Echo Simulation Method reflecting the Tissue Structure and Acoustic Characteristics of Skin

皮膚の組織構造と音響特性を反映したエコーシミュレーション法の検討

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1. Background

We aim to apply ultrasound tissue characterization in the surface of biological tissues, e.g. lymphnode, glandula mammaria, and skin [1]. Main component in skin tissues is a collagen fiber. Although its morphological informations, e.g. number density, orientation, and distributed interval, are related to the characteristics of the ultrasound echo signals, it is difficult to understand above relationship only in measurement results.

In this study, we demonstrated computer simulations from some scatterer medium models reflecting acoustic characteristics to examine the relationship between the structure of collagen fibers and characteristics of echo signals.

2. Theory of Echo Envelope Statistics Analysis

The Homodyned K distribution (HKD) is well known as a statistical model that models a low scatterering signals from such as a biological tissue and coherent signals with a periodically located and constant-amplitude component [2]. HKD is defined by

$$P_{HK}(A|s,\mu,\sigma^2) = \int_0^\infty zJ_0(zs)AJ_0(zA)\left(1+\frac{z^2\sigma^2}{2}\right)^{-\mu} dz. \quad (1)$$

where A is amplitude envelope, J_0 is the Bessel function of the first kind of order 0. The ratio of scattering to total signal power $1/(\kappa+1)$ is more preferable to the direct estimations of the structure parameter κ, i.e. the ratio of coherent to scattering signal power $s^2/2\mu\sigma^2$. The coherent signal power is high when $1/(\kappa+1)$ is less than about 0.5.

3. Materials and Methods

3.1 echo simulation methods

Radiofrequency (RF) echo signals were simulated using ultrasound simulation software Field II (J.A. Jensen, Technical University of Denmark) on MATLAB (The MathWorks Inc., Natick, MA). A single element transducer with a focal length of 19 mm and an aperture of 9.6 mm was simulated to transmission reception of ultrasound. The center frequency of transmission and reception was 15 MHz. Its excitation signal and impulse response were 2 wave of a sinusoid and were convolved it with Gaussian window with 50% fractional bandwidth at -6 dB, respectively. The sampling frequency was 250 MHz, and the pitch of scan lines was separated by 0.30 mm. Speed of sound was 1480 m/s. The point spread function (PSF), i.e. -6 dB bandwidth, was 0.11 mm in depth and 0.20 mm in lateral direction.

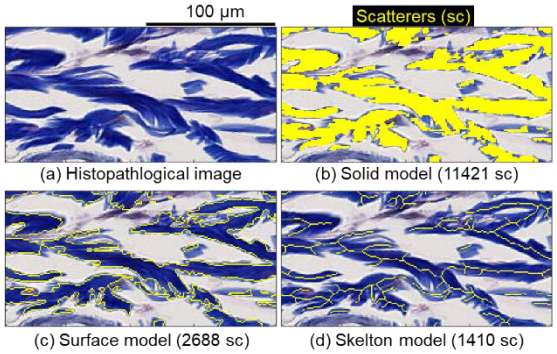

Fig. 1 Example of 3 kinds of scatterer medium model.

The amplitude envelope was calculated as norm of the Hilbert transform of RF echo signal in each scan line. The parameters (s, μ, σ^2) computation method of HKD based on first moment and two log–moments of A^2 [2] was applied in an analysis window which has the size of 0.66 mm in depth and 1.20 mm in lateral direction.

3.2 scatterer medium models

The scatterer medium models were made using the digital histopathological image of a normal human skin in a thigh. The image of 3.6 * 6.0 mm^2 (4096 * 6816 pixels) was segmented into collagen fibers and others using superpixels oversegmentation and k-means method in Lab color space [3]. The scatterers were placed on each pixel of the collagen fiber parts. The minimum pixel pitch of the original image was 9 µm.

The example images in PSF region were displayed in **Fig. 1**. Three kinds of the scatterer medium models were made: solid model, i.e. fill scatterers in all pixels, surface model, i.e. put scatterers on the bounraries, skelton model, i.e. put

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scatterers in the skeltons of the solid model. The Scatterer number density was from about 10^3 to 10^4 in each scatterer medium model, since it assumed that each scatterer overly interfered more than 10 scatterer number density per PSF, scatter distribution was decimated by a factor from 2 to 30 pixels (1.8 to 27 μm).

The scatterer amplitude (the parameter related to the contrasts in acoustic impedance between the scatterer and surrounding medium) of each scatterer was constant to 0.14 (impedance contrasts $Z_C - Z_I/(Z_C + Z_I)$, c.f. acoustic impedance of a collagen fiber and interstice were 2.0 MRayl and 1.5 MRayl).

