CT Quantification of Morphological Changes in Pulmonary Vasculature in Pulmonary Arterial Hypertension

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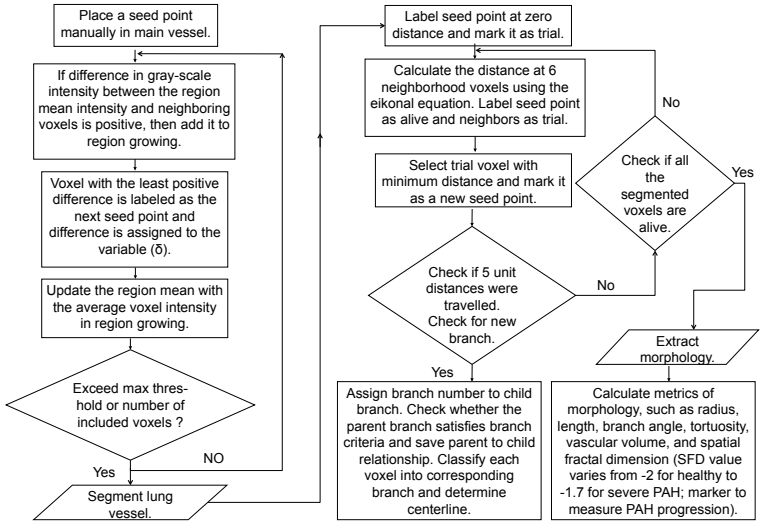
I. Introduction

Pulmonary arterial hypertension (PAH) occurs in idiopathic form and is associated with diseases, such as congenital heart malformation, scleroderma, HIV, and cirrhosis. Severe PAH is rare but has a dismal prognosis: even contemporary therapy provides only a 75% 3-year survival. In PAH, small and medium arterioles are progressively occluded by vascular and inflammatory cells. Although better and more convenient therapies are needed, such therapeutic advances will require a more thorough understanding of vascular remodeling, right ventricular (RV) compensation, and RV failure. The extraction of quantitative morphological features of pulmonary vasculature is important for the diagnosis of the extent or progression of PAH and is critical for the assessment of the efficacy of emerging drugs and interventions intended to improve outcomes in animal models and patients. The purpose of this work is to develop automated extraction of pulmonary vascular tree features from 3D-CT images and identify and quantify key biomarkers of disease progression in a rat model.

II. Methods

We used a seeded region growing method [1,2] to segment the pulmonary vasculature and a fast marching algorithm [3] to extract the morphology of the pulmonary arterial vasculature. A sequence of operations and parameters were empirically derived or created to accomplish the objectives.



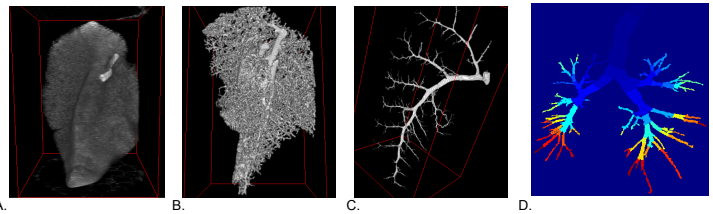


Figure 1. Images A,B, and C show the 3D rendering of rat pulmonary vasculature; image D shows extracted morphology in a 2D phantom. Image A shows a representative 3D volume of the healthy rat hemi-lung before segmentation. Image B shows a representative 3D volume of the hemi-lung after segmentation. Image C shows the 3D volume of the diseased hemi-lung. Image D shows the output of our algorithm applied to a 2D phantom, where each branch is given a unique color.

III. Results

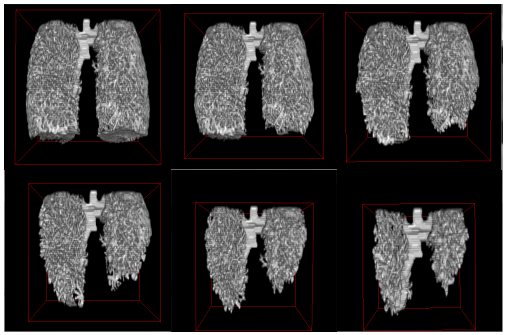


Figure 2. Rendering in 3D of the intermediate steps at every 200k voxels in the morphological extraction of an anthropomorphic phantom dataset [4]. The algorithm is stopped intermittently to mimic the progression of pulmonary vessel occlusion and the loss of vascular volume that is expected going from severe PAH to a normal lung.

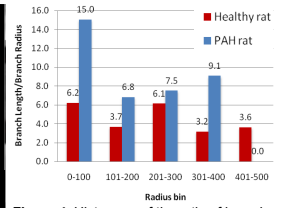


Figure 4. Histogram of the ratio of branch length over branch radius. Each bar in the graph represents the mean of the ratio of each branch in the bin size of 100 um radius, and the X axis represents bins of different radii. The ratio of branch length over branch radius is higher for the PAH rat because of the pruning of smaller branches, which causes an increase in the mean length of the branch. In PAH rats, the radii of the branches decreases, and the bar shifts to left; thus, there are no branches in the 401-500 um bin.

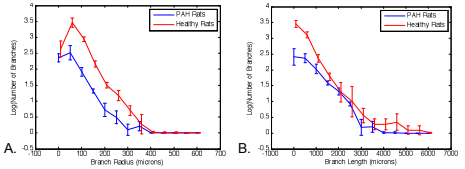


Figure 3. Each point represents the mean number of branches in bin size across 4 normal (red curve) and 3 PAH rats (blue curve). In figure A, the smaller and medium-sized vessels ranging from 50-100 um are pruned in large number in PAH rats, as compared to 150-250 um vessels. Figure B shows that a larger number of vessels ranging from 100-1000 um length are affected in PAH.

Voxels processed	No. of Branches	SFD Value	No. of Generations
200k	334	-1.5800	11
400k	10002	-1.6839	14
600k	1879	-1.7439	14
800k	2654	-1.7861	16
1000k	3695	-1.8222	16
1150k	4244	-1.8413	18

Table 1. Comparison of different metrics of vessel morphology to distinguish changes in vascular tree size when using different maximal voxel counts in the reconstruction of the vessels from the CT anthropomorphic phantom dataset.

IV. Conclusions/Future work

- Developed and implemented a semi-automated algorithm for extraction of lung vessel morphology and quantification of morphological changes in a PAH rat model using metrics of morphology. The algorithm was developed and tested initially on virtual phantoms and subsequently on X-ray CT scans of an anthropomorphic lung phantom.
- The aim of this work is to minimize human intervention and effort and to better quantify pulmonary vascular morphological changes.
- Future work will include application to patients and animal models at varying stage of disease progression and comparison of disease progression and treatment response in males and females.

V. References

1 R. Adams and L. Bischof, "Seeded region growing," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 16, no. 6, pp. 641–647, Jun. 1994.
2 Govindarajan ST, Chandrasekharan S, O'Dell WG, "Automatic Segmentation of Blood Vessel in the presence of Fibrosis in Volumetric Lung CT Images" BMES Scientific Meeting and Exhibition, Hartford Conn, October 2011
3 J. A. Sethian, "Fast Marching Methods," *SIAM Review*, vol. 41, no. 2, pp. 199–235, Jun. 1999.
4 National Biomedical Imaging Archive: database of thoracic CT scans of an anthropomorphic phantom.

VI. Acknowledgements

This work was funded through the University of Florida Shands Cancer Center.