a systematic approach to the diagnosis of different respiratory conditions via automated classification of acoustic patterns. An adapted capture chain of the sound is a relevant point preceding the analysis phase [13-15]. Typically, it is made up of the following elements [5,13,16]: sound capturing: the positioning of the microphone is important; actually, the chest acts like a reducer and a low-pass filter. Kraman., et al. [17] studied the effects of different microphones and conclude that the most adapted was the Electret microphone with conical coupler and a diameter from 10 to 15 mm; amplification of the signal; filtering and sampling; reduction of the cardiac sound and other skin noise; and sound recording. Cheetham and coll.'s article [18] develops the important points related to the digitalization of the auscultation sounds' records; it deals with sampling frequency, filtering, signal noise rapport that is introduced by the analogue / digital conversion.

Acquisition

Various methods and tools have been described to capture sound [11,19,20]:

1. Using a unique microphone: It is the more frequently used method. Usually, the sensor is an Electret microphone. The most frequently used sampling frequency is the one used for the telephony codec's (8k Hz), an analogue/digital conversion with a 16 bits resolution [1,21]. Other ones make use of an accelerometer; it is less sensitive to background noise [5,21], but performance is much less than the one of Electrets.
2. Use of several microphones and three-dimensional representations. This technique makes it possible to identify the location of the origin of the sounds; it is a dynamic method that shows structural and functional properties, useful for diagnosis [22,23].

3. Emission of a sound and analysis of its propagation. This technique, described in Mazic and coll.'s article [20], consists in emitting a sound with a loudspeaker introduced in the patient's mouth. The method processes the characteristics of sig nal's propagation through respiratory airways and chest. The analyzed parameters are energy ratios, signal time delays, and dominant frequency.
4. Measurement in closed loop-controlled ventilation [24,25].

There are a few types of sensors used in computer-based respiratory sound analysis and several comparisons were available in the on the various sensors used. In most cases, Electret microphones or contact microphone mounted on a stethoscope was used. The most important consideration in choosing the type of sensor is based on its ability to acquire a wide frequency range (150 to 2,000 Hz) for respiratory sound analysis. In our studies [5,26,27], we have focused on the use of a unique Electret microphone.

Noise filtering and heart sound cancelling

Heart sounds can introduce perturbations during the analysis of lung sounds. The spectrum of heart sounds is located between 20 and 100 Hz. According to Elphick and coll.'s article [28], the attenuation of heart sounds is obtained thanks to a simple band-pass filter [50 to 2,500 Hz]. Nevertheless, a high-pass filter at 100 Hz is not a good solution in so far as the main components of lung sounds are also located in this frequency range. Consequently, several methods have been tested [29]: Wavelets, adaptive filtering with recursive least squares algorithm, time/frequency filtering, reconstruction, autoregressive/mobile average estimation (AR/MA) in time/frequency domain of wavelet coefficients, independent component analysis, and entropy-based method. The filter proposed by Bahoura., *et al*. [30] is based on a wavelet packet transform, and the use of two filters which are defined in frequency and time domain. This filter provides more accurate and effective results than its rivals; experimental tests demonstrate very good performances. Moreover, the proposed technique allows better care the characteristics of stationary signals (normal sounds or wheezes). In this setting, Yadollahi., *et al.* [31] try to detect the segments of sound including heart sound, in order to suppress the heart components. They investigate methods using Shannon's entropy, Renyi's entropy and multiresolution product of wavelet coefficients. The most efficient method was Shannon's entropy. Among all these methods, the better results were obtained with adaptive filtering [32], time/frequency filtering and AR/MA estimation.

Deleting parasite noises

The "cleaning" of respiratory sounds must also take care of the reduction of background sound. This processing can be realized through two different methods [3]:

1. Noise reduction through adaptive filtering (deleting white Gaussian noise, deleting vocal sound, reducing measurement errors);
2. Noise reduction through wavelet packets (Donohoe's method, etc.).
3. The more recent techniques use simultaneous usage of several sensors.

Electrical safety

There is no specific standard for electronic stethoscope or recording devices. They need to conform to the European norm EN 60 601-1. The device being applied to the skin of the patient, it is critical for safety. Laszlo [16] reminds that the transducers are passive, but the metallic part of the head needs to be conforming to the "low safety voltage" directive. The biasing voltage is low and comes from a battery (the "low safety voltage" must be less than 60 V d.c.); the condenser, if present, must have a very low capacity (from 20 to 100 pF). The only current that might reach the patient is a dispersion current coming from the amplifier, which is avoided if the amplifier conforms to the IEC guideline IEC 601-1.

Respiratory sounds characteristics

For diagnosis of respiratory diseases clinicians largely rely on their auditory skills for interpretation of the sounds acquired using the stethoscope [5,11]. The success of this practice depends on the experience and training of these latter. As we see above, with the advancement in computer applications various new techniques are available for respiratory sound analysis. Applications developed using spectral analysis methods provide new insights in identification of different patterns of common respiratory sounds. These tools can to better characterize respiratory sounds [5]. They also may assist the clinician in faster and more accurate diagnosis of these diseases while minimizing human error.

Characteristics of human sounds

It is commonly admitted that respiratory sounds' frequency is in the frequency range between 50 to 2,500 Hz and that tracheal sounds can reach up to 4,000 Hz. This allows defining a sampling frequency at 8,000 Hz [1]. The spectrum of heart sounds is defined between 20 and 100 Hz for basic signals and higher frequency (upper than 500 Hz) for breaths. Abnormal sounds can be divided into two sub-classes [29]:

- Continuous or stationary sounds, e.g. wheezes, rhonchus, etc.;
- Discontinuous or non-stationary sounds, e.g. fine or coarse crackles.

Among these adventitious sounds, we can also quote squawks, snores and stridors. Now, we are going to detail the characteristics of the two more studied noises: wheezes and crackles [1,5].

Characteristics of the respiratory cycles

In regard to the description of Bahoura's data [3], the frequency of tracheal sounds may be located between 60 and 600 Hz for inspiration and between 60 and 700 Hz for expiration. For researches in this field, he proposes a Fourier transform with 4,096 points and two type of representation from respiratory sound: 1) the waterfall method with a representation of the spectrum in three dimensions (amplitude, frequency, time); and 2) the spectrogram method that was also detail upper in this article and in Reichert and coll.'s article [5]. These representations generally allow having a good visualization of respiratory cycles (Figure 3).

