Comparing semiautomated segmentation of traditional-resolution and high-resolution hyperpolarized ^{129}Xe MRI on COVID-19 survivors

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Introduction

Inhaled hyperpolarized gas MRI using ^{129}Xe or ^{3}He with semiautomated segmentation has been confirmed as a consistent method to quantify ventilation defect percentage (VDP) in patients with chronic obstructive pulmonary disease (COPD, Figure 1A), asthma (Figure 1B), and cystic fibrosis (Kirby et al., 2012). ^{129}Xe VDP calculated using a MATLAB-based semiautomated segmentation software 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 ^{129}Xe MRI scans, using MIM Software and in-house semiautomated 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 semiautomated 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=3x3x15mm^3) static-ventilation ^{129}Xe 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=3x3x3mm^3) using the homebuilt reconstruction software. Semiautomated 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. ^{129}Xe 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 ^{1}H (anatomical) images were segmented using a seeded-region growing algorithm. Each ^{129}Xe slice was then registered to its corresponding ^{1}H slice via manual landmark-based registration (Figure 2a, b) to generate voxel cluster maps (Figure 2c) and for the script to calculate ^{1}H volume, ^{129}Xe volume, and the volume of defects. Slice-by-slice VDP was calculated using the formula VDP = [(ventilation defect volume)/(proton volume)]*100%. Bulk VDP was calculated for each patient's low-res and high-res images by summation of the slice-by slice VDPs (Table 1). Difference between global mean VDP for corresponding low-resolution and high-resolution images was calculated, as well as percent difference.
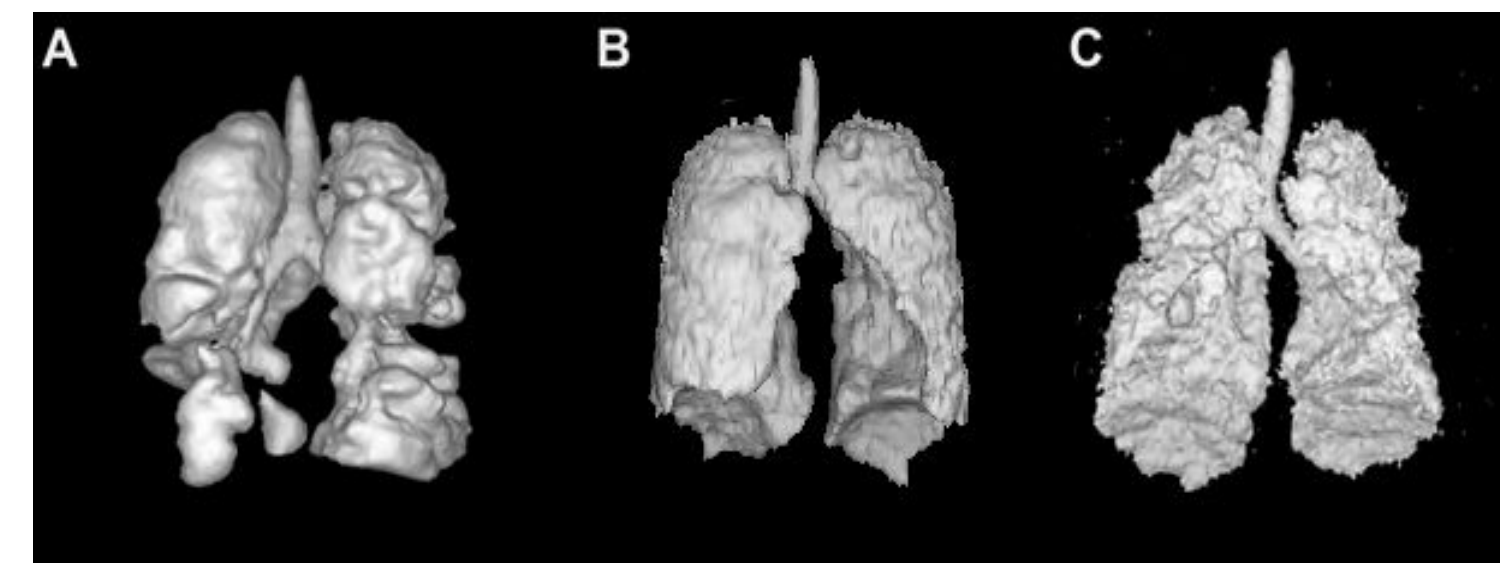
Results