4. Results and Discussions

Figure 2 shows an examples of scatterer number density (left), log-compressed amplitude envelope (middle), and computed $1/(\kappa + 1)$ (right) map decimated by 3.6 μm in each scatterer medium model. Log-compression was normalized with the maximum amplitude envelope of each model.

To compare the spatial similarity of the simulated echo amplitude envelope among three kinds of scatterer medium model quantitatively, Zero Mean Cross Correlation (ZNCC) was calculated. ZNCC of log-compressed amplitude envelope [dB] map between each pair of scatterer medium model, e.g. solid and surface model, is indicated as the solid line in **Fig. 3(a)**. All ZNCC of log-compressed amplitude envelope, i.e. texture of the amplitude envelope map, shift constant high similarity in each pair of scatterer medium model.

Additionally, the boxplots of scatterer number density of localized scatterer distribution and computed $1/(\kappa + 1)$ in each analysis window are shown in **Fig. 3(a)** and **3(b)**, respectively. When the

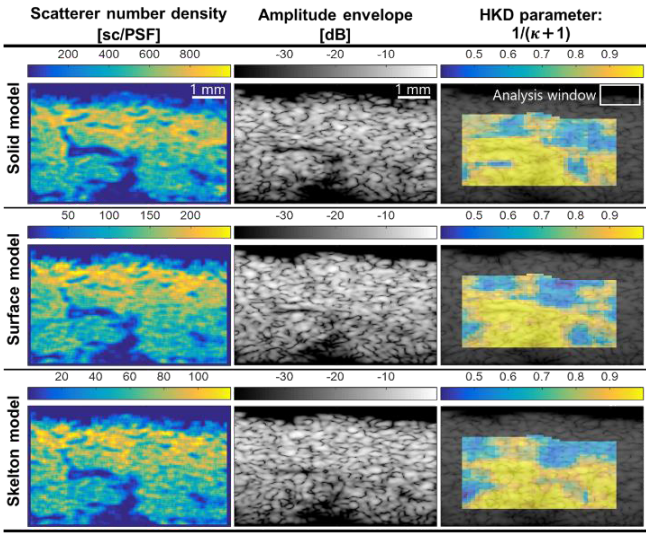

Fig. 2 Examples of scatterer number density (left), echo amplitude envelope (middle), and computed $1/(\kappa + 1)$ map (right) in each scatterer medium model.

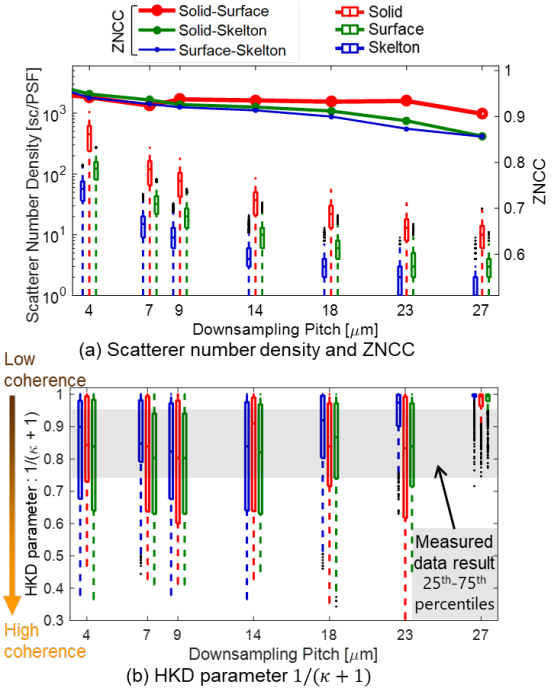

Fig. 3 Plots of ZNCC and boxplots of scatterer number density (a), and boxplots of computed $1/(\kappa + 1)$ (b).

downsampling pitch is wide, the scatterer number denisity is lower than the small scatterer number density case, however $1/(\kappa + 1)$ has no difference among three kinds of the scatterer medium model. Moreover, 25th to 75th percentile of $1/(\kappa + 1)$ except for more than 23 μm down sampling was consistent with the three-dimensional (3D) analysis result of simulation data identified with the histopathological image and acquired by 15 MHz single-element transducer.

It is considered that scatterer medium model including a point set can express the echo signals feature of collagen fibers where its structure is smaller than about the region of PSF $*$ 1/10. Moreover, skelton model also can be performed in about 1/10 low scatterer number density, i.e. low calculation cost, compared to solid model.

5. Conclusions

We considered the method of reproducing the scatterer medium models of collagen fibers in skin tissues and simulating echo signals from them. In the next step, it is necessary to consider 3D scatterer medium model and the spatial difference of acoustic characteristics.

Acknowledgment

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