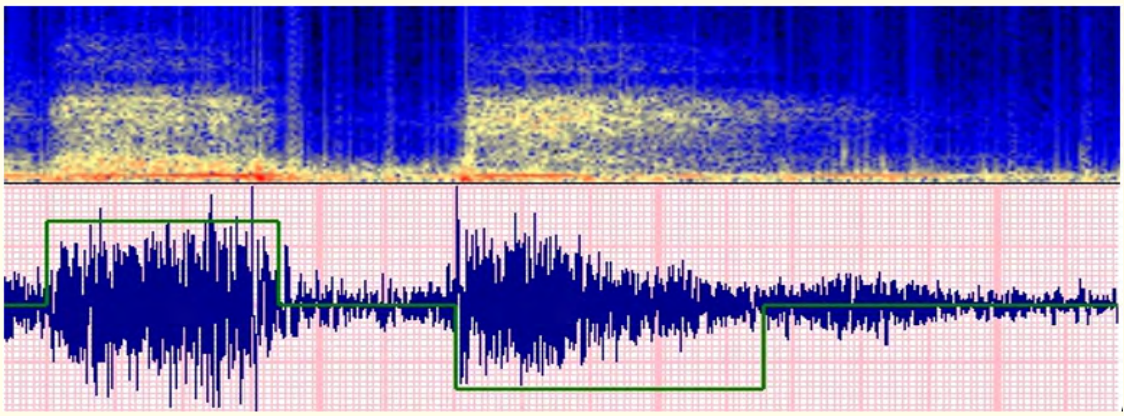

Figure 3: *Breathing cycles. Represents time and frequency characteristics of normal vesicular sounds. Upper green square represents breath-in phase and the lower one is for breath-out. This example shows quite the same frequency range in both phases. Intensity is decreasing for the breath-out phase, mainly because of loss in high pitches. In both phases, frequency energy is distributed between some Hz and 1,000 Hz. The red line corresponds to a maximum of energy below 100 Hz (data collected in the ASAP project [Analysis of Auscultatory and Pathological Sounds] developed by the French national agency for research [ANR 2006 - TLOG 21 04]).*

Normal respiratory sounds

Various normal sounds may be heard, based on the location where the stethoscope is listening to [1,5,9,11]. As see below, the sound of normal breathing heard over the surface of the chest is markedly influenced by the anatomical structures between the site of sound generation and the site of auscultation.

Vesicular sounds

Vesicular murmur may be heard on auscultation over most of the lungs areas [5,11]. Vesicular murmur rather well heard during inspiration, but they can only be heard during the beginning of the expiration phase. It consists in a soft, low intensity which may be weakened in following circumstances: extensive thickening of the wall (for instance in case of obesity or emphysema). The frequency range of normal respiratory sounds appears to be narrower than that of tracheal sounds, extending from below 100 Hz to 1,000 Hz, with a sharp drop at approximately 100 to 200 Hz [5,9,11]. Several mechanisms of vesicular sounds have been suggested, including turbulent f low, vortexes and other unknown mechanisms [1,5,11]. Vesicular murmur is abolished when: the lung is collapsed by the pressure of fluid or air in the pleural cavity, such as in cases of pneumothorax or pleurisy; in absence of ventilation in the affected lung area, e.g. in cases of lung compression, especially in atelectasis with retraction; and after pneumonectomy, on the operated side [1,5,9].

Broncho-vesicular sounds

Normal broncho-vesicular sounds may be heard between scapulae on posterior chest and center part of anterior chest [1,9,11]. This sound is a soft, nonmusical, heard on both phases of respiratory cycle (mimics tracheal sound).

Bronchial sounds

Bronchial sounds are located on chest near second and third intercostal space [1,5,11]. They are similar to tracheal sounds, with high pitch. They can be heard during both inspiration and expiration phases. Expiration phase is better heard than vesicular sounds. Sounds are high-pitched (higher than vesicular sounds), loud and tubular.

Tracheal sounds

They can be heard on the trachea, above the sternum, in the jugular notch, with a frequency range from 100 to 4,000 Hz, with a sharp drop in power at a frequency of approximately 800 Hz and little energy beyond 1,500 Hz. [5,9]. They are generated by turbulent airflow passing through the pharynx and the glottis. These sounds are not filtered by the chest wall and thus provide more information. They are produced by turbulent airflow in the pharynx, glottis and sub-glottis area.

Mouth sounds

Mouth sounds are being described as having a frequency range from 200 to 2,000 Hz: this is turbulent airflow below the glottis [5]. For a healthy person, breath sound from the mouth should be silent.

Abnormal respiratory sounds

Abnormal breath sounds include the absence or reduced intensity of sounds where they should be heard, or, as opposed, the presence of sounds where there should be none, and of course the presence of adventitious sounds [5,9,11]. Adventitious sounds are sounds which are superimposed on normal breath sounds. Adventitious sounds may be continuous or discontinuous based on their duration.

Continuous adventitious sounds

Continuous adventitious sounds (CAS) are characterized by duration over 250 ms [1,5,9,11]. They may further be subdivided based on their pitch: low pitch CAS include rhonchi and squawk. High pitched CAS may be wheeze or stridor.

Characteristics of wheezes and whistles

Of bronchial origin and variable intensity, wheezes are heard at a distance from the patient [5,9,11]. They include breath in wheezes, as well as sibilant wheezes heard during both phases of breathing.

