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Application of texture analysis to ventilation SPECT/CT data

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ABSTRACT

It is demonstrated that textural parameters calculated from functional pulmonary CT data have the potential to provide a robust and objective quantitative characterisation of inhomogeneity in lung function and classification of lung diseases in routine clinical applications. Clear recommendations are made for optimum data preparation and textural parameter selection.

A new set of platform-independent software tools are presented that are implemented as plug-ins for ImageJ. The tools allow segmentation and subsequent histogram-based and grey-level co-occurrence matrix based analysis of the regions of interest. The work-flow is optimised for use in a clinical environment for the analysis of transverse Computed Tomography (CT) scans and lung ventilation scans based on SPECT. Consistency tests are made against other texture analysis plug-ins and simulated lung CT data. The same methods are then applied to patient data consisting of a healthy reference group and one patient group each who suffered from asthma, chronic obstructive pulmonary disease (COPD), and COPD plus lung cancer. The potential for disease classification based on computer analysis is evaluated.

1. Introduction

Close to 10 percent of the world population are suffering from chronic lung diseases. The two most common categories, which account for 7.7%, are asthma and chronic obstructive pulmonary disease (COPD).

According to World Health Organisation (WHO) estimates, 300 million people suffer from asthma and 255 000 people died of asthma in 2005 [1] and an increase of 20% is expected over the next 10 years. Asthma is the most common chronic disease amongst children. It is characterised by episodic airway narrowing that occurs on exposure to stimuli, such as exercise, dust, pollens and cold air. Asthmatic lungs are characterised by inhomogeneous ventilation when studied by pulmonary function techniques or by imaging methods. The severity of the inhomogeneity, measured by pulmonary function, is strongly related to the sensitivity of airways to inhalants, i.e. dust, pollens, etc. Thus characterisation of the topographical pattern of ventilation in asthmatic lungs is important.

The WHO estimates (2007), currently 210 million people suffer from chronic obstructive pulmonary disease (COPD) with 3 million people dying of COPD in 2005 [2]. COPD is a chronic disease that is caused predominantly by tobacco smoking in western countries. COPD causes lung destruction, known as emphysema, and diseases of small and large airways, which result in cough, mucous production and airway narrowing with resultant breathlessness during exertion.

Single-photon emission computed tomography (SPECT) ventilation scanning [3] using Technetium-99 (Technegas™), is a three dimensional imaging technique used routinely in clinical nuclear medicine for diagnosis of diseases such as pulmonary embolism, when combined with imaging of blood flow [4]. Ventilation scans, however, have been adapted for studies of ventilation in airways disease [5–7]. SPECT imaging offers the potential to characterise the topographical distribution of ventilation so that inhomogeneity can be quantified at the regional level [8,9]. Combining imaging information with the pulmonary function measures of inhomogeneity will provide important information about the ventilatory abnormalities in asthma and COPD [10,11]. However, suitable methods for quantifying the distribution of ventilation from SPECT data have not been determined.

In this study, we investigate several potentially useful methods of quantifying the distribution of ventilation from SPECT ventilation data using both simulated SPECT data and data from well-described clinical groups. The new technique is based on texture analysis and can provide an objective indicator of abnormal lung conditions.

2. Methods

We developed new techniques for multiple 3D texture analysis and conventional 3D image analysis of clinical SPECT data of vol-

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umes representing lung tissue as identified from co-registered CT scans that were obtained at the time of the SPECT.

The new technique uses the anatomical CT to define the lung outlines, co-registers these with the functional SPECT data and performs an image analysis on the voxels of the SPECT thus defined as representing lung tissue. The image analysis comprises a traditional direct analysis of the grey levels in the SPECT slices and a texture parameters analysis derived from grey-level co-occurrence matrices (GLCM) [22].

2.1. Simulation data

We created a series of SPECT-V data sets based on simulated data to validate the software. The lung phantom used in the construction of the model was based upon X-ray computed tomography (CT) data from a male of height 178 cm, weighing 70 kg [12] in supine position, who was chosen for his similarity to the dosimetry standard mathematical phantom. The Monte Carlo simulation package used for this work was the Photon History Generator [13,14], which models the emission, scatter and attenuation of photons in a heterogeneous phantom, followed by the photons' subsequent collimation and detection [15].

Simulations were performed for a 23.6-mm-thick parallel-hole collimator, using a 32.5-cm radius of rotation. The isotope modelled was Tc99, collected with a symmetric 20% energy window centred around 140 keV into a 128×128 matrix with 120 views at equal angular spacing around 360°, resulting in 5 million counts total when no defects were present. Pixel resolution was 2.5 mm/pixel. To test for any dependence on brightness changes we repeated two simulations with 9 million counts. These settings were chosen to closely mimic typical clinical settings when collecting SPECT-V data (similar contrast, spatial resolution and signal to noise).

