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Molecular Diagnostics of Pulmonary Diseases Based on Analysis of Exhaled Breath Condensate

Tereza Kačerová, Petr Novotný, Ján Boroň and Petr Kačer

Abstract

Measurements of biomarkers in exhaled breath condensate (EBC) extend a novel route for monitoring lung physiology and provide a beneficial insight into the pathophysiology of a specific disease. From the medicinal point of view, biomarkers present in EBC depict rather the processes occurring in lungs than those in the entire system. Therefore, particular profiles of exhaled biomarkers (e.g. cys-LTs, LTB₄, 8-isoprostane, etc.) apparently reveal information exclusively applicable to differential lung disease diagnoses. This chapter describes the developed analytical method being applied to a clinical study for differential diagnostics of various phenotypes of asthma, chronic obstructive pulmonary disease, lung cancer, etc. In particular, having determined cys-LTs and LXs by the described method, and having applied them as biomarkers of bronchial asthma, their distinctive potential was demonstrated to differentially diagnose the specific disease, clearly suggesting this method to be reckoned as a beneficial alternative to existing diagnostic methods. Consecutively, the developed method was expanded to other asthma markers as aldehydes, nitrotyrosine, 8-isoprostane, PGE₂, adenosine and finally, a supplementary study was carried out, engaging in detecting serotonin. The multi-marker screening and importance in the diagnostics of pulmonary diseases are referenced in the text as well.

Keywords: exhaled breath condensate, pulmonary diseases, leukotrienes, lipoxins

1. Introduction

From the very beginnings of civilizations, with tracks from Mesopotamia, Egypt, and ancient Greece, medical practitioners examined the potential of exhaled breath (EB) parameters as health-related signs usable for identifying various ailments and essentially mapping different
physiological states. Via different odors, sounds, and breath dynamics often attributed to supernatural powers and superstitious believes, various lung diseases could be relatively well diagnosed and further progression could be predicted. For instance, the odors in EB as, for example, fruity traces of acetone aided to identify diabetes; a rather pungent characteristic odor was associated with a lung inflammation, while volatile vapors from urine revealed a kidney disease [1]. Modern investigations enlisted approx. 250 frequently detected volatile organic compounds (VOC’s) in EB [2]. Early analyses did not incorporate sample pre-treatments as sample concentration and exclusively depended on relatively modest gas chromatography (GC) methods. The progress of technology, however, over the decades has permitted much more precise and sophisticated analyses of EB, some of which have been implemented to the clinical practice, as, for example, ethanol levels in blood or typical inflammations caused by common pathogens as *Helicobacter pylori* using 13/14C-urea [3]. As mentioned above, the prime advantage of EB analysis is the patient’s comfort, especially eliminating the stressful intrusions to human organisms, yet there are challenges ahead. For instance, a breakthrough task is to find common internal standard reliably standardizing diagnoses for each pathological status. Furthermore, an opposite selection of multi-marker panel is to be conspicuously correlated to different health phenomena, providing the knowledge of characteristic concentrations. Moreover, it is often unclear which metabolic pathways in relation to different measured biomarkers are involved and some are probably yet to be discovered or decoded. Last but not the least, technological and procedural challenges include also the standardization in terms of the sample collection and treatment, and conceivably, endeavors to automatization of the complete process in the clinical practice.

### 2. Exhaled breath condensate

Compared to the currently widespread invasive and semi-invasive diagnostic methods, the analysis of exhaled breath condensate (EBC) is relatively new and has the first-rate potential to become a preferred and completely noninvasive alternative. EBC is a biological matrix reflecting the composition of the bronchoalveolar extra-cellular lung fluid. The main advantage of EBC as of a matrix is its specificity for the respiratory tract (the liquid is not influenced by process occurring in other parts of human organism). Many important biomolecules are present in exhaled breath in the form of an aerosol [4, 5] (Figure 1) which is condensed by cooling during the collection, forming the EBC matrix.