Wheeze and rhonchi are CAS which can be heard in most cases during expiration, but it might also be heard during inspiration or both. Wheeze is high pitched, while rhonchus is low pitched. Wheeze is caused by the narrowing of the airway, which causes an airflow limitation, while rhonchus is the consequence of the thickening of mucus in the larger airways. Wheezes, that Laënnec calls dry wheezing groan, or wheezing, are sounds that have duration (according to articles) greater than 50 ms [33] or 100 ms and lower than 250 ms [34]. The identification of continuous adventitious breath sounds, such as wheeze in the respiratory cycle, is of great importance in the diagnosis of obstructive airways pathologies [34]. In fact, Sovijarvi., *et al.* [1] indicate that wheezes can show acoustic characteristics symptomatic, not only of the presence of abnormalities in the respiratory system, but also of the severity and the location of the most frequently found airway obstructions in asthma and respiratory stenosis. In cases of localized wheezing, it can be heard during inspiration or during both phases, with similar pitch, caused by partial obstruction of the trachea or bronchi, due to the presence of a tumor or foreign body. In cases of diffuse wheezing, it is most often in the form of bilateral wheezing, of various tonalities, heard especially at the end of expiration and encountered in instances of bronchial asthma. In chronic obstructive bronchitis (bronchial pneumonia), there is also diffuse expiratory wheezing, due to vibration of the bronchial walls which tend to collapse at expiration. The frequency of wheezes lies within 100 and 2500 Hz, with a fundamental frequency between 100 (or 400 [30]) and 1,000 Hz [33] (or 1600 Hz [34]). On the other hand, Bahoura., *et al*. [30] indicates that wheezes have a dominant frequency greater than 400 Hz, contrary to rhonchus whose dominant frequency lies within 200 Hz and below. The spectrogram below shows that wheeze has several, usually up to 3 harmonic frequencies. The association between bronchiolitis and wheeze is known since more than 50 years (Figure 4), although the underlying factors that could explain this association are not yet understood. Infants aged < 6 months at the beginning of the winter season are at high risk for recurrent wheeze. Furthermore, infants with early and severe bronchiolitis, who have required hospital admission, are at significantly higher risk for both recurrent wheeze and subsequent asthma [31]. This association is well documented in Respiratory Syncytial Virus (RSV) bronchiolitis [31,32] but was recently demonstrated with other viruses [35]. Identifying continuous adventitious sounds like wheezes in the breathing cycle is of great importance for detecting pathologies linked to the obstruction of breathing respiratory airways. Sovijarvi., et al. indicate that wheezes show not only the presence but also the severity and localization of obstruction of the airways. Asthmatic subjects show wheezes during expiration phase; the latter have a duration range between 80 and 250 ms [20]. Fiz., *et al*. [36] and Albers., *et al*. [37] are able to identify objectively the presence of an obstructive pathology. Likewise, Meslier., *et al*. [38] associate wheezes to the following pathologies: infections such as croup (infection that generally affects infants from less than three years), whooping cough, laryngitis, acute trachea-bronchiolitis; laryngeal-, trachea-, or broncho-malacia; laryngeal or tracheal tumors; tracheal stenosis; emotional laryngeal stenosis; foreign body aspiration; airway compression; asthma (Figure 5) [39], identification of physiological nocturnal wheeze [40]; chronic obstructive pulmonary disease (COPD); and foreign body in the airways.

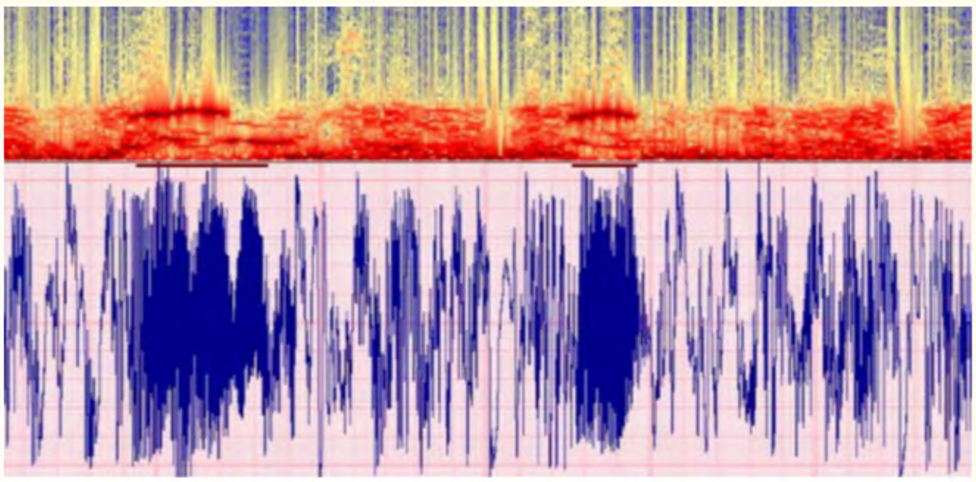

Figure 4: *Example of pneumo-phonogram and spectrogram of bronchiolitis with numerous wheeze in preschool children (data collected in the ASAP project [Analysis of Auscultatory and Pathological Sounds] developed by the French national agency for research [ANR 2006 - TLOG 21 04]).*

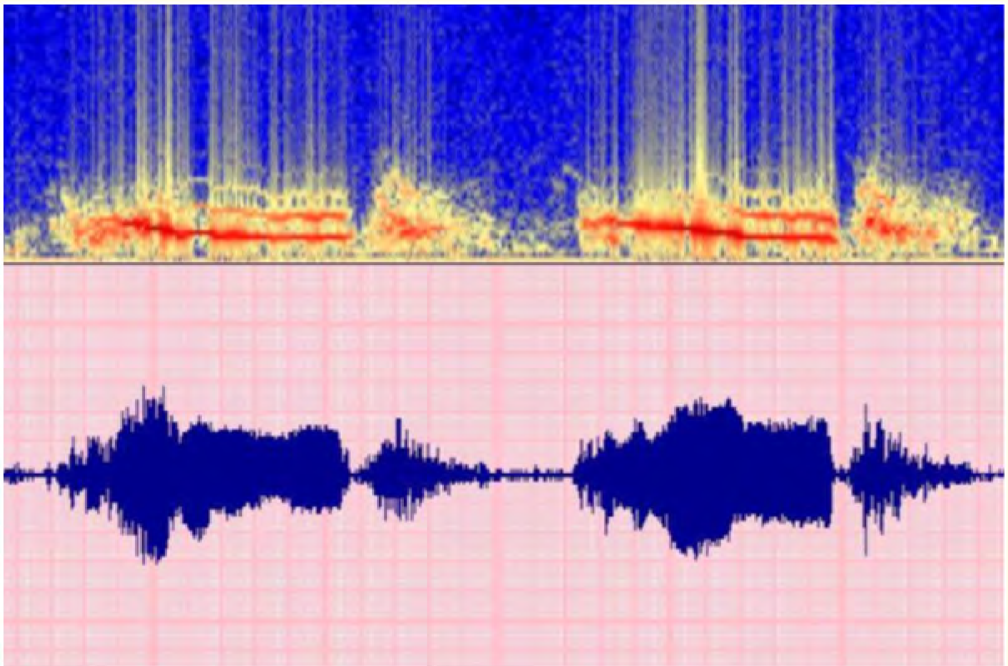

Figure 5: *Example of pneumo-phonogram and spectrogram of a wheeze sound in the context of asthma (data collected in the ASAP project [Analysis of Auscultatory and Pathological Sounds] developed by the French national agency for research [ANR 2006 - TLOG 21 04]).*

Rhonchi or snoring

Also of bronchial origin, sonorous rhonchi are low-pitched, in both inspiratory and expiratory phases, and altered by coughing [9,11]. They are encountered in acute or chronic bronchitis accompanied with bronchial hyper secretion. Usually cleared by coughing, the so-called fixed rhonchus on the other hand does not disappear after coughing effort and is generally associated with downstream bronchial obstruction, foreign body.

