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Quantitative breast lesion classification based on multichannel distributions in shear-wave imaging

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ABSTRACT

Background and objectives: A computer-aided diagnosis (CAD) system based on the quantified color distributions in shear-wave elastography (SWE) was developed to evaluate the malignancies of breast tumors.
Methods: For 57 benign and 31 malignant tumors, 18 SWE features were extracted from regions of interest (ROI), including the tumor and peritumoral areas. In the ROI, a histogram in each color channel was described using moments such as the mean, variance, skewness, and kurtosis. Moreover, three color channels were combined as a vector to evaluate tissue elasticity. The SWE features were then combined in a logistic regression classifier for breast tumor classification.
Results: The performance of the CAD system achieved an accuracy of 81%. Combining the CAD system with a BI-RADS assessment obtained an Az improvement from 0.77 to 0.89 (p-value <0.05).
Conclusions: The combination of the proposed CAD system based on SWE features and the BI-RADS assessment would provide a promising diagnostic suggestion.

1. Introduction

Breast lesion characteristics identified with B-mode ultrasound (US) are interpreted to distinguish between benign and malignant lesions in a clinical examination [1]. The description criteria and categories are defined in the Breast Imaging Reporting and Data System (BI-RADS) lexicon, which was developed by the American College of Radiology [2]. These descriptors, which are quantified in various computer-aided diagnosis (CAD) systems [3–10] to evaluate tumor malignancy, can be classified as morphology and texture characteristics.

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Recently, elasticity assessment was added as an associated feature of breast US in the fifth edition of BI-RADS [2]. Breast cancers such as scirrhous carcinoma and invasive cancers tend to be stiffer than many benign tumors [11,12]. On clinical examination, elastography as an imaging modality provides additional elasticity information by a cine loop or a single image [13,14]. Tissue elasticity information can be estimated based on the tissue displacements under a manual or automatic force [15]. According to the elasticity modulus, tissue elasticity is mapped to pixel values in the color elastographic images for display.

Shear-wave elastography (SWE) is an emerging technique that automatically emits the radiation force to estimate elasticity with less operator dependence than conventional elastography, which is based on manual compression [15]. Additionally, an observer can evaluate tissue stiffness via only one SWE image rather than a complete image cine loop as in conventional elastography. The SWE image provides tissue elasticity as the velocity of shear waves propagating in tissue and displays the corresponding kilopascals (kPas) on a color map. Using the elasticity information in the map, radiologists can re-evaluate the malignancies of tumors to reduce unnecessary biopsies [16–18]. However, the qualitative assessment of SWE images through visual observation is user dependent. To provide an objective evaluation, a quantitative analysis for interpreting elastography images would be helpful. Additionally, manually calculating the kPa value of each pixel is time consuming because the number of pixels in a region of interest (ROI) is usually greater than ten thousand (ex: 100×100). In this study, an automated method was proposed to analyze the color patterns in SWE images using individual colors or a combination of color channels. The quantified elasticity information was then used in a CAD system for breast tumor classification. Finally, the performance of a combined CAD system and BI-RADS assessment was evaluated. Using the quantified elasticity features, tumor malignancy could be better evaluated in a more efficient way for clinical use.

2. Materials and methods

2.1. Patients and data acquisition

Our institution review board approved this study, and informed consent was obtained from all patients. From November 2012 to December 2013, 81 patients had undergone elastography examinations. Three of them had two tumors, and two had three tumors. By core needle biopsy or fine-needle aspiration cytology, the 88 biopsy-proven cases were classified into 57 benign and 31 malignant tumors. Patients with benign tumors ranged in age from 26 to 77 years (mean = 50 ± 11). The pathology types were 25 fibrocystic changes, 22 fibroadenomas, and 10 papillomas. The measured sizes were 1.42 ± 1.20 cm. For malignant tumors, patients ranged in age from 30 to 76 years (mean = 54 ± 13). They exhibited 27 invasive ductal carcinomas (IDC), 1 invasive lobular carcinoma (ILC), and 3 ductal carcinoma in situ (DCIS), with measured sizes of 1.51 ± 0.76 cm. Radiologists who were blinded to the pathology report classified the tumors into BI-RADS assessment categories by B-mode findings. There were 2 (2%) tumors in BI-RADS 2 (benign), 17 (19%) in BI-RADS 3 (probably benign), 52 (59%) in BI-RADS 4 (suspicious abnormality), and 17 (19%) in BI-RADS 5 (highly suggestive of malignancy).

Both B-mode and elastography images were acquired using the Aixplorer ultrasound system (SuperSonic Image, Les Jardins de la Duranne, Aix en Provence, France) with a 5–14 MHz linear broadband transducer (SL15-4). During acquisition, the B-mode image was displayed first to show the anatomical information surrounding the target tumor. A ROI was centered on the target tumor and included tissues around the peritumoral areas to generate an SWE image. The elasticity information is described using Young's modulus, defined as $E = \sigma/\varepsilon$ where ε is the deformation of the tissue under the applied compression σ. For all cases, the default maximum kPa was 180 (7.7 m/s) in the color display, which is mapped from the value of the elasticity modulus.

2.2. SWE features

The acquired SWE images were color maps that conveyed elasticity information about the tissues. In this study, we proposed extracting a series of quantitative SWE features from the color maps to evaluate tumor elasticity automatically. SWE features included histogram distributions in individual and multiple color channels of the color map. Spatial correlation was also considered to generate more accurate elasticity features.

2.2.1. Single-channel features

Fig. 1(a) and (b) show shear-wave elastographic images for benign and malignant breast tumors. The elasticities of various tissues are shown in different colors. Tissues inside or around the benign tumor in Fig. 1(a) are soft and are shown in colors in the blue range. By separating the colors in the image into red (R), green (G), and blue (B) channels, the value distributions of different channels are distinct. As shown in the histograms in Fig. 1(a), the R and G histograms are left-biased, and the B histogram is center-weighted. In contrast, tissues around the malignant tumor in Fig. 1(b) are shown in various colors, with more well-distributed histograms in the R, G, and B channels. Consequently, we can compare the differences between histograms to reveal the color composition, which is the key characteristic to distinguish between benign and malignant tumors in elastography.

By regarding the color distribution in an SWE image as a probability distribution, the color image histogram can be characterized by its moments [19]. Moments [20,21] are specific quantitative measures of the shape. In the experiment, the 24-bit depth color was decomposed into 8-bit R, G, and B channels. The first-, second-, third-, and fourth-order central moments of the histograms in each channel were calculated to indicate the histogram shape (i.e., mean, variance, skewness, and kurtosis).

$$\text{Mean}_c = \frac{1}{N}\sum_{i=1}^{N} P_{ci} \tag{1}$$

$$\text{Variance}_c = \frac{1}{N}\sum_{i=1}^{N} (P_{ci} - \text{Mean}_c)^2 \tag{2}$$

$$\text{Skewness}_c = \frac{1}{N}\sum_{i=1}^{N} (P_{ci} - \text{Mean}_c)^3 \tag{3}$$