Statistical parameter estimation in ultrasound backscattering from tissue mimicking media

Jian-Feng Chen

Several tissue characterization parameters, including the effective scatterer number density and the backscatter coefficient, were derived from the statistical properties of ultrasonic echo signals. The effective scatterer number density is the actual scatterer number density in a medium multiplied by a frequency-dependent factor that depends on the differential scattering cross-sections of all scatterers. The method described in this thesis for determining the scatterer number density explicitly retains both the temporal nature of the data acquisition and the properties of the ultrasound field in the data reduction. Moreover, it accounts for the possibility that different sets of scatterers may dominate the echo signal at different frequencies.

The random processes involved in forming ultrasound echo signals from random media give rise to an uncertainty in the estimated effective scatterer number density. This uncertainty is evaluated using error propagation. The statistical uncertainty depends on the effective number of scatterers contributing to the segmented echo signal, increasing when the effective number of scatterers increases. Tests of the scatterer number density data reduction method and the statistical uncertainty estimator were done using phantoms with known ultrasound scattering properties. Good agreement was found between measured values and those calculated from first-principles.

The properties of the non-Gaussian and non-Rayleigh parameters of ultrasound echo signals are also studied. Both parameters depend on the measurement system, including the transducer field and pulse frequency content, as well as on the medium's properties. The latter is expressed in terms of the scatterer number density and the second and fourth moments of the medium's scattering function. A simple relationship between the non-Gaussian and non-Rayleigh parameters is derived and verified experimentally. Finally, a reference phantom method is proposed for measuring the effective scatterer number density in vivo.

Various groups are using the frequency dependent backscatter coefficient (or the spatial autocorrelation function) to characterize scatterer sizes in biological tissue. Generally, sparse scatterer concentrations are assumed in relating scattering parameters to this tissue property. For dense scattering media, we study whether the frequency dependent backscatter coefficient changes with the scatterer volume fraction. Two scattering models suggested by Debye and Yagi are reviewed. In these models, the spatial autocorrelation function describing mass density and compressibility fluctuations in the scattering medium has a characteristic length that depends on the scatterer volume fraction as well as the scatterer size. The models predict the frequency dependence of the backscatter coefficient will vary with the scatterer volume fraction. Qualitative agreement between the model predictions and experimental results are seen for sephadex-in-agar phantoms.