The collection of EBC is performed while using the condenser, which is currently available at a specialized clinical facility. During the collection, the exhaled air is led through the condenser into the cooling box that is pre-cooled to the temperature −20°C. In the cooling box, the aerosol particles are obtained and the gaseous phase is liquidized.

In the obtained liquid, typically known as EBC, more than 2000 compounds [6] have been identified so far and many of them are considered to represent sensitive biomarkers of lung diseases [7, 8]. The determination of the concentration of these molecules in EBC allows...
assessing the type and severity of ongoing pathological process or even the efficiency of a therapeutic procedure, etc. In case of numerous pulmonary diseases, H\textsubscript{2}O\textsubscript{2}, cysteinyl leukotrienes (cys-LTs), lipoxins (LXs), malverines, resolvins, isoprostanes, prostaglandines, glutathione, adenosine, thiobarbituric acid, aldehydes, nitrotyrosine, cytokines represent a specific group of biomarkers and their concentration levels are elevated (eventually lowered) in airways and lungs as a result of an ongoing allergic reaction, inflammation, oxidative stress, and other processes [9–12].

The most significant advantage of EBC compared to other biological matrices (as are, for example, urine and blood) is the fact that EBC is a highly specific fluid for the respiratory system, so any other biochemical processes in human organism do not influence it.

3. The collection of EBC

During the collection of EBC, the exhaled air is led through the condenser, where some components are condensed. The patients should breath calmly and regularly during the whole

![Image of exhaled breath condensate formation](http://dx.doi.org/10.5772/intechopen.74402)
The exhaled air flows through the mouthpiece and the one-way valve into the cooling cuff that is pre-cooled at the temperature of −20°C. In the cooling cuff, the aerosol particles and the obtained gaseous phase are condensed. This liquid is then gathered in the sample collection vial (the temperature remains the same) [13]. The whole process lasts approximately 7–12 min. It is necessary to obtain 120 l of EB in total, which corresponds to 1–2 ml of the condensate. The obtained condensate is then conserved in a micro-test-tube. In order to monitor the degrading process, the samples were labeled by deuterium-labeled internal standards. The prepared samples are then subsequently frozen and stored for a period not exceeding 6 months (~−80°C).

As the collection of EBC is a noninvasive diagnostic method that does not burden the patient, it can be used in several different clinical studies. A regular collection of EBC enables, for example, monitoring of the impact of climate conditions on the patients. Globally, collection of EBC is a method that is suitable for clinical studies that are trying to understand the process in the organism which corresponds to some external impulses (physical activity, air quality, allergens, etc.)

4. Bronchial asthma

Bronchial asthma is a relatively common pulmonary disease, which is usually characterized by dyspnoea combined with intervals of a normal breathing [14–19]. Typical symptoms of asthma include constricted bronchial tubes and an increased secretion of sputum, which is abnormally dense and viscous [16]. Various sources agree that on the global scale, the asthma incidence accounts for around 300 million people, while the prognoses that are negative in the sense of the future number will keep rising. On the other hand, wide ranges of relatively efficient anti-asthmatic therapies are available (e.g., glucocorticoid therapy, β2-receptors agonists, etc.) [17] enabling the majority of patients to live normal lives. However, there is still a small group of patients, who do not respond to any kind of current therapy. These patients are usually diagnosed as sever refractory asthmatics (SRA) [6], whose common feature is a lack of any response to any contemporarily available pharmacotherapy. SRA accounts for approximately 5% of all asthmatics, which represents 10 million of people [6].

