Comparing semi-automated segmentation of traditional-resolution and high-resolution hyperpolarized 129Xe MRI on COVID-19 survivors

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Introduction

Inhaled hyperpolarized gas MRI using 129Xe or 3He with semi-automated segmentation has been confirmed as a consistent method to quantify ventilation defect percentage in patients with chronic obstructive pulmonary disease (COPD, Figure 1A), asthma (Figure 1B), and cystic fibrosis (Kirby et al., 2012). 129Xe VDP was calculated using a MATLAB-based semi-automated segmentation software. It has been shown to be reproducible between independent observers using both single-site and intersite scans (Svenningsen et al., 2020). Previous studies have also investigated the congruency in VDP calculation between low-resolution and high-resolution 129Xe MRI scans, using MIM Software and in-house semi-automated MATLAB scripts (McAllister et al., 2020). High-resolution MRI scans utilize a significantly smaller voxel size to increase spatial resolution, theoretically allowing for increased accuracy when determining VDP by being less prone to partial volume effects. McAllister et al. found that low-resolution scans consistently underestimate VDP, with the size of the underestimation being dependent on the signal intensity threshold used.

The objective of this project was to determine whether the MATLAB-based semi-automated segmentation developed independently by Kirby et al. would show consistency in VDP calculation between low-resolution and high-resolution scans of the same patient.

Method

Traditional or low-resolution (voxel size=3x3x15mm3) static-ventilation 129Xe MRI scans of the COVID-19 Survivors (Figure 1C) were obtained from the Advanced Pulmonary Imaging Laboratory (London, ON). Low-res scans were converted into high-res scans (isotropic voxel=3x3x3mm3) using the homebuilt reconstruction software. Semi-automated segmentation using a MATLAB-based script produced by Kirby et al. was used to perform VDP calculation on both low-res and high-res files. 129Xe images were segmented using a hierarchical version of K-means clustering (where cluster 1 = areas of ventilation defect or background and clusters 2-5 = different gradations of signal intensity), and the corresponding 3He images were segmented using a seeded-region growing algorithm. Each 129Xe slice was then registered to its corresponding 3He slice via manual landmark-based registration (Figure 2a, b) to generate voxel cluster maps (Figure 2c) and for the script to calculate VDP. VDP calculation was performed consistently (i.e. by using only one observer to perform all calculations).

Results

In general, high-res images are more consistent between patients. This is likely due to the overestimation of the low-res-based VDP values for the patients with a small volume of the unventilated lung regions. Future studies on the consistency of VDP calculation between low-res and high-res scans should include larger sample sizes in order to confirm our findings. Overall, there appears to be some evidence from this study that using high-resolution scans avoids overestimation of VDP, when taking into account the segmentation technique of the observer.

Discussion and Conclusion

Semi-automated segmentation of high-resolution 129Xe images generated lower global mean VDP values than segmentation of corresponding low-resolution images, with the degree of difference varying from 4.0% to 18.0% in the 3 patients observed. This is in contrast to the findings of McAllister et al., who saw an increase in VDP for high-resolution scans, due to partial volume effects (PVEs). Partial volume effects occur when more than one tissue type is present in a single voxel, causing the signal intensity to be a combination of strengths depending on the proportions of tissue types present. MRI analysis theoretically requires each voxel to contain a single tissue type, generating a signal characteristic of that tissue type, so PVEs introduce significant error margins in quantitative measurement (Ballester et al.). This is especially relevant in MRI as the voxel size is often significant relative to the structure(s) or area being measured. PVEs also contribute to blurring of boundaries, making it difficult to define borders of anatomical structures. In high-res image analysis, voxel size is 5x less, minimizing the chance for a single voxel to contain multiple tissue types. However, the effect of PVEs on VDP calculation depends on the subjective interpretation of the observer on whether or not to include PVE-affected voxels in the volumes used to calculate VDP; this may explain the contrasting results determined by this study and McAllister et al. In general, high-res images should theoretically improve accuracy of VDP calculations, as long as the segmentation is performed consistently (i.e. by using only one observer to perform all calculations).

In summary, the difference between VDP calculations for low-res vs high-res images was not very consistent between patients. This is likely due to the overestimation of the low-res-based VDP values for patients with a small volume of the unventilated lung regions. Future studies on the consistency of VDP calculation between low-res and high-res scans should include larger sample sizes in order to confirm our findings. Overall, there appears to be some evidence from this study that using high-resolution scans avoids overestimation of VDP, when taking into account the segmentation technique of the observer.

Literature Cited


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