

PAPER • OPEN ACCESS

Determination of Numerical Indices of Lung Volume in Different Respiratory Phases

To cite this article: N S Bezrukov *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **272** 032105

View the [article online](#) for updates and enhancements.

Determination of Numerical Indices of Lung Volume in Different Respiratory Phases

N S Bezrukov^{1,2}, V P Kolosov¹, A V Il'in¹, J M Perelman¹

¹Far Eastern Scientific Center of Physiology and Pathology of Respiration,
Blagoveshchensk, Russia

²Amur State University, Blagoveshchensk, Russia

E-mail: jperelman@mail.ru

Abstract. The algorithm of lungs search on the computer-tomography slices is proposed. The example of calculating the numerical indices of the lung volume in the inspiratory and expiratory phases is given. The automated calculation of air trapping is used.

1. Introduction

The laboratory examination of patients plays a big role in the right diagnose. Different cells can become the object of the laboratory examination, including airway ciliated epithelium (CE). One of the ways to study cells is to expose them to the aggressive medium and analyze their functional parameters (motion, reproduction) [1-7].

Due to the introduction and spreading of modern methods of X-ray diagnostics in the past years, there has appeared a possibility to complement the examination of patients with asthma with the computed tomography (CT) [1,2]. CT is the most reliable method among all the other methods of X-ray diagnostics of respiratory organs with further computer processing of research results [1].

It is known that CT with the application of 3D-volumetry, zonal planimetry and densitometry for the analysis of lungs condition allows to increase the quality of pulmonary diseases prediction [3]. But this method has not become widely spread in medical institutions by the number of reasons:

- the results of the test depend on the subjective view of a doctor, his/her level of qualification in pulmonology;
- the absence of generally accepted formalized numerical indices at the out-put;
- large amount of images (the number of lung slices can be up to 350) complicates manual processing and the search for abnormalities.

To overcome these problems, it has been proposed to take as an indices the value of lung air volume in the inspiratory and expiratory phases the same way it was done in the works [1, 4]: inspiratory air volume of the right lung (IAVR), inspiratory air volume of the left lung (IAVL), expiratory air volume of the right lung (EAVR), expiratory air volume of the left lung (EAVL). It was also proposed to calculate the relative air trapping of the right and left lungs in the expiratory (RE-ATR and REATL) and in the inspiratory (RIATR and RIATL) phases through the square of the right (SR) and left (SL) lungs.

The algorithm of lungs search on the CT scan and automated calculation of indices was also developed.



2. Algorithm of lungs search on the axial sections of CT

The results of CT are kept in the open format DICOM. The format is formed with a big number of shots of axial sections of patient's chest. Each shot is made in the form of 2D matrix with lines and columns (fig. 1). In the points of the matrix there are standard volume units, called voxels (vox.) with values from the Hounsfield scale. Following the works [5, 6], mathematical programs are used as a tool to develop the algorithm.

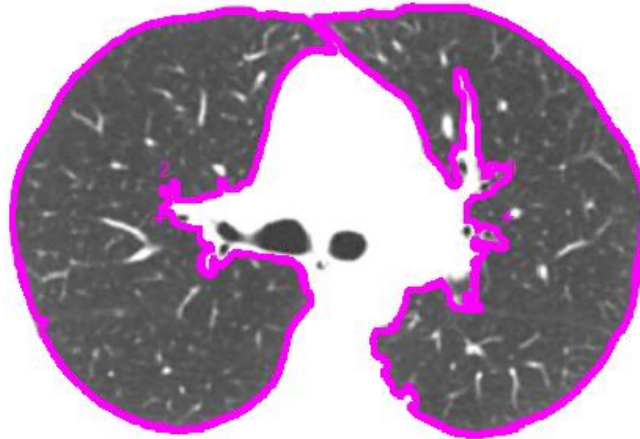


Figure 1. Axial section of lungs in the inspiratory phase.

Algorithm of lungs search on the axial sections is developed by the following rules:

1. The lung is sought in the restricted densitometric diapason from -250HU and lower. The diapason was found experimentally as in the period of inspiration the lungs are filled with air with densitometric diapason from -750 HP (fig. 1), and in the period of expiration there is little air in the lungs (predominantly in bronchi) and diapason begins from -250 HU (Fig. 2).
2. The part of the lung at the current section is always put on the part of the lung of the further section.
3. The patient has two lungs and in the shot they have a maximal size. The rule allows to exclude the trachea from calculations.
4. The search of the lung was done from the apex to the base. The lungs are first searched by statistical markers, by rule 2. The position of markers was found experimentally.