Figure 1. Representative 3D High-Resolution Isotropic-Voxel Static Ventilation ^{129}Xe MRI Images. **(A)** A 67-year-old ex-smoker with emphysema. This functional lung image clearly shows unventilated lung regions. **(B)** A 66 year old mild asthma patient. **(C)** A 35 year old COVID-19 Survivor. Image showing significant lung damage caused by COVID-19.
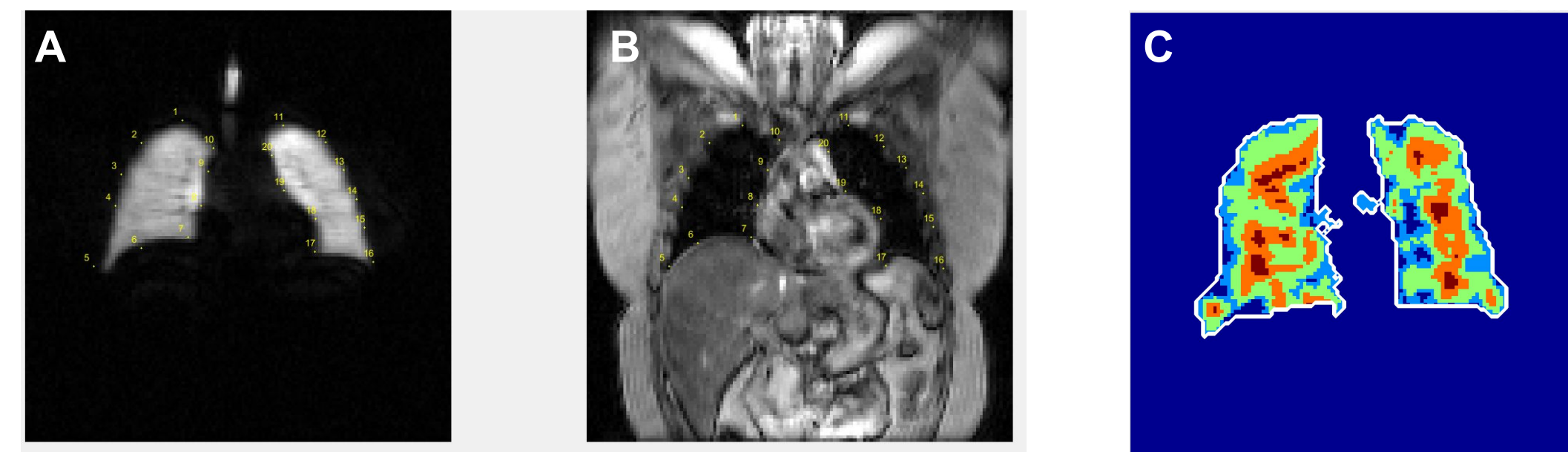

Figure 2. (A and B) Landmark-based affine registration approach of central ^{129}Xe and ^{1}H scans. Markers selected on the lung periphery as well as the primary bronchi, trachea, and/or carina if applicable. Markers placed in same order on ^{129}Xe and ^{1}H scans. Geometric operations (rotation, translation, scaling) performed by MATLAB script to align corresponding landmarks. **(C)** Voxel cluster map from a low-resolution slice after semiautomated segmentation and manual landmark-based registration. Gradation of signal intensity represented by cluster color; cluster 1 (blue) = no signal/background, cluster 5 (maroon) = hyperintense.

Table 1. Global mean VDP calculations for 3 patients using low-resolution and converted high-resolution scans and semiautomated segmentation scripts. VDP calculated as [(volume of ^{129}Xe scan after trachea/noise removal)/(volume of corresponding ^{1}H scan)] x 100, then summed to find bulk VDP and divided by number of slices used to find global mean VDP values.

	Global mean VDP (low-res)	Global mean VDP (high-res)
ROB005-002	31.525	30.216
ROB005-003	13.574	12.182
ROB005-004	13.630	11.065

Semiautomated segmentation of the converted high-res images produced lower VDP calculation values than for the low-resolution images, with a mean difference of 1.755, and mean percent difference of 11.94%.

Discussion and Conclusion

Semiautomated segmentation of high-resolution ^{129}Xe 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 anomalies 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 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.

Literature Cited

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