Figure 2 describes the immunopathogenesis of asthma [20]. The asthma attack starts by exposure to an allergen, which causes synthesis of immunoglobulin E (IgE). IgE then binds to the surface of mast cells. As there occurs a re-exposure to the same allergen, the interaction between allergen and antibody triggers the release of mediators as are prostaglandins (PGDs), cys-LTs, LTB, and platelet-activating factor (PAF). These mediators cause bronchoconstriction that is connected to an immediate drop in FEV1 (= forced expiratory volume in 1 s; the FEV1 is the volume exhaled during the first second of a forced expiratory maneuver started from the level of total lung capacity). The allergen-antibody interaction also causes production of a wide range of cytokines (e.g., interleukin 4 and 5 (IL-4 and IL-5), tumor necrosis factor (TNF) and tissue growth factor (TGF)). These cytokines then activate neutrophils and eosinophils. Neutrophils produce proteases and PAF, and at the same time, eosinophils produce eosinophil cationic protein (ECP) and major basic protein (MBP). These
products, eosinophils and neutrophils, cause mucus hypersecretion, edema, and constriction of smooth muscles. This is usually associated with the late asthma phase and it causes the second drop in FEV1.

4.1. The diagnostics of asthma

There are several options for the diagnostics of asthma; however, only an early and correct diagnosis of this life-threatening disease permits the physician to timely initiate an effective therapy and minimize the harm to the patient [18]. Several noninvasive methods are already in clinical use (e.g., spirometry, bronchomotoric tests, etc.). In some cases, invasive and semi-invasive methods appear to be an inevitable option to gain the correct diagnosis (e.g., open-lung biopsy and bronchoalveolar lavage) [21], yet it is to an unambiguous expense of the patient and often the health cost as well as a demanding laboratory examination.

Currently, a significant part of the relevant research centers focuses on methods of the so-called personalized diagnostics (or methods of personalized medicine), with the aim to stratify patients to characteristic groups (e.g., phenotypes) and thus achieve a more efficient therapy reflecting an individual phenotypic disposition (inclusive of genomic, proteomic and metabolomic profiles) [22, 23]. One of the examples of these endeavors (particularly for diagnostics of pulmonary diseases) is the measurement of a fractional exhaled nitric oxide (FeNO) [24–26] in EBC, helping to distinguish asthma from other pathogenetic processes diagnosed as chronic cough, gastroesophageal reflux disease (GERD), vocal cord dysfunction, bronchiitis, chronic obstructive pulmonary disease (COPD), etc.

4.2. Asthma phenotypes

As asthma is a disease affecting millions of people of all ages worldwide, many criteria can be used for its classification. Nevertheless, the predominantly used criterion is the severity of the disease, as is presented in Figure 3, followed by the age of the first exacerbation [9, 26].
5. Chronic obstructive pulmonary disease (COPD)

Chronic obstructive pulmonary disease (COPD) is a chronic inflammatory pulmonary disease [27–29]. The development of COPD usually lasts many years. During these years, bronchial tubes of COPD patients are getting more and more narrowed. COPD is also characterized by attacks of dyspnoea and persistent dry cough. The cough is often accompanied by expectorated mucus. In a late stage, it can cause obstructive, effortful, and painful breathing. These complications can be a hindrance also during simple physical activity. COPD patients are also prone to pneumonia. The main cause of COPD is often smoking. Other contributing factors include the genetic inheritance, a long exposition to dust particles, or a regular and frequent lung infection.

COPD is often divided into two main groups (phenotypes): chronic bronchitis and emphysema.
5.1. Chronic bronchitis

In chronic bronchitis [28], a typical symptom is a permanent constriction of bronchial tubes. Furthermore, an inhalation of harmful substances cause impairment of the respiratory mucous membrane, while a repeated damage to the membrane makes it thicker and lowers the tissue transparency. As a result, the affected cells increase the production of mucus, leading to the characteristic cough.

5.2. Emphysema

Emphysema is characterized by a loss of the pulmonary tissue, while the respiratory ways are abnormally widened distantly from terminal bronchioles [28].

The main cause of emphysema is smoking. The substances that are inhaled during smoking are led through the respiratory ways to bronchioles. In bronchioles, the substances provoke a local immune reaction, which is linked with the production of aggressive compounds via leucocytes (mainly free radicals responsible for oxidative stress). This reaction thus initiates a degradation of bronchioles. The afflicted bronchioles merge into huge lung sacs. These sacs have a smaller surface of the pulmonary tissue and thus the gas exchange between lungs and blood is limited.

