A texture analysis approach to quantify ventilation changes in hyperpolarised ^{3}He MRI of the rat lung in an asthma model

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Introduction

Hyperpolarized (HP) ^{3}He has been successfully used in pre-clinical magnetic resonance imaging (MRI) to study lung diseases, e.g. COPD or asthma [1,2]. In preclinical research, allergic asthma is investigated in rats sensitised with the antigen ovalbumin (OVA), followed by a challenge with aerosolised OVA to induce an inflammatory reaction of the lower airways. This causes non-focal ventilation defects that lead to heterogeneously distributed signal intensities in the ^{3}He MR images. Therefore, it is difficult to assess changes in ventilation after therapeutic intervention. Texture analysis has been used successfully to classify lung pathologies based on structural properties in CT images [3]. Thus, texture analysis should also be well suited to quantify changes in the ventilation pattern after therapeutical intervention measured with HP ^{3}He MRI. The aim of this work was to develop a method to quantify changes in lung ventilation in HP ^{3}He MRI using texture analysis.

Material and Methods

24 rats were sensitised with an injection of OVA and divided in four groups with six rats each: Group 1 (control group) was challenged and treated with saline. Group 2 (vehicle group) was challenged with OVA and treated with saline. Group 3 was challenged with OVA and treated with a low dose (0.1 mg/kg) of budesonide (SigmaAldrich, Sweden). Group 4 was challenged with OVA and treated with a high budesonide dose (1.0 mg/kg). The challenge with saline or aerosolised OVA was carried out 14 days after the sensitisation.

HP ^{3}He MRI was performed 48 h after the challenge on a 4.7 T MR scanner (Bruker BioSpin, Germany) with a 3D FLASH (TE/TR/FA: 1.0 ms/2.4 ms/3.5°, bandwidth: 75 kHz, FOV 50x30x36 mm^3, matrix: 96x96x24). A small animal ventilator system dedicated for HP ^{3}He was used during the experiments. Broncho-alveolar lavage (BAL) was performed after the imaging. The number of eosinophils was counted and used as reference.

Image analysis was performed on the 3D datasets of the HP ^{3}He MRI. At first, image background including non-ventilated regions was removed using the maximum entropy threshold method. Image texture was analysed by three different methods to assess different aspects of the ventilation patterns. I) First-order features, representing the distribution of signal intensities [3], and simple geometrical features. II) Second-order statistics features based on run length, where starting from a voxel, a run will continue in one direction until the last voxel with the same intensity as the start voxel is reached [4]. The detected image element is called a primitive, which can be described by its signal intensity, length and direction. III) Discrete wavelet transforms (DWT) to decompose the images in four different frequency sub-bands in order to calculated first-order statistics on the multiple scales. For the run length method, image binning was performed to reduce the number of grey-levels. Groups were compared using one-way ANOVA with Dunnett's multiple comparison test against the vehicle group. A p-value of $p < 0.05$ was considered as significant.

Results

The amount of eosinophils was significantly increased in the OVA/vehicle group compared to the control group (24-fold, $p < 0.001$). Comparing the budesonide-treated groups with the vehicle-treated group, the number of eosinophils in the low dose and high dose of budesonide groups were significantly reduced (2-fold $p < 0.05$ and 14-fold $p < 0.001$, respectively). Figure 1 shows example images from the four groups. The texture features of all methods found significant differences for the control and the high budesonide dose groups compared to the vehicle group. Only a geometrical feature and the wavelet method were able to reveal a significant difference between the low budesonide dose and the vehicle groups. Figure 2 shows the results of one run length (the short primitive emphasis) and a wavelet feature.

Discussion

The texture analysis was able to show differences between the control and the untreated vehicle groups as well as between the vehicle and the treatment groups. This is in agreement with the findings of the eosinophil cell counts, which were used as marker for the severity of inflammation. However, not all features could differentiate all groups. This is due to the different characteristics of the used methods, based directly on the image intensities of the original images, the length of structure primitives in the lung or the intensities of frequency sub-bands, i.e. different scales, each describing different image properties. In conclusion, texture analysis can be used to quantify changes of lung ventilation as measured with HP ^{3}He MRI after therapeutic intervention with budesonide. Possible further applications of the texture analysis could be the investigation of lung perfusion heterogeneity in contrast-enhanced pulmonary perfusion MRI or of structural changes on ^{1}H MRI morphological lung images.

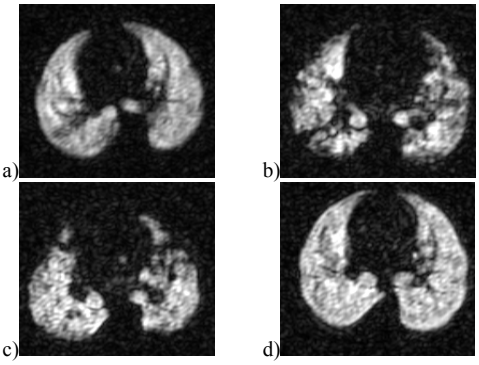

Figure 1. Example images of the lung ventilation as acquired with HP ^{3}MRI in the four study groups: a) control, b) vehicle, c) low budesonide dose and d) high budesonide dose. Note the very heterogeneous ventilation in the vehicle rat.

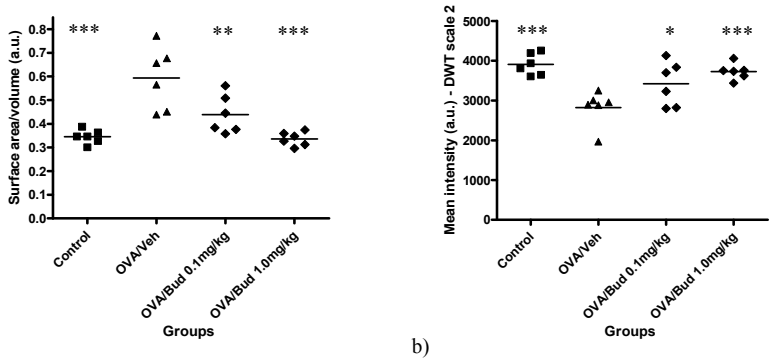

Figure 2. Comparison of the study groups by a) a geometrical feature (surface area/volume) and b) the mean intensity in the second sub-band as decomposed with DWT. The control and both treatment groups are significantly different from the untreated vehicle group (One-way ANOVA with Dunnett's multiple comparison test: *** $p<0.001$, ** $p<0.01$, * $p<0.05$). Veh=vehicle; Bud=budesonide

References

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