Improved Vessel Segmentation within Tumors using Implicit Active Contours Driven by Local Binary Fitting Energy

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INTRODUCTION

It is well known that once a tumor grows beyond a few cubic millimeters it can no longer rely on diffusion of metabolites to continue to grow and therefore must vascularize itself by a process known as angiogenesis (1). As all malignant tumors are believed to be angiogenesis dependent, the ability to map, in three dimensions, this phenomenon is of critical importance. In this contribution we apply our recently developed local binary fitting method of image segmentation (2) to the problem of separating angiogenic vessels amid a heterogeneous intensity background and show how it yields superior results than common methods of vessel segmentation which include simple intensity thresholding and the Chan-Vese model (3).

METHODS

Data Acquisition Female mice were injected subcutaneously with 10^6 LLC cells in the hind limb. Imaging was performed 8 days post-injection. Two days prior to imaging, jugular catheters were surgically implanted for easy delivery of the contrast medium. During the imaging session, the animals were anesthetized with a 2%/98% isoflourane/oxygen mixture, and body temperature was maintained by a warm air flow. The mice were imaged using a Varian 7.0 T scanner within a 25-mm litzcage coil. A bolus of 0.2 mmol/kg of Gd-DTPA-BSA will be injected 10 minutes prior to imaging. After scout images were acquired, the angiography measurements employed a 3D GRE sequence with the following parameters: TR/TE/α/nex=20ms/4.4ms/10^o/2, FOV = 35×28×28mm^3, matrix = 312×256×256, yielding a nearly isotropic (110 μm)^3 voxel size.

Data Analysis

We use the local binary fitting (LBF) (2) model for the vessel segmentation. The basic idea of the LBF model is to find an optimal contour/surface such that the intensities on the two sides of the contour/surface can be well approximated by two fitting values. The two fitting values are spatially varying due to the kernel function in the fitting error (energy). The kernel function restricts the fitting to a neighborhood. As a result, the optimal fitting values contain accurate local intensity information, which is crucial for the segmentation of images with intensity inhomogeneity. The LBF model is superior to the existing segmentation methods for images with intensity inhomogeneity, which causes considerable difficulties in applying existing image segmentation methods. It has also been shown (2) that the LBF model has desirable performance in segmenting vascular structures. These desirable features of LBF model makes it particularly suitable for vessel segmentation from the mouse MRA data.

RESULTS

Figure 1 presents representative results for a 2D cross-section of a section of tumor tissue. It is clear that the simple thresholding method misses sections of the tumor and the Chan-Vese model accepts large regions of the tumor as vasculature when they are clearly not. The LBF method appears to overcome these limitations. **Figure 2** presents 3D renderings of sections of the tumor vascular tree and the limitations of the two common methods become more apparent. In particular, the thresholding method misses significant portions of the vessel structure that appear with the other two methods and the Chan-Vese selects a large region of space which is not associated with vasculature. Again, the local binary fitting method seems to overcome these limitations.

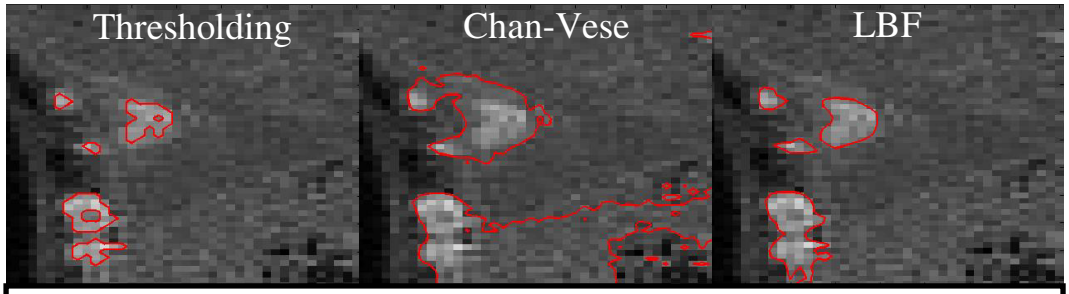

Figure 1. Comparison of the three methods in 2D cross-sections of the tumor. The local binary fitting model provides the most accurate segmentation of the blood vessels.

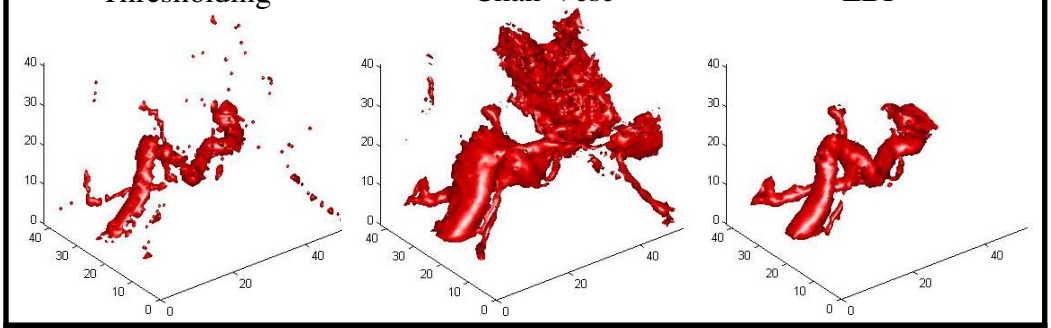

Figure 2. The errors and limitations of the thresholding and Chan-Vese algorithm become more evident in the 3D display of the vascular tree. The local binary fitting method appears to overcome these limitations.

DISCUSSION

The LBF algorithm is less sensitive to noise than thresholding and Chan-Vese model, provides more accurate segmentation and can be applied to images with substantial intensity inhomogeneities. This result has been seen in simulations and healthy human brain studies, but has not been applied to the tortuous neovasculature of a growing tumor. We therefore conclude that the proposed method represents an improvement of common existing techniques of vessel segmentation and should be useful to accurately visualize and quantify the vascular tree in 3D.

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