The second cause of this disease can be disequilibrium between proteases and their inhibitors—anti-proteases. Some COPD patients suffer from the lack of alfa-1-tripsin (an anti-protease), which is the reason for a higher number of proteases in the respiratory ways, which damage the pulmonary tissue [29].

5.3. Asthma and COPD

Similar to asthma, COPD is a pulmonary disease and shares many similar symptoms (e.g., pulmonary obstruction, over-production of mucus, attacks of cough and dyspnoea, etc.).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Asthma</th>
<th>COPD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (origin of the disease)</td>
<td>Childhood, anytime</td>
<td>40+</td>
</tr>
<tr>
<td>Development of the disease</td>
<td>Abrupt attack</td>
<td>Slower</td>
</tr>
<tr>
<td>Dyspnoea</td>
<td>Rather abrupt, variable</td>
<td>Often, rather permanent</td>
</tr>
<tr>
<td>Pulmonary obstruction</td>
<td>Mainly reversible</td>
<td>Often irreversible</td>
</tr>
<tr>
<td>Smoking</td>
<td>Not very common</td>
<td>80% of cases</td>
</tr>
<tr>
<td>Allergy</td>
<td>Often (or parents)</td>
<td>Rarely</td>
</tr>
<tr>
<td>Inflammation (can differ)</td>
<td>Rather eosinophil</td>
<td>Rather neutrophil</td>
</tr>
<tr>
<td>Bronchial hyperreactivity</td>
<td>Distinct</td>
<td>Less common</td>
</tr>
<tr>
<td>Glucocorticoid therapy</td>
<td>Mainly efficient</td>
<td>Rather inefficient</td>
</tr>
<tr>
<td>Mortality (inhabitants per year (world))</td>
<td>300 million (decreases)</td>
<td>600 million (increases)</td>
</tr>
</tbody>
</table>

Table 1. Asthma and COPD comparison.
Especially, these common characteristics cause that asthma and COPD are sometimes misdiagnosed [30–32]. This can cause an incorrect pharmacotherapy administration, followed by their health state not (or just slightly) improving.

However, several factors can be used to distinguish asthma from COPD (Table 1).

6. Biomarkers of pulmonary diseases present in EBC

The term biomarker herein refers to a measurable biomolecular factor applicable for the measurement of a disease progression or treatment-related biomolecular changes in the human organism. On a molecular scale, biomarker refers to “a subset of markers that might be discovered using metabolomics, proteomics, genomics and other -omics technologies or imaging technologies.” Biomarkers play a major role in medicinal biology. Biomarkers may be foreseen as a promising tool in the near future due to their unique potential for early diagnoses, which obviously permit disease prevention, a drug target identification, a drug response monitoring, etc. The collection and analyses of substances present in EBC provide a simple, noninvasive, real-time, point-of-care clinical and research tool for the evaluation of lung pathophysiology.

Very significant role is played by some biomarkers that are produced from the arachidonic acid (some of them were already mentioned above). Arachidonic acid ((5Z,8Z,11Z,14Z)-eicosa-5,8,11,14-tetraenoic acid) is a polyunsaturated omega-6 fatty acid present in phospholipid cell membranes [11, 12]. The products of the metabolism of arachidonic acid are called eicosanoids. These molecules are characterized by the 20C chain. The production of eicosanoids is enabled by different enzymes (Figure 4), the only exception are isoprostanes which emerge through oxidation of arachidonic acid (non-enzymatic pathway).

6.1. Arachidonic acid metabolites

Arachidonic acid is a polyunsaturated fatty acid present in phospholipid bilayer. In human organism, arachidonic acid acts as a vasodilator or regulates inflammation as a key intermediate. There are several pathways which allow transformation of the arachidonic acid in a number of different metabolites (Figure 4). Among the most significant products of its metabolism can be classified leukotrienes, lipoxins, isoprostanes, and prostanoids [6, 33].

