Fractal Analysis of Pulmonary Perfusion Deficits in Arterial Spin Labeled MR Techniques

N. Gumpeni[1], D. L. Levin[2], H. Sasaki[3], Q. Chen[4], R. R. Edelman[1,5], P. V. Prasad[1,5], V. M. Mai[1,5]

[1]Feinberg School of Medicine, Northwestern University, Chicago, IL, United States, [2]Department of Radiology, UCSD School of Medicine, San Diego, CA, United States, [3]Department of Grassland Ecology, National Institute of Livestock and Grassland Science, Nishinasuno, Tochigi, Japan, [4]Department of Radiology, NYU School of Medicine, New York, NY, United States, [5]Department of Radiology, Evanston Northwestern Healthcare, Evanston, IL, United States

Introduction

Arterial spin labeling techniques such as FAIR and FAIRER allow for high quality perfusion mapping of pulmonary parenchyma. The high level of detail down to the subsegmental level makes such techniques ideal in the evaluation of various types of lung pathology that may cause perfusion deficits [5]. However, the cause of a given perfusion deficit is not readily apparent from this MR study technique, requiring a knowledgeable and experienced radiologist for diagnoses. Thus, an objective method of analyzing arterial spin labeling perfusion studies could be a useful adjunct in the diagnostic process. Fractal analysis is a mathematical measure of the physical complexity of an object. The self-similarity of pulmonary vasculature allows differences in perfusion to be detected by measurement of the fractal dimension (FD), with less perfused areas showing less self-similarity and thus lower FD values. Our purpose in this study is to examine the applicability of fractal dimension analysis in differentiating normal (high FD) versus abnormal (low FD) perfusion in lung parenchyma.

Methods

Images for this study were compiled from a database of FAIR or FAIRER studies. This included 21 control images from 21 subjects with no known history of pulmonary disease and 16 images from 9 patients with known pulmonary disease (5 pulmonary embolism, 2 emphysema, 2 neoplasms). Multislice images were counted as separate cases for analysis. Fractal analysis was performed on binary and grayscale images by box-counting method to determine the 2D or 3D fractal dimension (FD2 and FD3), respectively (Fig 1), using Fractal Analysis System freeware (v. 3.40) (Hiroyuki Sasaki, Tochigi, Japan). Control images were analyzed on the basis of a global FD, encompassing one entire lung, or via the mean FD taken from three smaller ROIs in a single image. Patients' images were analyzed via the FD from a single ROI taken from the area of hypodensity (Fig 2) and compared to the mean FD of three ROIs taken from contralateral, presumably normal, lung tissue. All ROIs at the sub-global level were chosen to exclude large vessels. Student's t-test was used to evaluate the difference in means.

Results

The ROI-based FD2 and FD3 of perfusion deficits in patients' images were 1.585 ± 0.141 and 2.115 ± 0.222, respectively. FD2 and FD3 values for control images were 1.868 ± 0.037 and 2.228 ± 0.115, and for the normally perfused lung contralateral to the perfusion deficit, 1.850 ± 0.034 and 2.221 ± 0.130. Combination of contralateral normal lungs and control lungs yields FD2 and FD3 values of 1.863 ± 0.037 and 2.222 ± 0.147. FD2 values of perfusion deficits were significantly smaller than the FD2 values of control lung tissue and contralateral lung tissue with normal perfusion ($p<0.001$). FD3 values (from grayscale images) were not significantly different among the four groupings ($p>0.15$). Global FD values for patient lungs were less than those for control and contralateral lungs, but not significantly so ($p>0.2$).

Discussion

ROI based fractal analysis of FAIR/FAIRER perfusion images of lung pathology shows that perfusion deficits contain less self-similarity than normally perfused lung tissue. Inclusion of larger blood vessels or bronchioles makes global FD less sensitive to changes in perfusion. Subtle changes in the FD value may be able to distinguish the cause of a perfusion deficit, with neoplasms exhibiting a different extent of perfusion loss as compared to emphysema or embolus, for example. With further work, such analysis could provide a useful adjunct in the interpretation of perfusion changes observed in arterial spin labeled MRI studies.

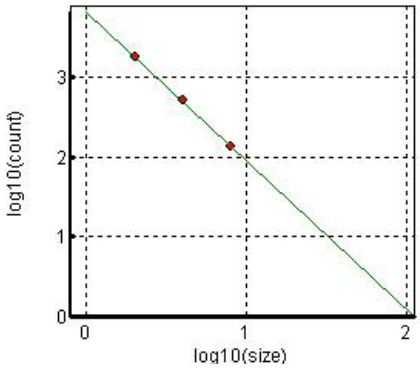

Figure 1. Box counting method. Double logarithm of box size (d) vs the number of boxes. The slope of the curve is FD.

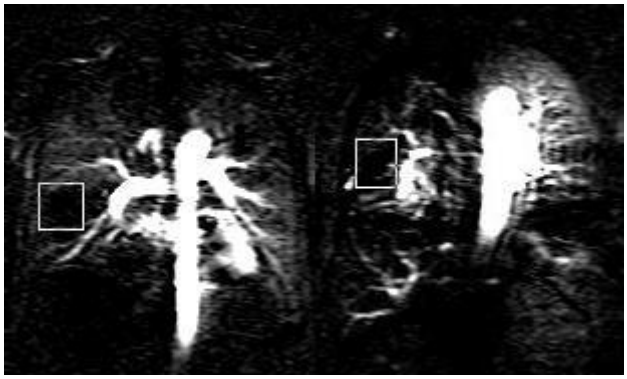

Figure 2. FAIRER images showing examples of ROI of perfusion deficit due to neoplasm (left) and pulmonary embolus (right).

References

(1) Majumdar S et al J Bone Miner Res 1997; 12:111-8. **(2)** Caldwell CB et al Phys Med Biol 1990; 35:235-47. **(3)** Gan RZ et al Am J Phsyiol 1993; 75: 432-40. **(4)** Kido S et al JCAT 2003; 27:56-61. **(5)** Mai V et al JMRI 1999; 9:483-7.

This work is supported by a grant from the American Heart Association.