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Experimental verification of strain uniformalization by damper layer in static elastography

静的エラストグラフィにおける緩衝層挿入による歪み均一化の実験的検証

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1. Introduction

Static elastography is a simpler and more conventional method of estimating elasticity than dynamic elastography[1, 2]. However, the estimated elasticity strongly depends on the applied stress distribution. An effective method of improving the nonuniformity of applied stress that occurs with different shapes of the transducer head is to insert a damper between the tissue being analyzed and the transducer head. The optimal values of the two main parameters in the damper design, i.e., the Young's modulus and the damper thickness, were investigated in the previous study through FEM (finite element method) simulation.[3, 4]

In this study, the experiments corresponded to the simulation were conducted to in order to assess the effectiveness of inserting a damper.

2. Experimental Method

Human tissue surfaces are not flat planes, but are actual surfaces with various curvatures. Thus, the shape of the phantom surface was fabricated convex as shown in Fig. 1. The convex-shaped surface consisted of a truncated sphere and a 6 cm diameter of a cylinder. The phantom consisted of three layers (upper soft, hard and lower soft) of 5, 2, and 4mm thicknesses and 230, 510, and 230 kPa Young's moduli, respectively. The middle layer was prepared for observing the effects of the damper insertion in the hard inclusion. All of the layers and the dampers were made of Urethane Gel (Exseal Corp., Gifu) and acryl powders with an average diameter of 20 μm as the ultrasonic reflector.

Sheet-shaped dampers between the transducer and the tissue surface had a thickness of 2 mm and the Young's modulus of 120, 232 and 500 kPa. A plano-concave damper had a thickness of 2 mm at the center and the same elasticity as the upper and lower soft layers. All the layers including the damper were given a Poisson's ratio of 0.49. The Young's modulus of the three phantom layers were measured with a setup drawn in Fig. 2. A 128 ch linear array transducer with the center frequency of 10 MHz was attached flat to the compression board.

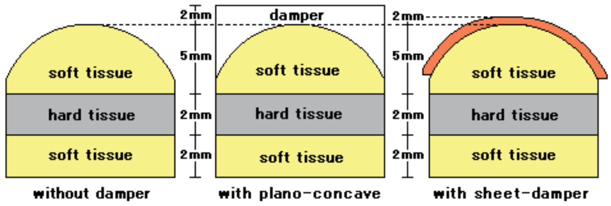

Fig. 1 Side view of tissue phantom.

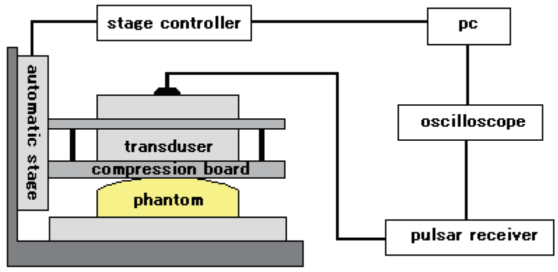

Fig. 2 Experimental setup

The experiments were executed with compression stroke of about 1 % of the total thickness with the dampers. The pulser-receiver (Model 5073PR, Olympus NDT, Japan) was used to generate the transmission wave at a pulse repetition frequency of 1 kHz and to amplify the received echo signals. Strain distribution estimation, based on one-dimensional cross-correlation processes, was executed between the pre- and post-compression signals. The correlation coefficient is given by

$$\rho = \frac{\sum_{i=i_0-M/2}^{i_0+M/2} (a_i - \bar{a})(b_{i+l} - \bar{b})}{\sqrt{\sum_{i=i_0-M/2}^{i_0+M/2} \left|a_i - \bar{a}\right|^2 \sum_{i=i_0-M/2}^{i_0+M/2} \left|b_{i+l} - \bar{b}\right|^2}} \quad , \qquad (1)$$

where i_0 is the center position of the correlation window, ρ_{il} is the correlation coefficient at $i = i_0 + l$, l is the shift within the correlation window length M, a and b are the data points of the pre- and post-

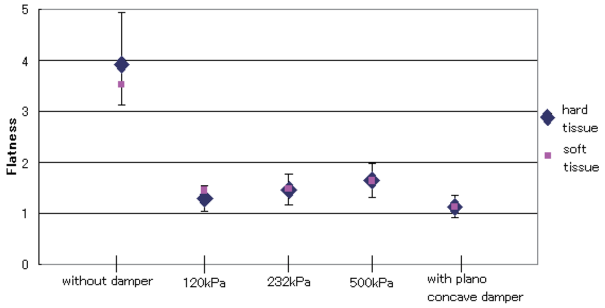

Fig. 3 Comparison of flatness with various damper conditions.

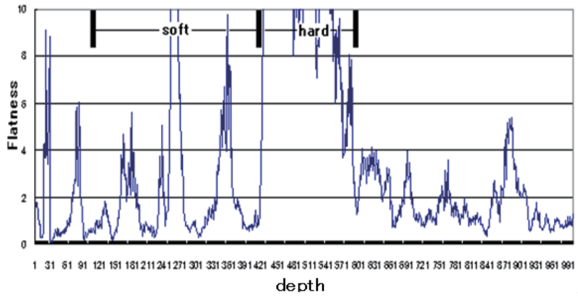

Fig. 4 Flatness distribution without plano-concave damper.

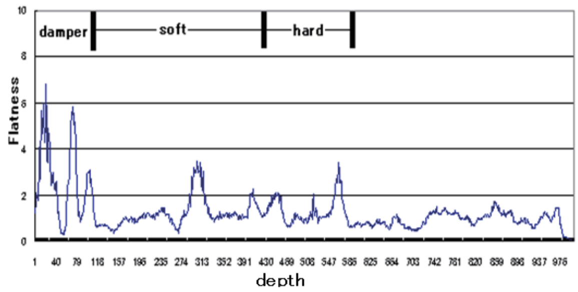

Fig. 5 Flatness distribution with plano-concave damper.

compressions, respectively, and a_1 and b_1 are the averages of a and b in the correlation windows, respectively. Tthe reduction in computation amount is preferred to the increase in accuracy in this study. Then, the relative applied strain ε can be estimated using the correlation coefficient ρ as follows:

$$\varepsilon = 1 - \rho, \tag{2}$$

Flatness, which is the ratio of the axial strain directly under the edge of the transducer ε_{edge} to the strain directly under the center of the transducer ε_{center} at the same depth, is defined as the assessment index, i.e.,

$$flatness = \frac{\varepsilon_{edge}}{\varepsilon_{center}}. \tag{3}$$

Thus, Flatness = 1 is clearly considered as ideal for applying uniform strain.

3. Results and Discussion

The flatness distributions were measured 20 times for cases both with and without the sheet-shaped damper, and the average values are plotted in Fig. 3. As indicated in Fig. 3, values close to 1 across a range of depths were obtained with the dampers; thus, strain uniformity was improved. In the case with the sheet-shaped damper, the softer the damper is, the better the flatness is.

Next, we discuss the cases with and without the plano-concave dampers. A clear improvement could be observed between the flatness distributions in the cases with and without the plano-concave dampers drawn in Figs. 4 and 5. In addition, a desirable flatness distribution was achieved with the plano-concave damper.

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