6.1.1. Leukotrienes

Leukotrienes (LTs) [6, 33] represent a group of biologically active molecules. LTs are produced by various tissue cells (e.g., leukocytes, macrophages, mastocytoma cells) as a response to both immunological and non-immunological stimuli. LTs are potent pro-inflammatory [33] mediators and their release is usually triggered by the organism coming in contact with an allergen. The interaction between LTs and their receptors can lead to a wide range of biological effects: leukocytes activation, bronchial smooth muscles contraction, vascular permeability stimulation and increased mucus production, etc. All of the described symptoms are typically connected not only to pathophysiology of bronchial obstruction, especially to asthma, but also to other lung inflammatory disorders.
been separated according to the type of glucocorticoid application. The results also show that on these terms more efficient was the *per oral* glucocorticoid therapy, as the cluster representing patients with *per oral* treatment is in the spectrum closer to the controls.

The study has also confirmed that the developed method can be used for such monitoring, which could in the future make the asthma pharmacotherapy more accurate. Furthermore, the method could also enable controlling of dosing and comparing of the efficacy of different anti-asthmatic drugs, which would globally improve asthma treatment.

8.3. Asthma and COPD separation

Apart from cys-LTs and LXs, EBC contains a wide range of other different biomarkers. The research has shown that biomarkers of oxidative stress play a significant role in the development of some pulmonary diseases. Examples of such biomarkers can be 8-isoprostan, MDA, HHE, HNE and other aldehydes and biomarkers connected to damage of proteins (O-Tyr, 3-CITyr and 3-NOTyr) or nucleic acids (8-OHdG, 8-OHG and 5-OHMeU).

These biomarkers allowed extension of the developed method, which was originally based on the detection of levels of cys-LTs and LXs. An example of such extensions can be separation of asthma and COPD on molecular level.

The metabolic fingerprinting of EBC of patients suffering from COPD showed a significant increase of biomarkers of neutrophil inflammation—LTB$_4$, and also biomarkers of oxidative stress (mainly O-Tyr and 8-isoprostane). The developed method was used in a clinical study that was aimed at detection and description of differences between COPD patients and SRA (SRA were chosen because their profile is quite similar to the profile of COPD patients and thus their diagnosis is often altered). The obtained results were compared to the analysis of EBC of healthy control subjects (two control groups were chosen—one for COPD patients and one for SRA).
According to the results, the PCA analysis has divided the patients into four groups based on their biomarker profiles. The results show that profiles of SRA and COPD patients were different, which allows an accurate separation of these two diseases. The figure also shows that the control groups were separated. Further, the results show that it is not possible with this method to separate (on the molecular level) the two phenotypes of COPD—chronical bronchitis and emphysema.

8.4. Biomarker panel for monitoring of pathogenesis of pulmonary diseases

As a significant part of the study, a panel of biomarkers that can be used for differentiation of various pulmonary diseases was designed. The analyzed biomarkers are divided into two main groups. The first group contained biomarkers of eosinophil inflammation—cys-LTs (\(\Sigma\)LTC\(_4\), LTD\(_4\), LTE\(_4\)), the anti-inflammatory eicosanoids—LXs (\(\Sigma\)LXA\(_4\), LXB\(_4\)) and anti-inflammatory resolvins (RvD1). The second group contained biomarker of neutrophil inflammation—LTB\(_4\), 8-isoprostane which is biomarker of oxidative stress connected to damage of phospholipid membrane, biomarkers of damage of proteins (\(\Sigma\)o-tyrosin, NO-tyrosin and Cl-tyrosin) and biomarkers of damage of nucleic acids (\(\Sigma\)5-OHMeU, 8-OHG and 8-OHdG).

