Development of A Computer Algorithm-Based Method for Identification of Blood Vessels on Dynamic Contrast Enhanced Breast MRI

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Purpose:

Breast MRI is a well-established clinical imaging modality for management of breast diseases. One major application in clinical practice is for lesion detection and diagnosis. The detection is based on contrast enhancement as well as the kinetics (the enhancement time course) for characterization of the lesion. Vessels often show strong contrast enhancement and the washout pattern in the enhancement kinetics, and may be mistakenly identified as suspicious lesions. If the vessels can be identified and excluded, this may reduce false positive results from the vessel contamination, and improve interpretation of other enhanced tissues. The procedure may be mostly useful in the development of automated CAD (computer-aided diagnosis) that searches through the entire breast to find enhanced hot spots. It may also be used to evaluate the changes of vessels for patients receiving neoadjuvant chemotherapy (pre-operative systemic therapy). In this work we proposed an algorithm based on the 2-D MIP (maximum intensity projection) to identify vessels based on connectivity of the vessel enhancements, then identifying the vessels along the perpendicular direction of the MIP based on the connectivity between adjacent imaging slices (that is, using the entire set of 3D images). The search results based on the algorithm were evaluated by comparing to the results outlined by the radiologist as the goldstandard.

Methods:

The study was conducted in 34 patients who received DCE-MRI for diagnosis of breast lesion, or for pre-treatment staging of biopsy-proven cancer. All MRI studies were performed on a 1.5T Philips Eclipse MR scanner. The algorithm consisted of 3 steps, as shown in Figure 1. Step-1) for 2-D detection, the major blood vessels are clearly shown on the maximum intensity projection (MIP, **Fig.1a**). Firstly, the global histogram equalization, a filter bank based on Wavelet Transform and Hessian Matrix [1], and highpass filtering were applied to enhance blood vessels while suppressing others (**Fig.1b**). Secondly, thresholding was applied to obtain the 2-D structure of blood vessels (**Fig.1c**). Thirdly, the lesion was identified on the 2-D MIP using the procedures that have been published previously [2]. The location of the lesion was first identified by placing a square box over the lesion, then a region growing algorithm was applied to obtain the lesion boundary, followed by morphological operations including dilation, erosion and hole-filling to mark the entire lesion (**Fig.1d**). Fourthly, the detected lesion was excluded and the result of vessel detection based on 2D MIP is shown in **Fig.1e**. Step-2) For the module of 3-D detection, it is needed to detect blood vessels that run perpendicular to the 2D MIP thus are difficult to recognize on the 2-D view. This is similar to viewing of angiography using a rotating 3D rendering display to differentiate the overlapping vessels. Firstly, we applied thresholding and morphological operations slice by slice to obtain the overall structure of blood vessels, resulting in **Fig.1f**. The threshold values applied in the 2-D and 3-D modules were determined empirically. Secondly, other components that were not from vessels (such as subtraction artifacts near the breast boundary that present as linear enhancements on subtraction image) were excluded based on 3-D connectivity (**Fig.1g**). Step-3) the results from the operation in 2-D and 3-D modules were combined by projecting the 2D results to the 3-D space, shown in **Fig.1h**. The radiologist was asked to draw vessels on a specially designed program by following the vascular track. The results were used as the goldstandard for evaluation.
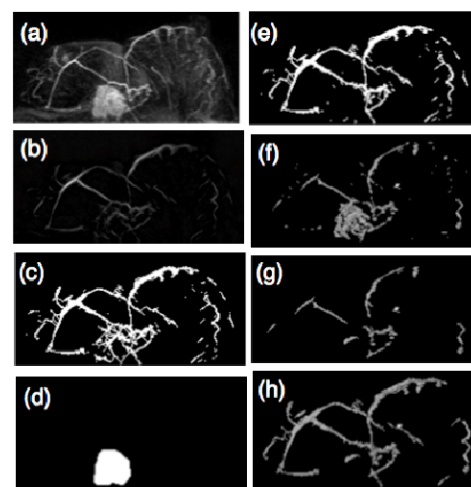

Fig.1. The process of vessel detection (a) original 2-D MIP showing vasculature and the tumor, (b) filtering, (c) 2-D thresholding, (d) tumor detection, (e) result of 2-D detection, (f) 3-D thresholding, (g) result of 3-D detection, (h) final result.

