Sonographic Classification of Thermally Coagulated Tissue

S. Siebers[1], U. Scheipers[1], C. Welp[2], J. Werner[2] and H. Ermert[1]

[1]Institute of High Frequency Engineering, Ruhr-University, 44780 Bochum
[2]Institut of Biomedical Engineering, Ruhr-University, 44780 Bochum
Email: stefan.siebers@rub.de

Zusammenfassung. Thermal ablation is well accepted for the treatment of tumors in cases where established therapeutic methods such as surgical resection are either inapplicable or ineffective. However, at present there is a lack of suitable imaging modalities for accurate online monitoring of the coagulation process. The aim of this work is to combine various tissue characterizing ultrasonic parameters in a classification system to differentiate between coagulated and noncoagulated tissue. As a measure of selectivity of each parameter, the area under the receiver operating characteristic (ROC) curve was estimated. The best parameter combination is processed by a classification system using linear classifiers. Classification results are presented in binary coagulation maps.

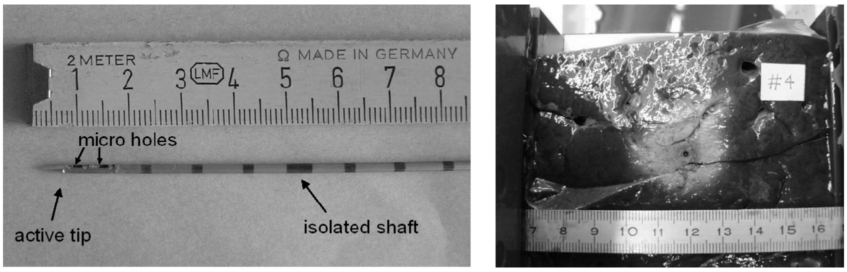
1 Introduction

With radiofrequency (RF) ablation, soft tissue areas up to 5 cm in diameter can be safely destroyed in one application. Monitoring of the coagulation process to visualize the coagulated zone as well as follow-up examinations are performed using different medical imaging techniques, such as CT, MRI and diagnostic ultrasound. In follow-up examinations contrast enhanced CT, MRI and ultrasound are reported to be useful to differentiate between coagulated and viable tissue [1].

However, online monitoring of the ablation process is still challenging. CT imaging is reported to be too imprecise when used during therapy. MRI allows the assessment of the temperature distribution inside the tissue and therefore of the extent of the coagulation using heat sensitive sequences. Nevertheless, specially designed MRI compatible equipment is required, apart from general disadvantages as expenses and complexity of this modality.

In conventional B-Mode imaging, often a hyperechogenic zone caused by microbubbles of gas is visible. However, the gaseous zone is not correlated with the coagulation inevitably, therefore, using B-Mode imaging exclusively is reported to be insufficient. In addition, the effect on B-Mode images is strongly dependent on the therapeutic device used. Therefore, alternative ultrasound based methods have been widely examined towards their applicability for monitoring of thermal

Abb. 1. Needle electrode (left) and photograph of the coagulated zone (right). The active tip of the needle electrode has 6 micro holes for infusion of saline solution into the tissue. The electrode was placed perpendicular to the imaging plane.



therapies, including temperature estimation [2], attenuation estimation [3], and elastography [4]. However, in general one parameter was used exclusively.

In this work, the application of tissue characterizing parameters from spatial and spectral domain is proposed to characterize coagulated tissue. The usage of spectral parameters is motivated by findings that reveal alterations in the spectral behavior of coagulated tissue. Therefore, in this study spectral parameters including attenuation estimates are used. Since changes in intensity and texture in B-Mode images during the experiments can be observed, texture parameters of first and second order have also been added to the investigation.

The parameters are combined in a multi parameter approach. In a first step, various parameters are evaluated towards their potential in differentiating coagulated from viable tissue. The best performing combination of parameters is processed by a classification system using linear classifiers.