Characteristics of stridor sound

Inspiration phase has much more energy than expiration one [5,9]. Energy is mainly below 500 Hz, but peaks are available above 2,000 Hz (Figure 6). Stridor is a CAS like a wheeze, with sibilant and musical sound. It is heard in most cases during the inspiration phase. It is caused by a turbulent airflow in the larynx or in lower bronchial tree. Associated diseases are epiglottitis, foreign body, croup or laryngeal edema. The pitch of a stridor sound is high (above 500 Hz), continuous for more than 250 ms.

Squawk

Squawk signal is continuous for about 200 ms [1,11]. Squawk usually occurs during inspiration, with a low pitch between 200 to 300 Hz. It often goes with pneumonia.

Discontinuous adventitious sounds (DAS)

Characteristics of crackles

Crackles correspond to short explosive sounds, generally associated with pulmonary disorders [41-43] (e.g. lungs' infection, pneumonia, pulmonary edema). They are generally generated during the airways opening that were abnormally closed during the inspiration

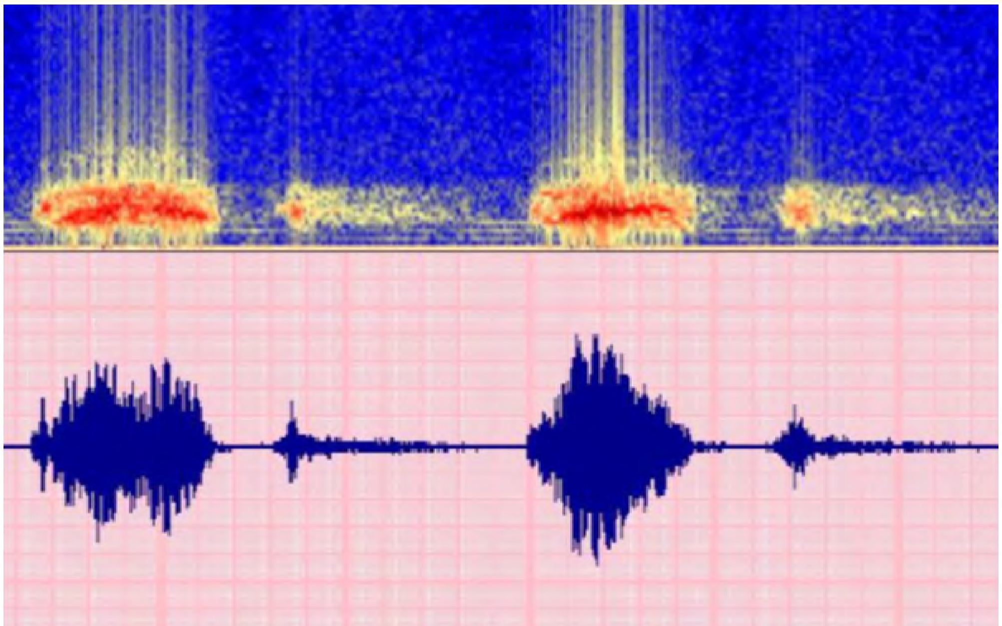

Figure 6: *Example of pneumo-phonogram and spectrogram of a stridor sound in the context of tracheal carcinoma (data collected in the ASAP project [Analysis of Auscultatory and Pathological Sounds] developed by the French national agency for research [ANR 2006 - TLOG 21 04]).*

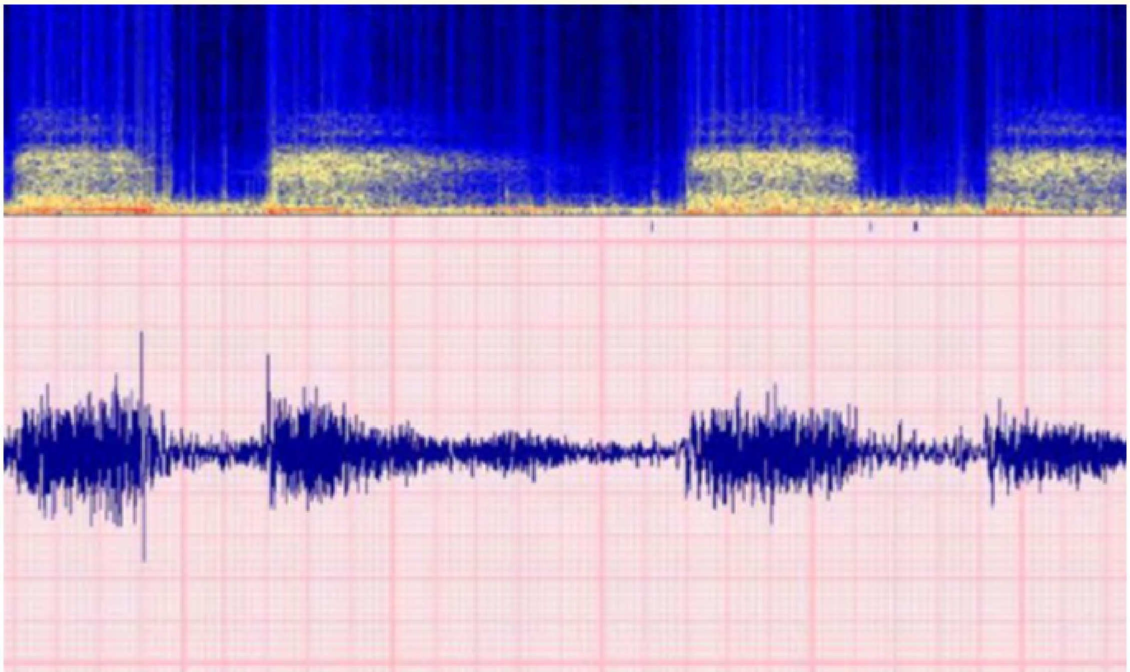

Figure 7: *Example of pneumo-phonogram and spectrogram of crackles in the context of pneumoniae (data collected in the ASAP project [Analysis of Auscultatory and Pathological Sounds] developed by the French national agency for research [ANR 2006 - TLOG 21 04]).*

