Quantification of Lung Ventilation Using Voxel-based Delta Radiomics Extracted From Thoracic 4DCT

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INTRODUCTION

In the treatment of lung cancer, spatially-encoded measures of pulmonary function may facilitate radiation treatment plans that can reduce dose to functioning lung, thus reducing the rate of thoracic complication from ionizing radiation[1]. A key limitation of pulmonary functional imaging is its dependence on exotic radiotracers and specialized imaging equipment. As such, many medical centers especially small clinics, do not have access to these sophisticated imaging capabilities.

Several validation studies of computed tomography ventilation imaging (CTVI) have demonstrated that 4DCT images contain valuable information that is related to pulmonary function[2,3]. A recent study performed a radiomic analysis of the lungs and investigated associations with pulmonary functions[4]. Key findings demonstrated that lung texture and density were collectively responsible for the association between pulmonary function and CT images. Remarkedly, these results suggest potential radiomic-based CTVI approaches that move beyond conventional first-order statistics and Jacobian calculations.

AIM

This study is aimed to develop a pulmonary radiomic filtering technique, where radiomic features are generalized as image filters and spatially-mapped throughout the lungs to create a multi-dimension tensor object describing the lung tissue. Here, we apply such a technique to derive novel CTVI images and demonstrate that differences in radiomic feature maps throughout the respiratory cycle are comparable to both conventional CTVI techniques and PET-based functional imaging.

METHOD

This study included 25 non-small lung cancer patients with Galligas 4DPET/CT images from the VAMPIRE dataset[5,6]. The overall workflow is shown in figure 1.

- CT images in exhale phase (EOE) and inhale phase (EOI) were both registered to average phase using contour-based deformable image registration (DIR).
- Sixty-two radiomic features were spatially extracted from deformed images using sliding window kernels and in-house solfware.
- Sixty-two delta feature maps were derived from EOE and EOI feature maps.
- Delta feature maps were compared with reference Galligas PET images by calculating voxel-wise Spearman correlation.
- Different kernel sizes were applied to characterize the sensitivity of this approach.

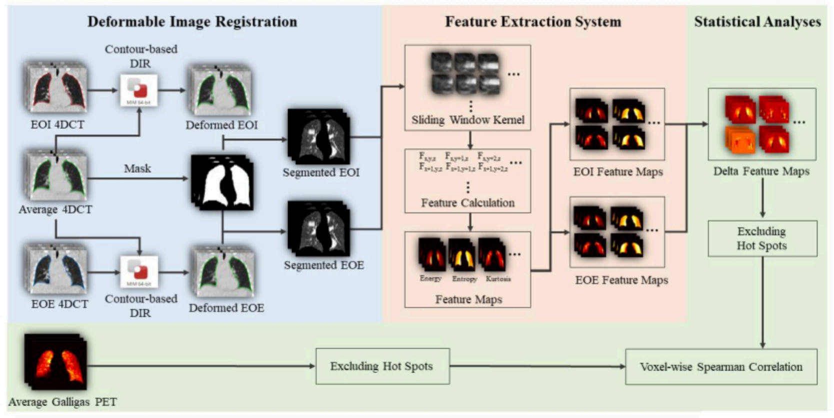

Figure 1. Schematic flow chart for the study generating delta feature maps from thoracic 4DCT.

RESULTS

Quantitative and qualitative comparison

The Spearman Correlations (r_s) were calculated between all 62 delta feature maps (kernel size 5x5x5 cm3) and their corresponding reference Galligas PET images for a cohort of 24 subjects. These results are shown in figure 2. For comparison, the correlations based on average CT images are listed as the 63rd feature. The overall highest r_s values were achieved by No. 1 first-order energy, with a range of $0.18 \le r_s \le 0.69$, and average $\overline{r_s} = 0.45 \pm 0.16$. We compared the correlation results with CT ventilation studies that utilized the same dataset[7]. The mean correlation of HU-based CTVI is $\overline{r_s} = 0.42 \pm 0.20$ and Jacobian-based CTVI is $\overline{r_s} = 0.19 \pm 0.23$.

