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Original Contribution

COMPUTER-AIDED DIAGNOSIS BASED ON QUANTITATIVE ELASTOGRAPHIC FEATURES WITH SUPERSONIC SHEAR WAVE IMAGING

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Abstract—Supersonic shear wave imaging (SSI) has recently been explored as a technique to evaluate tissue elasticity modulus and has become a valuable tool for tumor characterization. The purpose of this study was to develop a novel computer-aided diagnosis (CAD) system that can acquire quantitative elastographic information from color SSI elastography images automatically and objectively for the purpose of classifying benign and malignant breast tumors. Conventional ultrasonography (US) and SSI elastography images of 125 breast tumors (81 benign, 44 malignant), in 93 consecutive patients (mean age: 40 y, age range: 16–75 y), were obtained. After reconstruction of tissue elasticity data and automatic segmentation of each breast tumor, 10 quantitative elastographic features of the tumor and peri-tumoral areas, respectively (elasticity modulus mean, maximum and standard deviation, hardness degree and elasticity ratio), were computed and evaluated. A support vector machine (SVM) classifier was used for optimum classification *via* combination of these features. The B-mode Breast Imaging Reporting and Data System (BI-RADS) was used to compare gray-scale US and SSI elastography with respect to diagnostic performance. Histopathologic examination was used as the reference standard. Student's *t*-test, the Mann-Whitney *U*-test, the point biserial correlation coefficient and receiver operating characteristic curve analysis were performed for statistical analysis. As a result, the accuracy, sensitivity, specificity, positive predictive value and negative predictive value of benign/malignant classification were 95.2% (119/125), 90.9% (40/44), 97.5% (79/81), 95.2% (40/42) and 95.2% (79/83) for the CAD scheme, respectively, and 79.2% (99/125), 90.9% (40/44), 72.8% (59/81), 64.5% (40/62) and 93.7% (59/63) for BI-RADS assessment, respectively. The area under the receiver operating characteristic curve (A_z value) for the proposed CAD system using the combination of elastographic features was significantly higher than the A_z value for visual assessment by the radiologists using BI-RADS (0.97 vs. 0.91). The results indicate that SSI elastography could be used for computer-aided feature extraction, and the proposed CAD method could improve the diagnostic accuracy of classification of breast tumors to avoid unnecessary biopsy. Furthermore, elastographic features of the peri-tumoral area have the potential to provide critical information in differential diagnosis. (E-mail: hr.zheng@siat.ac.cn) **© 2014 World Federation for Ultrasound in Medicine & Biology.**

Key Words: **Supersonic shear wave imaging, Breast tumor, Computer-aided diagnosis, Quantitative elastographic features, Breast Imaging Reporting and Data System.**

INTRODUCTION

Ultrasound elastography has been developed to evaluate the stiffness of biologic soft tissue and has become a routine tool in addition to diagnostic ultrasonography (US) during the past 5 y (Bercoff et al. 2004; Hall et al. 2003; Ophir et al. 1991). Some pathologic conditions, such as breast tumors, lead to considerable changes in soft tissue structure, modifying elastic properties and substantially resulting in increased stiffness (Athanasiou et al. 2010; Cho et al. 2008). This property serves as the basis for differentiation of benign from malignant breast tumors using elastography. Although elastography provides diagnostic performance comparable to that of conventional morphologic US (Berg et al. 2012; Evans et al. 2010; Slapa et al. 2012), significant inter-observer variability and non-uniform

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diagnostic criteria limit its wide usage. Further improvement of the technique and establishment of robust diagnostic criteria are necessary.