2 Experiments and Data Acquisition

Measurements were performed on bovine liver samples in vitro. Coagulation was induced using an RF-ablation device (Elektrotom HiTT 106, Integra ME GmbH, Tuttlingen, Germany). The system consists of a 60 W, 375 kHz RF generator to which needle and neutral electrode are connected, and of a piston pump which delivers saline solution to the needle electrode for open perfusion (Fig. 1). Ultrasonic imaging of liver samples was done using a Siemens Antares diagnostic ultrasound system (3.5 MHz (C5-2) curved array transducer). RF data were acquired using the Siemens Axius Direct Ultrasound Research Interface (URI), which provides RF data at 40 MHz sampling rate and 16 bit resolution. Afterwards the liver samples were sliced along the imaging plane and photographs of the coagulated zone were taken to serve as a reference (Fig. 1).

In total, 10 experiments have been carried out for this study. The power of the RF generator was set to 20 W, saline flow was set to 75 ml/h. Duration of the coagulation process was varied from 5 to 8 minutes to produce coagulations of different size.

3 Calculation of Tissue Characterizing Parameters

Each set of RF data was subdivided into up to 1700 overlapping ROIs in order to allow a spatially resolved calculation of parameters. The size of the window was set to 128 samples (3.9 mm) axially and 16 lines (4 degrees) laterally. Overlap was set to 50 % axially and laterally.

The coagulated zone as well as the noncoagulated zone were delineated in the B-Mode images according to the photographs and, thus, binary masks were created having the same size as the B-Mode images. The masks were used to create two classes for coagulated and noncoagulated tissue.

All texture parameters were calculated after demodulating the RF signals using Hilbert transform. Moreover, for the calculation of second order texture parameters, image data were quantized to 64 intensity levels.

First order texture parameters account for variations in intensity without spatial reference, second order texture parameters account for changes in the spatial arrangement of intensities. First order parameters used in this study were maximum, minimum, mean value, signal-to-noise ratio, squared signal-to-noise ratio, standard deviation, contrast, entropy, kurtosis, skewness, and full-width-at-half-maximum of intensities. Second order texture parameters were extracted from normalized cooccurrence matrices [5] and include contrast, inverse difference moment, entropy, second angular moment, and correlation.

To consider changes in spectral properties due to the coagulation process, 21 parameters from the frequency domain were calculated. Spectral estimates were obtained using Fourier transform (FT) as well as autoregressive modeling (AR) using the Burg method. The optimal order of the AR-model was determined using the Akaike information criterion to be 14.

As backscatter measures midband, slope and intercept values of a straight-line fit to the spectrum were used. Frequency dependent attenuation coefficients were also used. The center frequency for attenuation estimation was determined using spectral moments as well as a least square fit to the spectrum. Estimates of attenuation coefficients were obtained using multi-narrowband [6] and spectral shift method [7]. Furthermore, estimated coefficients of the autoregressive model of order 14 were used as tissue characterizing parameters.

4 Classification

The Maximum-Likelihood measure was used for classification. Out of the 2863 ROIs obtained using the binary masks, 1322 ROIs represent group 1 (coagulated) and 1541 ROIs represent group 2 (noncoagulated). The parameter values were assumed to be approximately normally distributed. Each ROI was classified separately. Classification was done by total cross validation over cases, i.e. for classification of one ROI the remaining ROIs of the same case were left out and thus not included in the training data set. The best parameter combination found by sequential forward selection was processed by the classifier. Classification results were visualized in binary coagulation maps. Sensitivity and specificity for each coagulation map were determined.

Abb. 2. Classification result. B-Mode image with superimposed manually delineated coagulation zone (left), and B-Mode image with superimposed coagulation map obtained by the classification system (right).

