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● *Original Contribution*

MONITORING STIFFNESS CHANGES IN LESIONS AFTER RADIOFREQUENCY ABLATION AT DIFFERENT TEMPERATURES AND DURATIONS OF ABLATION

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Abstract—The variations in the stiffness or stiffness contrast of lesions resulting from radiofrequency (RF) ablation of canine liver tissue at different temperatures and for different ablation durations at a specified temperature are analyzed. Tissue stiffness, in general, increases with temperature; however, an anomaly exists around 80 ° C, where the stiffness of the lesion is lower than that of the lesion ablated at 70 °C. On the other hand, the stiffness increases monotonically with the duration of ablation. Plots illustrating the ratio of mean strains in normal canine liver tissue to mean strains in ablated thermal lesions demonstrate the variation in the stiffness contrast of the thermal lesions. The contrast-to-noise ratio (CNRe) of the lesions, which serves as an indicator of the detectability of the lesions under the different experimental imaging conditions described above, is also presented. The results presented in this paper show that the elastographic depiction of stiffer thermal lesions is better, in terms of the CNRe parameter. An important criterion in the elastographic depiction of RF-ablated regions of tissue is the trade-off between ablation temperature and duration of ablation. Tissue necrosis can occur either by ablating tissue to high temperatures for short durations or to lower temperatures for longer durations. In this paper, we attempt to characterize the elastographic depiction of thermal lesions under these different experimental conditions. This paper provides results that may be utilized by practitioners of RF ablation to decide the ablation temperature and duration, on the basis of the strain images of normal liver tissue and ablated thermal lesions discussed in this paper. (E-mail: tvarghese@wisc.edu) © 2005 World Federation for Ultrasound in Medicine & Biology.

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INTRODUCTION

Manual palpation is used extensively to detect lesions in organs such as the breast, prostate and liver. This is due to the fact that pathologic and stiffness changes in body tissue are generally well correlated (Fung 1981). For example, cancers such as scirrhous carcinoma of the breast manifest as extremely hard nodules (Anderson 1953; Krouskop et al. 1998). However, this method is sometimes rendered ineffective with smaller lesions, due to the deep location of lesions in the body. In addition, many lesions are not echogenic, which makes them ultrasonically undetectable. As an example, tumors of the breast or prostate may not be visible in standard ultrasound (US) examinations, even though they are significantly stiffer than surrounding tissue (Garra et al. 1997; Hall et al. 2003).

Elastography is an imaging modality used to image tissue strains resulting from external quasistatic compression of tissue (Ophir et al. 1991; Varghese et al. 2001). It is very useful in obtaining new information from lesions with the above-mentioned characteristics because the echogenicity and stiffness of tissue are generally uncorrelated (Garra et al. 1997; Hall et al. 2003). Thus, elastograms provide information related to the stiffness distribution in the tissue. This property can be used to study the variations in the stiffness of thermally coagulated regions in tissue, as a function of temperature and duration of heating. The success of elastography depends on the variation in the elastic moduli or the Young's modulus contrast in the tissue. The greater the

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range of elastic moduli in the tissue, the better is the contrast on the elastogram of the tissue.

The motivation for studying the variations in stiffness of thermal lesions is due to the fact that the stiffness changes may provide a means to ascertain if the ablation procedure was successful in inducing complete thermal necrosis of cancerous tissue. The dependence of lesion stiffness on temperature and duration of ablation was another motivating factor for this study. When radiofrequency (RF) ablation is performed at temperatures greater than 60 °C, uniform necrosis of the tissue occurs, forming the thermal lesion or coagulated region (Zervas and Kuwayama 1972). The high temperatures encountered in RF ablation lead to increased protein denaturation, which induces elevation of the elastic modulus of the treated region of tissue (Righetti et al. 1999; Wu et al. 2001; Varghese et al. 2002, 2003). This leads to the thermal lesions being significantly stiffer than the surrounding normal tissue, culminating in good contrast in the elastograms of these thermal lesions. The study in this paper focuses on the changes observed in the elastograms (local axial-strain images) of the thermal lesion at different temperatures above 60 °C. These results may provide clinical RF ablation practitioners with more accurate information about the boundaries of the ablated or treated region. This, in turn, would help in determining if the cancerous region has been completely ablated.

