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Vascular morphologic information of three-dimensional power Doppler ultrasound is valuable in the classification of breast lesions

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Abstract

Doppler ultrasound imaging provides vascular information that could characterize benign and malignant breast masses in many previous publications. In this study, we applied vascular quantification and morphology features derived from three-dimensional power Doppler ultrasound as classifiers based on support vector machine. An Az value under the receiver operating characteristic (ROC) curve was used to measure the significance of each vascularization feature. Sixty solid breast tumors were assessed. According to the Az value for the ROC curve of the selected features, the classification performance of the proposed method was 0.8423, indicating that vascular morphologic information is valuable in the classification of breast lesions.

Keywords: Angiogenesis; Three-dimensional power Doppler; Vascularization; Breast tumor; Morphological feature

1. Introduction

Breast cancer is the most common female cancer in the Western countries [1]. In Taiwan, breast cancer is also the first leading cause of female cancer and is the fourth leading cause of cancer death. Early diagnosis and treatment are the most effective ways of reducing mortality from breast cancer [1,2]. Mammography is an evidence-based screening modality for the early detection of breast cancer that can reduce mortality [3–5]. Breast ultrasound examination is relatively simple, convenient, and noninvasive and also is an important tool as an adjunct to mammography in the diagnosis of breast cancer. With the advances in ultrasound techniques, more and more vascular information can be analyzed from an ultrasound examination, which is more convenient and safer than other instruments. In recent years, the use of ultrasound images to diagnose breast tumors has become more widespread and popular. The use of ultrasonic images to analyze the homogeneity of an internal echo can assist in differentiating between benign and malignant lesions. Furthermore, many studies have investigated the vascularity of breast lesion by using color or Doppler imaging and demonstrated that color and power Doppler imaging is helpful in characterizing breast malignancy and useful in differentiating between malignant and benign breast lesions [6,7].

Three-dimensional (3D) power Doppler ultrasound images are one of the most commonly used ultrasound images to diagnose diseases. Hsiao et al. [8] assessed the vascularization of tumor through 3D power Doppler ultrasound and proposed a decision model for the classification of benign and malignant breast tumors.

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Chen et al. [9] proposed a computer-aided diagnosis (CAD) algorithm, which is effective and reliable in distinguishing between benign and malignant lesions/tumors. Then, there is a new CAD system based on a 3D thinning algorithm and neural network for quantifying 3D power Doppler ultrasound images [10]. Thus, the application of vascular morphology in ultrasound images to characterize benign and malignant breast masses has become an important issue in recent years.

Angiogenesis is a physiological process involving the growth of new blood vessels from preexisting vessels. Angiogenesis has been confirmed to be related to tumor growth and invasion [11,12]. Metastasis of tumors also has a close relationship with angiogenesis. High-resolution ultrasound with color/power Doppler setting can provide information of a breast tumor. However, the vascularization of tumor is usually irregular and complex; solely vascular signal information is not enough to obtain a good diagnostic performance. Vascular structure may include vascular length, curvature, branches, and divisions. These structures may have clues in the classification of solid breast tumors; these signals should be analyzed using a scientific method [13].

3D power Doppler ultrasound images provide directional information to observe blood flow and feature extractions from the vascularization of the tumor. This study developed a CAD for power Doppler imaging to assist physicians in diagnosis of breast tumors. The proposed CAD classified breast tumors as benign or malignant using a support vector machine (SVM). Vascular features, extracted from 3D power Doppler ultrasound imaging, were considered for the differentiation of benign and malignant breast tumors. Furthermore, the SVM model was employed as a classifier to assess the capabilities of 3D power Doppler ultrasonographic technology in the differential diagnosis of solid breast tumors.

2. Materials and methods

2.1. Data acquisition

Sixty pathologically proved breast tumors were included in this study. Data were collected from January to June 2007; there were 30 benign and 30 malignant breast tumors. All patients signed inform consent, and this study was approved by the institutional review board of our hospital. In this study, sonographic examinations were done using 3D power Doppler ultrasound with the high-definition flow (HDF) function (Voluson 730, GE Medical Systems, Zipf, Austria). A linear-array broadband probe with a frequency of 6–12 MHz, a scan width of 37.5 mm, and a sweep angle of 5° to 29° was used to obtain 3D volume scanning. The physician kept a fixed sweep angle of 20° and power Doppler settings of midfrequency, 0.9-kHz pulse repetition frequency, −0.6 gain, and a ‘low 1’ wall motion filter in all cases. All obtained images were stored on the hard disk and transferred to a personal computer using a Digital Imaging and Communication in Medicine connection for image analysis. Each 3D power Doppler image contained 155 to 199 2D images, and the width and the high of each image were 199 and 140 to 200 pixels, respectively.

2.2. Vascular centerline extraction

The 3D power Doppler ultrasound images include a considerable amount of noise and speckles that make vascular centerline extraction difficult. Thus, preprocessing is a significant issue before extraction. An effective preprocessing method should aim to reduce noise and preserve the useful vascular information. This study used a 3D Gaussian low-pass filter to smooth images. The Gaussian filter is a weighted average filter that is based on the Gaussian function for calculating the weighted from the voxels in the mask. After preprocessing, an automatic extracting method was used to locate the centerline of each vessel.

A parallel 3D 12-subiteration morphological thinning operator [14] was utilized to conserve the time required to sketch the vascular centerlines. It produces either curve skeletons or surface skeletons from 3D binary objects in (26, 6)-connectivity by repetitive iterations until no more points need to be removed. Then the vascular centerlines are identified as the extracted skeletons after removing the multiple voxel-wide skeletons. Moreover, the color of the voxel from the 3D power Doppler ultrasound imaging with the HDF function indicates the direction information of blood flow which would annotate to each point in the vascular centerline. Fig. 1 shows the process of vascular centerline extraction in 3D power Doppler ultrasound imaging.

2.3. Feature extraction

To quantify the vascularization of tumor, two fundamental indices—the vascularization index (VI) and the flow index (FI)—were evaluated from 3D power Doppler ultrasound. The VI index, representing the vessel in the tissue, is the ratio of the number of color voxels and the number of total voxels in the volume. The FI index, representing the average intensity of flow, is the mean intensity of color voxels. Moreover, 11 vascular morphological features were also estimated:

1. Number of vascular centerlines (denoted as NT).
2. Sum of the length of vascular centerlines (denoted as LV).
3. Number of branching points of the vascular centerlines (denoted as NB).
4. Ratio of the number of branching points to the number of points on the vascular centerlines (denoted as RB).