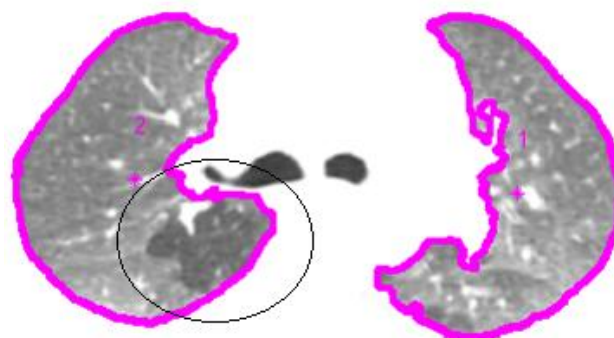


Figure 2. Axial section of lungs in the expiratory phase.

The algorithm works the following way: at the current section rule 1 allows to identify all the objects under study. Then all the objects that do not correspond to rule 2 are excluded. If there are more than 2 objects, then rule 3 is used. If there are less than 2 objects, then it means that data are

wrong and this section is not included into calculations. According to rule 4, the next section is considered. The results of the algorithm work are shown in Fig. 1.

In the identified objects the following are calculated:

- the square of the section of the right and left lungs;
- air volume of the right and left lungs (in densitometric diapason from -850 and lower, which corresponds to the air density [2]);
- relative air trapping of the right and left lungs (the ratio of lung air volume to the square of the lung).

3. The example of lung numerical indices calculation

By the suggested algorithm there were found lungs in the asthma patient. Then the values in the inspiratory (Fig. 3, 4, 5) and expiratory (Fig. 6, 7, 8) phases were calculated. At the plot there is a section number in the Y-axis and there is a square of the section in voxels in the X-axis.

At Fig. 3 there is a result of calculation of SP and SL in the inspiratory phase and at Fig. 6 in the expiratory one. The volume of the lung and how much the studied part of the lung has changed are found by the plot. Thus at 190 section at inspiration (Fig. 3) the values of the square were 32500 for the left lung and 28500 for the right one, and at expiration (Fig. 6) there were 19400 for the left one and 14600 for the right one. It means that the lungs at expiration decreased by 41% and 49%, respectively. The sections are shown at Fig. 1 and Fig. 2.

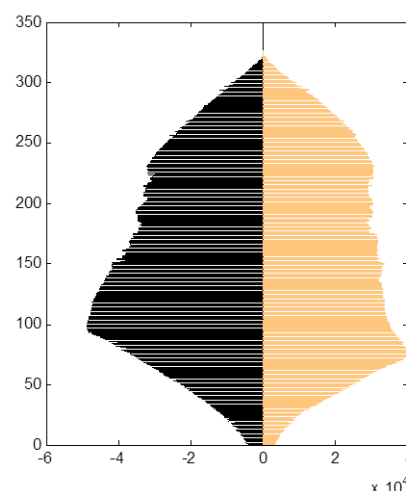


Figure 3. The square of the right and left lung in the inspiratory phase.

Fig. 4 shows the result of the calculation of inspired air volume of the right and left lungs, and Fig. 7 presents expired air trapping. At inspiration lungs are filled with maximum air, that's why IAVR follows the shape of SR, and IAVL the shape of SL. At expiration the lungs have minimum air, that's why EAVR differs from SR and EAVL from SL. At Fig. 7 in 190 section of the left lung the deviation of EAVL (marked with an oval) is fixed, which is proved by the presence of air at the axial section of the left lung (Fig. 2) (the dark part of the figure, marked with an oval).

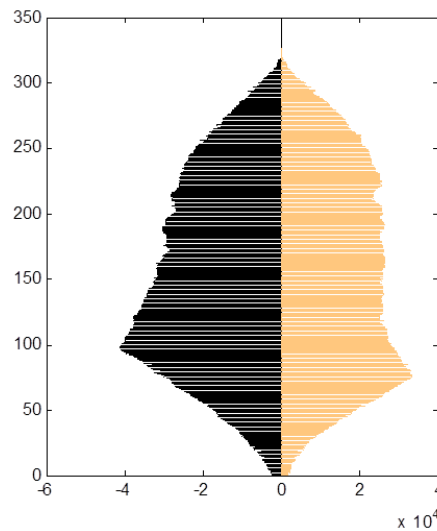


Figure 4. Inspiratory air trapping of the right and left lungs.