A series of studies were performed in four groups, distinguished by the size of individual defects, to simulate the effects of non-ventilated lung tissue. Defects in groups 1–4 were $1 \times 1 \times 1$ pixels (15 mm^3), $2 \times 2 \times 2$ pixels (125 mm^3), $3 \times 3 \times 3$ pixels (422 mm^3) and $4 \times 4 \times 4$ pixels (1000 mm^3) in size, respectively. These were distributed uniformly throughout both lung halves in a random manner. Within each group, the amount of lung tissue involved in defects varied from 0% (normal) up to 40% in steps of 5%, giving 9 studies in each group.

These simulated lung data sets were then subjected to normal clinical processing. Lungs were reconstructed at the same resolution as routine SPECT data (128 slices with 128×128 pixels, voxel size 4.664 mm^3). The lung outlines were known from the original phantom and converted to a binary mask which was then subjected to 2 iterations with the standard ImageJ erosion operation using a count of 3 (minimum 3 of the nearest neighbour pixels need to be background pixels for the present pixel to be eroded).

2.2. Clinical data

Three groups of patients were studied to evaluate the applicability of the new methods. Five patients had asthma (data set A), and 10 current or ex-smokers that had either diagnosed COPD (data set C) or were being evaluated for treatment of lung cancer (PELICAN[1] data set) who had a wide range of severity of COPD, and scans from 5 patients who underwent lung scanning for suspected pulmonary embolism but who were considered to have normal lung scans on routine clinical assessment (data set N).

All subjects inhaled Technegas as the ventilation imaging agent. Patients had scans according to the standard clinical protocol whereby Technegas was inhaled from the Technegas generator by 1–2 deep inspirations followed by a breath hold to maximise Technegas particle deposition.

Subjects had a ventilation SPECT scan and a CT scan acquired by a dual-detector variable angle hybrid SPECT/CT system (Phillips SKYLight and Picker PQ5000 CT). All SPECT studies were acquired using a 128×128 matrix, at 15 s per stop with 3° steps over 360°. Low-dose CT was performed using non-contrast (30 mA, 10 kVp, pitch 1.5, slice thickness 4 mm). Study was acquired during tidal breathing. CT images are reconstructed using a 512×512 matrix with a smooth algorithm.

Spirometry, including the predicted forced experitory volume during 1 s (FEV1), was obtained in all groups except the normal group, using standard methods in the lung function laboratory.

2.3. Software

Custom plug-ins were developed for ImageJ [26] to read and write CT data routinely stored in Interfile data format [16]. Segmentation of the lungs in the CT datasets is done with a custom written plug-in "Extract_Lungs" (Fig. 1), which was more efficient than existing segmentation plug-ins [17,18]. Segmentation uses an edge-following algorithm that stays between an upper and lower grey-value threshold.

Up to 5 regions of interest per slice are supported which are categorised as belonging to either the left or right lung. A custom-built ROI manager allows superimposition of the ROIs onto SPECT ventilation data (Fig. 2). The identified volumes are analysed for total area, mean, median, modal, minimum, and maximum grey values, kurtosis, integrated optical density (IOD), and histogram. Weighted means are calculated for left, right and total lung.

Anatomical CT data after segmentation were registered to corresponding functional data (SPECT) with the ImageJ plug-in Align3_TP [17] with all parameters left to their default values. The outlines of the registered lung mask were then auto-detected with our segmentation algorithm resulting in ImageJ standard ROIs (regions of interest). Our modified ROI manager limits all subsequent analysis to within the defined ROIs.

From these ROIs that represent the total lung volume, GLCMs are calculated for the x, y, z, and invariant orientation for a set of up to 5 chosen distances. These are then subjected to standard texture analysis. We verified the correct implementation of the GLCM algorithm by comparing results from an independently written plug-in [19], which calculates 4 of the 12 textural features we determine, and found both to be consistent.

Fig. 3 illustrates the complete work-flow. More detail on the software is described in Appendix B.

Our objective was software that is easily available, widely used, modular in design, open source and not limited to a specific operating system. ImageJ [20,21,26] fulfils all these criteria perfectly. Furthermore, there is a large collection of plug-ins publicly available (http://rsb.info.nih.gov/ij/plugins/).

2.4. Analysis

In both the simulated and the clinical data the volumes representing lung tissue were identified as described above. All voxels outside the eroded ROIs were excluded from the analysis. Note that lung tissue outlines were registered to the reconstructed SPECT data, thus avoiding any interpolation in the SPECT data set.

All SPECT data sets, simulated and clinical, were prepared in two parallel streams: *CS* (contrast stretched) and *HM* (histogram matched). The contrast stretched data set was created by first stretching the contrast within the 16-bit grey-levels image stack

[1] PELICAN study: Predicting Exercise tolerance and Lung function using Imaging in patients undergoing CANcer Surgery, Royal North Shore Hospital, internal study, 2007.