Conventional sonography has also been used to monitor the RF ablation of hepatic tumors (Solbiati et al. 1997a, 1997b, 2001). However, the region of necrosis is not easily observable on standard US images due to the intrinsically low contrast between normal and ablated tissue (Goldberg et al. 1998; Goldberg 2001). Local tissue stiffness is directly related to the elastic modulus of the tissue, and tissue strain is inversely related to the elastic modulus. In elastographic imaging, tissue stiffness is monitored using strain images to ascertain ablation temperature and durations necessary to ensure complete tumor ablation. Ablation temperatures at or above 100 °C can induce charring of target tissue surrounding the ablation electrode, reducing the efficiency of the RF ablation treatment by hindering heat transfer. However, if ablation is performed at lower temperatures, the duration of ablation may have to be increased to ensure complete tumor destruction. Hence, the aim in this paper using elastographic techniques is to find a balance between practically achievable operating temperature and ablation durations for complete tumor destruction.

Stiffer regions in tissue generally experience lower strains when subjected to compression. Regions experiencing lower strain are represented in an elastogram by pixels with lower grey-scale values and regions experiencing higher strain are represented by pixels with higher grey-scale values. Thus, the darker region corresponding to the thermal lesion shows that the ablated region is stiffer than the surrounding region. As a result, a measure of the stiffness of the thermal lesion (termed stiffness contrast), in relation to that of the normal liver, is obtained. The stiffness contrast is defined as the ratio of the mean pixel (strain) value of the normal liver acquired at room temperature before RF ablation to that of the mean thermal lesion strain obtained from the different elastograms. All the elastographic imaging studies presented in this paper were performed at room temperature. The contrast measured in this unconventional manner serves as an indicator of the comparative stiffness of the thermal lesion. Because thermal lesions experience lower strains when compared with the normal liver, the value of the stiffness contrast provides a direct interpretation of the thermal lesion stiffness. Computation of the stiffness contrast in this manner also enables the estimation of these parameters from similar depths in tissue. Lesion detectability has been previously quantified using the contrast-to-noise ratio (CNR_e) parameter (Varghese and Ophir 1998). The variation in the CNR_e of the thermal lesion with ablation temperature and duration is also evaluated in this paper.

MATERIALS AND METHODS

This study was conducted under an approved protocol from the University of Wisconsin Research Animal Resources Center.

Elastographic imaging

Elastograms obtained by imaging thermally coagulated regions or thermal lesions created by ablating liver tissue *in vitro*, using RF ablation, are utilized to evaluate the contrast and CNR_e characteristics of the stiffer regions seen on the elastograms. Elastograms are able to provide clear differentiation of the stiffer regions from normal softer tissue regions (due to the high contrast), enabling accurate detection of lesion boundaries (*i.e.*, margin delineation) (Righetti et al. 1999; Wu et al. 2001; Varghese et al. 2002, 2003). Canine liver tissue specimens with RF-ablated lesions were encased in gelatin phantoms that provide a smooth surface for external compression for elastography. RF ablation was performed using a RITA model 1500 electrosurgical device (RITA Medical Systems, Mountain View, CA). This device consists of RF ablation electrodes with a 15-gauge shaft, through which multiple sharp tines, each with a diameter of 0.053 cm (0.021 inches; 25 gauge), can be deployed. When fully extended, the tines are in an "umbrella" configuration at 45 ° intervals. The electrically active surface consists of the last 1 cm of the electrode tip and the tines. The electrode was inserted into the liver and the tines were deployed, ensuring that all the tines were within the liver parenchyma.