At Fig. 5 there is a result of calculation of RIATL and RIATR, and at Fig. 8 of REATL and REATR. Relative air trapping has a non-dimensional value in diapason from 0 till 1, which allows to use it for comparison of the research results from different patients. At expiration lungs are filled with maximum air, that's why RIATL and RIATR tend to 1, but as the patient has asthma, relative air trapping of the apex of the lung (the section number is more than 300) and at the lung base (the section number is less than 50) within the diapason from 0.8 till 0.5 doesn't increase 0.9 at the whole diapason.

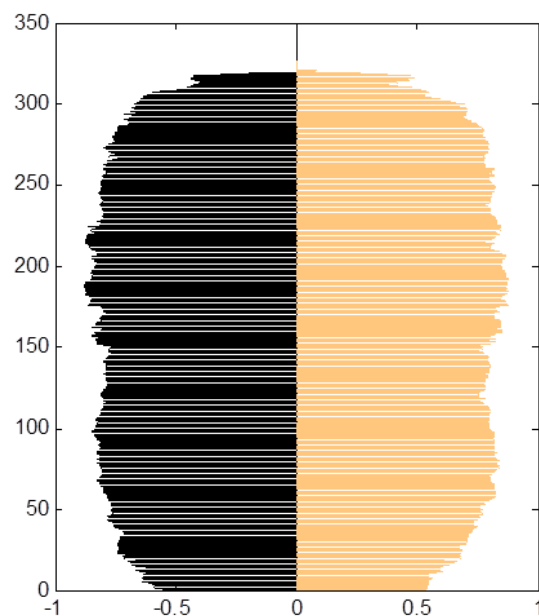


Figure 5. Relative inhaled air trapping of the right and left lung.

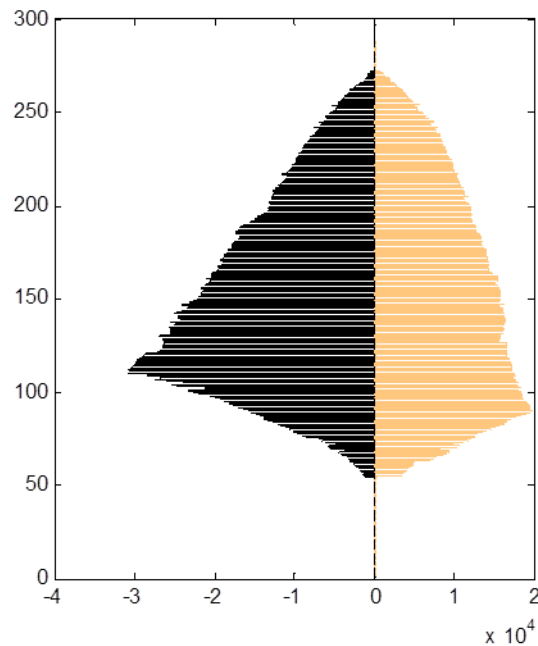


Figure 6. The square of the right and left lungs in the expiratory phase.

Lungs have a minimal quantity of air at expiration, that's why REATL and REATR tend to 0 (Fig. 8). Because of the disease of the patient there is increased air trapping in different parts (including above and below) in the diapason 0.03-0.07.

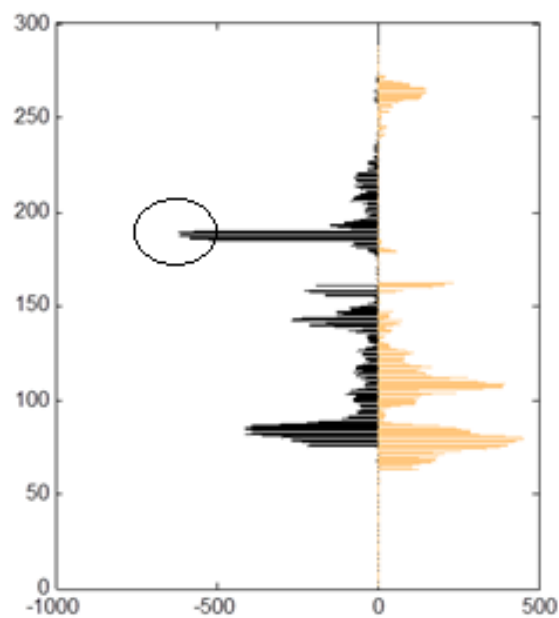


Figure 7. Expiratory air trapping of the right and left lungs.