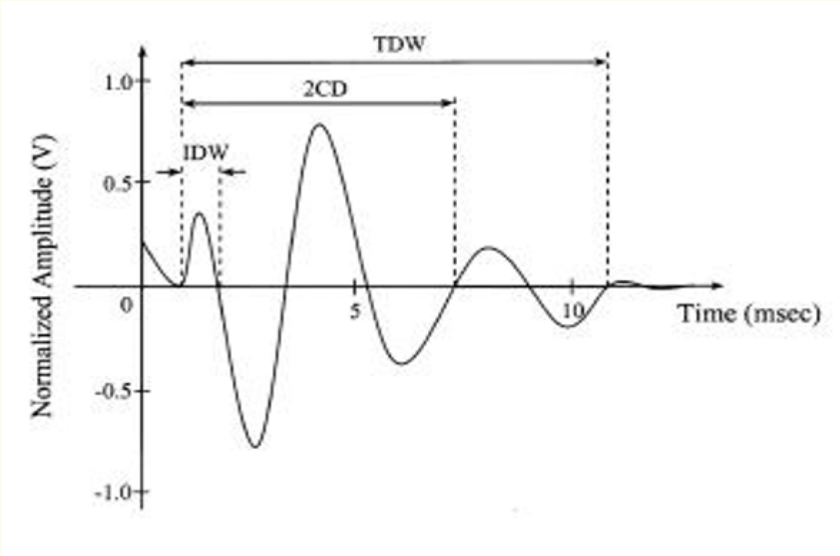

Figure 8: *Waveform of a crackle.*

phase, or during the closing in end-expiration (Figure 7). Crackles detection is important in so far as their number is a possible indicator of the severity of a pulmonary affection [41], airways disorders [44]. Nevertheless, all the more as their number, their positioning in the respiratory cycle and the waveform of their signal are characteristics of the lung pathologic case [1,5]. Crackles generally begin with a width deflection, followed by a long and damped sinusoidal wave [45,46] such as represented in figure 8. IDW or initial deflection width represents the duration between the beginning of the crackle and the first deflection. 2CD (two-cycle duration) is the duration from the beginning of the crackle to the date at which the waveform did two complete cycles. TDW corresponds to the total duration of the signal crackle. It is accepted that the duration of a crackle is lower than 20 ms and the frequency range is between 100 and 200 Hz [30]. In addition, crackles can be divided into two families: "Fine" crackles (Laënnec called them wet groan or "crépitations" in French) that are characterized, according to several authors by IDW = 0,50 ms or 0,90 ms, 2CD = 3,3 ms or 6 ms, and TDW = 4 ms [47,48]. Fine crackles are exclusively detected during breath in cycle. Fine crackles are usually associated with pneumonia, congestive heart failure and lung fibrosis. Also called fine rales or crepitations, they emit discontinuous, thin, dry noises, high and evenly pitched, occurring in spells during inspiration. They become more distinctive after coughing and usually point to an alveolar disease process. Due to alveolar wall detachment and their pathological features, they are observed primarily in cases of pneumonia, interstitial alveolar or pulmonary edema subsequent to heart failure, but also in pulmonary fibrosis and in certain interstitial pneumonias.

"Coarse" crackles ("râle muqueux" or "gargouillement" according to Laënnec's description) that are characterized by IDW = 1,0 ms, 2CD = 5,1 ms, TDW = 6,7 ms for [43] and by IDW = 1,25 ms, 2CD = 9,50 ms for [46]. They are generally inspiratory but can also be expiratory. Coarse crackles are generated by air bubbles in large bronchi. Coarse crackles come together with chronic bronchitis, as well as COPD. In this setting they are also called mucous rales, bubbling rales, coarse crackles or rales are discontinuous and of short duration. Emitted sounds are irregular, uneven, intense, observed in both phases of respiration and altered by coughing. They make a gurgling noise in the large airways often associated with bronchial congestion due to hypersecretion of mucus. They are predominantly observed in bronchitis.

Piirila and coll.'s article [41] describes the principal pathologies where crackles can be found: pulmonary fibrosis (2CD < 8 ms, frequency around 200 Hz); asbestosis (crackles' duration around 10 ms); bronchiectasis (2CD > 9 ms, they generally appear late in the inspiratory cycle and have a relatively long duration compared to the respiratory phase); COPD (2CD > 9 ms, generally starting early in inspiration and ending before the mid-point of inspiration); heart failure (2CD > 10 ms); pneumonia (2CD between 9 and 11 ms, they appear mid-point of inspiration); and sarcoidosis.

Pleural Rub

Pleural rub is a discontinuous signal with duration above 15 ms and a pitch below 350 Hz [1]. This non-polyphonic (musical) signal depicts the rubbing of pleural membranes against each other. This may be caused by an inflammation of lung membrane, or lung tumor. It can be heard both on inspiration and on expiration. Pleural rubs are usually caused by inflammation of the pleural membrane, or by pleural tumor [5]. Some authors describe pleural rub as a dry grating and superficial sounds, unchanged by coughing. Their Intensity may be discrete, like the «rustle of silk paper», or intense, such as the "creaking sound of new leather". They are due to the two inflamed pleural layers rubbing against each other. They occur at the onset of pleurisy, at its upper limit or after fluid evacuation. The differential diagnosis with that of coarse crackles may be difficult, but unlike the latter, pleural rubs appear soon after the start of inspiration.

Summary of normal and adventitious sounds

Pramono., *et al.* [49] gives a useful summary of normal breath sounds characteristics. As shown in table 1, most of the energy is below 1,000 Hz for the signals that are captured over the lung. It goes up to 2,000 Hz in the mouth, and up to 5,000 Hz on the trachea, with a drop at 800 Hz. Table 2 gives the details of the energy of the adventitious sounds [1,5,11].