The first two graphs show results of the analysis of EBC of patients suffering from SRA and moderate persistent asthma. The results are compared with the analysis of EBC of healthy control subjects.
According to the graph (Figure 11), it is obvious that EBC of patients who suffer from asthma contained increased levels of cys-LTs (the highest levels—SRA, this confirms the study mentioned above). On the contrary, EBC of asthmatics contained lowered levels of the anti-inflammatory LXs and resolvins. Considering the asthma-phenotyping-study, it can be also said that the results of analysis of EBC of SRA and controls were inverse.

Figure 12 shows the results of the monitoring of LTB₄, 8-isoprostane, biomarkers of damage of proteins and nucleic acids. Levels of LTB₄ showed the same trend as cys-LTs, for example, the highest levels were detected in EBC of SRA and the lowest in EBC of healthy controls. At the same time, levels of 8-isoprostane were slightly elevated among the group of patients with moderate persistent asthma and even more among SRA. The differences in levels of biomarkers responsible for damage of proteins and nucleic acids were slightly higher in EBC of asthmatics, but the differences were not so significant, which means that these biomarkers are not so specific and influential in case of bronchial asthma.

Figures 13 and 14 show same biomarkers as the previous Figures 11 and 12, but in EBC of patients who suffer from COPD, asbestosis and lung cancer.

From Figure 13, it is quite obvious that biomarkers cys-LTs, LXs and resolvins do not play a significant role in pathogenesis of these diseases, as their levels are comparable to those detected among healthy control subjects (the levels are just slightly elevated and only COPD patients show some more noticeable deviations).

Figure 14 shows that illnesses characterized by damage of the pulmonary tissue are usually connected to increased levels of biomarkers of oxidative stress. One of these significant

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![Figure 11](image1.png)

**Figure 11.** Evaluated clinical results: levels of cys-LTs, LXs and resolvins in EBC of SRA, moderate persistent asthma and healthy controls.
Figure 12. Evaluated clinical results: levels of LTB₄, 8-isoprostane, biomarkers of proteins and nucleic acids damage in EBC of SRA, moderate persistent asthma and healthy controls.

Figure 13. Evaluated clinical results: levels of cys-LTs, LXs, and resolvins in EBC of COPD, asbestosis, and lung cancer patients.
indicators of ongoing tissue necrosis processes is 8-isoprostane. The analysis of EBC showed that the levels of this biomarker are increased among COPD and asbestosis patients and even more among people suffering from lung cancer. Similar information is provided by the biomarkers of proteins damage (tyrosines) and nucleic acids damage (5-OHMeU, 8-OHG, and 8-OHdG). The levels of these molecules were elevated in EBC of patients with COPD and asbestosis and it can be said that the highest levels are specific for lung cancer (average concentration of tyrosines is approximately 75 pg/ml of EBC for healthy controls and 160 pg/ml of EBC for patients with lung cancer).

8.5. Serotonin in EBC of SRA

Based on the clinical experience, it is proved that SRA patients positively respond to SSRI (selective serotonin reuptake inhibitors) antidepressants therapy. SSRI antidepressants usually improve physical state of patients, which may seem as a quite logical coincidence. However, much more surprising is the fact that when SRA patients are prescribed SSRI antidepressants, their breath functions improve significantly. This phenomenon prompted to performed research aimed at the detection of serotonin in EBC of SRA. The obtained results were compared with serotonin levels in EBC of other asthma phenotypes and healthy control subjects.

According to the results (Figure 15), it is obvious that the levels of serotonin in EBC of SRA are different as compared to other asthma phenotypes and healthy control subjects. However,
surprisingly, the levels were significantly elevated (in case of SRA patients) which is against all expectations (it was expected to detect lower levels of serotonin, which would provide a possible explanation of positive SRA’s responsiveness to SSRI antidepressants therapy). Probably, even more interesting is the fact the levels of serotonin of other asthma phenotypes and health controls were the same, which indicates that the deviation appears only among SRA.