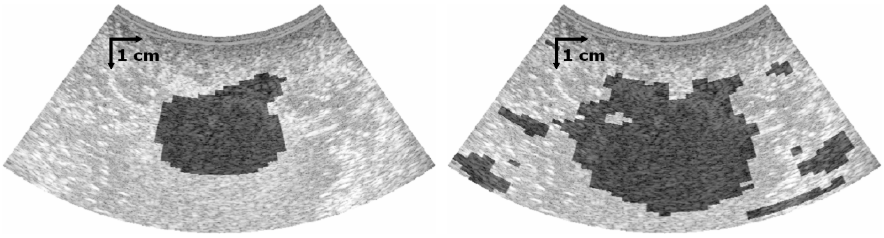


Tabelle 1. Sensitivities and specificities for the 10 cases

Case	1	2	3	4	5	6	7	8	9	10	$\sum$
SE	0.86	1.00	0.99	0.99	0.97	1.00	0.93	1.00	0.93	1.00	0.97±0.05
SP	0.90	0.84	0.91	0.81	0.79	0.91	0.90	0.61	0.88	0.88	0.84±0.09

5 Results and Discussion

Each ROI was classified separately by total cross validation over cases. The classification results were presented in scan converted binary coagulation maps and superimposed on the B-Mode images (Fig. 2). In 9 out of 10 experiments the determined coagulated zone was of the same order of magnitude as the coagulated zone determined from the photographs. Classification results using the maximum-likelihood classifier are presented in Table 1. Sensitivity SE and specificity SP were determined for each coagulation map using the photographs as the gold standard, yielding SE=0.97±0.05 and SP=0.84±0.09, respectively. The lower specificity is mainly caused by a slight overestimation of the coagulated zone. This may be partly due to the coarse resolution caused by the ROI size used. Therefore, future steps will include an investigation of the influence of the ROI size to find a trade-off between resolution and variance of the parameter estimates.

Another source of error is introduced by manually delineating the coagulated zone in the B-Mode images. However, this can be overcome by an automated registration of photographs and B-Mode images.

The evaluation of 40 parameters confirmed that differentiating between coagulated and noncoagulated tissue using one parameter exclusively is not recommendable. For example, using the best performing parameter SNR on its own for classification yielded sensitivity and specificity of SE=0.93±0.05 and SP=0.73±0.05. Similar experiences have been made within the scope of other ultrasonic tissue characterizing applications [8,9].

6 Acknowledgements

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Literaturverzeichnis

1. Goldberg SN, Gazelle GS, Mueller PR. Thermal ablation therapy for focal malignancy. Am J Roentgenol 2000;174:323–331.
2. Simon C, Vanbaren P, Ebbini E. Two-dimensional temperature estimation using diagnostic ultrasound. IEEE Trans Ultrason Ferroelectr Freq Control 1998;45(4):1088–1099.
3. Bevan PD, Shedar MD. B-scan ultrasound imaging of thermal coagulation in bovine liver: Frequency shift attenuation mapping. Ultrasound Med Biol 2001;27(6):809–817.
4. Righetti R, Kallel F, Stafford R, Price R, Krouskop T, Hazle J, et al. Elastographic Chracterization Of HIFU-Induced Lesions In Canine Livers. Ultrasound Med Biol 1999;25(7):1099–1113.
5. Haralick RM, Shanmugam K, Dinstein I. Textural Features For Image Classification. IEEE Trans Syst Man Cybern 1973;SMC-3(6).
6. Cloostermans MJTM, Thijssen JM. A beam corrected estimation of the frequency dependent attenuation of biological tissues from backscattered ultrasound. Ultrason Imaging 1983;5:136–147.
7. Fink M, Hottier F, Cardoso JF. Ultrasonic signal processing for in vivo attenuation measurement - short time fourier analysis. Ultrason Imaging 1983;5:117–135.
8. Scheipers U, Ermert H, Sommerfeld HJ, Schürmann MGarcia, Senge T, Philippou S. Ultrasonic multifeature tissue characterization for prostate diagnostics. Ultrasound Med Biol 2003;29(8):1137–1149.
9. Siebers S, Geier B, Scheipers U, Vogt M, Mumme A, Ermert H. Classification of venous thrombosis combining ultrasound elastography and tissue characterization. In: IEEE Ultrason Symp; 2004.