Results:

In order to quantitatively evaluate the detection of vessels based on our algorithm, a thinning process was applied to change the identified vessels to a vasculature skeleton, so the results can be compared to the vascular track marked by the radiologist. The skeleton of **Fig.1h** is shown in **Fig.2a**. For any vascular pixel determined by the radiologist, if a vascular pixel in the skeleton determined by the computer algorithm is within 3-pixel difference, we consider this vessel pixel to be correctly detected. Since the thinning skeleton and the radiologist's drawing may be within the same vessel but at a slightly different pixel location, this criterion will allow the vessel to be considered correctly identified. The vascular pixels that are identified by the algorithm but not marked by the radiologist are considered as incorrect-detection. The pixels drawn by radiologists but not detected by the algorithm are considered as missed-detection. Fig.2b presents the evaluation results for the thinning vascular skeleton shown in Fig.2a. Correct-detection, incorrect-detection and missed-detection are marked in red, yellow and green respectively. The overall performance was evaluated using the 34 cases. In every case, the correct-, incorrect-, and missed-detection rates were obtained, and averaged to give the mean value. Table 1 lists the mean and the range in 34 test cases. Ten cases have correct-detection rate > 90%, 15 cases between 80% and 90%, and 9 cases < 80%. For incorrect-detection rates, 11 cases are < 10%, 15 cases between 10% and 20%, 7 cases between 20% and 30%, and 1 case is > 30%. For missed-detection rates, 6 cases are < 10%, 11 cases between 10% and 20%, 8 cases between 20% and 30%, and 9 cases are > 30%. The missed detection rate was mainly from very faint vascular pixels that were identified by the radiologist, but difficult to be detected by the algorithm due to lack of clear contrast.
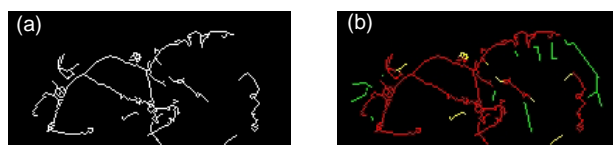

Fig.2. (a) The skeleton of the detected blood vessels, (b) quantitative evaluation results: red-correct, yellow-incorrect, green-missed.

Table 1. Quantitative Evaluation Results Compared to Goldstandard.

	Mean	Range
Correct-Detection Rate	84.9%	68.3% ~ 100%
Incorrect-Detection Rate	15.1%	0 ~ 31.7%
Missed-Detection Rate	21.3%	1.5% ~ 51.1%

Discussion:

We have presented a method using computer algorithm to identify blood vessels. Despite that the quality of vessels shown on DCE-MRI used for breast imaging is not comparable to the typical quality of MR angiography, special algorithms can be applied to identify vessels. It was found that 25 of 34 cases have the correct-detection rate higher than 80%, suggesting that most of blood vessels can be recognized by the proposed method. The main difficulty leading to incorrect and missed detection includes: a) low spatial resolution of breast MRI, b) motion artifacts and noise, c) low enhancement of small blood vessels. For lesions that present as non-mass type enhancements, the lesion could not be detected and excluded, and that added further difficulty in differentiating between lesion enhancement and vessel enhancement. The algorithm can be improved by implementing an adaptive algorithm for threshold selection, and detecting blood vessels based on their 3-D morphological features and topological properties such as the geometric flows of blood vessels. The application of this vessel identification method on the development of CAD for automated search of lesion by excluding vessel contamination is reported in another abstract.

References: [1] Nakayama et al. IEEE Trans. Biomed. Eng. 2006; 53:273-283. [2] Nie et al. ISMRM proceedings, 2008; Program #3752.