The interpretation of these results is quite complicated. One of the possible hypotheses is that SRA could be a different disease that would only demonstrate itself as asthma (i.e., patients have similar symptoms as asthmatics, but the cause of the disease could be different). However, this theory will require further research in the future. One of the possible extensions could be monitoring of levels of serotonin in cerebrospinal fluid, which would provide information about the process behind the blood-brain barrier. On the other hand, the study proved that there many significant physiological differences between SRA and other asthmatics, which could be used in the future for the development of a possible drug against SRA.

9. Conclusions

Measurements of biomarkers in EBC offer a novel way of monitoring lung inflammation, damage by oxidation stress with an insight into the pathophysiology of different diseases. The described diagnostic method was based on the detection and quantification of biomarkers in a matrix specific for the respiratory tract—EBC. As the collection of EBC is completely noninvasive, the method offers a broad spectrum of application. The method is applicable to children as well as to senior people and it is appropriate also in case of longitudinal studies that are trying to precisely understand the processes occurring on the molecular level in the respiratory tract. The method can be easily repeated which proves its suitability for regular monitoring of the pharmacotherapy efficiency or the impact of various allergens. The results obtained from the EBC analysis represent reliable characterization of the exhaled biomarkers.

Figure 15. Evaluated clinical results: levels of 5-HT in EBC of SRA, moderate persistent asthma and healthy controls.
profile (LXs, cys-LTs, LTB₄, 8-isoprostane, tyrosines, etc.), which is relevant for diagnostics, separation, and phenotyping of different respiratory diseases. Nevertheless, EBC analysis requires standardization and validation including sample collection and sample pre-analysis treatment (e.g., internal standardization, storing, pre-treatment method application, etc.).

Model clinical studies were carried out as a part of the work, which applied a methodology based on the molecular diagnostics of EBC. The method allowed an asthma phenotyping, which was founded on the fact that the concentration levels of cys-LTs and LXs are not only complementary but also intra-related by a dynamic equilibrium. This phenomenon, however, affords not only asthma phenotyping but also other diagnostics as, for example, monitoring of efficacy of the used pharmacotherapy. The analysis of EBC also showed that the detected biomarkers can be used for the differentiation of various pulmonary diseases (more specifically (apart from asthma) COPD, asbestosis, and lung cancer). Increased (or decreased) levels of some biomarkers are specific only for some diseases and thus these can be selectively differentiated as much as, for example, asthma from COPD.

Additionally, an experiment was conducted and focused on determining serotonin in EBC. The aim of this study was to assess the positive effects of the SSRI (selective serotonin re-uptake inhibitors) antidepressants on SRA. High levels of serotonin were detected in EBC of SRA patients, which was in contradiction to the initial assumption. Simultaneously, a hypothesis was formulated stating that SRA probably functions on different molecular principles. This could have probably been the reason for SRA inefficiency with the commonly used drugs.

For the future research, one can only recommend focusing on large longitudinal studies to ascertain whether sequential measurements in individual patients reflect asthma severity and the degree of a lung inflammation, and on studies engaged to the relationships between the concentrations of asthma biomarkers and its symptoms. In order to implement the EBC analysis to the clinical practice as well as reliably guiding the pharmacological treatment of asthma and the effect of drugs on asthma markers present in EBC, further controlled studies are required to be conducted. In particular, studies are recommended determining the expediency of the EBC analysis for predicting a treatment response, and assessing new therapies. Obviously, this outlines a great deal of work to be done. The fact that EBC analyses are currently used in various clinical trials and studies corroborates the above arguments. On the other hand, it is important to proclaim that the fact whether and when EBC analyses will become applicable to the clinical settings is still difficult to predict.

Acknowledgements

The work was supported from The Ministry of Education, Youth and Sports of the Czech Republic under the NPU I (LQ1604) National Sustainability Program II (Project BIOCEV-FAR) and by the project “BIOCEV” (CZ.1.05/1.1.00/02.0109). European Regional Development Fund-Project “PharmaBrain” (No. CZ. CZ.02.1.01/0.0/0.0/16_025/0007444), project AZV MZ 17-31852A and by the “Sustainability for the National Institute of Mental Health (LO1611).
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