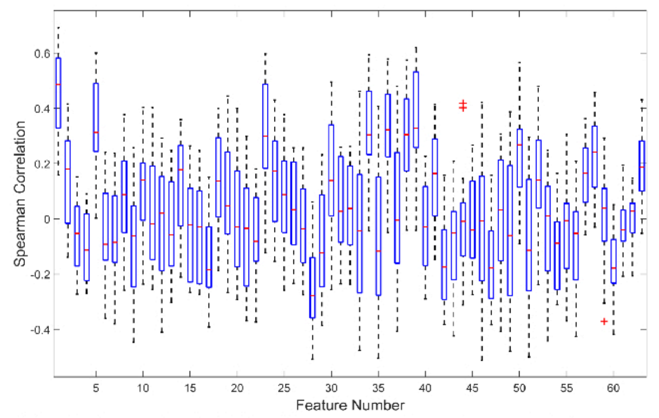

Figure 2. Boxplot showing the distribution of Spearman correlations between delta feature maps and the corresponding Galligas PET images. Each box refers to a radiomic feature. For each box, the upper, middle, and lower edges show the upper, middle, and lower quartiles. The whiskers extend to the most extreme data points not considering outliers. Outliers are indicated by "+" symbols.

Illustrating example in Figure 3 shows the changes in two radiomic feature maps as measured across registered EOE and EOI phases of a set of 4DCT images. Corresponding Galligas PET functional images are also shown as references for pulmonary functions. The selected features, first-order energy and short run high gray level emphasis (SRHGLE), demonstrated relatively high correlations with reference Galligas PET images (RefVIs).

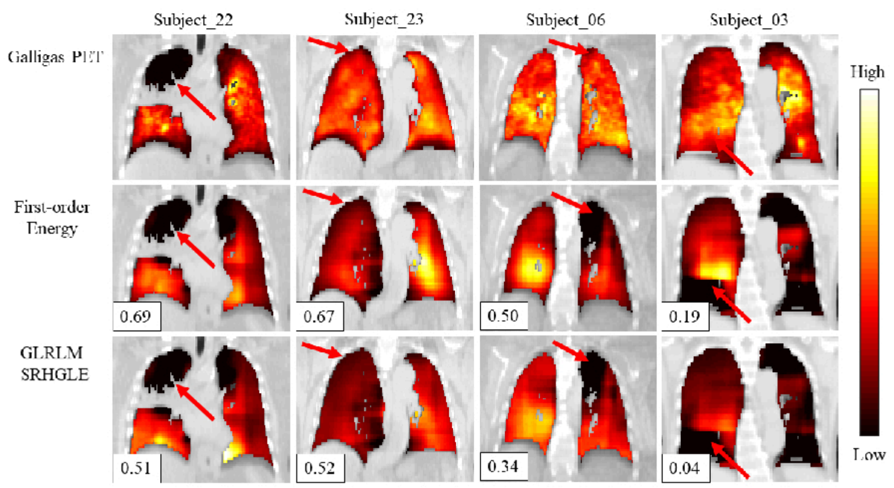

Figure 3. Comparing delta first-order energy map, delta gray level run length-short run high gray level emphasis (GLRLM-SRHGLE) map with reference Galligas PET images for different cases. Arrows point to the regions of interest. For delta feature maps, the labeled numbers are Spearman correlations with Galligas PET.

Generally, in subject 22 and subject 23, the two feature maps demonstrate good agreement with RefVIs. In subject 6, similarities are observed in the right lung, but the left apex shows difference: feature maps indicate defect in left apex which does not exist in RefVI. In the worst case of subject 3, feature maps indicate large defect regions both in right and left lung, while RefVI only indicates marginal defect.

Impact of kernel sizes

We characterized the sensitivity of our approach to kernel size. The mean correlations between RefVIs and first-order energy maps derived using different kernels are plot in figure 4. Kernels are divided into four groups: (1) cubic kernels, with sizes from 10x10x2 to 80x80x16 (correspond to 1x1x1 cm3 to 8x8x8 cm3, x direction is from posterior to anterior, y direction is from right to left, and z direction is from foot to head); (2) cuboid kernels, with sizes from 10x10x4 to 80x80x32; (3) cuboid kernels, with sizes from 10x20x2 to 80x160x16 ; (4) cuboid kernels, with sizes from 10x10x10 to 80x80x80.

at low in-plane widths in x direction, correlations increase with kernel width in all four groups. In group 1 and group 2, correlations finally saturate with increasing kernel sizes, while in group 3 and group 4, the correlations drop down after the kernel exceeds the range of the lung.