Detection of known markers

Known markers commonly analyzed by automatic tools are crackles and wheezes [1,5,11]. The principal algorithm families of detection of these markers are summarized in the table 3. Different analysis methods are described. We can quote temporal analysis of the waveform for crackles searching, and frequency analysis (Fourier transform, spectrogram in 2D or 3D [1], sonogram [50]) used for wheeze detection. In techniques of spectral analysis, the main parameters are the average frequency of the spectrum, the frequency of maximal power, the number of dominant peaks, the factor of exponential decreasing [5]. Finally, time-amplitude and time-frequency analysis are classically implemented thanks to a wavelet transform. Among the complex solution, we can quote the use of a multi-layer perception in a neuronal network, genetic algorithms and a hybrid solution between both. The search of the parameters is performed through a learning method. Guler., *et al.* [51] notice that the hybrid solution is the most effective. Finally, Murphy., *et al.* [52] demonstrate that a multi-channel analyzer (several sensors used simultaneously) is able to detect significant differences between the pulmonary sounds of patients suffering from pneumonia and patients without symptoms.

Wheeze detection

As we explained before, Bahoura [3] describes a spectral analysis technique for wheeze detection. In fact, the main characteristic of sounds stands in peaks of energy that can be visualized in the spectrum. The limits of this method stand in the existence, in normal pulmonary sounds, of peaks similar to those charactering wheezes [5]. Consequently, an important rate of erroneous detections of generated. The difficulties found during the automatic wheeze detection tools can be overcome thanks to a joint time-frequency analysis [5]. As follows, the principle is: the detection in frequency domain of a peak that could correspond to a wheeze will be followed by a second test in time domain in order to confirm true wheezes and reject erroneous ones. According to Homs-Cobrera., *et al.* [53], significant parameters are frequencies and mean number of wheeze detected. They use parameters: number of wheezes, mean wheeze frequency with highest power peak, mean wheeze frequency with highest mean power, mean frequency, percentile of maneuver occupied by wheezes. The parameters are defined after dividing the frequency range into bands of 50 Hz from 150 to 200 Hz. Moreover, the present algorithm indicates that there is a significant correlation between the number of wheezes detected and the signal amplitude; due to a simultaneous dependence between normalization factor and fuzzy rules thresholds. Spectrograms provide a graphical time-frequency representation of the wheezes' location. Nevertheless, this is not sufficient to objectively characterize sounds. Another process used for the automatic wheeze detection was proposed in references [3] and [53]. It is based on the use of wavelet packets decomposition, in two stages. Firstly, it consists in frequency detection with wheeze extraction. Then, an inverse transform and a reconstruction of the useful signal; a temporal detection, here also makes it possible to eliminate false detection, generated by a superposition of spectral domains of some normal sounds and wheezes. From spectrograms generated with recorded sounds, Lin., *et al.* [54] made a 2D bilateral filtering for edge-preserving smoothing. The results indicated a high efficiency of the system; authors ambition using this system for asthmatic patient monitoring and the study of airways' physiology. Similarly, a method of continuous wavelet transform is described in Hadjileontiadis and coll.'s article

[34], combined with a scale-dependent threshold. This method seems to provide a higher good detection rate. In this setting, Meslier and Charbonneau's article [38] also describes an automatic wheeze analysis and quantification of a spectral analysis. These algorithms are based on the definition of a threshold upon which the presence of peaks in frequency domain is characteristic of a wheeze. This threshold differs from one article to the other (thus, a peak can be characterized by a power 15 time greater than current average, or 3 times greater than average value. All these studies define constant threshold, based on power measurements. Qui., *et al.* [55] confirms that frequency analysis alone generates a relative important number of erroneous detection. This article describes a new algorithm based on auditory modelling, called "frequency and duration dependent threshold (fddt) algorithm". Parameters for average frequency and wheeze duration are obtained automatically. The notion of threshold depends on the frequency and duration introduced in a new wheeze detection algorithm. The threshold is no more based on global power, but on power corresponding to a particular frequency range. The choice of energy instead of power was done according to previous studies results [5]. Actually, the latter indicates that energies threshold was more suited to short-time sounds detection (lower than 200 ms).

Crackles detection

Crackles analysis can be spitted into three major stages: 1) a noise reduction filter is applied in order to the delete the residual stationary noise in a non-stationary signal; 2) a search of the waveform corresponding to a crackle; and 3) detected crackles, classified in two categories: fine and coarse crackles [5,11]. Kayha and Yilmaz [56] propose an automatic system of crackles detection and classification. The proposed system uses a stationary/non-stationary filter and a wavelet packet transform (also called WPST-NST) that allows isolating crackles from vesicular sounds. Kawamura and coll.'s article [57] shows the existence of a correlation between respiratory sounds and high-resolution computed tomography findings. Two parameters, two cycles and the initial deflexion width of crackles were induced by time-expanded waveform analysis. Kayha., *et al*. [58] describe a system based on increasing transient by an adaptive filter and implementing nonlinear operators to wavelet decomposed respiratory sounds. Yeginerand., *et al.* also describe in their article the utilization of wavelet networks in order to model pulmonary crackles [45]. In this setting, the algorithm proposed by Vannuccini., *et al.* [46] uses a stationary/non-stationary fuzzy-based filter (FST-NST). Results of the separation have a relatively good accuracy. The proposed algorithm deals with non-stationary crackles and fuzzy rules. The FST-NST filter was applied to sounds coming from three databases. First, crackles were separated from vesicular sound. Next, "fuzzy if-then rules" were used. The results of the separation are reliable, objective, and high quality, in so far as the FST-NST filter automatically identifies the location of crackles in the original signal [46,47]. Hadjileontiadis., *et al.* [48] detect crackles and bowel sounds thanks to a fractal dimension analysis of the records. Results seem to be conclusive, and, moreover, robust to noise stress. The comparison of the results coming from different methods is summarized in the following table 4 [5]. The best results of classification were obtained using wavelet analysis. The representation of Prony's parameters indicates a correlation between the type of pathology, crackles occurrence compared to pulmonary volume, and Prony's frequency [56].

