Dependency of Ultrasonic Nakagami Images on The Mechanical Properties of Scattering Medium

Po-Hsiang Tsui[1,2,*,†] Yung-Liang Wan[1,3,†] Yu-Ting Chien[1] Chia-Chun Yeh[1]

Chiao-Yin Wang[1]

[1]*Department of Medical Imaging and Radiological Sciences, College of Medicine, Chang Gung University, Taoyuan 320, Taiwan, ROC*
[2]*Healthy Aging Research Center, Chang Gung University, Taoyuan 320, Taiwan, ROC*
[3]*Department of Medical Imaging and Intervention, Chang Gung Memorial Hospital at Linkou, Taoyuan 333, Taiwan, ROC*

Received 12 Jan 2012; Accepted 5 Apr 2012; doi: 10.5405/jmbe.1101

Abstract

Nakagami images based on backscattered statistics have been demonstrated to complement the ultrasonic B-scan technique for evaluating the arrangements and concentrations of scatterers in the scattering medium. This study explores the relationship between Nakagami images and the mechanical properties of the scattering medium. Experiments were performed on phantoms with various stiffnesses and scatterer concentrations. A commercial supersonic shear imaging system was used to measure the shear modulus of each phantom. The ultrasonic backscattered signals from the phantoms were acquired using a single-element ultrasound scanner for Nakagami imaging. The Nakagami images were compared with the supersonic shear images to explore the dependency of the Nakagami parameter on the medium stiffness. The brightness of the shading in the Nakagami image increased with increasing stiffness of the phantom. For the scattering medium with a low scatterer concentration (8 scatterers·mm^{-3}), the average Nakagami parameter increased from 0.35 to 0.46 when the average shear modulus increased from 11.7 to 167.6 kPa. The average Nakagami parameter measured in the medium with a high scatterer concentration (32 scatterers·mm^{-3}) increased from 0.8 to 0.89 when the shear modulus increased from 12.3 to 174.5 kPa. This study demonstrates that the features of Nakagami images depend on the stiffness of the scattering medium.

Keywords: Nakagami image, Tissue stiffness, Supersonic shear imaging

1. Introduction

Ultrasound grayscale (B-mode) imaging is an important clinical tool for examining the internal structures of tissues [1]. The B-scan intensity is affected by many factors, such as image processing, system settings, and user operations [2,3]. Consequently, B-scan images provide only a primarily qualitative description of morphology, without quantifying tissue properties. The raw ultrasonic radio-frequency (RF) signals backscattered from tissues may contain valuable information that complements the B-scan images for tissue characterization. The statistical properties of backscattered signals depend on the scatterer properties [4-6]. When the resolution cell of the transducer contains a large number of randomly distributed scatterers, the probability density function (pdf) of the backscattered envelope conforms to the Rayleigh distribution [7,8]. If the resolution cell contains scatterers with randomly varying scattering cross-sections, with a comparatively high degree of variance, the envelope statistics conform to a pre- Rayleigh distribution. When the resolution cell contains periodically located scatterers in addition to randomly distributed scatterers, the envelope follows a post-Rayleigh distribution [9]. Non-Rayleigh statistical models, such as Rician [8], K [10], homodyned K [11], and generalized K [12] models, have been developed to encompass the various backscattering conditions.

The Nakagami distribution, initially proposed to describe the statistics of radar echoes [13], has been applied to the statistical analysis of backscattered signals [14-17]. The Nakagami distribution provides a general model for all the backscattering conditions encountered in medical ultrasound. It was found to be strongly related to the statistics of the backscattered signal, with the corresponding Nakagami parameter varying according to the statistics of the backscattered signal [16]. Research has shown that the Nakagami parameter can be used to distinguish various scatterer properties [9,18-20]. Some Nakagami compound distributions, including the Nakagami-Gamma [21,22], Nakagami-lognormal and

† These authors contributed equally to this work
* Corresponding author: Po-Hsiang Tsui
Tel: +886-3-2118800 ext. 3795; Fax: +886-3- 2118700
E-mail: tsuiph@mail.cgu.edu.tw