Histograms should not be used to segment functional lung MRI

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Abstract

Magnetic resonance imaging using hyperpolarized gases, most notably He-3 and Xe-129, has made possible the novel visualization of airspaces, such as the human lung. The advent and refinement of these imaging capabilities has furthered the development of various avenues of research into the growth, development, and disease associated with the pulmonary system. In conjunction with the improvements associated with image acquisition, multiple image analysis approaches have been proposed and developed for quantifying such images with much research effort devoted to semantic segmentation, or voxelwise classification, into clinically-oriented categories based on ventilation levels. Given the functional nature of these images and the consequent complexity of the segmentation task, many of these algorithmic approaches reduce the complex spatial image intensity information to intensity-only considerations, specifically those associated with the intensity histogram. This results in the loss of important spatial cues for identifying unique imaging features, specifically ventilation defects (as spatial objects) which have been identified as correlating with lung pathophysiology. In this work, we demonstrate the interrelatedness of the most common approaches for ventilation-based segmentation of hyperpolarized gas lung imaging which rely on the intensity histogram for driving voxelwise classification. We also illustrate the underlying assumptions associated with each approach and how these assumptions lead to suboptimal performance. We then illustrate how a deep learning-based solution is constructed in a multi-scale, hierarchically feature-based (i.e., spatial) manner which circumvents the problematic issues associated with existing histogram-based approaches. Importantly, we provide this newly reported deep learning functionality and evaluation framework as open-source through the well-known Advanced Normalization Tools (ANTs) library.

Introduction

Early hyperpolarized gas pulmonary imaging research reported findings in qualitative terms.

Descriptions:

- "^{3}He MRI depicts anatomical structures reliably" [Bachert:1996aa]
- "hypointense areas"[1]
- "signal intensity inhomogeneities"[1]
- "wedge-shaped areas with less signal intensity"[1]
- "patchy or wedge-shaped defects"[2]
- "ventilation defects"[3]
- "defects were pleural-based, frequently wedge-shaped, and varied in size from tiny to segmental"[3]

Subsequently, initial attempts at quantification were limited to ennumerating the number of "ventilation defects" or estimating ventilation defect percentage (as a percentage of total lung volume).

Additional sophistication:

- linear binning
- (semi-automated) k-means
- some percentage of the global mean intensity
- Gaussian mixture modeling with Markov Random Field prior-based smoothing

, particularly with respect to so-called "ventilation defects." These regions were defined as:

- "regions of the lung that would normally be ventilated, but in which helium was likely absent."[???]

Results

Discussion

Methods

References

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