Respiratory cycle detection

In order to provide exploitable results, information must always be brought to a respiratory cycle [28]. Therefore, it is interesting to automatically detect inspiration/expiration phases. In Benedetto and coll.'s article [24], another characteristic of pulmonary signals is used: spectral power of pulmonary sounds during inspiration phase is higher than those during expiratory phase. This characteristic can be used, alone, to allow stage detection. Likewise, Chuah and Moussavi [4] use a processing of the average value of the spectral power to qualify respiratory cycle. This analysis is completed by the processing of the average value of tracheal spectral power to determine the begging of respirations. Moussari., *et al.* [59] use the average power spectrum of breath signal and the difference between average tracheal power spectrum and chest signal to detect respiratory phase. The results are between 31 and 69% good classification. Besides, the average power spectra difference between inspiration and expiration, in frequency range 150 - 450 Hz is maximum 10 dB. This method works fine for artificial sounds; nevertheless, it doesn't allow classifying real auscultation sounds [5]. Finally, Leng., *et al.* [60] propose to qualify sound while using a fractal dimension and a parameter called "variance fractal dimension". Contrary to crackles or wheezes detection, the main methods of respiratory phase detection use AI algorithms [5]. Thus, Guler., *et al.* [61] use a six-phase classification: begin, middle, end inspiration, and begin, middle, end expiration; this method leans on the utilization of a multistage classification. The extracted features are autoregressive parameters and cepstral coefficients. The development of such tool faces with two major difficulties: respiratory signals are not stationary in so far as the volume of lungs is changing; and respiratory sounds present a great variability depending on age, mass, pathology evaluation state [5]. In this setting, Guler and coll.'s base their study on a multilayer perceptron [51]. On individual segment, it provides approximately 60% good recognition in expert phase. Carlos and Verbandt [62] use two artificial independent neural networks (ANN): their algorithm is based in two neural networks ANN inspiration; and ANN expiration. First, a pre-processing is done; it normalizes the signal in amplitude (between 0 and 1).

The next stage deals with the ANN with one hidden layer. The parameters are obtained thanks to a learning algorithm using back-propagation technics. Afterwards, a stage of post-processing is applied; it consists in removing the uncertain "1" that are situated between at least five "0" and inversely.

Respiratory sounds classification

In respiratory auscultation, there is no universal pattern or parameters' - attached to auscultation - threshold indicating the presence or absence of a pathology. Therefore, Zheng., *et al.* [63] propose to establish a personalized pattern, combining information coming from sounds and other measurement applied to the patient. They aimed at recognizing pattern of pulmonary sounds. The method applied can be divided into two stages: characterize the variables that can be extracted from the waveform of pulmonary sound, and the changing in these variables that will provide information concerning the pattern variations. In this context, Guler., *et al.* [61] focus on AI technics; they combined neural network and genetic algorithm for analysis of respiratory sounds. First, they selected complete respiratory cycles, on which a PSD (Power Spectrum Density) of 256 was applied. Then, a multilayer perceptron (MLP) neural network was employed in order to detect the presence or absence of adventitious sounds (wheezes and crackles). The search of optimal parameters was done thanks to a learning method. Each sound is associated to several characteristics and to a diagnosis. Hundred twenty-nine specific characteristics were checked of (PSD0, etc., PSD128). Afterwards, different learning rules were used in order to associate characteristics and diagnosis. Kahya., *et al.* [64] make a comparison between k-NN (k-nearest neighbor) and ANN (artificial neural networks). They use different features extracted from the respiratory signal; actually, each cycle is divided into six segments with three features: autoregressive coefficient, wavelet coefficient and crackles' parameters. Moreover, the performance of the classifiers was measured thanks to the following statistical parameters: sensitivity: number of pathological subjects classified correctly/total number of pathological subjects; specificity: number of healthy subjects classified correctly/total number of healthy subjects; and accuracy: number of subjects' correctly classified/ total number of subjects. Then, Kahya., *et al.* added crackle parameters to the observed features in order to increase the performance of classification [65]. As previously K-NN and multinomiaux classifiers were used. It was observed that addition of crackles parameters to feature vectors and fusion of phase decisions improved classification results [5,11]. In this setting, the study by Yeginer., *et al*. [66] focuses on four pathologies: asthma, bronchiectasis, COPD and pneumonia. The sound is divided into six sub-phases: early (30%), mid (40%), late (30%) inspiration and expiration. Classification experiments are applied to each sub-phase. Neural classifiers (multi-layer perceptron MLP with hidden layer with ten nodes) were used with the following parameters: autoregressive parameters, error prediction, ratios of expiration/inspiration duration. The weigh and biases of the MLP are updated thanks to Levenberg-Marquardt's optimization algorithm that is one of the fastest. Then, the classification is realized in three stages: healthy/pathological classification, restrictive / obstructive classification, and classification between the pathologies (e.g. asthma and bronchiectasis). The accuracy is calculated by "global number of segment correctly classified / global number of segments". Finally, the performances of classification are around 70/80%. The study by Pittner and Kamarthi [67] aims at describing a preprocessing method to reduce the entry pattern size in neural networks, and to increase the performance of estimation or classification. The results indicate that wavelet expansions are significant signal sensors and allow extracting important features. Several authors realize classification of normal and adventitious sounds in two stages: linear prediction of coefficients, and features of the energetic envelope [5,68,69]. Seven types of respiratory sound were thus classified, among which four normal sounds: vesicular breath sounds (V), bronchial breath sounds (B), broncho-vesicular breath sounds (BV), and tracheal breath sounds (T). The features extracted were: fast Fourier transform (FFT), PDS estimation by means of linear prediction (LCP). Nevertheless, in this study, a manual decision of the inspiration / expiration periods was realized. The main objectives are: characterize quantitatively several respiratory sounds and provide an automatic classification method of these types of sounds. Finally, the diagnostic will be done by a physician, and based on the sound analysis associated with other diagnostic values. And on 105 experiments, only 5 generated errors. In another way, Dokur and Olmez [70] use wavelet transforms. The best samples are selected by dynamic programming. Then a Grow and Learn neural network is used for classification. The process of decision is made up of three stages: process normalization, feature extraction, artificial neural network by classification. To our knowledge, multi-layer perceptron is currently frequently used in biomedical signal processing [5,9]. Nevertheless, they present three main drawbacks: backpropagation algorithm takes too long time during learning phase; the number of nodes in the hidden layers must be defined before the learning phase. The structure is not automatically determined by the training algorithm; and back-propagation algorithm may be caught by local minima, which decreases network performances [5].

Factors influencing respiratory sounds and measurement

Age and corpulence

Differences due to age are all the more visible for infants. Elphick and coll [50] notice that stethoscope evaluation is not very accurate for wheeze and crackle detection [28]. Actually, audible respiratory sounds in early childhood have acoustics characteristics distinct from those generally heard in adults. Therefore, Mazic., *et al.* [20] propose to use more objective methods to automatic detect wheeze in asthmatics infants, during forced breathing.

Subject conditions

For testing lungs auscultation, several academic societies and authors have published guidelines that are helpful, even for short term recording [5,11,72]. This includes body position, location of the microphones and respiratory maneuvers. E.g. for body position, it is recommended that the patient be sited, with the hands on the thighs to avoid contact of the arms with the axillary areas location of the microphones. Thus, because a large number of sites has been adopted (> 50) by the investigators, there is a need to define anatomically the microphone locations that have proved to be most relevant: trachea: on the sternal notch; chest, posterior etc. Sovijarvi., *et al.* provide a list of standard position [10,12,14].