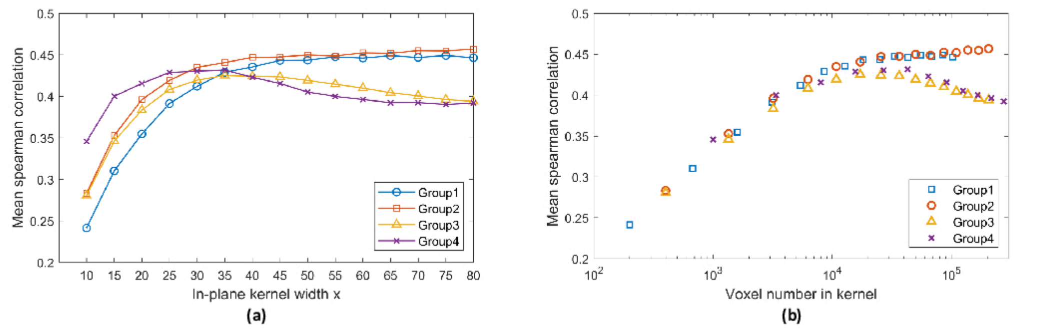

Figure 4. (a) Mean Spearman Correlations with Galligas PET images across all patients versus kernel dimension in x direction; (b) Mean Spearman Correlations with Galligas PET images across all patients versus number of voxels in kernel.

Figure 5 shows an example of first-order energy delta maps that were derived based on different kernels. Similar to the case in figure 5, all the feature maps generated with small kernels are not continuous, with large fluctuations. With increasing kernel sizes, delta feature maps become more and more smooth. However, when using extreme large kernel sizes, sub-regional hot areas will propagate to other regions.

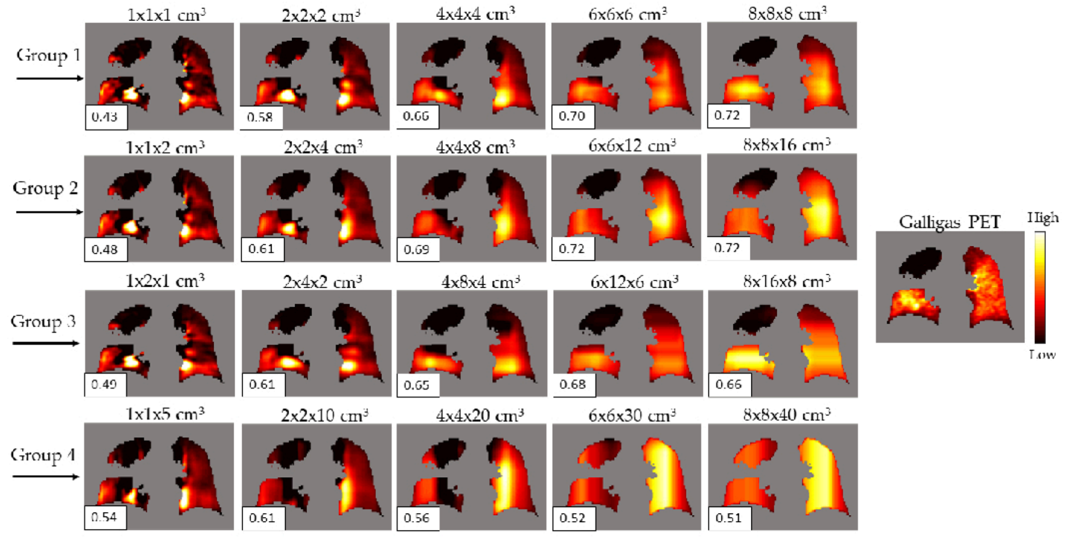

Figure 5. Comparing delta feature maps derived with different kernel sizes with corresponding Galligas PET image. The enclosed numbers are Spearman correlations with Galligas PET. The numbers above each delta map indicate the kernel sizes used in the derivation.

CONCLUSIONS

We have built a novel voxel-based radiomic feature extraction approach to quantify ventilation function using thoracic 4DCT. Statistical analyses results shown delta feature maps were correlated with Galligas PET images. The highest spearman correlation was achieved by first-order energy with mean value of $\overline{r_s} = 0.45 \pm 0.16$, which is comparable to the performance with HU-based CTVI. It has the potential to generate synthetic ventilation images to support functional avoidance radiotherapy and improve the plan quality for lung cancer patients.

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