Two main types of ultrasound-based elasticity imaging are currently available in clinical diagnosis: real-time elastography (RTE) and supersonic shear wave imaging (SSI) (Balleyguier et al. 2013). The first modality is generally based on tracking tissue displacements induced by applied compression to obtain strain estimates, and it provides a qualitative image that represents the relative elasticity distribution between a lesion and the surrounding normal tissue (Hall et al. 2003; Ophir et al. 1991). On RTE images, malignant breast tumors mostly appear harder and exhibit areas larger than the gray-scale abnormality on corresponding B-mode images, whereas benign tumors tend to appear similar or slightly smaller on elasticity images than on B-mode images (Chung et al. 2010; Garra et al. 1997). Because of this property, several clinical studies on RTE have been reported in the literature. A 5-point scale visual scoring system, using the degree and uniformity of the color depicted in the hypo-echoic abnormality, has almost the same diagnostic ability as conventional US (Itoh et al. 2006). Strain ratio is an index that has recently been proposed to compare two areas of different stiffness, and can provide semi-quantitative information for tumor classification and improve diagnostic confidence (Ning et al. 2012; Zhi et al. 2010). In addition, to evaluate RTE images objectively, some computer-aided quantifications of strain features have also been reported, such as strain difference (Moon et al. 2009), softness degree (Landoni et al. 2012; Moon et al. 2011) and hard area ratio (Ding et al. 2012). These methods are satisfactory in differentiating benign and malignant masses of the breast, prostate and thyroid. However, RTE itself has certain limitations. The main pitfall of this modality is that the extent of applied compression influences the elasticity image and, consequently, strain feature values (Hall et al. 2003). Moreover, RTE images are currently evaluated by the examiner, resulting in significant inter-observer variability (Regner et al. 2006; Yoon et al. 2011).

Supersonic shear wave imaging, a recently developed quantitative elastography technique, is based on the combination of an acoustic radiation force created by a focused ultrasound beam and an ultra-fast imaging sequence (typically $>$5000 frames/s) capable of capturing the propagation of the resulting shear waves (Bercoff et al. 2004; Tanter et al. 2008). The local shear wave velocity is recovered, enabling construction of a 2-D map of the elasticity modulus. The elasticity data are converted into translucent color-scale images and are superimposed on gray-scale B-mode images. Because the radiation force is produced by a conventional linear array probe rather than the operator, SSI elastography is more reproducible than RTE (Cosgrove et al. 2012). Within a given region-of-interest (ROI), defined by an electronic cursor, values of the maximum stiffness, mean stiffness and standard deviation are calculated and displayed. On SSI elastography images, many malignant tumors are not uniformly stiff, and the maximum areas of stiffness are always found in the peri-tumoral stroma rather than the tumor itself (Berg et al. 2012; Evans et al. 2012). Until recently, studies on SSI elastography have focused on the stiffest area on color maps, whether it was within or adjacent to the tumor (Berg et al. 2012; Evans et al. 2010). Furthermore, manual evaluation of elasticity information has also been limited by inter-observer variability. To the best of our knowledge, a computer-aided diagnosis (CAD) system based on SSI elastography has not yet been addressed. Quantitative analysis of the elastographic features of a tumor and its adjacent area has the potential to improve diagnostic accuracy in distinguishing malignant from benign breast tumors to avoid unnecessary biopsy.

The purpose of this study was to develop quantitative elastographic features for the tumor and peri-tumoral areas with SSI elastography images and evaluate their diagnostic performance in the classification of benign and malignant breast tumors. To facilitate automatic and systematic diagnoses, a new CAD system using a support vector machine (SVM) classifier was proposed. The proposed system was validated by correlating the results of quantitative analysis of SSI elastography images with the diagnosis assessed by the Breast Imaging Reporting and Data System (BI-RADS) and histopathologic examination (American College of Radiology 2003).

METHODS

Patients and breast tumors

This study was a retrospective study, and neither patient approval nor informed consent was required for the review of medical records or ultrasound images. The study group consisted of patients with visible breast abnormalities on routine B-mode scans. Between June 2012 and November 2012, a total of 125 biopsy-proven breast tumors (81 benign, 44 malignant) in 93 consecutive women (mean age: 40 y, age range: 16–75 y) were collected. The study group included 61 patients with one tumor and 32 patients with two tumors. To obtain independent and valid samples, for all 32 patients with two tumors, US examinations of the two tumors were respectively performed on different breasts (one lesion from the left breast and the other from the right breast). The tumor sizes determined on B-mode images ranged from 0.4 to 3.2 cm (mean = 1.2 cm). The malignant tumors included 34 cases of invasive ductal carcinoma, 2 cases of invasive