Non-stationary signals linked to lungs' air volume variations

The static characterization of the process evolves in respiratory cycle [1,39]. In fact, respiratory sounds are non-stationary in particularly because of the changing lung volume [1,72]. Thus, in order to correctly interpret the results, it is recommended to bring back to pulmonary air volume.

Respiratory maneuvers

The airflow and the volume have a strong influence on the collected sounds [72]. In particular wheezes and crackles characteristics and amount are related to the air volume as well as the disease. For instance, crackles have been shown to appear early in the inspiration in patients with COPD and late in the inspiration in patients with fibrosing alveolitis. Thus, positioning crackles during the breathing cycles and calculating the number and place of crackles is helpful for establishing a diagnosis. This may only be achieved with the help of a structured protocol to respiratory sound recording and a systematic respiratory sounds analysis, perhaps with automatic and intelligent tools [1,5]. The automatic tool that we developed during the project "Analysis of Auscultatory and Pathological Sounds" (ASAP), financed by the French national agency for research (Agence Nationale pour la Recherche, through the protocol ANR 2006 - TLOG 21 04) [27].

Environmental conditions

Noise not related to the relevant breathing signal is generated by the body of the patient or by external sources. Standardization of noise conditions is addressed in reference [1,9,72]. External sources are continuous noise and transient noise [27]. Continuous noise is generated by motors, hard disks, air-conditioning ducts, fluorescent light bulbs, transformers, fans in electronic equipment and computers; these noises usually generate 50 Hz or 60 Hz harmonics and can therefore be very easily filtered. Traffic in the street is also a continuous noise but without harmonics. Transient noise include speech, music, noise from airplanes, trains, cars, slamming doors, furniture squeaks, phone rings, alarms from monitors or other electronic devices. Body sounds are either related to breathing (chest motion, muscle sounds, skin friction, sounds induced by airflow in devices, and tubes and valves for monitoring of airflow and volume) or not related to breathing (heart sounds and murmurs, vascular sounds, swallowing, burping, bowel sounds, joint crackles, speech or other noises from the patient) [5,27]. External sounds can be easily filtered with the use of an additional sound capture that will record and subtract environmental noise. A project has been proposed by the US army, with auscultation inside helicopters. The noise generated by the body itself cannot be detected by an additional microphone.

Standardization of the measurement protocol

In order to overcome these limitations, The European Community has financed the BIOMED 1 Concerted Action project entitled "Computerized Respiratory Sound Analysis" (CORSA) 'see before) [33]. Thus, the CORSA project describes auscultations' points, type of sensors, filtering, sampling frequency, technique of FFT, definition of a spectrogram average, and used of standard flows.

Automated respiratory sound analysis devices

Pramono., *et al.* [49] gives a short list of available automated respiratory sounds devices. These tools aim at overcoming the limitations of conventional auscultation (it cannot provide continuous monitoring, it needs to be performed by an expert with lot of experience, limitation of human ear are well known, and increase with ageing which is antonymic with experience, etc.) [5,27]. In addition, noises might disturb the auscultation process. Automatic tools are expected to overcome these drawbacks. The National Institute for Health Research (NIH) provides a list of already available commercial systems (review in [73]), such as: the Wheezometer® [74], the Wholter® [75], the VRI® [76], the LSA-2000® [77], the LEOSound® [78], the multichannel STG® [79] and STG® for PC [80] or handheld STG® [81]. Wheezometer® and Wholter® have been developed by Karmelsonix. Wheezometer® makes use of a sensor to be placed over the trachea and will detect wheezes and evaluate the percentage of time where wheezes have been detected in the breathing signal [74]. Wholter® is intended for home monitoring [75]. LSA-2000® has up to 4 sensors attached over the chest to detect interstitial pneumoniae [77]. LEOSound® uses 3 sensors to collect, to analyze and to store data for wheeze and cough detection [78]. STG® tools were developed by Dr R. Murphy [80,81]. The multichannel STG® has 14 sensors placed over the lung, the heart and the trachea. It aims at identifying wheezes, crackles and rhonchi. Smaller devices have benne developed, to be connected either to a PC or to a handheld device. The above-mentioned devices have not yet portable, easy to use devices. In this setting, we are currently testing and studying different algorithm in the context of the ASAP project [5,27]. The next stage of this project will consist in exploiting all the richness of the sound. This augmentation of the spectrum studied and linked to signal analysis techniques will allow the definition of potential new characteristic physiological or pathological markers. Today, extensive researches are conducted with several smartphones in the context of Android or IOS. Thus, in several studies, the iPhone seems to be able of capturing characteristics of breath disorders by detecting wheezy characteristics in breath sounds. The comparison of the signals recorded by the iPhone and the stethoscope resulted in decent coherence on frequencies lower than 1000 Hz (data from the Glasgow University team on sounds analysis research). It also turns out that the stethoscope only detects frequency components up to 2000 Hz, so it begs the question if it is unnecessary to analyze any frequencies above that value.

Conclusions and Perspectives

In order to analysis respiratory sounds in the context of EBM or in health 2.0 and medicine 2.0, studies demonstrate the need of performing an exhaustive scientific approach. This latter, account of both the definition of a semiology, the consolidation of definition of known characteristics markers, the definition of common or even universal semantics, and must include the development of determinist tools that will allow the detection of these markers. It is precisely the context of the ambitious ASAP project. This Project is handled by a multidisciplinary team, mainly including medical resources from University Hospital of Strasbourg (Strasbourg, France) and scientific support from Alcatel-Lucent®. Among the most identified outcome from the project, it is force in to create auscultation school housed by the University of Strasbourg (Strasbourg, France). In this context, a recent meta-analysis from Gurung*., et al*. [82] shows that computerized analysis of recorded respiratory sounds may be a promising adjunct to chest auscultation as a diagnostic aid in both clinical and research settings. In this study, they found that computerized respiratory sound analysis performs at a relatively high level of sensitivity and specificity in a small number of studies. Overall sensitivity for the detection of abnormal respiratory sounds using computerized respiratory sound analysis was 80% and overall specificity was 85% [82]. In this setting, we have documented with new tools to signal display a better accuracy of diagnosis in 30 medical students.

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