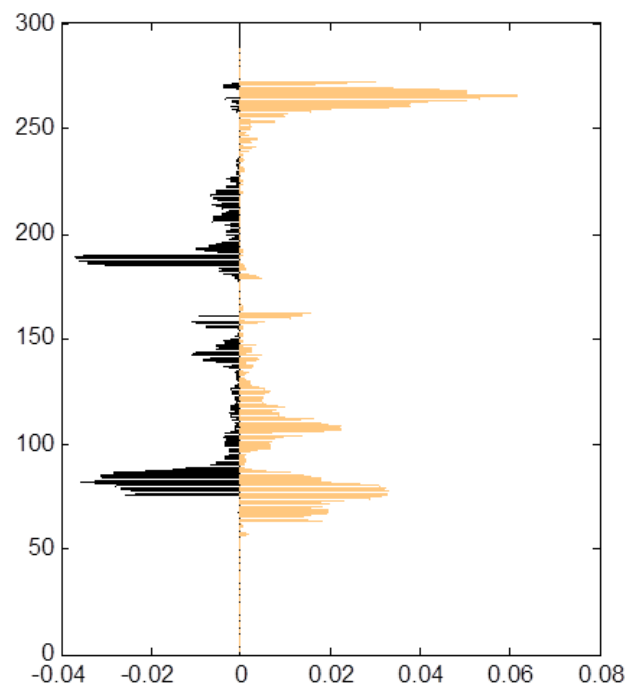


Figure 8. Relative expiratory air trapping of the right and left lungs.

Automated calculation allows to analyze irregularity of pulmonary ventilation at all sections of CT (for inspiration there are 350 sections, for expiration 300), unlike the work [2] where there were analyzed only 3 sections because of the manual type of calculation.

4. Conclusion

The suggested algorithm of lungs search in CT scans showed high robustness under numerical experiment, but it has its restrictions: if the patient doesn't have one lung (or it is developed poorly), then algorithm will not work. Automated calculation allows significantly reduce the workload on the doctor.

By the plot of RIATL and RIATR it is possible to determine problem zones in lungs. The application of RIATL and RIATR allows the specialist to use the relative system of units (all the values are in diapason from 0 till 1), which will simplify the analysis at the research and development of diagnostic models.

5. References

- [1] Lenshin A V, Il'in A V, Odireyev A N 2012 Post processing multiplanar and 3D reconstructions in diagnostics of sarcoid lymphadenopathy by data of multi-spiral computed tomography *Bûlleten' fiziologii i patologii dyhaniâ* **46** 2012 116-131
- [2] Il'in A V, Perelman J M, Lenshin A V, Prikhodko A G 2014 Application of computed tomography with 3D volumetry in diagnostics of disturbance of ventilation function of lungs in patients with bronchial asthma *Bûlleten' fiziologii i patologii dyhaniâ* **51** 33-37
- [3] Il'in A V, Lenshin A V, Odireyev A N, Perelman J M 2013 New method of X-ray diagnostics of disturbances of ventilation function of lungs through multi-spiral computer tomography *Bûlleten' fiziologii i patologii dyhaniâ* **47** 40-47
- [4] Il'in A V, Perelman J M, Prikhodko A G, Lenshin A V 2015 Prediction of achievement of bronchial asthma control with application of indices of bronchial conductance and air trapping of lungs In: *Materials of XI International Scientific Conference "System analysis in medicine"* (SAM 2015) *Blagoveshchensk* 107-110

- [5] Bezrukov N S, Shmatok M I 2015 A new way of registration of activity of airway ciliated epithelium cilia. In.: Materials of XI International Scientific Conference "System analysis in medicine" (SAM 2015) *Blagoveshchensk* 50-56
- [6] Bezrukov N S, Karavanov Ya V 2009 The way of detecting cells on the image of the blood clot. *Informatika i sistemy upravleniâ* **2** 59–61
- [7] Solovev D B, Merkusheva A E 2017 Increase in Efficiency of Use of Pedestrian Radiation Portal Monitors *IOP Conf. Series: Materials Science and Engineering* **262** **1-6** (Paper № 012200) Available: <https://doi.org/10.1088/1757-899X/262/1/012200>